UNIVERSAL
LIBRARY

OU_170211

UNIVERSAL
LIBRARY

# CLASS-BOOK OF GEOLOGY

MACMILLAN AND CO., LIMITED
LONDON · BOMBAY · CALCUTTA · MADRAS
MELBOURNE

THE MACMILLAN COMPANY
NEW YORK · BOSTON · CHICAGO
DALLAS · ATLANTA · SAN FRANCISCO

THE MACMILLAN COMPANY
OF CANADA, LIMITED
TORONTO

# CLASS-BOOK
OF
# GEOLOGY

BY

SIR ARCHIBALD GEIKIE, O.M., F.R.S.

MACMILLAN AND CO., LIMITED
ST. MARTIN'S STREET, LONDON
1937

COPYRIGHT

*First Edition* 1886 *Second Edition* 1890 *Reprinted* 1891 *Third Edition* 18
*Reprinted* 1893, 1894, *March and September*, 1896, 1897, 1899, 1900
*Fourth Edition* 1902 *Reprinted* 1903
*Fifth Edition* 1909
*Sixth Edition* 1915
*Reprinted* 1919, 1921, 1927, 1937

PRINTED IN GREAT BRITAIN
BY R. & R. CLARK, LIMITED, EDINBURGH

# PREFACE

## TO THE FIRST EDITION (1886)

THE present volume completes a series of educational works on Physical Geography and Geology, projected by me many years ago. In the *Primers*, published in 1873, the most elementary facts and principles were presented in such a way as I thought most likely to attract the learner, by stimulating at once his faculties of observation and reflection. The continued sale of large editions of these little books in this country and in America, and the translation of them into most European languages, leads me to believe that the practical methods of instruction adopted in them have been found useful. They were followed in 1877 by my *Class-Book of Physical Geography*, in which, upon as far as possible the same line of treatment, the subject was developed with greater breadth and fulness. This volume was meant to be immediately succeeded by a corresponding one on Geology, but pressure of other engagements has delayed till now the completion of this plan.

So many introductory works on Geology have been written that some apology or explanation seems required from an author who adds to their number. Experience of the practical work of teaching science long ago convinced me that what the

young learner primarily needs is a class-book which will awaken his curiosity and interest. There should be enough of detail to enable him to understand how conclusions are arrived at. All through its chapters he should see how observation, generalisation, and induction go hand in hand in the progress of scientific research. But it should not be overloaded with technical details which, though of the highest importance, cannot be adequately understood until considerable advance has been made in the study. It ought to present a broad, luminous picture of each branch of the subject, necessarily, of course, incomplete, but perfectly correct and intelligible as far as it goes. This picture should be amplified in detail by a skilful teacher. It may, however, so arrest the attention of the learner himself as to lead him to seek, of his own accord, in larger treatises, fuller sources of information. To this ideal standard of a class-book I have striven in some measure to approach.

Originally, I purposed that this present volume should be uniform in size with the *Class-Book of Physical Geography*. But, as the illustrations were in progress, the advantage of adopting a larger page became evident, and with this greater scope and my own enthusiasm for the subject the book has gradually grown into what it now is. With few exceptions, the woodcuts have been drawn and engraved expressly for this volume. Mr. Sharman has kindly made for me most of the drawings of the fossils. The landscape sketches are chiefly from my own note-books. I have to thank Messrs. J. D. Cooper and M. Lacour for the skill with which they have given in wood-engraving the expression of the originals.

## PREFACE TO THE FOURTH EDITION (1902)

In preparing a Fourth Edition of this Class-Book I have endeavoured to keep it abreast of the continued advance of Geology. Some parts of it have been re-arranged and to some extent re-written, and considerable additions have been made throughout the volume. In compliance with frequent representations made to me by friends in the United States, I have inserted fuller references to North American Geology, and in illustration of them have been favoured by my friend Mr. C. D. Walcott, the Director of the United States Geological Survey, with the use of a series of photographs taken by himself and members of his staff, which were selected for me by his eminent coadjutor Mr. G. K. Gilbert, and from which a number of fresh cuts have been prepared. I am much indebted also to my colleague Dr. F. L. Kitchin for his valuable assistance in reading the proofs of Part IV., and for supplying a thorough revision of the Table of the Vegetable and Animal Kingdoms in the Appendix.

---

In this Sixth Edition the book has again been revised and brought abreast of the onward progress of the science.

*December* 1914.

# CONTENTS

## CHAPTER I

PAGE

INTRODUCTORY . . . . . 1

## PART I

## THE MATERIALS FOR THE HISTORY OF THE EARTH

## CHAPTER II

THE INFLUENCE OF THE ATMOSPHERE IN THE CHANGES OF THE EARTH'S SURFACE . . . 10

## CHAPTER III

THE INFLUENCE OF RUNNING WATER IN GEOLOGICAL CHANGES, AND HOW IT IS RECORDED . . . 26

## CHAPTER IV

THE MEMORIALS LEFT BY LAKES . . . . . 48

CHAPTER V

PAGE

HOW SPRINGS LEAVE THEIR MARK IN GEOLOGICAL HISTORY . . . . . 57

CHAPTER VI

ICE-RECORDS . . . . . 69

CHAPTER VII

THE MEMORIALS OF THE PRESENCE OF THE SEA . . 80

CHAPTER VIII

HOW PLANTS AND ANIMALS INSCRIBE THEIR RECORDS IN GEOLOGICAL HISTORY . . . . . 91

CHAPTER IX

THE RECORDS LEFT BY VOLCANOES AND EARTHQUAKES 103

PART II

ROCKS, AND HOW THEY TELL THE HISTORY OF THE EARTH

CHAPTER X

THE MORE IMPORTANT ELEMENTS AND MINERALS OF THE EARTH'S CRUST . . . . . 127

CHAPTER XI

PAGE

THE MORE IMPORTANT ROCKS OF THE EARTH'S CRUST 154

PART III

THE STRUCTURE OF THE CRUST OF THE EARTH

CHAPTER XII

SEDIMENTARY ROCKS—THEIR ORIGINAL STRUCTURES . 192

CHAPTER XIII

SEDIMENTARY ROCKS—STRUCTURE SUPERINDUCED IN THEM AFTER THEIR FORMATION . . . . 207

CHAPTER XIV

ERUPTIVE ROCKS AND MINERAL VEINS IN THE ARCHITECTURE OF THE EARTH'S CRUST . . 224

CHAPTER XV

HOW FOSSILS HAVE BEEN ENTOMBED AND PRESERVED, AND HOW THEY ARE USED IN INVESTIGATING THE STRUCTURE OF THE EARTH'S CRUST, AND IN STUDYING GEOLOGICAL HISTORY . . . . . 237

# PART IV

## THE GEOLOGICAL RECORD OF THE HISTORY OF THE EARTH

### CHAPTER XVI

PAGE

THE EARLIEST CONDITIONS OF THE GLOBE — THE ARCHÆAN PERIODS . . . . 251

### CHAPTER XVII

THE PALÆOZOIC PERIODS—CAMBRIAN . . . . . 264

### CHAPTER XVIII

SILURIAN . . . . . 276

### CHAPTER XIX

DEVONIAN AND OLD RED SANDSTONE . . . . . 287

### CHAPTER XX

CARBONIFEROUS . . . . . 296

### CHAPTER XXI

PERMIAN . . . . . 314

### CHAPTER XXII

THE MESOZOIC PERIODS—TRIASSIC . . . . . 323

## CHAPTER XXIII

PAGE
JURASSIC . . . . . 332

## CHAPTER XXIV

CRETACEOUS . . . . . 348

## CHAPTER XXV

TERTIARY OR CAINOZOIC—EOCENE—OLIGOCENE . . 365

## CHAPTER XXVI

MIOCENE—PLIOCENE . . . . . 381

## CHAPTER XXVII

POST-TERTIARY OR QUATERNARY PERIODS — PLEISTOCENE OR POST-PLIOCENE—RECENT . . . . 395

APPENDIX . . . . . 415

INDEX . . . . . 431

# LIST OF ILLUSTRATIONS


| FIG. | | PAGE |
|---|---|---|
| 1. | Weathering of rock, as shown by old masonry (The "false-bedding" and other original structures of the stone are revealed by weathering) . . . | 12 |
| 2 | Passage of sandstone upwards into soil | 15 |
| 3 | Passage of granite upwards into soil | 16 |
| 4. | Talus-slopes at the foot of a line of cliffs | 20 |
| 5. | Section of rain-wash or brick-earth | 20 |
| 6 | Sand-dunes . . | 22 |
| 7. | "Jail and Court-house Rocks"—typical outliers or "buttes" of soft sandstone, developed by atmospheric denudation in a semi-arid region, Platte River, Western Nebraska . | 23 |
| 8 | Erosion of limestone by the solvent action of a peaty stream, Durness, Sutherlandshire . . . | 28 |
| 9. | Pot-holes worn out by the gyration of stones in the bed of a stream . . . . . | 33 |
| 10 | Windings of the Mississippi river . | 34 |
| 11. | Windings of the gorge of the Moselle above Cochem . | 35 |
| 12. | Section at the Horse-Shoe Fall, Niagara . | 36 |
| 13 | Grand Cañon of the Colorado . . . | 37 |
| 14 | Gullies torn out of the side of a mountain by descending torrents, with cones of detritus at their base . . . . . | 40 |
| 15. | Flat stones in a bank of river-shingle, showing the direction of the current that transported and left them . . | 41 |
| 16. | Section of alluvium showing direction of currents . | 42 |
| 17. | River-terraces . . . . . | 43 |
| 18. | Section of river-terraces . | 44 |
| 19. | Alluvial terraces on the side of an emptied reservoir . . | 49 |
| 20. | Parallel roads of Glen Roy . . . . . | 50 |
| 21 | Stages in the filling up of a lake . . . | 51 |
| 22. | Well-worn shingle on the shore of a large lake (Lake Ontario) | 52 |
| 23 | Piece of shell-marl containing shells of *Limnæa peregra* . . | 53 |

| FIG | | PAGE |
|---|---|---|
| 24 | View of Axmouth landslip (as it appeared in April 1885) | 59 |
| 25 | Section of cavern with stalactites and stalagmite | 62 |
| 26 | Section showing successive layers of growth in a stalactite | 64 |
| 27 | Travertine with impressions of leaves | 66 |
| 28 | Glacier with medial and lateral moraines | 71 |
| 29 | Perched blocks scattered over ice-worn surface of rock | 72 |
| 30. | Glacier-borne block of granite resting on red sandstone, Corrie, Isle of Arran, Scotland | 73 |
| 31 | Front of Muir Glacier, Alaska, in June 1899, the ice-cliff is from 200 to 300 feet high | 74 |
| 32 | Stone from the Boulder-clay of Central Scotland, which has been smoothed and striated under an ice-sheet | 75 |
| 33 | Ice-striation on the floor and side of a valley | 76 |
| 34. | "Moulin pot-holes" in granite, High Sierra, California | 78 |
| 35 | Buller of Buchan—a caldron-shaped cavity or blow-hole worn out of granite by the sea on the coast of Aberdeenshire | 81 |
| 36. | The Stacks of Duncansby, Caithness, a wave-beaten coast-line | 83 |
| 37 | Section of submarine plain | 84 |
| 38 | Storm-beach ponding back a stream and forming a lake, west coast of Sutherlandshire | 87 |
| 39 | Section of a peat-bog | 93 |
| 40. | Diatom-earth from floor of Antarctic Ocean, magnified 300 diameters | 94 |
| 41 | Recent limestone (cockle, etc.) | 95 |
| 42 | Globigerina ooze magnified | 96 |
| 43 | Section of a coral-reef | 97 |
| 44 | Cellular Lava with a few of the cells filled up with infiltrated mineral matter (Amygdales) | 107 |
| 45 | Section of a lava-current | 108 |
| 46. | Elongation of cells in direction of flow of a lava-stream | 109 |
| 47. | Volcanic block ejected during the deposition of strata in water | 112 |
| 48 | Volcanoes on lines of fissure | 114 |
| 49 | Volcanic Necks, Texas | 116 |
| 50. | Outline of a Volcanic Neck | 117 |
| 51. | Ground-plan of the structure of the Neck shown in Fig 50 | 117 |
| 52 | Section through the same Neck as in Figs 50 and 51 | 118 |
| 53. | Volcanic dykes rising through the bedded tuff of a crater | 119 |
| 54 | Raised marine terraces, or Strand-lines, Alten Fjord, Norway | 124 |
| 55 | Group of Quartz-crystals (Rock-crystal) | 131 |
| 56 | Calcite (Iceland spar), showing its characteristic rhombohedral cleavage | 138 |
| 57 | Cube, octahedron, dodecahedron | 139 |
| 58. | Tetragonal prism and pyramid | 139 |

| FIG | | PAGE |
|---|---|---|
| 59 | Orthorhombic prism | 139 |
| 60 | Hexagonal prism, rhombohedron, and scalenohedron | 140 |
| 61 | Monoclinic prism Crystal of Augite | 140 |
| 62 | Triclinic prism Crystal of Albite felspar | 140 |
| 63. | Section of a pebble of Chalcedony | 142 |
| 64 | Piece of Hæmatite, showing the nodular external form and the internal crystalline structure | 143 |
| 65 | Octahedral crystals of Magnetite in chlorite-schist | 144 |
| 66 | Dendritic markings due to arborescent deposit of earthy manganese oxide | 145 |
| 67 | Cavity in a lava, filled with zeolite which has crystallised in long slender needles | 147 |
| 68 | Hornblende crystal | 148 |
| 69 | Magnified section of an Olivine crystal | 148 |
| 70 | Calcite in the form of "nail-head spar" | 150 |
| 71 | Calcite in the form of dog-tooth spar | 150 |
| 72 | Sphærosiderite or Clay-ironstone concretion enclosing portion of a fern | 151 |
| 73 | Gypsum crystals | 152 |
| 74 | Group of fluor-spar crystals | 153 |
| 75 | Concretions | 155 |
| 76 | Section of a Septarian nodule, with coprolite of a fish as a nucleus | 156 |
| 77 | Piece of Oolite | 157 |
| 78 | Piece of Pisolite | 157 |
| 79 | Cavities in quartz containing liquids (magnified) | 158 |
| 80 | Various forms of Crystallites (highly magnified) | 159 |
| 81. | Porphyritic structure | 160 |
| 82 | Spherulitic and fluxion-structure | 161 |
| 83 | Schistose structure | 162 |
| 84 | Brecciated structure—volcanic breccia, a rock composed of angular fragments of lava, in a paste of finer volcanic debris | 165 |
| 85 | Conglomerate | 166 |
| 86. | Concretionary forms assumed by Dolomite, Magnesian Limestone Durham | 172 |
| 87 | Weathered surface of a limestone composed of the broken stems of encrinites | 175 |
| 88 | Group of crystals of felspar, quartz, and mica, from a cavity in the Mourne Mountain granite | 178 |
| 89 | Columnar basalts of the Isle of Staffa, resting upon tuff (to the right is Fingal's Cave) | 185 |
| 90 | Section of stratified rocks | 193 |
| 91 | Section showing alternation of beds | 195 |
| 92. | False-bedded sandstone | 196 |

| FIG | | PAGE |
|---|---|---|
| 93 | Ripple-marked surface of sandstone | 197 |
| 94 | Cast of sun-cracked surface preserved in the next succeeding layer of sediment | 198 |
| 95. | Rain-prints on fine mud | 199 |
| 96 | Regular alternation of limestone and shale, Greenhorn formation (Cretaceous), Colorado | 200 |
| 97 | Vertical trees (*Sigillaria*) in sandstone, Swansea (Logan) | 202 |
| 98 | Hills formed out of horizontal sedimentary rocks | 203 |
| 99 | Section of Overlap | 204 |
| 100 | Unconformability | 204 |
| 101. | Joints in a stratified rock | 208 |
| 102 | Dip and Strike | 210 |
| 103 | Clinometer | 210 |
| 104 | Dip, Strike, and Outcrop | 211 |
| 105 | Inclined strata shown to be parts of curves | 212 |
| 106 | Curved strata (Anticlinal fold), near St Abb's Head | 213 |
| 107 | Curved strata (Synclinal fold) near Banff | 214 |
| 108 | Anticlines and Synclines | 215 |
| 109 | Section of the Grosse Windgalle (10,482 feet), Canton Uri, Switzerland, showing crumpled and inverted strata thrown into a flat fold (after Heim) | 215 |
| 110 | Distortion of fossils by the shearing of rocks | 216 |
| 111 | Curved and cleaved rocks Coast of Wigtonshire | 217 |
| 112 | Examples of normal Faults | 218 |
| 113 | Sections to show the relations of Plications to reversed Faults | 219 |
| 114 | Throw of a Fault | 219 |
| 115 | Section showing Thrust-planes, Loch Maree, Scotland | 220 |
| 116. | Ordinary unaltered red sandstone, Keeshorn, Ross-shire (magnified) | 222 |
| 117 | Sheared red sandstone forming now a micaceous schist, Keeshorn, Ross-shire (magnified) | 222 |
| 118 | Outline and section of a Boss traversing stratified rocks | 226 |
| 119 | Ground-plan of Granite-boss with ring of Contact-Metamorphism | 227 |
| 120 | Sill or Intrusive Sheet | 228 |
| 121. | Interstratified or Contemporaneous Sheets | 229 |
| 122. | Section to illustrate evidence of contemporaneous volcanic action | 229 |
| 123 | Succession of lava-sheets and volcanic conglomerates, Cañon of Yellowstone River, Yellowstone Natural Park | 231 |
| 124 | Map of Dykes near Muirkirk, Ayrshire | 233 |
| 125. | Section of a Volcanic neck | 233 |
| 126 | Section of a Mineral vein | 235 |
| 127 | Common Cockle (*Cardium edule*) | 241 |
| 128 | Fragment of crumpled Schist | 259 |

| FIG. | | PAGE |
|---|---|---|
| 129. | Fucoid-like impression (*Eophyton Linneanum*) from Cambrian rocks ($\frac{1}{3}$) | 269 |
| 130 | *Oldhamia radiata* (natural size), Ireland | 270 |
| 131 | Hydrozoon from the Cambrian rocks | 270 |
| 132 | Cambrian Trilobites | 272 |
| 133 | Cambrian Brachiopod (*Lingulella Davisii*), natural size | 273 |
| 134 | *Chondrites verisimilis*, natural size | 277 |
| 135 | Graptolites from Silurian rocks | 278 |
| 136 | Silurian Corals | 279 |
| 137. | Silurian Echinoderms | 280 |
| 138. | Filled-up Burrows or Trails left by a sea-worm on the bed of the Silurian sea (*Lumbricaria antiqua*, $\frac{1}{3}$) | 281 |
| 139. | Lower and Upper Silurian Trilobites | 282 |
| 140 | Silurian Phyllocarid Crustacean | 283 |
| 141 | Silurian Brachiopods | 283 |
| 142 | Silurian Lamellibranch | 284 |
| 143 | Silurian Gasteropod | 284 |
| 144 | Silurian Cephalopods | 285 |
| 145 | Plants of the Devonian period | 288 |
| 146 | Overlapping scales of an Old Red Sandstone fish | 290 |
| 147 | Scale-covered Old Red Sandstone fishes | 290 |
| 148 | Old Red Sandstone Placoderms | 291 |
| 149 | Devonian Eurypterid Crustacean | 292 |
| 150 | Devonian Trilobites | 292 |
| 151 | Devonian Corals | 293 |
| 152 | Devonian Brachiopods | 294 |
| 153 | Devonian Lamellibranch and Cephalopod | 294 |
| 154 | Section of part of the Cape Breton coal-field, showing a succession of buried trees and land-surfaces | 299 |
| 155 | Carboniferous Ferns | 300 |
| 156 | Carboniferous Lycopod | 301 |
| 157 | Carboniferous Equisetaceous Plants | 302 |
| 158 | Sigillaria with Stigmaria roots | 302 |
| 159 | *Cordaites alloiodus* | 303 |
| 160 | Carboniferous Scorpion | 304 |
| 161 | Carboniferous Foraminifer | 306 |
| 162 | Carboniferous Rugose Corals | 306 |
| 163 | Carboniferous Sea-Urchin | 307 |
| 164. | Carboniferous Crinoid | 307 |
| 165 | Carboniferous Blastoid | 307 |
| 166 | Carboniferous Trilobite | 307 |
| 167 | Carboniferous Polyzoon | 308 |
| 168 | Carboniferous Brachiopods | 309 |

| FIG. | | PAGE |
|---|---|---|
| 169. | Carboniferous Lamellibranchs | 309 |
| 170 | Carboniferous Gasteropods | 310 |
| 171 | Carboniferous Pteropod | 310 |
| 172 | Carboniferous Cephalopods | 310 |
| 173 | Carboniferous Fishes | 311 |
| 174 | Permian Plants | 317 |
| 175 | Permian Brachiopods | 318 |
| 176 | Permian Lamellibranchs | 319 |
| 177 | Permian Ganoid Fish | 319 |
| 178 | Permian Labyrinthodont | 320 |
| 179 | Triassic Plants | 325 |
| 180 | Triassic Crinoid | 326 |
| 181 | Triassic Lamellibranchs | 327 |
| 182 | Triassic Cephalopods | 327 |
| 183 | Triassic Lizard | 328 |
| 184 | Triassic Crocodile (Scutes) | 328 |
| 185 | Triassic Monotreme Teeth | 328 |
| 186. | Jurassic Cycad | 333 |
| 187 | Jurassic reef-building Coral | 333 |
| 188 | Jurassic Crinoid | 334 |
| 189 | Jurassic Sea-urchin | 334 |
| 190 | Jurassic Lamellibranchs | 335 |
| 191 | Jurassic Ammonites | 336 |
| 192 | Jurassic Belemnite | 336 |
| 193 | Jurassic Crustacean | 337 |
| 194 | Jurassic Fish | 338 |
| 195 | Jurassic Sea-lizard | 338 |
| 196 | Jurassic Pterosaur | 339 |
| 197 | Jurassic Bird | 340 |
| 198 | Jurassic Marsupial | 341 |
| 199 | Cretaceous Plants | 350 |
| 200 | Cretaceous Foraminifera | 351 |
| 201 | Cretaceous Sponge | 351 |
| 202. | Cretaceous Sea-urchins | 352 |
| 203 | Cretaceous Lamellibranchs | 353 |
| 204 | Cretaceous Lamellibranchs | 353 |
| 205 | Cretaceous Cephalopods | 354 |
| 206 | Cretaceous Fish | 355 |
| 207 | Cretaceous Deinosaur | 356 |
| 208 | Eocene Plant | 369 |
| 209 | Eocene Molluscs | 369 |
| 210. | Eocene Mammal | 370 |
| 211. | Skull of *Uintatherium ingens* | 371 |

| FIG. | | PAGE |
|---|---|---|
| 212 | Typical "Bad Lands," carved by denudation out of Tertiary strata at the base of Scott's Bluff, Western Nebraska | 375 |
| 213. | Oligocene Molluscs | 377 |
| 214. | Miocene Plants | 382 |
| 215 | *Mastodon angustidens* | 383 |
| 216 | Skull of *Deinotherium giganteum* | 384 |
| 217 | Pliocene Plants | 389 |
| 218. | Pliocene Marine Shells | 390 |
| 219 | *Helladotherium Duvernoyi*—a gigantic animal belonging to the same family as the living giraffe, Pikermi, Attica | 394 |
| 220 | Pleistocene or Glacial Shells | 401 |
| 221 | Mammoth, from the skeleton in the Musée Royal, Brussels | 402 |
| 222 | Back view of skull of musk-sheep, Brick-earth, Crayford, Kent | 402 |
| 223 | Palæolithic Implements | 408 |
| 224 | Antler of Reindeer found at Bilney Moor, East Dereham, Norfolk | 410 |
| 225 | Neolithic Implements | 411 |

# CHAPTER I

## INTRODUCTORY

THE main features of the dry land on which we live seem to remain unchanged from year to year. The valleys and plains familiar to our forefathers are still familiar to us, bearing the same meadows and woodlands, the same hamlets and villages, though generation after generation of men has meanwhile passed away. The hills and mountains now rise along the sky-line as they did long centuries ago, catching as of old the fresh rains of heaven and gathering them into the brooks and rivers which, through unknown ages, have never ceased to flow seawards. So steadfast do these features appear to stand, and so strong a contrast do they offer to the shortness and changeableness of human life, that they have become typical in our minds of all that is ancient and durable. We speak of the firm earth, of the everlasting hills, of the imperishable mountains, as if, where all else is fleeting and mutable, these forms at least remain unchanged.

And yet attentive observation of what takes place from day to day around us shows that the surface of a country is not now exactly as it used to be. We notice various changes of its topography going on now, which have doubtless been in progress for a long time, and the accumulated effect of which may ultimately transform altogether the character of a landscape. A strong gale, for instance, will level thousands of trees in its pathway, turning a tract of forest or woodland into a space which may eventually become a quaking morass, to be still later perhaps turned into arable ground by the farmer. A flooded river will in a few hours cut away large slices from its banks, and spreading over field and meadows, will bury many acres of fertile land under a covering of barren sand and shingle. A long-continued, heavy rain, by

loosening masses of earth or rock on steep slopes, causes destructive landslips. A hard frost splinters the naked fronts of crags and cliffs, and breaks up bare soil In short, every shower of rain and gust of wind, if we could only watch them narrowly enough, would be found to have done something towards modifying the surface of the land. Along the sea-margin, too, how ceaseless is the progress of change! In most places, the waves are cutting away the land, sometimes even at so fast a rate as two or three feet in a year Here and there, on the other hand, they cast sand and silt ashore so as to increase the breadth of the dry land.

These are ordinary everyday causes of alteration, and though singly insignificant enough, their united effect after long centuries cannot but be great. From time to time, however, other less frequent but more powerful influences come into play. In most large regions of the globe, the ground is often convulsed by earthquakes, many of which leave permanent scars upon the surface of the land Volcanoes, too, in many countries pour forth streams of molten rock and showers of dust and cinders that bury the surrounding districts and greatly alter their appearance.

Turning to the pages of human history, we find there the records of similar changes in bygone times. Lakes, on which our rude forefathers paddled their canoes and built their wattled island-dwellings, have wholly disappeared Bogs, over whose treacherous surface these early hunters could not follow the chase of deer or elk or bison, have become meadows and fields Forests, where they hunted the wild boar, have been turned into grassy pastures. Cities have been entirely destroyed by earthquakes or have been entombed under the piles of ashes discharged from a burning mountain So great have been the inroads of the sea that, in some instances, the sites of what a few hundred years ago were farms and hamlets, now lie under the sea half a mile or more from the modern shore. Elsewhere the land has gained upon the sea, and the harbours of an earlier time are now several miles distant from the coast-line

But man has naturally kept note only of the more impressive changes; in other words, of those which have had most influence upon his own doings. We may be certain, however, that there have been innumerable minor alterations of the surface of the land within human history, of which no chronicler has made mention, either because they seemed too trivial, or because they took place so imperceptibly as never to be noticed. Fortunately, in many cases, these mutations of the land have written their own memorials,

which can be as satisfactorily interpreted as the ancient manuscripts from which our early national history is compiled.

In illustration of the character of these natural chronicles, let us for a moment consider the subsoil beneath cities that have been inhabited for many centuries. In London, for example, when excavations are made for drainage, building, or other purposes, there are sometimes found, many feet below the level of the present streets, mosaic pavements and foundations, together with earthen vessels, bronze implements, ornaments, coins, and other relics of Roman time. Now, if we knew nothing, from actual authentic history, of the existence of such a people as the Romans, or of their former presence in England, these discoveries, deep beneath the surface of modern London, would prove that long before the present streets were built, the site of the city was occupied by a civilised race which employed bronze and iron for the useful purposes of life, had a metal coinage, and showed not a little artistic skill in its pottery, glass, and sculpture But down beneath the rubbish wherein the Roman remains are embedded, lie gravels and sands from which rudely-fashioned human implements of flint have been obtained. Whence we further learn that, before the civilised metal-using people appeared, an earlier race had been there, which employed weapons and instruments of roughly chipped flint.

That this was the order of appearance of the successive peoples that have inhabited the site of London is, of course, obvious But let us ask ourselves why it is obvious. We observe that there are, broadly speaking, three layers or deposits from which the evidence is derived The upper layer is that which contains the foundations and rubbish of modern London. Next comes that which encloses the relics of the Roman occupation. At the bottom lies the layer that preserves the scanty traces of the early flint-folk The upper deposit is necessarily the newest, for it could not be laid down until after the accumulation of those below it, which must, of course, be progressively older, as they are traced deeper from the surface. By the mere fact that the layers lie one above another, we are furnished with a simple clue which enables us to determine their relative time of formation. We may know nothing whatever as to how old they are, measured by years or centuries. But we can be absolutely certain of what is termed their "order of superposition," or chronological sequence (p. 247); in other words, we can be confident that the bottom layer came first and the top layer last.

This kind of observation and reasoning will enable us to detect almost everywhere proofs that the surface of the land has not always been what it is to-day. In some districts, for example, when the dark layer of vegetable soil is turned up which supports the plants that keep the land so green, there may be found below it sand and gravel, full of smooth well-rounded stones. Such materials are to be seen in the course of formation where water keeps them moving to and fro, as on the beds of rivers, the margins of lakes, or the shores of the sea. Wherever smoothed rolled pebbles occur, they point to the influence of moving water; so that we conclude, even though the site is now dry land, that the sand and gravel underneath it prove it to have been formerly under water. Again, below the soil in other regions, lie layers of oysters and other sea-shells. These remains, spread out like similar shells on the beach or bed of the sea at the present day, enable us to infer that where they lie the sea once rolled.

Pits, quarries, or other excavations that disclose still deeper layers of material, bring before us interesting and impressive testimony regarding the ancient mutations of the land. Suppose, by way of further illustration, that underneath a bed of sand full of oyster-shells, there lies a dark brown band of peat. This substance, composed of mosses and other water-loving plants, is formed in boggy places by the growth of marshy vegetation. Below the peat there might occur a layer of soft white marl full of lake-shells, such as may be observed on the bottoms of many lakes at the present time (compare Fig 39). These three layers—oyster-bed, peat, and marl—would present a perfectly clear and intelligible record of a curious series of changes in the site of the locality. The bottom layer of white marl with its peculiar shells would show that at one time the place was occupied by a lake. The next layer of peat would indicate that, by the growth of marshy vegetation, the lake was gradually changed into a morass. The upper layer of oyster-shells would prove that the ground was then submerged beneath the sea. The present condition of the ground shows that subsequently the sea retired and the locality passed into dry land as it is to-day.

It is evident that by this method of examination information may be gathered regarding early conditions of the earth's surface, long before the authentic dates of human history. Such inquiries form the subject of Geology, which is the science that investigates the History of the Earth. The records in which this history is chronicled are the soils and rocks under our feet. It is the task

of the geologist so to arrange and interpret these records as to show through what successive changes the globe has passed, and how the dry land has come to wear the aspect which it presents at the present time.

Just as the historian would be wholly unable to decipher the inscriptions of an ancient race of people unless a key had first been discovered to the language in which they are written, so the geologist would find himself baffled in his efforts to trace backward the history of the earth if he were not provided with a clue to the interpretation of the records in which that history is contained. Such a clue is furnished to him by a study of the operations of nature now in progress upon the earth's surface. Only in so far as he makes himself acquainted with these modern changes, can he hope to follow intelligently and successfully the story of earlier phases in the earth's progress. It will be seen that this truth has already been illustrated in the instances above given of the evidence that the surface of the land has not been always as it is now. The beds of sand and gravel, of oyster-shells, of peat and of marl, would have told us nothing as to ancient geography had we not been able to ascertain their origin and history by finding corresponding materials now in course of accumulation. To one ignorant of the peculiarities of fresh-water shells, the layer of marl would have conveyed no intelligible meaning. But knowing and recognising these peculiarities, we feel sure that the marl marks the site of a former lake. Thus the study of the Present supplies a key that unlocks the secrets of the Past.

In order, therefore, to trace back the history of the Earth, the geologist must begin by carefully watching the changes that now take place, and by observing how nature elaborates the materials that preserve more or less completely the record of these changes. In the following pages, I propose to follow this method of inquiry, and, as far as the subject will permit, to start with no assumptions which the learner cannot easily verify for himself. We shall begin with the familiar everyday operations of the air, rain, frost, and other natural agents. As these have been fully described in my *Elementary Lessons in Physical Geography*, it will not be needful here to consider them again in detail. We shall rather pass on to inquire in what various ways they are engaged in contributing to the formation of new mineral accumulations, and in thereby providing fresh materials for the preservation of the facts on which geological history is founded. Having thus traced how new rocks are formed, we may then proceed to arrange the similar rocks of

older time, marking what are the peculiarities of each and how they may best be classified.

If the labours of the geologist were concerned merely with the former mutations of the earth's surface,—how sea and land have changed places, how rivers have altered their courses, how lakes have been filled up, how valleys have been excavated, how mountains, peaks, and precipices have been carved, how plains have been spread out, and how the story of these revolutions has been written in enduring characters upon the very framework of the land,—he would feel the want of one of the great sources of interest in the study of the present face of nature. We naturally connect all modern changes of the earth's surface with the life of the plants and animals that flourish there, and more especially with their influence on the progress of Man himself If there were no similar connection of the ancient changes with once living things—if the history of the earth were merely one of dead inert matter—it would lose much of its interest for us. But happily that history includes the records of successive generations of plants and animals which, from early times, have peopled land and sea. Remains of these organisms have been preserved in the deposits of different ages, and can be compared and contrasted with those of the modern world.

To realise how such preservation has been possible, and how far the forms so retained afford an adequate picture of the life of the time to which they belonged, we must turn once more to watch how nature deals with this matter at the present time. Of the millions of flowers, shrubs, and trees which year after year clothe the land with beauty, how many relics are preserved? Where are the successive generations of insect, bird, and beast which have appeared in this country since man first set foot upon its soil? They have utterly vanished. If all their living descendants could suddenly be swept away, how could we tell that such plants and animals ever lived at all? It must be confessed that the vast majority of them leave no trace behind. Nevertheless we should be able to recover relics of some of them by searching in the comparatively few places where, at the present day, dead plants and animals are entombed and preserved. From the alluvial terraces of rivers, from the silt of lake-bottoms, from the depths of peat-mosses, from the floors of subterranean caverns, from the incrustations left by springs, we might recover traces of some at least of the living things that people the land. And from these fragmentary and incomplete records we might conjecture what

may have been the general character of the life of the time. By searching the similar records of earlier ages, the geologist has brought to light many profoundly interesting vestiges of vegetation and of animal life belonging to types that have long since passed away

It must be evident, however, that were we to confine our inquiries merely to the Earth's surface, we should necessarily gain only an imperfect view of the general history of our globe. Beneath that surface, as volcanoes show, there lies a hot interior, which must have profoundly influenced the changes of the outer parts or crust of the planet The study of volcanoes enables us to penetrate, as it were, a little way into that interior, and to understand some of the processes in progress there. But our knowledge of the inside of the Earth can obviously be based only to a very limited extent on direct observation, for man cannot penetrate far below the surface. The deepest mines do not go deep enough to reach materials differing in any essential respect from those visible above ground. Nevertheless, by inference from such observations as can be made, and by repeated and varied experiments in laboratories, imitating as closely as can be devised what may be supposed to be the conditions that exist deep within the globe, some probable conclusions can be drawn even as to the changes that take place in those deeper recesses that lie for ever concealed from our eyes. These conclusions will be stated in later chapters of this book, and the rocks will be described, on the origin of which they appear to throw light

I have compared the soils and rocks with which geology deals to the records out of which the historian writes the chronicles of a nation We might vary the simile by likening them to the materials employed in the construction of a great building It is of course interesting enough to know what kinds of marble, granite, mortar, wood, brass, or iron have been chosen by an architect. But much more important is it to inquire how these various substances have been grouped together so as to form such a building. In like manner, besides the nature and mode of origin of the various rocks of which the visible and accessible part of the earth consists, we ought to know how these varied substances have been arranged so as to build up what we can see of the outer part or crust of our globe. In short, we should try to trace what may be called the architecture of the planet, noting how each variety of rock occupies its own characteristic place, and how they are all grouped and braced together in the solid framework

of the land. This then will be the next subject for consideration in this volume.

But in a great historical edifice, like one of the Gothic minsters of Europe, for example, there are often several different styles. A student of architecture can detect these distinctions, and by their means can show that a cathedral has not been completed in one age; that it may even have been partially destroyed and rebuilt during successive centuries, only finally taking its present form after many political vicissitudes and many changes of architectural taste. Each edifice has thus a separate history, which is recorded by the way the materials have been shaped and put together in the various parts of the masonry. So it is with the architecture of the Earth. We have evidence of many demolitions and rebuildings, and the story of their general progress can still be deciphered among the rocks. It is the business of Geology to trace out that story, to put all the scattered materials together, and to make known through what a long succession of changes the Earth has reached its present state. An outline of what science has accomplished in this task will form the last and concluding part of this book.

In the following chapters I wish two principles to be kept steadily in view. In the first place, looking upon Geology as the study of the Earth's history, we need not at first concern ourselves with any details, save those that may be needed to enable us clearly to understand what the general character and progress of this history have been. In a science which embraces so vast a range as Geology, the multiplicity of facts to be examined and remembered may seem at first to be almost overwhelming. But a selection of the essential facts is sufficient to give the learner a clear view of the general principles and conclusions of the science, and to enable him to enter with intelligence and interest into more detailed treatises. In the second place, Geology is essentially a science of observation. The facts with which it deals should, as far as possible, be verified by our own personal examination. We should lose no opportunity of seeing with our own eyes the actual progress of the changes which it investigates, and the proofs which it adduces of similar changes in the far past. To do this will lead us into the fields and hills, to the banks of rivers and lakes, and to the shores of the sea. We can hardly take any country walk, indeed, in which with duly observant eye we may not detect either some geological operation in actual progress, or the evidence of one which was completed long ago. Having

learnt what to look for and how to interpret it when seen, we are as it were gifted with a new sense. Every landscape comes to possess a fresh interest and charm, for we carry about with us everywhere an added power of enjoyment, whether the scenery has long been familiar or presents itself for the first time. I would therefore seek at the outset to impress upon those who propose to read the following pages, that one of the main objects with which this book is written is to foster a habit of observation, and to serve as a guide to what they are themselves to look for, rather than merely to relate what has been seen and determined by others. If they will so learn these lessons, I feel sure that they will never regret the time and labour they may spend over the task.

# PART I

# THE MATERIALS FOR THE HISTORY OF THE EARTH

## CHAPTER II

### THE INFLUENCE OF THE ATMOSPHERE IN THE CHANGES OF THE EARTH'S SURFACE

IN the history of mankind no sharp line can be drawn between the events that are happening now or have happened within the last few generations, and those that took place long ago, and which are sometimes, though inaccurately, spoken of as historical Every people is enacting its history to-day just as fully as it did many centuries ago The historian recognises this continuity in human progress. He knows that the feelings and aspirations which guided mankind in old times were essentially the same influences that impel them now, and therefore that the wider his knowledge of his fellowmen of the present day, the broader will be his grasp in dealing with the transactions of former generations. So too is it with the history of the Earth. That history is in progress now as really as it has ever been, and its events are being recorded in the same way and by the same agents as in the far past Its continuity has never been broken. Obviously, therefore, if we would explore its records "in the dark backward and abysm of time," we should first make ourselves familiar with the manner in which these records are being written from day to day before our eyes.

In this first Part, attention will accordingly be given to the changes in progress upon the Earth at the present time, and to the various ways in which the passing of these changes is chronicled

in natural records. We shall watch the actual transaction of geological history, and mark in what way its incidents inscribe themselves on the page of the earth's surface.[1] Every day and hour witness the enacting of some geological event, trifling and transient or stupendous and durable. Sometimes the event leaves behind it only an imperceptible trace of its passage, at other times it graves itself almost imperishably in the annals of the globe. In tracing the origin and development of these geological annals of the present time, we shall best qualify ourselves for deciphering the records of the early revolutions of the planet. We are thereby led to study the various chronicles compiled respectively by the air, rain, rivers, springs, glaciers, the sea, plants and animals, volcanoes and earthquakes—in other words, all the deposits left by the operations of these agents, the scars or other features made by them upon the earth's surface, and all other memorials of geological change. Having learnt how modern deposits are produced, and how they preserve the story of their origin, we shall then be able to group with them the corresponding deposits of earlier times, and to embrace all the geological records, ancient as well as modern, in one general scheme of classification. Such a scheme will enable us to see the continuity of the materials of geological history, and will fix definitely for us the character and relative position of all the chief rocks out of which the visible part of the globe is composed.

**Weathering.**—The gradual change that overtakes everything on the face of the earth is expressed in all languages by familiar phrases which imply that the mere passing of time is the cause of the change. As Sir Thomas Browne quaintly said more than two hundred years ago, "time antiquates antiquities, and hath an art to make dust of all things." We speak of the dust of antiquity and the gnawing tooth of time. We say that things are time-eaten, worn with age, crumbling under a weight of years. Nothing suggests such epithets so strikingly as an old building. We know that the masonry at first was smooth and fresh; but now we describe it as weather-beaten, decayed, corroded. So distinctive is this appearance that it is always looked for in an ancient piece of stone-work; and if not seen, its absence at once suggests a doubt whether the masonry can really be old. No

[1] For descriptions of the ordinary operations of geological agents the reader is referred to my *Elementary Lessons in Physical Geography*. My object now is to direct attention to what is most enduring in these operations, and in what various ways they form permanent geological records

matter of what varieties of stone the edifice may have been built, a few generations may be enough to give them this look of venerable antiquity. The surface that was left smoothly polished by the builders grows rough and uneven, with scars and holes eaten into it (Fig. 1). Portions of the original polish that may here and there have escaped, serve as a measure of how much has actually been removed from the rest of the surface.

Now, if in the lapse of time, stone which has been artificially dressed is wasted away, we may be quite certain that the same stone in its natural position on the slope of a hill or valley, or by the edge of a river or of the sea, must decay in a similar way. Indeed, an examination of any crumbling building will show that, in proportion as the chiselled surface disappears, the stone puts on the ordinary look which it wears where it has never been cut by man, and where only the finger of time has touched it. Could we remove some of the decayed stones from the building and insert them into a natural crag or cliff of the same kind of stone, their peculiar time-worn aspect would be found to be so exactly that of the rest of the cliff that probably no one would ever suspect that a mason's tools had once been upon them.

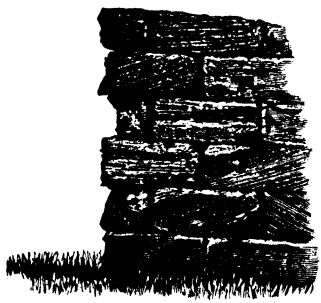


FIG. 1.—Weathering of rock, as shown by old masonry. (The "false-bedding" and other original structures of the stone are revealed by weathering.)

From this identity of surface between the time-worn stones of an old building and the stone of a cliff we may confidently infer that the decay so characteristic of ancient masonry is as marked upon natural faces of rock. The gradual disappearance of the artificial smoothness given by the mason, and its replacement by the ordinary natural rough surface of the stone, shows that this natural surface must also be the result of decay. And as the peculiar crumbling character is universal, we may be sure that the decay with which it is connected must be general over the globe.

But the mere passing of time obviously cannot change anything, and to say that it does is only a convenient figure of speech. It is not time, but the natural processes which require time for their

work, that produce the widespread decay over the surface of the earth. Of these natural processes, there are four that specially deserve consideration—changes of temperature, saturation and desiccation, frost, and rain.

(1) Changes of Temperature.—In countries where the days are excessively hot, with nights correspondingly cool, the surfaces of rocks heated sometimes, as in parts of Africa, up to more than 130° Fahr. by a tropical sun, undergo considerable expansion in consequence of this increase of temperature. At night, on the other hand, the rapid radiation quickly chills the stone and causes it to contract. Hence the superficial parts, being in a perpetual state of strain, from time to time suddenly split open, or gradually peel off. The face of a cliff is thus worn slowly backward, and the prostrate blocks that fall from it are reduced to smaller fragments and finally to dust. Where, as in Europe and the settled parts of North America, the contrasts of temperature are not so marked, the same kind of waste takes place in a less striking manner.

(2) Saturation and Desiccation.—Another cause of the decay of the exposed surfaces of rocks is to be sought in the alternate soaking of them with rain and drying of them in sunshine, whereby the component particles of the stone are loosened and fall to powder. Some kinds of stone freshly quarried and left to this kind of action are rapidly disintegrated. The rock called shale (see p. 168) is peculiarly liable to decay from this cause. The cliffs into which it sometimes rises show at their base long trails of rubbish entirely derived from its waste.

(3) Frost.—A third and familiar source of decay in stone exposed to the atmosphere is to be found in the action of Frost. The water that falls from the air upon the surface of the land soaks into the soil and into the pores of rocks. When the temperature of the air falls below the freezing point, the imprisoned moisture expands as it passes into ice, and in expanding pushes aside the particles between which it is entangled. Where this takes place in soil, the pebbles and the grains of sand and earth are separated from each other by the ice that shoots between them. They are all frozen into a solid mass that rings like stone under our feet; but, as soon as a thaw sets in, the ice that formed the binding cement passes into water which converts the soil into soft earth or mud. This process, repeated winter after winter, breaks up the materials of the soil, and enables

them to be more easily made use of by plants, and more readily blown away by wind or washed off by rain. Where the action of frost affects the surface of a rock, the particles separated from each other are eventually blown or washed away, or the rock peels off in thin crusts or breaks up into angular pieces, which are gradually disintegrated and removed.

(4) Rain.—One further cause of decay may be sought in the remarkable power possessed by Rain of chemically corroding stones. In falling through the atmosphere, rain absorbs the gases of the air, and with their aid attacks surfaces of rock. With the oxygen thus acquired, it *oxidises* those substances which can still take more of this gas, causing them to *rust* (pp. 130, 132). As a consequence of this alteration, the cohesion of the particles is usually weakened, and the stone crumbles down. With the aid of its carbon-dioxide, or carbonic acid, rain-water dissolves and removes some of the more soluble ingredients in the form of carbonates, thereby also usually loosening the component particles of the stone. In general, the influence of rain is to cause the exposed parts of rocks to rot from the surface inward. Where the ground is protected with vegetation, the decay is no doubt retarded; but in the absence of vegetation, the outer crust of the decayed layer is apt to be washed off by rain, or when dried to powder may be blown away and scattered by wind As fast as it is removed from the surface, however, it is renewed underneath by the continued soaking of rain into the stone.

In bare limestone districts, the solvent action of rain-water gives rise to some singular forms of ground. Pure limestone being wholly soluble, its surface is dissolved without leaving any residue from which soil could be formed, so that in many places wide spaces of bare verdureless stone are exposed. On these the rain, acting with special vigour along the numerous lines of division or "joints" (p. 207) by which the rock is traversed, hollows out such an intricate assemblage of furrows, channels, clefts, fissures, and gullies, that the surface becomes in places hardly passable. Some of these gullies descend to a great depth underground, where they join the system of subterranean tunnels and caverns described in Chapter V. (p. 61), where this subject is more fully explained.

Hence one of the first lessons to be learnt—when from the common evidence that lies around us we seek to know what has been the history of the ground on which we live—is one of

ceaseless decay. All over the land, in all kinds of climates, and from various causes, bare surfaces of soil and rock yield to the influences of the atmosphere or weather. The decay thus set in motion is commonly called "weathering." That it may often be comparatively rapid is familiarly and instructively shown in buildings or open-air monuments of which the dates are precisely known. Marble tombstones in the graveyards of large towns, for example, hardly keep their inscriptions legible for even so long as a century. Before that time, the surface of the stone has crumbled away into a kind of sand. Everywhere over the land, the weather-eaten surfaces, the crumbling crust of decayed stone, and the scattered blocks and trains of rubbish, tell their tale of universal waste.

It is well to take numerous opportunities of observing the progress of this decay in different situations and on various kinds of materials. We can thus best realise the important part which weathering must play in the changes of the earth's surface, and we prepare ourselves for the consideration of the next question that arises, What becomes of all the rotted material?—a question to answer which leads us into the very foundations of geological history

Openings from the soil down into the rock underneath often afford instructive lessons regarding the decay of the surface of the land. Fig. 2, for instance, is a drawing of one of these sections, in which a gradual passage may be traced from solid sandstone (*a*) underneath up into broken-up sandstone (*b*), and thence into the earthy layer (*c*) that supports the vegetation of the surface. Traced from below upwards, the rock is found to become more and more broken and crumbling, with an increasing number of rootlets that strike freely through it in all directions, until it passes insensibly into the uppermost dark layer of vegetable soil or humus. This dark layer owes its characteristic brown or black colour mainly to the decaying remains of vegetation diffused through it. Again, granite in its unweathered state is a hard, compact, crystalline rock that may be quarried out in large solid blocks (*a* in Fig. 3), yet when traced upward to within a few feet from the surface it

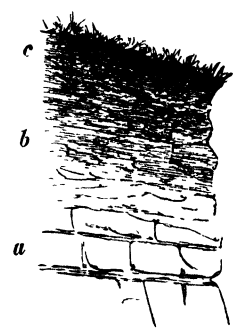



FIG. 2.—Passage of sandstone upwards into soil.

may be seen to have been split by innumerable rents into fragments which are nevertheless still lying in their original position. As these fragments are attacked by percolating moisture, their surfaces decay, leaving the still unweathered parts as rounded blocks (*b*), which might at first be mistaken for transported boulders. They are, however, parts of the rock broken up in place, and not fragments that have been carried from a distance. The little quartz-veins that traverse the solid granite can be recognised running through the decayed and fresh parts alike. But, besides being broken into pieces, the granite, owing to the solution and removal of some part of its substance, rots away and loses its cohesion. Some of the smaller pieces can be crumbled down between the fingers, and this decay increases upwards, until the rock becomes a mere sand or sandy clay in which a few harder kernels are still left. Into this soft layer roots may descend from the surface, and, like the sandstone, the granite merges above into the overlying soil (*c*).

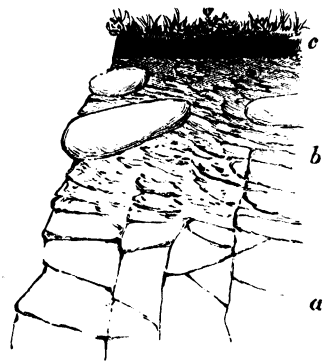



FIG. 3.—Passage of granite upwards into soil.

Soil and Subsoil.—In such sections as the foregoing, three distinct layers can be recognised which pass into each other. At the bottom lies the *rock*, either undecayed or at least still fresh enough to show its true nature. Next comes the broken-up crumbling layer through which stray roots descend, and which is known as the *subsoil*. At the top lies the dark band, crowded with rootlets and forming the true *soil*. These three layers obviously represent successive stages in the decay of the surface of the land. The soil is the layer of most complete decay. The subsoil is an intermediate band where the progress of decomposition has not advanced so far, while the shattered rock underneath shows the earlier stages of disintegration. Vegetation sends its roots and rootlets through the rotted rock. As the plants die, they are succeeded by others, and the rotted remains of their successive generations gradually darken the uppermost decomposed layer. Worms, insects, and larger animals that may die

on the surface, likewise add their mouldering remains to this uppermost deposit. And thus from animals and plants there is furnished to the soil that *organic matter* on which its fertility so much depends.

The very decay of the vegetation helps to promote that of the underlying rock, for it supplies various organic acids ready to be absorbed by percolating rain-water, the power of which to decompose rocks is thereby increased. A complete series of chemical changes is thus set on foot. The organic matter in its decay abstracts oxygen from the air and from surrounding objects. Rocks and minerals have their insoluble peroxides reduced to protoxides which, in combination with organic acids or with carbonic acid, are removed in solution. By this abstraction, red rocks and soils are bleached, and the coherence of even compact stones is weakened, until they crumble down into soil. The carbonates, such for instance as the carbonate of iron, are sparingly soluble in water containing carbonic acid, but some of them are then liable to oxidation, when they become insoluble, and are precipitated to the bottom. Hence ferruginous minerals are decomposed by decaying organic matter, and their iron, removed first as protoxide, is deposited elsewhere as peroxide. In this way beds of haematite and limonite (p. 143) may be formed.

It is obvious, then, that in answer to the question, What becomes of the rotted material produced by weathering? we may confidently assert that, over surfaces of land protected by a cover of vegetation, this material in large measure accumulates where it is formed. Such accumulation will naturally take place chiefly on flat or gently inclined ground. Where the slope is steep, the decomposed layer will tend to travel down-hill by mere gravitation, and to be further impelled downward by descending rain-water.

If there is so intimate a connection between the soil at the surface and the rock underneath, we can readily understand that soils should vary from one district to another, according to the nature of the underlying rocks. Clays will produce clayey soil, sandstones, sandy soil, or, where these two kinds of rock occur together, they may give rise to sandy clay or loam. Hence, knowing what the underlying rock is, we may usually infer what must be the character of the overlying soil, or, from the nature of the soil, we may form an opinion respecting the quality of the rock that lies below.

But it will probably occur to the thoughtful observer that when once a covering of soil and subsoil has been formed over a level

piece of ground, especially where there is also an overlying carpet of verdure, the process of decay should cease—the very layer of rotted material coming eventually to protect the rock from further disintegration. Undoubtedly, under these circumstances, weathering is reduced to its feeblest condition. But that it still continues will be evident from some considerations, the force of which will be better understood a few pages further on. If the process were wholly arrested, then in course of time plants growing on the surface would extract from the soil all the nutriment they could get out of it, and with the increasing impoverishment of the soil, they would dwindle away and finally die out, until perhaps only the simpler forms of vegetation would grow on the site. Something of this kind not improbably takes place where forests decay and are replaced by scrub and grass. But the long-continued vigorous growth of the same kind of plants upon a tract of land doubtless indicates that in some way the process of weathering is not entirely arrested, but that, as generation succeeds generation, the plants are still able to draw nutriment from fresh portions of decomposed rock. A cutting made through the soil and subsoil shows that roots force their way downward into the rock, which splits up and allows percolating water to soak downwards through it. The subsoil thus gradually eats its way into the solid rock below. Influences are at work also, whereby there is an imperceptible removal of material from the surface of the soil. Notable among these influences are Rain, Wind, and Earthworms.

Wherever soil is bare of vegetation it is directly exposed to removal by Rain. Ground is seldom so flat that rain may not flow a little way along the surface before sinking underneath. In its flow, it carries off the finer particles of the soil. These may travel each time only a short way, but as the operation is repeated, they are in the course of years gradually moved down to lower ground or to some runnel or brook that sweeps them away seaward. Both on gentle and on steep slopes, this transporting power of rain is continually removing the upper layer of bared soil.

Where soil is exposed to the sun, it is liable to be dried into mere dust, which is borne off by Wind. How readily this may happen is often strikingly seen after dry weather in spring-time. The earth of ploughed fields becomes loose and powdery, and clouds of its finer particles are carried up into the air and transported to other farms, as gusts of wind sweep across. "March dust," which is a proverbial expression, may be remembered as an

illustration of one way in which the upper parts of the soil are removed (see p. 21).

Even where a grassy turf protects the general surface, bare places may commonly be found whence this covering has been removed. Rabbits, moles, and other animals throw out soil from their burrows. Mice sometimes lay it bare by eating the pasture down to the roots. The common Earthworms bring up to daylight in the course of a year an almost incredible quantity of it in their castings. Darwin estimated that this quantity is in some places not less than 10 tons per annum over an acre of ground. Only the finest particles of mould are swallowed by worms and voided by them at the surface, and it is precisely these which are most apt to be washed off by rain or to be dried and blown away as dust by the wind. Where it remains on the ground, the soil brought up by worms covers over stones and other objects lying there, which consequently seem to sink into the earth. The operations of these animals cause the materials of the soil to be thoroughly mixed. In tropical countries, the termite or "white ant" conveys a prodigious amount of fine earth up into the open air. With this material it builds hills sometimes 60 feet high and visible for a distance of several miles; likewise tunnels and chambers, which it plasters all over the stems and branches of trees, often so continuously that hardly any bark can be seen. The fine soil thus exposed is liable to be blown away by the wind or washed off by the fierce tropical rains

Although, therefore, the layer of vegetable soil which covers the land appears to be a permanent protection, it does not really prevent a large amount of material from being removed even from grassy ground It forms the record of the slow and almost imperceptible geological changes that affect the regions where it accumulates,—the quiet fall of rain, the gradual rotting away of the upper part of the underlying rock, the growth and decay of a long succession of generations of plants, the ceaseless labours of the earthworm, the scarcely appreciable removal of material from the surface by the action of rain and wind, and the equally insensible descent of the crumbling subsoil farther and farther into the solid stone below Having learnt how all this is told by the soil beneath our feet, we should be ready to recognise in the soil of former ages a similar chronicle of quiet atmospheric disintegration.

Talus.—Besides soil and subsoil, there are other forms in which decomposed rock accumulates on the surface of the land.

Where a large mass of bare rock rises up as a steep bank or cliff, it is liable to constant degradation, and the materials detached from its surface accumulate down the slopes, forming what is known as a *Talus* (Fig. 4). In mountainous or hilly regions,

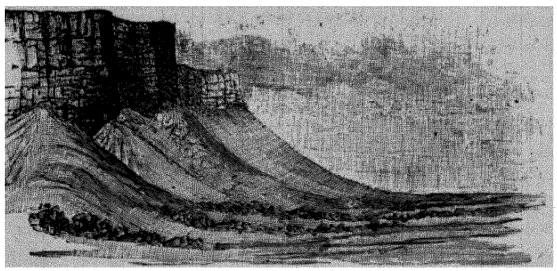


FIG. 4.—Talus-slopes at the foot of a line of cliffs.

where rocky precipices rise high into the air, there gather at their feet and down their clefts long trails or *screes* of loose blocks that have been split off from them by the weather. Such slopes, especially where they are not too steep, and where the rubbish that forms them is not too coarse, may be more or less covered with vegetation, which in some measure arrests the descent of the debris. But from time to time, during heavy rains, deep gullies are torn out of them by rapidly formed torrents, which sweep down their materials to lower levels (Fig. 14). The sections laid bare in these gullies show that the rubbish is arranged in more or less distinct layers which lie generally parallel with the surface of the slope; in other words, it is rudely stratified, and its layers or strata are inclined at the angle of the declivity which seldom exceeds 35°.

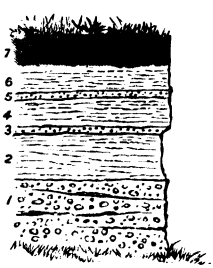



FIG. 5.—Section of rain-wash or brick-earth. 7. Vegetable soil. 6. Brick-earth. 5. White sand. 4. Brick-earth. 3. White sand. 2. Brick-earth. 1. Gravel with seams of sand.

Rain-wash, Brick-earth.—On more gentle slopes, even where no bare rock projects into the air, the fall of rain gradually washes down the upper parts of the soil to lower levels. Hence arise thick accumulations of what is known as *rain-wash*—soil mixed often with angular fragments of still undecomposed rock, and not infrequently forming a kind of brick-earth

(Fig. 5) Deposits of this nature are still gathering now, though their lower portions may be of great antiquity. In the south-east of England, for instance, the brick-earths contain the bones of animals that have long since passed away.

Dust.—By the action of wind, above referred to, a vast amount of fine dust and sand is carried up into the air and strewn far and wide over the land. In dry countries, such as large tracts of Central Asia, the air is often thick with a fine yellow dust which may entirely obscure the sun at mid-day, and which settles over everything. After many centuries, a deposit, which may be hundreds of feet deep, is thus accumulated on the surface of the land Some of the ancient cities of the Old World, Nineveh and Babylon for example, after being long abandoned by man, have gradually been buried under the fine soil drifted over them by the wind and intercepted and protected by the weeds that grew up over the ruins. Even in regions where, as in Britain, there is a large annual rainfall, seasons of drought occur, during which there may be a considerable drifting of the finer particles of soil by the wind. We probably hardly realise how much the soil may be lowered here and heightened there from this cause.

Sand-dunes.—Some of the most striking and familiar examples of the accumulation of loose deposits by the wind are those to which the name of Dunes is given (Fig 6). On sandy shores, exposed to winds that blow landwards, the sand is dried and then carried away from the beach, gathering into long mounds or ridges which run parallel to the coast-line. These ridges are often 50 or 60 feet, sometimes even more than 250 feet high, with deep troughs and irregular circular hollows between them, and they occasionally form a strip several miles broad, bordering the sea. The particles of sand are driven inland by the wind, and the dunes gradually bury fields, roads, and villages, unless their progress is arrested by the growth of vegetation over their shifting surfaces. On many parts of the west coast of Europe, the dunes are marching into the interior at the rate of 20 feet in a year. Hence large tracts of land have within historic times been entirely lost under them In the north of Scotland, for example, an ancient and extensive barony, so noted for its fertility that it was called "the granary of Moray," was devastated about the middle of the seventeenth century by the moving sands, which now rise in barren ridges more than 100 feet above the site of the buried land. In the interior of continents also, where with great dryness of climate there is a continual disintegration of the surface of rocks, wide

wastes of sand accumulate, as in the deserts of Libya, Arabia, and Gobi, in the heart of Australia, and in many of the western parts of the United States.

There can be no doubt, however, that though the layer of vegetable soil, the heaps of rubbish that gather on slopes and at the base of rocky banks and precipices, and the widespread drifting of dust and sand over the land, afford evidence that much of the material arising from the general decay of the surface of the land accumulates under various forms upon that surface, nevertheless its stay there is not permanent. Wind and rain are continually removing it, sometimes in vast quantities, into the sea.

FIG. 6.—Sand-dunes.

Every brook, made muddy by heavy rain, is an example of this transport, for the mud that discolours the water is simply the finer material of the soil washed off by rain. When we reflect upon the multitude of streams, large and small, in all parts of the globe, and consider that they are all busy carrying their freights of mud to the sea, we can in some measure appreciate how great must be the total annual amount of material so removed. What becomes of this material will form the subject of succeeding chapters.

Results of Weathering.—In the course of time the operation of the different atmospheric agents which have been described in this chapter brings out the most astonishing changes in the topography of the land. The softer rocks are worn down and

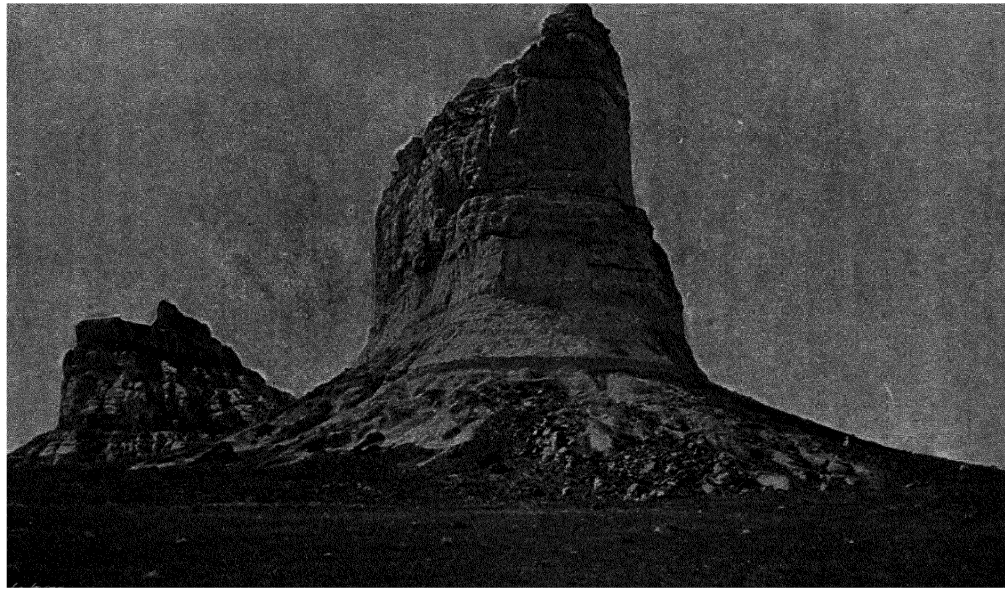


FIG. 7.—"Jail and Court-house Rocks"—typical outliers or "buttes" of soft sandstone, developed by atmospheric denudation in a semi-arid region; Platte River, Western Nebraska. (Phot. by Mr. N. H. Darton, U.S. Geol. Survey.)

the harder masses are left projecting. Thus hills and valleys may be carved out of a surface which at first, when the process began, may have been nearly flat. It is hardly possible to exaggerate the importance of the part taken by these destructive agents in producing the present topography of the dry land. In regions where the climate is dry and the rocks at the surface consist of horizontal stratified formations, the reality and results of atmospheric erosion are most impressively displayed. No part of the world has furnished more admirable illustrations of this department of geology than the Western States of the American Union As shown in Fig 7, some of the most abrupt and singular rock-scenery may be traced entirely to this kind of slow, long continued sculpture, by air, temperature, rain, frost, and the other agents above enumerated. The "Bad Lands" of these regions (Fig. 212) are marvellous examples of the same processes.

**Summary.**—The first lesson to be learnt from an examination of the surface of the land is, that everywhere decay is in progress upon it. Wherever the solid rock rises into the air, it breaks up and crumbles away under the various influences combined in the process of Weathering. The wasted materials caused by this universal disintegration partly accumulate where they are formed, and make soil. But in large measure, also, they are blown away by wind and washed off by rain. Even where they appear to be securely protected by a covering of vegetation, the common earth-worm brings the finer parts of them up to the surface, where they come within reach of rain and wind, so that on tracts permanently grassed over, there may be a continuous and not inconsiderable removal of fine soil from the surface. In proportion as the upper layers of soil are removed, roots and percolating water are enabled to reach down farther into the solid rock, which is broken up into subsoil, and thus the general surface of the land is insensibly lowered.

Besides accumulating *in situ* as subsoil and soil, the debris of decomposed rock forms talus-slopes and screes at the foot of crags, and a layer of rain-wash or brick-earth over gentler slopes Where the action of wind comes markedly into play, tracts of sand-dunes may be piled up along the borders of the sea and of lakes, or in the arid interior of continents; and wide regions have been in course of time buried under the fine dust which is sometimes so thick in the air as to obscure the noonday sun But in none of these forms can the accumulation of decomposed material be regarded as permanent. So long as it is exposed to the

influences of the atmosphere, this material is still liable to be swept away from the surface of the land and borne outwards into the sea

One of the prominent results of this universal waste of the surface has been the gradual carving out of the surface of the land into heights and hollows. In general, the harder materials better resist the processes of destruction and are allowed to project in hills and ridges, while the softer rocks are worn away into valleys and plains. As will be afterwards shown, original hollows on the surface of a newly upheaved tract of land would, from the first, guide the descent of the drainage towards the sea, and after long ages of ceaseless erosion (p 32) might be carved into valleys, glens, and ravines, while the intervening ground, even though formed of as destructible materials, being less rapidly worn down, would be left as ridges and hills Hence the existing scenery of the land has in large measure been produced by the sculpturing action of the different agents of atmospheric disintegration

## CHAPTER III

### THE INFLUENCE OF RUNNING WATER IN GEOLOGICAL CHANGES, AND HOW IT IS RECORDED

It appears, then, that from various causes all over the globe, there is a continual decay of the surface of the land, that the decomposed material partly accumulates as soil, subsoil, and sheets or heaps of loose earth or sand, but that much of it is washed off the land by rain or blown into the rivers or into the sea by wind. We have now to consider the part taken by Running Water in this transport. From the single rain-drop up to the mighty river, every portion of the water that flows over the land is busy with its own share of the work. When we reflect on the amount of rain that falls annually over the land, and on the number of streams, large and small, that are ceaselessly at work, we realise how difficult it must be to form any fit notion of the entire amount of change which, even in a single year, these agents work upon the surface of the earth.

The influence of rain in the decay of the surface of the land was briefly alluded to in the last chapter. As soon as a drop of rain reaches the ground, it begins its appointed geological task, dissolving what it can carry off in solution, and pushing forward and downward whatever it has power to move. As the rain-drops gather into runnels, the same duty, but on a greater scale, is performed by them, and as the runnels unite into larger streams, and these into broader and fuller rivers, the operations, though becoming colossal in magnitude, remain essentially the same in kind In the operations of the nearest brook, we see before us in miniature a sample of the changes produced by the thousands of rivers which, in all quarters of the globe, are flowing from the mountains to the sea Watching these operations from day to day, we discover that they may all be classed under two heads. In the first place,

the brook hollows out the channel in which it flows and thus aids in the general waste of the surface of the land; and in the second place, it carries away fine silt and other material resulting from that waste, and either deposits it again on the land or carries it out to sea. Rivers are thus at once agents that themselves directly degrade the land, and that sweep the loosened detritus towards the ocean. An acquaintance with each of these kinds of work is needful to enable us to understand the nature of the records which river-action leaves behind it.

## i. Erosive and transporting Power of Running Water

**Chemical Action.**—We have seen that rain in its descent from the clouds absorbs air, and that with the oxygen and carbonic acid which it thus obtains it proceeds to corrode the surfaces of rock on which it falls. When it reaches the ground and absorbs the acids termed "humous," which are supplied by the decomposing vegetation of the soil, it acquires increased power of eating into the stones over which it flows. When it rolls along as a runnel, brook, or river, it no doubt still attacks chemically the rocks of its channel, though its action in this respect is not so easily detected. In some circumstances, however, the solvent influence of river-water upon solid rocks is strikingly displayed. Where the water contains a large proportion of the acids of the soil, and flows over a kind of rock specially liable to be eaten away by these acids, the most favourable conditions are presented for observing the change. Thus, a stream which issues from a peat-bog is usually dark brown in colour, from the vegetable solutions which it extracts from the moss. Among these solutions are some of the organic acids referred to, ready to eat into the surface of the rocks or loose stones which the stream may encounter in its descent. No kind of rock is more liable than limestone to corrosion under such circumstances. Peaty water flowing over it eats it away with comparative rapidity, while those portions of the rock that rise above the stream escape solution, except in so far as they are attacked by rain. Hence arise some curious features in the scenery of limestone districts. The walls of limestone above the water, being attacked only by the atmosphere, are not eaten away so fast as their base, over which the stream flows. They are consequently undermined, and are sometimes cut into dark tunnels and passages (Fig. 8). Even where the solvent action of the

water of rivers is otherwise inappreciable, it can be detected by means of chemical analysis. Thus rivers, partly by the action of their water upon the loose stones and solid rocks of their channels, and partly by the contributions they receive from Springs (which will be afterwards described), convey a vast amount of dissolved material into the sea. The mineral substance thus invisibly transported consists of various salts. One of the most abundant of these —carbonate of lime or calcium-carbonate—is the substance that forms limestone, and furnishes the mineral matter required for the hard parts of a large proportion of the lower animals. It is a matter

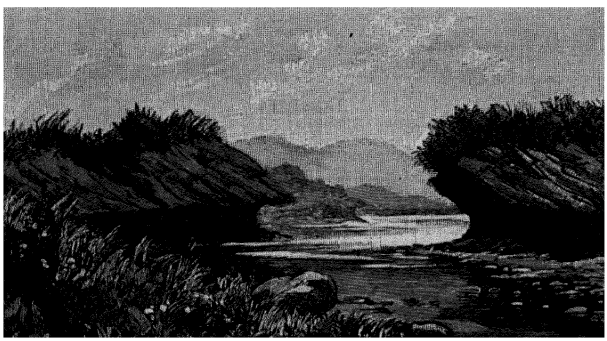


FIG. 8.—Erosion of limestone by the solvent action of a peaty stream, Durness, Sutherlandshire.

of some interest to know that this substance, so indispensable for the formation of the shells of so great a number of sea-creatures, is constantly supplied to the sea by the streams that flow into it.[1] The rivers of Western Europe, for instance, have been ascertained to convey about 1 part of dissolved mineral matter in every 5000 parts of water, and of this mineral matter about a half consists of carbonate of lime. It has been estimated that the Rhine bears enough carbonate of lime into the sea every year to make three hundred and thirty-two thousand millions of oysters of the usual

[1] There is now reason, however, to suspect that the carbonate of lime in marine organisms is not derived so much from the comparatively minute proportion of that substance present in solution in sea-water, as from the much more abundant sulphate of lime which undergoes apparently a process of chemical transformation into carbonate within the living animals.

size. Another abundant ingredient of river-water is gypsum or sulphate of lime, of which the Thames is computed to carry annually past London not less than 180,000 tons.

It would be difficult to determine what proportion of mineral matter annually transported by rivers to the sea is supplied to them by springs, and how much is due to their own chemical action and to that of the rain and brooks which flow into them But, obviously, whether removed from the rocks at the surface or from those underground, this chemically dissolved mineral matter represents so much loss from the solid land. Its amount can be approximately estimated by ascertaining the average proportion of dissolved substances in the river-waters of a country and the amount of water discharged into the sea. When this calculation is made we learn what an important element in the degradation of the land is the solvent action of rain, springs, and streams. It has been computed, for instance, that more than eight millions of tons of dissolved mineral matter are removed from the rocks of England and Wales in a single year, which is equivalent to a general lowering of the surface of the country, by chemical solution alone, at a rate of .0077 of a foot in a century or one foot in about 13,000 years.

**Mechanical Action**—(1) Transport —The dissolved material, large though its total amount is thus seen to be, forms but a small proportion of the total quantity of mineral substances conveyed by rivers from land to sea A single shower of rain washes off fine dust and soil from the surface of the ground into the nearest brook, which then rolls along with a discoloured current. An increase in the volume of the water enables a stream to sweep along sand, gravel, and blocks of stone lying in its channel, and to keep these materials moving until, as the declivity lessens and the rain ceases, the current becomes too feeble to do more than lazily carry onward the fine silt that discolours it. Every stream, large or small, is ceaselessly busy transporting mud, sand, or gravel. And as the ultimate destination of all this sediment is the bottom of the sea, it is evident that if there be no compensating influences at work to repair the constant loss, the land must in the end be all worn away

Some of the most instructive lessons regarding the work of running water on land are afforded by the beds of mountain-torrents. Huge blocks, detached from the crags and cliffs on either side, may there be seen cumbering the pathway of the water, which seems quite powerless to move such masses and can

only sweep round them or find a passage beneath them. But visit such a torrent when it is swollen with heavy rains or rapidly melted snow, and you will hear the stones knocking against each other or on the rocky bottom, as they are driven downwards by the flood. When the stream is at its lowest, in dry summer weather, follow its course a little way down hill, and you will see that by degrees the blocks, losing their sharp edges, have become rounded boulders, and that these are gradually replaced by coarse shingle, and then by finer gravel. In the quieter reaches of the water, sheets of sand begin to make their appearance, and at last when the stream reaches the plains, no sediment of coarser grain than mere silt may be seen in its channel. It is thus obvious that in the constant transport maintained by watercourses, the carried materials, by being rolled along rocky channels and continually ground against each other, diminish in size as they descend. A river flowing from a range of mountains to the distant ocean may be likened to a mill, into which large angular masses of rock are cast at the upper end, and out of which only fine sand and silt are discharged at the lower.

Partly, therefore, owing to the fine dust and soil swept into them by wind and rain from the slowly decomposing surface of the land, and partly to the friction of the detritus which they sweep along their channels, rivers always contain more or less mineral matter suspended in their water or travelling with the current on the bottom. The amount of material thus transported varies greatly in different rivers, and at successive seasons even in the same river. In some cases, the rainfall is spread so equably through the year that the rivers flow onward with a quiet monotony, never rising much above nor sinking much below their average level. In such circumstances, the amount of sediment they carry downward is proportionately small. On the other hand, where either from heavy periodical rains or from rapid melting of snow, rivers are liable to floods, they acquire an enormously increased power of transport, and their burden of sediment is proportionately augmented. In a few days or weeks of high water, they may convey to the sea a hundredfold the amount of mineral matter which they could carry in a whole year of their quieter mood

Measurements have been made of the proportions of sediment in the waters of different rivers at various seasons of the year. The results, as might be expected, show great variations. Thus

the Garonne, rising among the higher peaks of the Pyrenees, drains a large area of the south of France, and is subject to floods by which an enormous quantity of sediment is swept down from the mountains to the plains. Its proportion of mud has been estimated to be as much as 1 part in 100 parts of water. The Durance, which takes its source high on the western flank of the Cottian Alps, is one of the rapidest and muddiest rivers in Europe. Its angle of slope varies from 1 in 208 to 1 in 467, the average declivity of the great rivers of the globe being probably not more than 1 in 2600, while that of a navigable stream ought not to exceed 10 inches per mile or 1 in 6336. The Durance is, therefore, rather a torrent than a river. With this rapidity of descent is conjoined an excessive capacity for transporting sediment. In floods of exceptional severity, the proportion of mud in that stream has been estimated at one-tenth by weight of the water, while the average proportion for nine years from 1867 to 1875 was about $\frac{1}{35}$. Probably the best general average is to be obtained from a river which drains a wide region exhibiting considerable diversities of climate, topography, rocks, and soils. The Mississippi presents a good illustration of these diversities, and has accordingly been taken as a kind of typical river, furnishing, so to speak, a standard by which the operations of other rivers may be compared, and which may perhaps be assumed as a fair average for all the rivers of the globe. Numerous measurements have been made of the proportion of sediment carried into the Gulf of Mexico by this vast river, with the result of showing that the average amount of sediment is by weight 1 part in every 1500 parts of water, or little more than one-third of the proportion in the water of the Durance.

If now we assume that, all over the world, the general average proportion of sediment floating in the water of rivers is 1 part in every 1500 of water, we can readily understand how seriously in the course of time must the land be lowered by the constant removal of so much decomposed rock from its surface. Knowing the area of the basin drained by a river, and also the proportion of sediment in its water, we can easily calculate the general loss from the surface of the basin. The ratio of the weight or specific gravity of the silt to that of solid rock may be taken to be as 19 is to 25. Accordingly the Mississippi conveys annually from its drainage basin an amount of sediment equivalent to the removal of $\frac{1}{6000}$ part of a foot of rock from the general surface of the basin. At this rate, one foot of rock will be worn away every

6000 years. If we take the general height of the land of the whole globe to be 2100 feet, and suppose it to be continuously wasted at the same rate at which the Mississippi basin is now suffering, then the whole dry land would be carried into the sea in 12,600,000 years. Or if we assume the mean height of Europe to be 940 feet and that this continent is degraded at the Mississippi rate of waste until the last vestige of it disappears, the process of destruction would be completed in 5,640,000 years. Such estimates are not intended to be close approximations to the truth. As the land is lowered, the rate of decay will gradually diminish, so that the later stages of decay will be enormously protracted. But by taking the rate of operation now ascertained to be in progress in such a river basin as the Mississippi, we obtain a valuable standard of comparison, and learn that the degradation of the land is much more rapid than might have been supposed.

(2) Erosion.—But rivers are not merely carriers of the mud, sand, and gravel swept into their channels by other agencies. By keeping these materials in motion, the currents reduce them in size, and at the same time employ them to hollow out the channels wherein they move. The mutual friction that grinds down large blocks of rock into sand and mud, tells also upon the rocky beds along which the material is driven. The most solid rocks are worn down; deep long gorges are dug out, and the water-courses, when they have once chosen their sites, remain on them and sink gradually deeper and deeper beneath the general level of the country. The surfaces of stone exposed to this attrition assume the familiar smoothed and rounded appearance which is known as *water-worn*. The loose stones lying in the channel of a stream, and the solid rocks as high up as floods can scour them, present this characteristic aspect. Here and there, where a few stones have been caught in an eddy of the current, and are kept in constant gyration, they reduce each other in dimensions, and at the same time grind out a hollow in the underlying rock. The sand and mud produced by the friction are swept off by the current, and the stones when sufficiently reduced in size are also carried away. But their places are eventually taken by other blocks brought down by floods, so that the supply of grinding material to the whirling eddy is kept up until the original hollow is enlarged into a wide deep caldron, at the bottom of which the stones can only be stirred by the heaviest floods. Cavities of this kind, known as *pot-holes*, are of frequent occurrence in rocky

watercourses as well as on rocky shores, in short, wherever eddies of water can keep shingle rotating upon solid rock. As they often coalesce by the wearing away of the intervening wall of rock, they greatly aid in the deepening of a watercourse. In most rocky gorges, a succession of old pot-holes may be traced far above the present level of the stream (Fig. 9).

That it is by means of the gravel and other detritus pushed

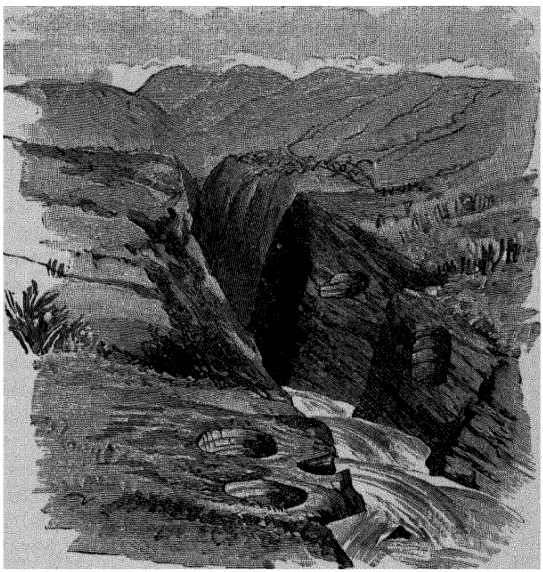


FIG. 9.—Pot-holes worn out by the gyration of stones in the bed of a stream.

along the bottom by the current, rather than by the mere friction of the water on its bed, that a river excavates its channel, is most strikingly shown immediately below a lake. In traversing a lake, the tributary streams deposit their sediment on its bottom, because the still water checks their current and, by depriving the water of its more rapid movement, compels it to drop its burden of gravel, sand, and silt (see p. 48). Filtered in this way, the water of the various streams that unite in the lake escapes at the lower end as a clear transparent river. The Rhone, for instance, flows into the

Lake of Geneva as a turbid stream; it issues from that great reservoir at Geneva as a rushing current of the bluest, most translucent water which, though it sweeps over ledges of rock, has not yet been able to grind them down into a deep channel. The Niagara, also, filtered by Lake Erie, has not acquired sediment enough to enable it to cut deeply into the rocks over which it foams in its rapids before throwing itself over the great Falls.

One of the most characteristic features of streams is the singularly sinuous courses which they follow. As a rule, too, the flatter the ground over which they flow, the more do they wind. Not uncommonly they form loops, the nearest bends of which in the end unite, and as the current passes along the now straightened channel, the old one is left to become by degrees a lake or pond of stagnant water, then a marsh, and lastly, dry ground (Fig. 10). We might suppose that in flowing off the land, water would take the shortest and most direct road to the sea. But this is far from being the case The slightest inequalities of level have originally determined sinuosities of the channels, while trifling differences in the hardness of the banks, in the accumulation of sediment, and in the direction of the currents and eddies, have been enough to turn a stream now to one side now to another, until it has assumed its present meandering course How easily this may be done can be instructively observed on a roadway or other bare surface of ground. When quite dry and smooth, hardly any depressions in which water would flow may be detected on such a surface. But after a heavy shower of rain, runnels of muddy water will be seen coursing down the slope in serpentine channels that at once recall the winding rivers of a great drainage-system. The slightest

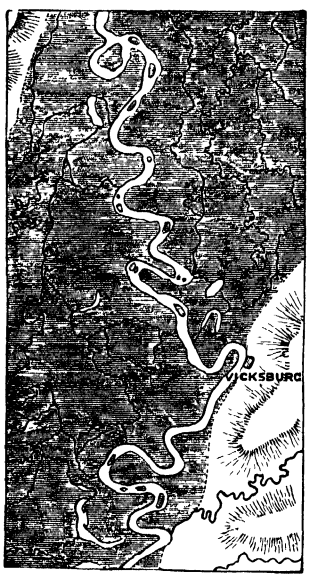



FIG 10 — Windings of the Mississippi river The shaded part marks the alluvial plain

differences of level have been enough to turn the water from side to side. A mere pebble or projecting heap of earth or tuft of grass has sufficed to cause a bend. The water, though always descending, can only reach the bottom by keeping the lowest levels, and turning from right to left as these guide it

When a river has once taken its course and has begun to excavate its channel, only some great disturbance, such as a landslip, an earthquake, or a volcanic eruption, can turn it out of that course. If its original pathway has been a winding one, it goes on digging out its bed which, with all its bends, gradually sinks below the level of the surrounding country. The deep and picturesque gorge (Fig. 11) in which the Moselle winds from Trèves to Coblenz has in this way been slowly eroded out of the undulating tableland across which the river originally flowed.

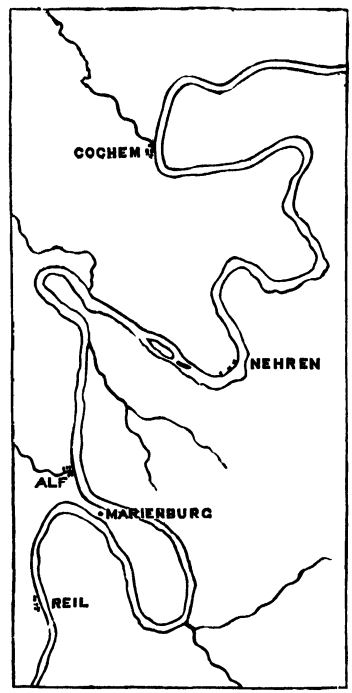



FIG 11.—Windings of the gorge of the Moselle above Cochem

In another and most characteristic way, the shape of the ground and the nature and arrangement of the rocks over which they flow, materially influence rivers in the forms into which they carve their channels. The Rhone and the Niagara, for instance, though filtered by the lakes through which they flow, do not run far before plunging into deep ravines. Obviously such ravines cannot have been dug out by the same process of mechanical attrition whereby river-channels in general are eroded Yet the frequency of gorges in river scenery shows that they cannot be due to any exceptional operation. They may generally be accounted for by some arrangement of rocks wherein a bed of

harder material is underlain by one more easily removable. Where a stream, after flowing over the upper bed, encounters the decomposable bed below, it eats away the latter more rapidly. The overlying hard rock is thus undermined, and, as its support is destroyed, slice after slice is cut away from it. The waterfall which this kind of structure produces continues to eat its way backward or up the course of the stream, so long as the necessary conditions are maintained of hard rocks lying upon soft. Any change of structure which would bring the hard rocks down to the bed of the channel, and remove the soft rocks from the action of the current and the dash of the spray, would gradually destroy the waterfall It is obvious that, by cutting its way backward, a waterfall excavates a ravine

The renowned Falls of Niagara supply a striking illustration of the process now described The vast body of water which issues from Lake Erie, after flowing through a level country for a few miles, rushes down its rapids and then plunges over a precipice of flat limestone. Beneath this hard rock lie comparatively easily eroded shales and sandstones (Fig. 12) As the water loosens and removes the lower rock, large portions of the face of the precipice behind the Falls are from time to time precipitated into the boiling flood below. The waterfall is thus slowly prolonging the ravine below the Falls. The magnificent gorge in which the Niagara, after its tumultuous descent, flows sullenly to Lake Ontario is not less than 7 miles long, from 200 to 400 yards wide, and from 200 to 300 feet deep. There is no reason to doubt that this chasm has been entirely dug out by the gradual recession of the Falls from the cliffs at Queenstown, over which the river at first poured We may form some conception of the amount of rock thus removed from the estimate that it would make a rampart about 12 feet high and 6 feet thick extending right round the whole globe at the equator. Still more gigantic are the gorges or cañons of the Colorado and its tributaries in Western America.

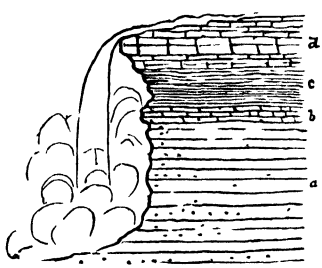



FIG 12 —Section at the Horse-Shoe Fall, Niagara

*a*, Medina Sandstone, 300 feet, *b*, Clinton Limestone and Shale, 30 feet, *c*, Niagara Shale, 80 feet, *d*, Niagara Limestone, 165 feet, of which 85 feet are seen at the Fall

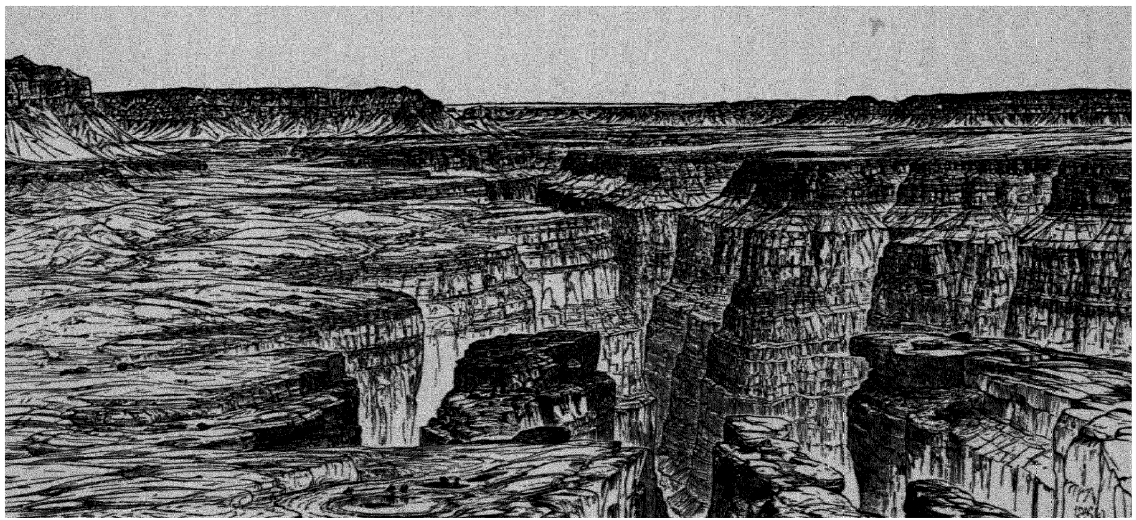


FIG. 13.—Grand Cañon of the Colorado. (Holmes.)

The Grand Cañon of the Colorado is 300 miles long, and in some places more than 6000 feet deep (Fig. 13). The country traversed by it is a network of profound ravines, at the bottom of which the streams flow that have eroded them out of the table-land.

It is obvious that eventually there must be a limit to the deepening of a river-channel, when the slope of the bed has been so reduced that the current can only flow along languidly, without possessing any longer the velocity necessary for sweeping along the coarser detritus by which the channel is worn away. When this condition has been reached the river is said to have arrived at a *base-level of erosion.* We see this result most conspicuously in broad alluvial plains across which the streams that traverse them no longer deepen their channels, but rather tend to raise them by allowing more of the transported sediment to settle down upon them.

## ii. Deposition of Materials by Running Water

Permanent Records of River-Action.—If, then, all the streams on the surface of the globe are engaged in the double task of digging out their channels and carrying away the loose materials that arise from the decomposition of the surface of the land, let us ask ourselves what memorials of these operations they leave behind them. In what form do the running waters of the land inscribe their annals in geological history? If these waters could suddenly be dried up all over the earth, how could we tell what changes they had once worked upon the surface of the land? Can we detect the traces of ancient rivers where there are no rivers now?

From what has been said in this chapter it will be evident that in answer to such questions as these, we may affirm that one unmistakable evidence of the former presence of rivers is to be found in the channels which they have eroded. The gorges, rocky defiles, pot-holes, and water-worn rocks which mark the pathway of a stream would long remain as striking memorials of the work of running water. In districts, now dry and barren, such as large regions in the Levant, there are abundant channels (*wadies*) now seldom or never occupied by a stream, but which were evidently at one time the beds of active torrents.

Alluvium.—But more universal testimony to the work of

running water is to be found in the deposits which it has accumulated. To these deposits the general name of *alluvium* has been given. Spreading out on either side, sometimes far beyond the limits of the ordinary or modern channels, these deposits, even when worn into fragmentary patches, retain their clear record of the operations of rivers.

The power possessed by running water to carry forward sediment depends mainly upon the velocity of the current. The more rapidly a stream flows, the more sediment can it transport, and the larger are the blocks which it can move The velocity is regulated chiefly by the angle of slope; the greater the declivity, the higher is the velocity and the larger the capacity of the stream to carry down debris Any cause, therefore, which lessens the velocity of a current diminishes its carrying power. If water, bearing along gravel, sand, or mud, is checked in its flow, some of these materials will drop and remain at rest on the bottom. In the course of every stream, various conditions arise whereby the velocity of the current is reduced. One of the most obvious of these is a diminution in the slope of the channel, either existing in the original form of the ground or effected by the stream itself, as where it reaches a base-level of erosion. Another is the union of a rapid tributary with a more gently flowing stream. A third is the junction of a stream with the still waters of a lake (see p. 48) or with the sea. In these circumstances, the flow of the water being checked, the sediment at once begins to fall to the bottom.

Let us in imagination follow the course of a river from the mountains to the sea, marking as we go the circumstances under which the accumulation of sediment takes place, and noting illustrations of this law of deposition. We find that among the mountains where the river takes its rise, the torrents that rush down the declivities have torn out of them such vast quantities of soil and rock as to seam them with deep clefts and gullies. Where each of these rapid streamlets reaches the valley below, its rapidity of motion is at once lessened, and with this slackening of speed and consequent loss of carrying power, there is an accompanying deposit of detritus. Blocks of rock, angular rubbish, rounded shingle, sand, and earth are thrown down in the form of a cone, of which the apex starts from the bottom of the gully and the base spreads out over the plain (Fig. 14) Such cones vary in dimensions according to the size of the torrent and the comparative ease with which the rocks of the mountain-side can be

loosened and removed. Some of them, thrown down by the transient runnels of the last sudden rain-storm, may not be more than a few cubic yards in bulk. But on the skirts of mountainous regions they may grow into masses hundreds of feet thick and many miles in diameter. The valleys in a range of mountains afford many striking examples of these *alluvial cones* or *fans*, as they are called.

FIG. 14.—Gullies torn out of the side of a mountain by descending torrents, with cones of detritus at their base

Where the tributary torrents are numerous, a succession of such cones or fans, nearly or quite touching each other, spreads over the floor of a valley. From this cause, so large an amount of detritus has within historic times been swept down into some of the valleys of the Tyrol that churches and other buildings are now half-buried in the accumulation.

Looking more closely at the materials brought down by the

torrents, we find them arranged in rude irregular layers, sloping downwards into the plain, the coarsest and most angular detritus lying nearest to the mountains, while more rounded and water-worn shingle or sand extends to the lower margin of the cone. This grouping of irregular layers of angular and half-rounded detritus is characteristic of the action of torrents. Hence, where it occurs, even though no water may run there at the present day, it may be regarded as indicating that at some former time a torrent swept down detritus over that site.

Quitting the more abrupt declivities, and augmented by numerous tributaries from either side, the stream whose course we are tracing loses the character of a torrent and assumes that of a river. It still flows with velocity enough to carry along not only mud and sand, but even somewhat coarse gravel. The large angular blocks of the torrential part of its course, however, are no longer to be seen, and all the detritus becomes more and more rounded and smoothed as we follow it towards the plains. At many places, deposits of gravel or sand take place, more especially at the inner side of the curves which the stream makes as it winds down the valley. Sweeping with a more rapid flow round the outer side of each curve, the current lingers in eddies on the inner side and drops there a quantity of sediment When the water is low, strips of bare sand and shingle on the concave side of each bend of the stream form a distinctive feature in river scenery. It is interesting to walk along one of these strips and to mark how the current has left its record there The stones are well smoothed and rounded, showing that they have been rolled far enough along the bottom of the channel to lose their original sharp edges, and to pass from the state of rough angular detritus into that of thoroughly water-worn gravel Further, they will be found not to lie entirely at random, as might at first sight be imagined A little examination will show that where the stones are oblong, they are generally placed with their longer axis pointing across the stream. This would naturally be the position which they would assume where the current kept rolling them forward along the channel. Those which are flat in shape will be observed usually to slope up stream. That the sloping face must look in the direction from which the current

FIG 15.—Flat stones in a bank of river-shingle, showing the direction of the current (indicated by the arrow) that transported and left them

moves will be evident from Fig. 15, where a current, moving in the direction of the arrow and gradually diminishing in force, would no longer be able to overturn the stones which it had so placed as to offer the least obstacle to its passage. Had the current flowed from the opposite quarter, it would have found the upturned edges of the stones exposed to it, and would have readily overturned them until they found a position in which they again presented least resistance to the water. In a section of gravel, it is thus often quite possible to tell from what quarter the current flowed that deposited the pebbles.

Yet another feature in the arrangement of the materials is well seen where a digging has been made in one of the alluvial banks, but better still in a section of one of the terraces to be immediately referred to. The layers of gravel or sand in some bands may be observed to be inclined at a steeper angle than in others, as shown in the accompanying figure (Fig. 16). In such cases, it will be noticed that the slope of the more inclined layers is down the stream, and hence that their direction gives a clue to that of the current which arranged them. We may watch similar layers in the act of deposition among shallow pools into which currents are discharging sediment. The gravel or sand may be observed moving along the bottom, and then falling over the edge of a bank into the bottom of the pool. As the sediment advances by successive additions to its steep slope in front, it gradually fills the pool up Its progress may be compared to that of a railway embankment formed by the discharge of waggon-loads of rubbish down its end. A section through such an embankment would reveal a series of bands of variously coloured materials inclined steeply towards the direction in which the waggon-loads were thrown down. Yet the top of the embankment may be kept quite level for the permanent way. The nearly level bands (*b*, *c*) in Fig. 16 represent the general bottom on which the sediment accumulated, while the steeper lines in the lower gravel (*a*) point to the existence and direction of the

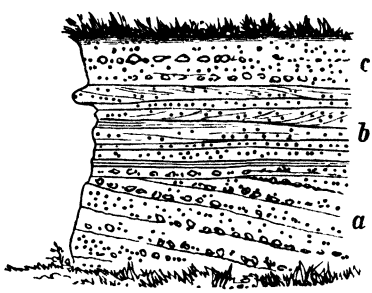



FIG. 16.—Section of alluvium showing direction of currents.

currents by which sediment was pushed forward along that bottom. (Compare pp. 195, 196.)

As the river flows onward through a gradually expanding valley, another characteristic feature becomes prominent. Flanking each side of the flat land through which the stream pursues its winding course, there runs a steep slope or bank a few feet or yards in height, terminating above in a second or higher plain, which again may be bordered with another similar bank, above which there may lie a third plain. These slopes and plains form a group of terraces, rising step by step above and away from the river, sometimes to a height of several hundred feet, and occasionally to the number of 6 or 8 or even more (Figs. 17 and 18).

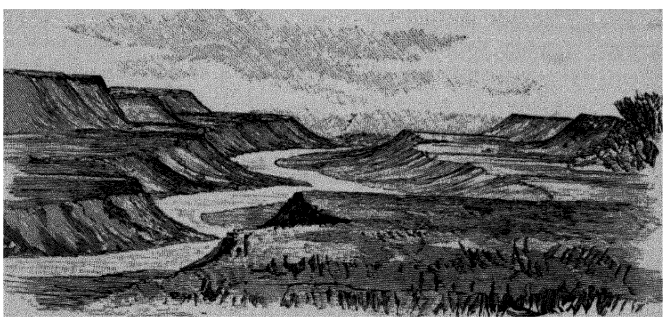


FIG. 17.—River-terraces.

Here and there, by the narrowing of the intervening strip of plain, two terraces merge into one, and at some places the river in winding down the valley has cut away great slices from one or more of the terraces, perhaps even entirely removing some of them from one or both sides and eating back into the rock out of which the valley has been excavated. Even when the floor of a river has been reduced to a base-level of erosion, the stream in flood may undermine banks of soft material, and thus widen and alter its channel, though no longer capable of deepening it. Sections are thus exposed showing a succession of gravels, sands, and loams like those of the present river. From the line of the uppermost terrace down to the spits of shingle now forming in the channel, we have evidently a chronological arranged series of river-deposits, the oldest being at the top and the youngest at the bottom. But how could the

river have flowed at the level of these high gravels, so far above its present limits? An examination of the behaviour of the stream during floods will help towards an answer to this question.

When from heavy rains or melted snows the river overflows its banks, it spreads out over the level ground on either side The tract liable to be thus submerged during inundations is called the *flood-plain* As the river rises in flood, it becomes more and more turbid from the quantity of mud and silt poured into it by its tributaries on either side. Its increase in volume likewise augments its velocity, and consequently its power of transporting the coarser detritus resting on its bed. Large quantities of shingle may thus be swept out of the ordinary channel and be strewn across the nearer parts of the flood-plain. As the current spreads over this plain, its velocity and transporting

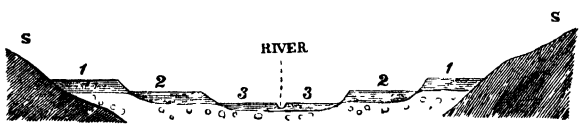



FIG 18 —Section of river-terraces

capacity diminish, and consequently sediment begins to be thrown down. Grass, bushes, and trees, growing on the flood-plain, filter some of the sediment out of the water. Fine mud and sand, for instance, adhere to the leaves and stems, whence they are eventually washed off by rain into the soil underneath. In this way, the flood-plain is gradually heightened by the river itself. At the same time, before a base-level of excavation is reached, the bed of the river is deepened by the scour of the current, until, in the end, even the highest floods are no longer able to inundate the flood-plain. The difference of level between that plain and the surface of the river gradually increases; by degrees the river begins to cut away the edges of the terrace which it cannot now overflow, and to form a new flood-plain at a lower level. In this manner, it slowly lowers its bed, and leaves on either side a set of alluvial terraces to mark successive stages in the process of excavation. If, during this process, the level of the land should be raised, the slope of the rivers, and consequently their scour, would be augmented, and they would thereby acquire greater capacity for eroding their channels and leaving terraces above

them. Even those which had brought down their floors to a level below which they could no longer erode them, might thus recommence the process of erosion There is reason to believe that this cause has acted both in Europe and North America.

While it is obvious that the highest terraces must be the oldest, and that the series is progressively younger down to the terrace that is being formed at the present time, nevertheless, in the materials comprising any one terrace, those lying at the top must be the youngest. This apparent contradiction arises from the double action of the river in eroding its bed and depositing its sediment. If there were no lowering of the channel, then the deposits would follow the usual order of sequence, the oldest being below and the youngest above. This order is maintained in the constituents of each single terrace, for the lowermost layers of gravel must evidently have been accumulated before the deposit of those that overlie them But when the level of the water is lowered, the next set of deposits must, though younger, lie on a lower platform than those that preceded them. In no case, however, will the older beds, though higher in position, be found really to overlie the younger. They have been formed at different levels.

The gravel, sand, and loam laid down by a river are marked, as we have seen, by an arrangement in layers, beds, or strata lying one upon another. This *stratified* disposition, indeed, is characteristic of all sedimentary accumulations, and is best developed where currents have been most active in transporting and assorting the materials (p 193). It is the feature that first catches the eye in any river-bank, where a section of the older deposits or alluvium is exposed. Beds of coarser and finer detritus alternate with each other, but the coarsest are generally to be observed below and the finest above The "deltas" accumulated by rivers in lakes and in the sea will be noticed in Chapters IV. and VII.

But besides the inorganic detritus carried forward by a river, we have also to consider the fate of the remains of plants and the carcases of animals that are swept down, especially during floods. Swollen by sudden and heavy rains, a river will rise above its ordinary level and uproot trees and shrubs. On such occasions, too, moles and rabbits are drowned and buried in their burrows on the alluvial flood-plain. Birds, insects, and even some of the larger mammals are from time to time drowned, swept away by

floods and buried in the sediment, and their remains, where of a durable kind or where sufficiently covered over, may be preserved for an indefinite period. The shells and fishes living in the river itself may also be killed during the flood, and may be entombed with the other organisms in the sediment.

**Summary.**—The material produced by the universal decay of the surface of the land is washed off by rain and swept seawards by brooks and rivers. The rate at which the general level of the land is being lowered by the operation of running water may be approximately ascertained by measuring or estimating the amount of mineral matter carried seaward every year from a definite region, such as a river-basin. Taking merely the matter in mechanical suspension, and assuming that the proportion of it transported annually in the water of the Mississippi may be regarded as an average proportion for the rivers of Europe, we find that this continent, at the Mississippi rate of degradation, might be reduced to the sea-level in rather less than 6,000,000 years.

In pursuing their course over the land, running waters gradually deepen and widen the channels in which they flow, partly by chemically dissolving the rocks and partly by rubbing them down by the friction of the transported sand, gravel, and stones. When they have once chosen their channels, they usually keep to them, and the sinuous windings, at first determined by trifling inequalities on the surface of country across which the streams first began to flow, are gradually deepened into picturesque gorges. In the excavation of such ravines, waterfalls play an important part by gradually receding up stream. River-channels, especially if cut deeply into the solid rock, remain as enduring monuments of the work of running water. The process of erosion goes on until the slope of a river-bed has been so lowered that the current can no longer drive along the sediment that is employed in excavating its channel. When a base-level of erosion is thus reached only the finer silt and sand are borne along or are allowed to sink to the bottom.

But still more important as geological records, because more frequent and covering a larger area, are the deposits which rivers leave as their memorials. Whatever checks the velocity of a current weakens its transporting power, and causes it to drop some of its sediment to the bottom. Accordingly, accumulations of sediment occur at the foot of torrent slopes, along the lower and more level ground, especially on the inner or concave side of

the loops, over the flood-plains, and finally in the deltas formed where rivers enter lakes or the sea In these various situations, thick stratified beds of silt, sand, and gravel may be formed, enclosing the remains of the plants and animals living on the land at the time. As a river deepens its channel, it leaves on either side alluvial terraces that mark successive flood-plains over which it has flowed.

## CHAPTER IV

### THE MEMORIALS LEFT BY LAKES

**Fresh-Water Lakes.**—According to the law stated in last chapter, that when water is checked in its flow, it must drop some of its sediment, lakes are pre-eminently places for the deposition and accumulation of mineral matter. In their quiet depths, the debris worn away from the surface of the land is filtered out of the water and allowed to gather undisturbed upon the bottom. The tributary streams may enter a large lake swollen and muddy, but the escaping river is transparent. It is evident, therefore, that lakes must be continually silting up, and that when this process is complete, the site of a lake will be occupied by a series of deposits comprising a record of how the water was made to disappear.

To those who know the aspect of lakes only in fine weather, they may seem places where geological operations are at their very minimum of activity. The placid surface of the water ripples upon beaches of gravel or spits of sand; reeds and marshy plants grow out into the shallows; the few streamlets that tumble down from the surrounding hills furnish perhaps the only sounds that break the stillness, but their music and motion are at once hushed when they lose themselves in the lake. The scene might serve as the very emblem of perfectly undisturbed conditions of repose. But come back to this same scene during an autumn storm, when the mists have gathered all round the hills, and the rain, after pouring down for hours, has turned every gully into the track of a roaring torrent. Each tributary brook, hardly visible perhaps in drought, now rushes foaming and muddy from its dell and sweeps out into the lake. The large streams bear along on their swift brown currents trunks of trees, leaves, twigs, with now and then the carcase of some animal that has been drowned by the rising

flood. Hour after hour, from every side, these innumerable swollen waters bear their freights of gravel, sand, and mud into the lake. Hundreds or thousands of tons of sediment must thus be swept down during a single storm. When we multiply this result by the number of storms in a year and by the number of years in an ordinary human life, we need not be surprised to be told that even within the memory of the present generation, and still more within historic times, conspicuous changes have taken place in many lakes.

Filling up of Lakes.—In the Lake of Lucerne, for example, the River Reuss, which bears down the drainage of the huge mountains round the St. Gothard, deposits about 7,000,000 cubic feet of sediment every year. Since the year 1714 the Kander,

FIG. 19.—Alluvial terraces on the side of an emptied reservoir

which drains the northern flanks of the centre of the Bernese Oberland, is said to have thrown into the lower end of the Lake of Thun such an amount of sediment as to form an area of 230 acres, now partly woodland, partly meadow and marsh Since the time of the Romans, the Rhone has filled up the upper end of the Lake of Geneva to such an extent that a Roman harbour, still called Port Valais, is now nearly two miles from the edge of the lake, the intervening ground having been converted first into marshes and then into meadows and farms.

It is at the mouths of streams pouring into a lake that the process of filling up is most rapid and striking. But it may be detected at many other places round the margin. Instructive lessons on this subject may be learned at a reservoir formed by damming back the waters of a steep-sided valley, and liable to be sometimes nearly dry (Fig. 19). In such a situation, when the water is low, it may be noticed that a series of parallel lines runs all round the sides of the reservoir, and that these lines

consist of gravel, sand, or earth. Each of them marks a former level of the water, and they show that the reservoir was not drained off at once but intermittently, each pause in the diminution of level being marked by a notch or platform in the slope of sediment. It is easy to watch how these lines are formed along the present margin of the water. The loose debris from the bare slope above, partly by its own gravitation, partly by the wash of rain, slides down into the water. But as soon as it gets there, its further

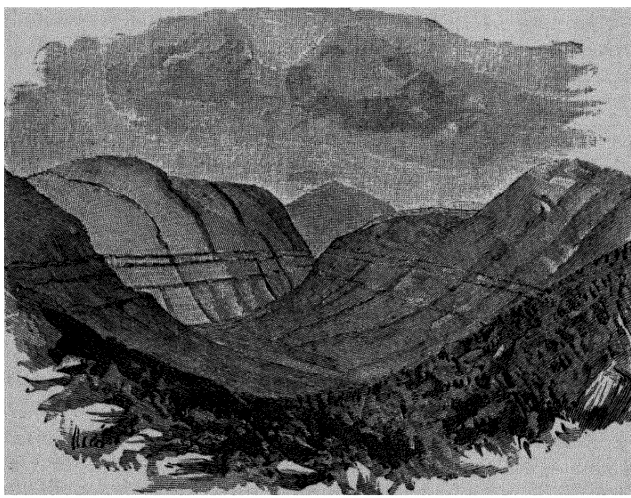


FIG. 20.—Parallel roads of Glen Roy.

downward movement is checked. By the ripple of the water it is gently moved up and down, but keeps on the whole just below the line to which the water reaches. So long as it is concealed under the water, its position and extent can hardly be realised. But as soon as the level of the reservoir sinks, the sediment is left as a marked shelf or terrace. In natural lakes, the same process is going on, though, in like manner, scarcely recognisable, because hidden under the water. But if by any means a lake could be rapidly emptied, its former level would be marked by a shelf or alluvial terrace. In some cases, the barrier of a lake has been removed, and the sinking of the water has revealed the terrace. The famous "parallel roads" of Glen Roy, in the

west of Scotland, are notable examples (Fig. 20). The valleys in that region were anciently dammed up by large glaciers. The drainage accumulated behind the ice, filled up the valleys, and converted them into a series of lakes or fresh-water "fjords." The former levels of these sheets of water and the successive stages of their diminution and disappearance are shown by the series of alluvial shelves known as "parallel roads." The highest of these is 1155 feet, the middle 1077 feet, and the lowest 862 feet above the level of the sea.

Thus, partly by the washing of detritus down from the adjoining slopes by rain, partly by the sediment carried into them by streams, and partly by the growth of marshy vegetation along their margins, lakes are visibly diminishing in size. In mountainous countries, every stage of this appearance may be observed

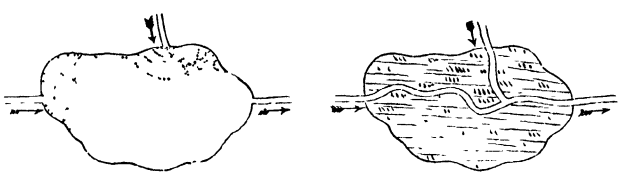



FIG. 21.—Stages in the filling up of a lake. In A two streamlets are represented as pouring their "deltas" into a lake. In B they have filled the lake up, converting it into a meadow across which they wind on their way down the valley.

(Fig. 21). Where the lakes are deep, the tongues of sediment or "deltas" which the streams push in front of them have not yet been able to advance far from the shore. Where, on the other hand, the water is shallow, every tributary has built up an alluvial plain which grows outwards and along the coast, until it unites with those of its neighbours to form a nearly continuous belt of flat meadow and marsh round the lake. By degrees, as this belt increases in width, the lake narrows, until the whole tract is finally converted into an alluvial plain, through which the river and its tributaries wind on their way to lower levels. The successive flat meadow-like expansions, so abundant in the valleys of hilly and mountainous regions, were probably in many cases originally lakes which have in this manner been gradually filled up.

Lake Deposits.—On large sheets of fresh water many of the phenomena of waves and of erosion and deposition may be

witnessed on a great scale. The shingle that gathers on their shores rivals, in coarseness and in its rolled water-worn character, the accumulations of an exposed sea-coast (Fig. 22). Much fine sediment is produced by the trituration of these beach stones, and is swept by the wind-driven currents out into deeper water. Thus by the action of the waters of the lakes themselves great abrasion

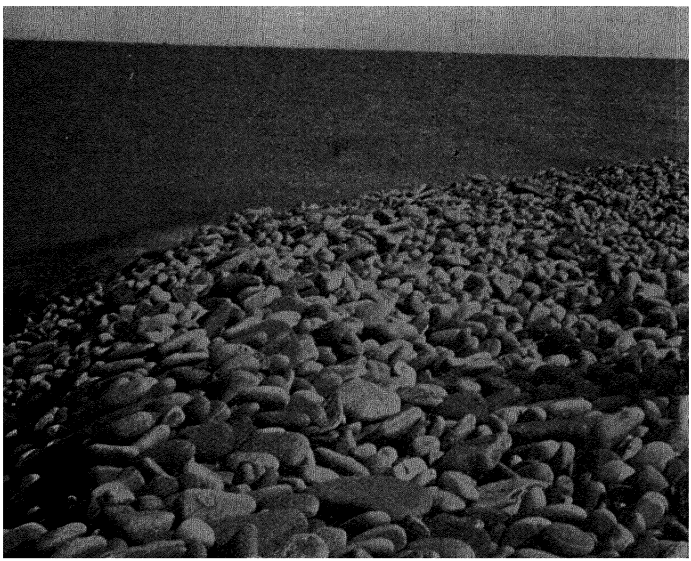


FIG. 22.—Well-worn shingle on the shore of a large lake (Lake Ontario). Photograph by Mr. G. K. Gilbert, U.S. Geol. Survey.

may take place, and a good deal of detritus may be deposited on the lake-floors. At Sirmione, on the Lago di Garda, the waves raised in the lake during northerly gales have cut back a limestone island, so as to form a high cliff with a flat rock-platform or beach at its base. At the inner margin of this beach the foot of the cliff has been hollowed out into little caves, thus supplying an interesting counterpart to the action of the open sea on an exposed line of rocky coast (p. 81). In general, the deposits in lakes are due rather to materials brought into them by rivers than to the operation of the lake-waters.

The bottoms of lakes must evidently contain many interesting relics. Dispersed through the shingle, sand, and mud that gather there, are the remains of plants and animals that lived on the surrounding land. Leaves, fruits, twigs, branches, and trunks embedded in the silt may preserve for an indefinite period their record of the vegetation of the time. The wings or wing-cases of insects, the shells of land-snails, the bones of birds and mammals, carried down into the depths of a lake and entombed in the silt there, will remain as a chronicle of the kind of animals that haunted the surrounding hills and valleys.

The layers of gravel, sand, and silt laid down on the floor of a lake differ in some respects from those deposited in the terraces of a river, being generally finer in grain, and including a larger proportion of silt, mud, or clay among them, especially away from the margin of the lake. They are, no doubt, further distinguished by the greater abundance of the remains of plants and animals preserved in them.

But lakes likewise serve as receptacles for a series of deposits which are peculiar to them, and which consequently have much interest and importance, inasmuch as they furnish a ready means of detecting the sites of lakes that have long disappeared. The molluscs that live in lacustrine waters are distinct from the snails of the adjoining shores. Their dead shells gather on the bottoms of some lakes in such numbers as to form there a deposit of the white crumbling marl, already referred to on p. 4. In course of time this deposit may grow to be many feet or yards in thickness. The shells in the upper parts may be quite fresh, some of the animals having only recently died; but they become more and more decayed below until, towards the bottom of the deposit, the marl passes into a more compact chalk-like substance in which few or no shells may be recognisable (Fig. 23). On the sites of lakes that have been naturally filled up or artificially drained, such marl has been extensively dug as

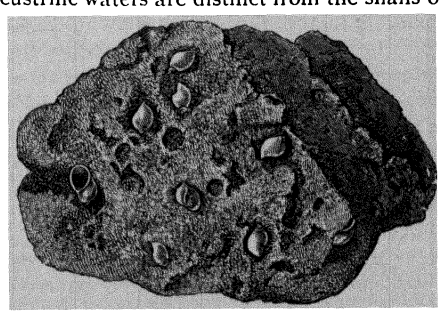


FIG. 23.—Piece of shell-marl containing shells of *Limnæa peregra*

a manure for land. Besides the shells from the decay of which it is chiefly formed, it sometimes yields the bones of deer, oxen, and other animals, whose carcases must originally have sunk to the bottom of the lake and been there gradually covered up in the growing mass of marl. Many examples of these marl-deposits are to be found among the drained lakes of Scotland and Ireland.

Yet another peculiar accumulation is met with on the bottom of some lakes, particularly in Sweden. In the neighbourhood of banks of reeds and on the sloping shallows of the larger lakes, a deposit of hydrated peroxide of iron takes place, in the form of concretions varying in size from small grains like gunpowder up to cakes measuring six inches across. The iron is no doubt dissolved out of the rocks of the neighbourhood by water containing organic acids or carbonic acid. In this condition, it is liable to be oxidised on exposure. As after oxidation it can no longer be retained in solution, it is precipitated to the bottom where it collects in grains which by successive additions to their surface become pellets, balls, or cakes. Possibly some of the microscopic plants (diatoms) which abound on the bottoms of the lakes may facilitate the accumulation of the iron by abstracting this substance from the water and depositing it inside their siliceous coverings. Beds of concretionary brown ironstone are formed in Sweden from ten to 200 yards long, 5 to 15 yards broad, and from 8 to 30 inches thick. During winter when the lakes are frozen over, the iron is raked up from the bottom through holes made for the purpose in the ice, and is largely used for the manufacture of iron in the Swedish furnaces. When the iron has been removed, it begins to form again, and instances are known where, after the supply had been completely exhausted, beds several inches in thickness were deposited in twenty-six years (p. 175)

Among the rocks which form the dry land of the globe there occur masses of limestone, sandstone, marl, and other materials which can be proved to have been deposited in lakes, because they contain a type of plant and animal remains similar to that found in modern lakes. From evidence of this nature the existence and wide extent of ancient and long-vanished lakes have been determined in Europe and North America. Their deposits have yielded an extraordinary number and variety of extinct land-animals, as will be more fully stated in Chapter XXV. Hence a careful study of existing lakes enables us to follow with more interest and success the history of the lacustrine waters of former ages.

**Salt-Lakes.**—The salt-lakes of desert regions present a wholly peculiar series of deposits. These sheets of water have no outlet; yet there is reason to believe that most of them were at first fresh, and discharged their outflow like ordinary lakes. Owing to geological changes of level and of climate, they have long ceased to overflow. The water that runs into them, instead of escaping by a river, is evaporated back into the air. But the various mineral salts carried by it in solution from rocks and soils are not evaporated also. They remain behind in the lakes, which are consequently becoming gradually salter. Among the salts thus introduced, common salt (sodium-chloride) and gypsum (calcium-sulphate) are two of the most important. These substances, as the water evaporates in the shallows, bays, and pools, are precipitated to the bottom where they form solid layers of salt and gypsum. The latter substance begins to be thrown down when 37 per cent of the water containing it has been evaporated. The sodium-chloride does not appear until 93 per cent of the water has disappeared In the order of deposit, therefore, gypsum comes before the salt (see p. 150). Some bitter lakes contain sodium-carbonate, in others magnesium-chloride is abundant. The Dead Sea, the Great Salt Lake of Utah, and many other salt-lakes and inland seas furnish interesting evidence of the way in which they have gradually changed. In the upper terraces of the Great Salt Lake, 1000 feet or more above the present level of the water, fresh-water shells occur, showing that the basin was at first fresh. The valley-bottoms around saline lakes are now crusted with gypsum, salt, or other efflorescence, and their waters are almost wholly devoid of life. Such conditions as these help us to understand how great deposits of gypsum and rock-salt were formed in England, Germany, and many other regions where the climate would not now permit of any such condensation of the water (Chapter XXII.).

**Summary.**—The records inscribed by lakes in geological history consist of layers of various kinds of sediment. These deposits may form mere shelves or terraces along the margin of the water which, if drained off, will leave them as evidence of its former levels Partly by the erosive action of the shore-waters of the lakes themselves when agitated by the winds, but chiefly by the long-continued operations of rain, brooks, and rivers, continually bringing down sediment, lakes are gradually filled up with alluvium, and finally become flat meadow-land with tributary streams running through it. The deposits that thus replace

the lacustrine water consist mainly of sand or gravel near shore, while finer silt occupies the site of the deeper water. They may also include beds of marl formed of fresh-water shells, and sheets of brown iron ore. Throughout them all, remains of the plants and animals of the surrounding land are likely to be entombed and preserved.

Salt lakes leave, as their enduring memorial, beds of rock-salt and gypsum, sometimes carbonate of soda and other salts. Many of them were at first fresh, as is shown by the presence of ordinary fresh-water shells in their upper terraces. But by change of climate and long-continued excess of evaporation over precipitation, the water has gradually become more and more saline, and has sometimes disappeared altogether, leaving behind it deposits of common salt, gypsum, and other chemical precipitates.

## CHAPTER V

### HOW SPRINGS LEAVE THEIR MARK IN GEOLOGICAL HISTORY

THE changes made by running water upon the land are not confined to that portion of the rainfall which courses along the surface. Even when it sinks underground and seems to have passed out of the general circulation, the subterranean moisture does not remain inactive After travelling for a longer or shorter distance through the pores of rocks, or along their joints and other divisional planes, it finds its way once more to daylight and reappears in *Springs*.[1] In this underground journey, it corrodes rocks, somewhat in the same way as rain attacks those that are exposed to the outer air, and it works some curious changes upon the face of the land Subterranean water thus leaves distinct and characteristic memorials as its contribution to geological history

There are two aspects in which the work of underground water may be considered here In the first place, portions of the substance of subterranean rocks are removed by the percolating water and in large measure carried up above ground ; in the second place, some of these materials are laid down again in a new form and take a conspicuous place among the geological monuments of their time.

In the removal of mineral substance, water percolating through rocks acts in two distinct ways, mechanical and chemical, each of which shows itself in its own peculiar effects upon the surface.

(1) **Mechanical Action.**—While slowly filtering through subterranean porous materials, water tends to remove loose particles and thus to lessen the support of overlying rocks. But even where there is no transport, the water itself, by saturating a porous layer that rests upon a more or less impervious one, loosens the cohesion

[1] *Physical Geography Class-Book*, p. 240

of that porous layer. The overlying mass of rock is thus made to rest upon a watery and weakened platform, and if from its position it should have a tendency to gravitate in any given direction, it may at last yield to this tendency and slide downwards. Along the sides of sea-cliffs, on the precipitous slopes of valleys or river-gorges, or on the declivities of hills and mountains, the conditions are often extremely favourable for the descent of large masses of rock from higher to lower levels.

Remarkable illustrations of such *Landslips*, as they are called, from time to time take place on coast-lines and on the sides of ravines and hills. Where porous sandy rocks rest upon more or less impervious clays, the percolating water is arrested in its descent, and thrown out along the base of the slopes. After much wet weather, the upper surface of the clays becomes, as it were, lubricated by the accumulation of water, and large slices of the overlying rocks, having their support thereby weakened, break off from the solid ground behind and slide downwards. A memorable example of this process occurred at Christmas time, in the year 1839, on the south coast of England, not far from Axmouth. At that locality, the chalk-downs end off in a line of broken cliff rising 500 feet above the sea. From the edge of the downs flanked by this cliff, a tract about 800 yards long, containing not less than 30 acres of arable land, sank down with all its fields, hedgerows, and pathways. This sunken mass, where it broke away from the upland, left behind it a new cliff, showing along the crest the truncated ends of the fields, of which the continuation was to be found in a chasm more than 200 feet deep. While the ground sank into this defile and was tilted steeply towards the base of the cliff, it was torn up by a long rent running on the whole in the line of the cliff, and by many parallel and transverse fissures. Although more than half a century has passed since this landslip occurred, the cliff remains much as it was at first, and the sunken fields with their bits of hedgerow still slope steeply down to the bottom of the declivity (Fig. 24). But the lapse of time has allowed the influence of the atmosphere to come into play. The outstanding dislocated fragments with their vertical walls and flat tops, showing segments of fields, have been gradually worn into tower-like masses with sloping declivities of debris. The long parallel rent has been widened by rain into a defile with shelving sides. Everywhere the rawness of the original fissures has been softened by the rich tapestry of verdure which the genial climate of that southern coast fosters in every sheltered nook. But the scars

FIG. 24.—View of Axmouth landslip (as it appeared in April 1885).

have not been healed, and they will no doubt remain still visible for many a year to come.

Landslips, of which there is no historical record, have produced some of the most picturesque scenery along the south coast of England. Masses that have slipped away from the main cliff have so grouped themselves down the slopes that hillocks and hollows succeed each other in endless confusion, as in the well-known Undercliff of the Isle of Wight. Some of the tumbled rocks are still fresh enough to show that they have fallen at no very remote period, or even that the slipping still continues; others, again, have yielded so much to the weather that their date doubtless goes far back into the past, and some of them are crowned with what are now venerable ruins.

The most stupendous landslips on record have occurred in mountainous countries. Upwards of 150 destructive examples have been chronicled in Switzerland. Of these, one of the most memorable was that of the Rossberg, a mountain lying behind the Rigi, and composed of thick masses of hard red sandstone and conglomerate, so arranged as to slope down into the valley of Goldau. The summer of the year 1806 having been particularly wet, so large an amount of water had collected in the more porous layers of rock as to weaken the support of the overlying mass; consequently a large part of the side of the mountain suddenly gave way and rushed down into the valley, burying under the debris about a square German mile of fertile land, four villages containing 330 cottages and outhouses, and 457 inhabitants To this day, huge angular blocks of sandstone lying on the farther side of the valley bear witness to the destruction caused by this landslip, and the scar on the mountain-slope whence the fallen masses descended is still fresh.

(2) **Chemical Action**—(*a*) Solution—But it is by its chemical action on the rocks through which it flows that subterranean water removes by far the largest amount of mineral matter, and produces the greatest geological change. Even pure water will dissolve a minute quantity of the substance of many rocks. But rain is far from being chemically pure water. In previous chapters it has been described as taking oxygen and carbonic acid out of the air in its descent, and abstracting organic acids and carbonic acid from the soil through which it sinks. By help of these ingredients, the water is enabled to attack even the most durable rocks, and to carry some of their dissolved substance up to the surface of the ground.

One of the substances most readily attacked and removed, even by pure water, is the mineral known as carbonate of lime. Among other impurities, natural waters generally contain carbonic acid, which may be derived from the air or from the soil; occasionally from some deeper subterranean source. The presence of this acid gives the water greatly increased solvent power, enabling it readily to attack carbonate of lime, whether in the form of limestone, or diffused through rocks composed mainly of other substances. Even lime, which is not in the form of carbonate, but is united with silica in various crystalline minerals (silicates, p. 145), may by this means be decomposed and combined with carbonic acid. It is then removed in solution as carbonate. So long as the water retains enough of free carbonic acid, it can keep the carbonate of lime in solution and carry it onward.

Limestone is a rock almost entirely composed of carbonate of lime. It occurs in most parts of the world, covering sometimes tracts of hundreds or thousands of square miles, and often rising into groups of hills, or even into ranges of mountains (see pp 170, 174). The remarkable solvent action of rain-water on exposed surfaces of limestone has been already referred to in Chapter II. The abundance of this rock affords ample opportunity for the display of similar action on the part of subterranean water. Continuing the same process of solution which we have seen to work such changes at the surface, the water trickles down the vertical joints and along the planes between the limestone beds. As it flows on, it dissolves and removes the stone, until in the course of centuries these passages are gradually enlarged into clefts, tunnels, and caverns. The ground becomes honeycombed with openings into dark subterranean chambers, and running streams fall into these openings and continue their course underground.

Every country which possesses large limestone tracts furnishes examples of the way in which such labyrinthine tunnels and systems of caverns are excavated. In England, for example, the Peak Cavern of Derbyshire is believed to be 2300 feet long, and in some places 120 feet high. On a much more magnificent scale are the caverns of Adelsberg near Trieste, which have been explored to a distance of between four and five miles, but are probably still more extensive. The river Poik has broken into one part of the labyrinth of chambers, through which it rushes before emerging again to the light. Narrow tunnels expand into spacious halls, beyond which egress is again afforded by low

passages into other lofty recesses. The most stupendous chamber measures 669 feet in length, 630 feet in breadth, and 111 feet in height. From the roofs hang pendent white *stalactites* (p. 64), which, uniting with the floor, form pillars showing endless varieties of form and size (Fig. 25). Still more gigantic is the system of subterranean passages in the Mammoth Cave of Kentucky, the accessible parts of which are believed to have a combined length of about 150 miles. The largest cavern in this vast labyrinth has an area of two acres, and is covered by a vault 125 feet high.

Of the mineral matter dissolved by permeating water out of the rocks underground, by far the larger part is discharged by springs into rivers, and ultimately finds its way to the sea. The

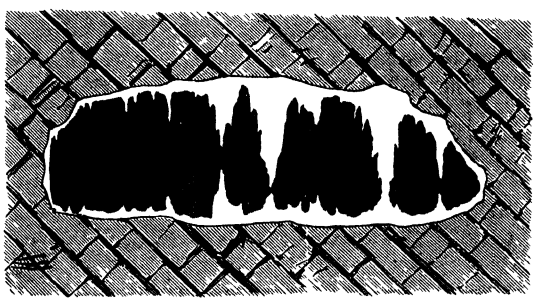


FIG 25.—Section of cavern with stalactites and stalagmite

total amount of material thus supplied to the sea every year must be enormous Much of it, indeed, is abstracted from ocean-water by the numerous tribes of marine plants and animals In particular, the lime, silica, and organic matter are readily seized upon to build up the framework and furnish the food of these creatures. But probably more mineral matter is supplied in solution than is required by the organisms of the sea, in which case the water of the sea must be gradually growing heavier and salter

(*b*) Deposition.—But it is the smaller proportion of the material not conveyed into the sea that specially demands attention. Every spring, even the purest and most transparent, contains mineral solutions in sufficient quantity to be detected by chemical analysis. Hence all plants and animals that drink the water of springs and rivers necessarily imbibe these solutions which, indeed, supply some of the mineral salts whereof the harder

parts both of plants and animals are more or less constructed. Many springs, however, contain so large a proportion of mineral matter, that when they reach the surface and begin to evaporate, they drop their solutions as a precipitate, which settles down upon the bottom or on objects within reach of the water. After years of undisturbed continuance, extensive sheets of mineral material may in this manner be accumulated, which remain as enduring monuments of the work of underground water, even long after the springs that formed them may have ceased to flow.

*Calcareous Springs.*—Among the accumulations of this nature by far the most frequent and important are those formed by what are called Calcareous Springs. In regions abounding in limestone or rocks containing much carbonate of lime, the subterranean waters which, as we have seen, gradually erode such vast systems of tunnels, clefts, and caverns, carry away the dissolved rock, and retain it in solution only so long as they can keep their carbonic acid. As soon as they begin to evaporate and to lose some of this acid, they lose also the power of retaining so much carbonate of lime in solution. This substance is accordingly dropped as a fine white precipitate, which gathers on the surfaces over which the water trickles or flows.

The most familiar example of this process is to be seen under the arches of bridges and vaults. Long pendent white stalks or *stalactites* hang from between the joints of the masonry, while wavy ribs of the same substance run down the piers or walls, and even collect upon the ground (*stalagmite*) A few years may suffice to drape an archway with a kind of fringe of these pencil-like icicles of stone. Percolating from above through the joints between the stones of the masonry, the rain-water, armed with its minute proportion of carbonic acid at once attacks the lime of the mortar and forms carbonate of lime, which is carried downward in solution. Arriving at the surface of the arch, the water gathers into a drop, which remains hanging there for a brief interval before it falls to the ground. That interval suffices to allow some of the carbonic acid to escape, and some of the water to evaporate. Consequently, round the outer rim of the drop a slight precipitation of white chalky carbonate of lime takes place. This circular pellicle, after the drop falls, is increased by a similar deposit from the next drop, and thus drop by drop the original rim or ring is gradually lengthened into a tube which may eventually be filled up inside, and may be thickened irregularly outside by the trickle of calcareous water (Fig. 26). But the

deposition on the roof does not exhaust the stock of dissolved carbonate. When the drops reach the ground the same process of evaporation and precipitation continues. Little mounds of the same white substance are built up on the floor, and, if the place remain undisturbed, may grow until they unite with the stalactites from the roof, forming white pillars that reach from floor to ceiling (Fig. 25, and p. 170).

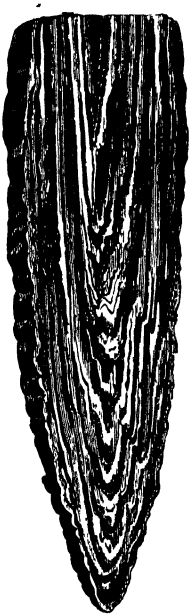


Fig. 26.—Section showing successive layers of growth in a stalactite

It is in limestone caverns that stalactitic growth is seen on the most colossal scale. These quiet recesses having remained undisturbed for many ages, the process of solution and precipitation has advanced without interruption until, in many cases, vast caverns have been transformed into grottoes of the most marvellous beauty. White glistening fringes and curtains of crystalline carbonate of lime, or *spar*, as it is popularly called, hang in endless variety and beauty of form from the roof. Pillars of every dimension, from slender wands up to thick-ribbed columns like those of a cathedral, connect the roof and the pavement. The walls, projecting in massive buttresses and retiring into alcoves, are everywhere festooned with a grotesque drapery of stone. The floor is crowded with mounds and bosses of strangely imitative forms which recall some of the oddest shapes above-ground. Wandering through such a scene, the visitor somehow feels himself to be in another world, where much of the architecture and ornament belongs to styles utterly unlike those which can be seen anywhere else.

The material composing stalactite and stalagmite is at first, as already stated, a fine white chalky pulp-like substance which dries into a white powder. But as the deposition continues, the older layers, being impregnated with calcareous water, receive a precipitation of carbonate of lime between their minute pores and crevices, and assume a crystalline structure Solidifying and hardening by degrees, they end by becoming a compact crystalline stone (spar) which rings under the hammer.

The numerous caverns of limestone districts have offered

ready shelter to various kinds of wild animals and to man himself Some of them (*Bone-Caves*) have been hyæna-dens, and from under their hard floor of stalagmite the bones of hyænas and of the creatures they fed upon are disinterred in abundance. Rude human implements have likewise been obtained from the same deposits, showing that man was contemporary with animals which have long been extinct. The solvent action of underground water has thus been of the utmost service in geological history, first, in forming caverns that could be used as retreats, and then in providing the stalagmite which sealed up and preserved the relics of the denizens left upon the cavern-floors (pp. 101, 176, 408, 411).

Calcareous springs, issuing from limestone or other rock abounding in lime, deposit carbonate of lime as a white precipitate. So large is the proportion of this mineral contained in some waters that thick and extensive accumulations of it have been formed The substance thus deposited is known by the name of *Calcareous Tufa*, *Calc-sinter*, or *Travertine*. It varies in texture, some kinds being loose and crumbling, others hard and crystalline. In many places it is composed of thin layers or laminæ, of which sixty may be counted in the thickness of an inch, but bound together into a solid stone. These laminæ mark the successive layers of deposit. They are formed parallel to the surface over which the water flows or trickles, hence they may be observed not only on the flat bottoms of pools, but irregularly enveloping the walls of a stream-channel as far up as the dash of water or spray can reach. Rounded bosses may thus be formed above the level of a stream, and the recesses may be hung with stalactites.

The calcareous springs of Northern and Central Italy have long been noted for the large amount of their dissolved lime, the rapidity with which it is deposited, and the extensive masses in which it has accumulated. Thus at San Filippo in Tuscany, it is deposited in places at the rate of one foot in four months, and it has been piled up to a depth of at least 250 feet, forming a hill a mile and a quarter long, and a third of a mile broad. So compact are many of the Italian travertines that they have from time immemorial been extensively used as a building stone, which can be dressed and is remarkably durable. Many of the finest buildings of ancient and modern Rome have been constructed of travertine.

A familiar feature of many calcareous springs deserves notice here. The precipitation of calc-sinter is not always due merely

to evaporation In many cases, where the proportion of carbonate of lime in solution is so small that under ordinary circumstances no precipitation of it would take place, large masses of it have been deposited in a peculiar fibrous form. On examination, this precipitation will be found to be caused by the action of plants, particularly bog-mosses which, decomposing the carbonic acid in the water, cause the lime-carbonate to be deposited along their stems and leaflets. The plants are thus incrusted with sinter which, preserving their forms, looks as if it were composed of heaps of moss turned into stone. Hence the name of *petrifying* springs often given to waters where this process is to be seen.

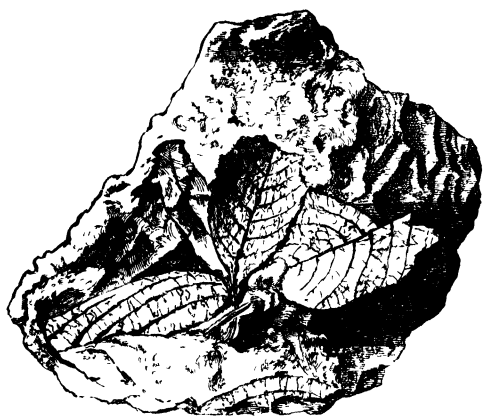


FIG. 27.—Travertine with impressions of leaves

There is, however, no true petrifaction or conversion of the actual substance of the plants into stone The fibres are merely incrusted with travertine, inside of which they eventually die and decay. But as the plants continue to grow outward, they increase the sinter by fresh layers, while the inner and dead parts of the mass are filled up and solidified by the deposit of the precipitate within their cavities.

A growing accumulation of travertine presents a special interest to the geologist from the fact that it offers exceptional facilities for the preservation of remains of the plants and animals of the neighbourhood. Leaves, flowers, or fruit from the surrounding trees and shrubs are blown into pools or fall upon moist

surfaces where the precipitation of lime is actively going on (Fig. 27). Dead insects, snail-shells, birds, small mammals, and other denizens of the district may fall or be carried into similar positions. These remains may be rapidly enclosed within the stony substance before they have time to decay, and even if they should afterwards moulder into dust, the sinter enclosing them retains the mould of their forms, even of such fragile objects as flowers, and thus preserves for an indefinite period the record of their former existence.

*Chalybeate Springs.*—A second but less abundant deposit from springs is found in regions where the rocks below-ground contain decomposing sulphide of iron (p. 153) Water percolating through such rocks and oxidising the sulphur of that mineral, forms sulphate of iron (ferrous sulphate), which it removes in solution. The presence of any notable quantity of this sulphate is at once revealed by the marked inky taste of the water and by the yellowish-brown precipitate of ochre on the sides and bottom of the channel. Such water is termed *Chalybeate.* When it mixes with other water containing dissolved carbonates (which are so generally present in running water), the sulphate is decomposed, the sulphuric acid passing over to the lime or alkali of the carbonate, while the iron takes up oxygen and falls to the bottom as a yellowish-brown precipitate (limonite, p. 143). This interchange of combinations, with the consequent precipitation of iron-oxide, may continue for a considerable distance from the outflow of the chalybeate water. Nearest the source the deposit of hydrated ferric oxide or ochre is thickest. It encloses leaves, stems, and other organic remains, and preserves moulds or casts of their forms. It may also cement the loose sand and shingle of a river-bottom into solid rock (pp. 144, 175)

*Siliceous Springs*—One other deposit from spring-water may be enumerated here. In volcanic regions, hot springs (geysers) rise to the surface which, besides other mineral ingredients, contain a considerable proportion of *silica* (p. 130) This substance is deposited as *Siliceous Sinter* round the vents whence the water is discharged, where it forms a white stone rising into mounds and terraces with fringes and bunches of coral-like growth. Where many springs have risen in the same district, their respective sheets of sinter may unite, and thus extensive tracts have been buried under the deposit. In Iceland, for example, one of the sheets is said to be two leagues long, a quarter of a league wide, and a hundred feet thick. In the Yellowstone Park of North America, many valleys are floored over with heaps of sinter, and in New

Zealand other extensive accumulations of the same material have been formed. It is obvious that, like travertine, siliceous sinter may readily entomb and preserve a record of the plants and animals that lived at the time of its deposition.

**Summary**.—The underground circulation of water produces changes that leave durable records in geological history These changes are of two kinds. (1) Landslips are caused, by which the forms of cliffs, hills, and mountains are permanently altered. Vast labyrinths of subterranean tunnels, galleries, and caverns are dissolved out of calcareous rocks, and openings are made from these passages up to the surface, whereby rivers are engulfed. Many of the caves thus hollowed out have served as dens of wild beasts, and dwelling-places for man, and the relics of these inhabitants have been preserved under the stalagmite of the floors (2) An enormous quantity of mineral matter is brought up to the surface by springs Most of the solutions are conveyed ultimately to the sea, where they partly supply the substances required by the teeming population of marine plants and animals But, under favourable circumstances, considerable deposits of mineral matter are made by springs, more especially in the form of travertine, siliceous sinter, and ochre. In these deposits the remains of terrestrial vegetation, also of insects, birds, mammals, and other animals, are not infrequently preserved, and remain as enduring memorials of the life of the time when they flourished.

## CHAPTER VI

### ICE-RECORDS

ICE in various ways alters the surface of the land. By disintegrating and eroding even the most durable rocks, and by removing loose materials and piling them up elsewhere, it greatly modifies the details of a landscape. As it assumes various forms, so it accomplishes its work with considerable diversity. The action of frost upon soil and bare surfaces of rock has already (p. 13) been described. We have now to consider the action of frozen rivers and lakes, snow and glaciers, which have each their own characteristic style of operation, and leave behind them their distinctive contribution to the geological history of the earth.

**Frozen Rivers and Lakes.**—In countries with a severe winter climate, the rivers and lakes are frozen over, and the cake of ice that covers them may be more than two feet thick. When this cake is broken up in early summer, large masses of it are driven ashore, tearing up the littoral boulders, gravel, sand, or mud, and pushing them to a height of many feet above the ordinary level of the water. When the ice melts, huge heaps of detritus are found to have been piled up by it, which may long remain as monuments of its power. Not only so, but large fragments of the ice that has been formed along shore and has enclosed blocks of stone, gravel, and sand, are driven away and may travel many miles before they melt and drop their freight of stones. On the St. Lawrence and on the coast of Labrador, there is a constant transportation of boulders by this means. Further, besides freezing over the surface, the water not infrequently forms a loose spongy kind of ice on the bottom (*Anchor-ice, Ground-ice*) which encloses stones and gravel, and carries them up to the surface where it joins the cake of ice there. This bottom-ice is formed abundantly on some parts of the Canadian rivers. Swept down by the current, it accumulates

against the bars or banks, or is pushed over the upper ice, and from time to time gathers into temporary barriers, the bursting of which may cause destructive floods. In the river St. Lawrence, banks and islets have been to a large extent worn down by the grating of successive ice-rafts upon them.

**Snow.**—On level or gently inclined ground, whence snow disappears merely by melting or evaporation, it exercises, while it remains, a protective influence upon the soil and vegetation, shielding them from the action of frost. On slopes of sufficient declivity, however, the sheet of snow acquires a tendency to descend by gravitation, as we may often see on house-roofs in winter In many cases, it creeps or slides down the sides of a hill or valley, and in so doing pushes forward any loose material that may lie on the surface. By this means, in exposed situations, vegetation, soil, subsoil, stones, and loose objects are gradually thrust down-hill, so as to bare the rock for further disintegration. But where the declivities are steep enough to allow the snow to break off in large sheets and to rush rapidly down, the most striking changes are observable. Such descending masses are known as *Avalanches*. Varying from 10 to 50 feet or more in thickness and several hundred yards broad and long, they sweep down the mountain sides with terrific force, carrying away trees, soil, houses, and even large blocks of rock. The winter of 1884-85 was especially remarkable for the number of avalanches in the valleys of the Alps, and for the enormous loss of life and property which they caused. In such mountain ground, not only are declivities bared of their trees, soil, and boulders, but huge mounds of debris are piled up in the valleys below. Frequently, also, such a quantity of snow, ice, and rubbish is thrown across the course of a stream as to dam back the water, which accumulates until it overflows or sweeps away the barrier. In another but indirect way, snow may powerfully affect the surface of a district where, by rapid melting, it so swells the rivers as to give rise to destructive floods.

While, therefore, the influence of snow is on the whole to protect the surface of the land, it shows itself in mountainous regions singularly destructive, and leaves, as chief memorials of this destructiveness, the mounds and rough heaps of earth and stones that mark where the down-rushing avalanches have come to rest.

**Glaciers and Ice-Sheets** leave their record in characters so distinct as not to be easily confounded with those of any other

kind of geological agent. The changes which they produce on the surface of the land may be divided into two parts: (1) the transport of materials from high ground to lower levels, and (2) the erosion of their beds.

(1) Transport.—As a glacier descends its valley, it receives upon its surface the earth, sand, mud, gravel, boulders, and masses of rock that roll or are washed down from the slopes on either side. Most of this rubbish accumulates on the edges of the glacier, where it is slowly borne to lower levels as the ice creeps downwards. But some of it falls into the crevasses or rents by

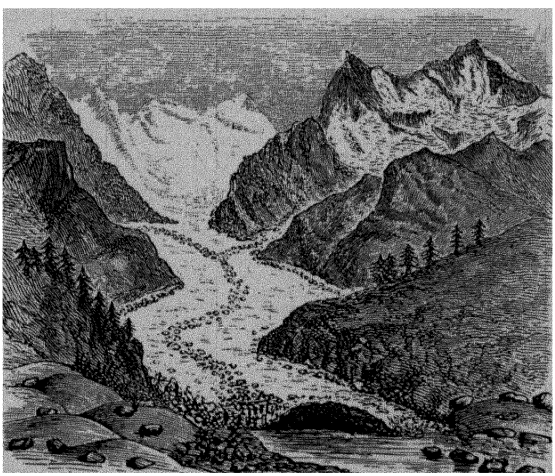


FIG. 28.—Glacier with medial and lateral moraines.

which the ice is split, and may either be imprisoned within the glacier, or may reach the rocky floor over which the ice is sliding. The rubbish borne onward upon the surface of the glacier is known as *moraine-stuff* (Fig. 28). The mounds of it running along each side of the glacier form *lateral moraines*, those on the right-hand side as we look down the length of the valley being the right lateral moraine, those on the other side the left lateral moraine. Where two glaciers unite, the left lateral moraine of the one joins the right lateral moraine of the other, forming what is called a *medial moraine* that runs down the middle of the united glacier. Where a glacier has many tributaries bearing much moraine-stuff, its

surface may be like a bare plain covered with earth and stones, so that, except where a yawning crevasse reveals the clear blue gleam of the ice below, nothing but earth and stones meets the eye. When the glacier melts, the detritus is thrown in heaps upon the valley, forming there the *terminal moraine.*

Glaciers, like rivers, are subject to variations of level. Even from year to year they slowly sink below their previous limit or rise above it. The glacier of La Brenva, for example, on the Italian side of Mont Blanc, subsided no less than 300 feet in the first half of the nineteenth century. One notable consequence of such diminution is that the blocks of rock lying on the edges of a glacier are stranded on the side of the valley, as the ice shrinks

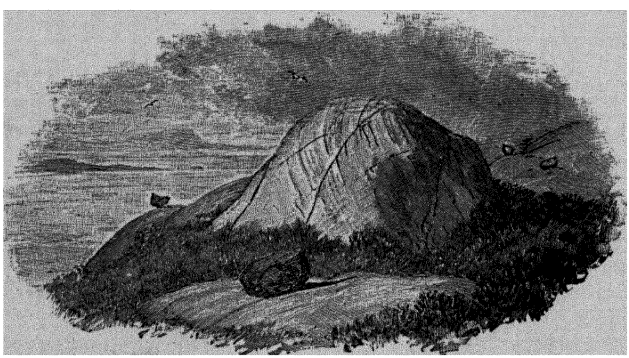


FIG. 29.—Perched blocks scattered over ice-worn surface of rock.

away from them. Such *Perched Blocks* or *Erratics* (Figs. 29, 30), as they are called, afford an excellent means of noting how much higher and longer a glacier has once been than it is now. Their great size (some of them are as large as good-sized cottages) and their peculiar positions make it quite certain that they could not have been transported by any current of water. They are often poised on the tops of crags, on the very edges of precipices, or on steep slopes where they could never have been left by any flood, even had the flood been capable of moving them. The agent that deposited them in such positions must have been one that acted very quietly and slowly, letting the blocks gently sink into the sites they now occupy. The only agent known to us that could have done this is glacier-ice. We can actually see similar blocks on the glaciers now, and others which have only

recently been stranded on the side of a valley from which the ice has sunk. In the Swiss valleys, the scattered ice-borne boulders may be observed by hundreds, far above the existing level of the glaciers and many miles beyond where these now end. If the origin of the dispersed erratics is self-evident in a valley where a glacier is still busy transporting them, those that occur in valleys which are now destitute of glaciers can offer no difficulty; they

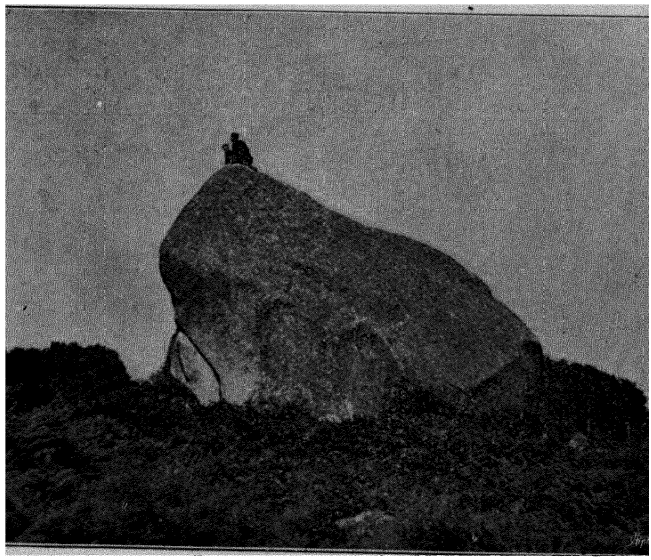


FIG. 30.—Glacier-borne block of granite resting on red sandstone, Corrie, Isle of Arran, Scotland.

become, indeed, striking monuments that glaciers once existed there.

Scattered erratic blocks offer much interesting evidence of the movements of the ice by which they were transported. In a glacier-valley, the blocks that fall upon the ice remain on the side from which they have descended. Hence, if there is any notable difference between the rocks of the two sides, this difference will be recognisable in the composition of the moraines, and will remain distinct even to the end of the glacier. If, therefore, in a district from which the glaciers have disappeared, we can trace

up the scattered blocks to their sources among the mountains, we thereby obtain evidence of the actual track followed by the vanished glaciers. The limits to which these blocks are traceable do not, of course, absolutely fix the limits of the ice that transported them. They prove, however, that the ice extended at least as far as they occur, but it may obviously have risen higher and advanced farther than the space within which the blocks are now confined. In Europe, some striking examples occur of the use of this kind of evidence. Thus the peculiar blocks of the Valais can be traced all the way to the site of the modern city of Lyons. There can therefore be no doubt that the glacier of the Rhone once extended

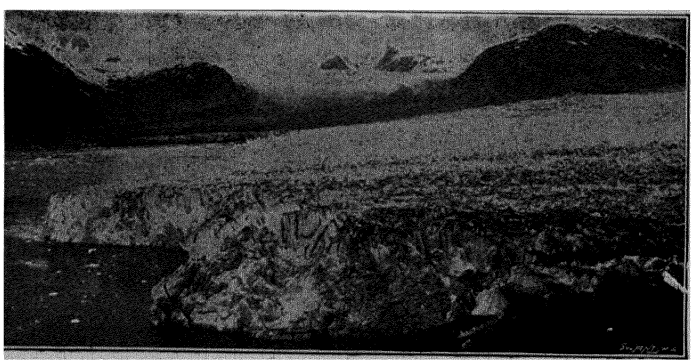


FIG. 31.—Front of Muir Glacier, Alaska, in June 1899, the ice-cliff is from 200 to 300 feet high. Photograph by Mr. G. K. Gilbert, U.S. Geol. Survey.

over all that intervening country and reached at least as far as Lyons,—a distance of not less than 170 miles from where it now ends. Again, from the occurrence of blocks of some of the characteristic rocks of Southern Scandinavia, in Northern Germany, Belgium, and the east of England, we learn that a great sheet of ice once filled up the bed of the Baltic and the North Sea, carrying with it immense numbers of northern erratics. In Britain, where there are now neither glaciers nor snow-fields, the abundant dispersion of boulders from the chief tracts of high ground shows that this country was once in large part buried under ice. In the northern United States and in Canada, similar proofs remain of the former extension of great sheets of ice that moved southward beyond where the city of New York now stands. The aspect of these regions must have closely resembled that of Alaska

and Greenland at the present time (Fig. 31). The evidence for these statements will be more fully given in a later part of this Volume (Chapter XXVII.).

Besides the moraine-stuff carried along on the surface, abundant loose detritus and blocks of rock are pushed onwards under the ice, and sometimes enclosed within its mass. The great Greenland glaciers or ice-sheet include much detritus in their lower portions. When a glacier retires, this earthy and stony debris, where not swept away by the escaping river, is left on the floor of the valley. One remarkable feature of the stones in it is that a large proportion of them are smoothed, polished, and covered

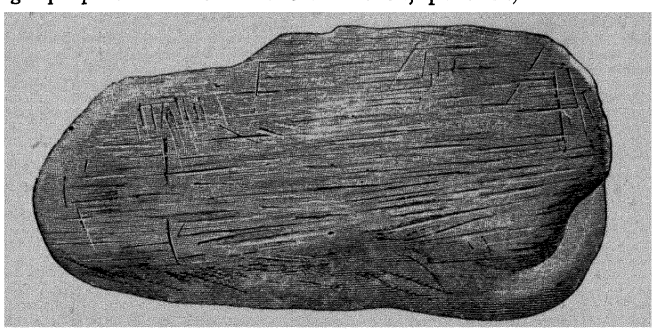


FIG. 32.—Stone from the Boulder-clay of Central Scotland, which has been smoothed and striated under an ice-sheet.

with fine scratches or ruts, such as would be made by hard sharp-pointed fragments of stone or grains of sand. These markings run for the most part along the length of each oblong stone, but not infrequently cross each other, and sometimes an older may be noticed partially effaced by a newer set. This peculiar striation is a most characteristic mark of the action of glaciers. The stones under the ice are fixed in the line of least resistance—that is, end on (p. 41). In this position, under the weight of hundreds of feet of ice, they are pressed upon the floor over which the glacier is travelling. Every sharp edge of stone or grain of sand, driven along the surface of a block, or over which the block itself is slowly drawn, engraves a fine scratch or a deeper rut (Fig. 32). As the block moves onwards, it is more and more scratched, losing its corners and edges, and becoming smaller and smoother till, if it travel far enough, it may be entirely ground into sand or mud.

(2) Erosion.—The same process of erosion is carried on upon the solid rocks over which the ice moves. These are smoothed, striated, and polished by the friction of the grains of sand, pebbles, and blocks of stone crushed against them by the slowly creeping mass of ice. Every boss of rock that looks toward the quarter from which the overlying ice is moving is ground away, while those that face to the opposite side, being more or less protected, remain comparatively sharp and unworn. The

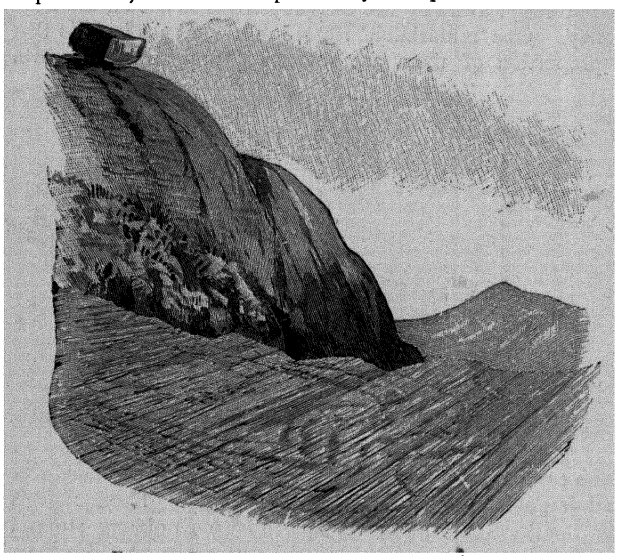


FIG. 33.—Ice-striation on the floor and side of a valley.

polish and striation are especially noteworthy. From the fine scratches, such as are made by grains of sand, up to deep flutings or ruts like those of cart-wheels in unmended roadways, or to still wider and deeper hollows, all the friction-markings run on smoothed and polished surfaces, in a general uniform direction, which is that of the motion of the glacier. The degree of polish of the surface and the delicacy of the striæ and flutings depend in great measure upon the texture of the stone over which the ice has moved. Hard close-grained rocks like limestone have received and retained their ice-worn surface with such perfection that they sometimes look like sheets of artificially polished marble. Such

striated surfaces could only be produced by some agent possessing rigidity enough to hold the sand-grains and stones in position, and press them steadily onward upon the rocks. A river polishes the rocks of its channel by driving shingle and sand across them; but the currents are perpetually tossing these materials now to one side, now to another, so that smoothed and polished surfaces are produced, but with nothing at all resembling striation. A glacier, however, by keeping its grinding materials fixed in the bottom of the ice, engraves its characteristic parallel striæ and groovings, as it slowly creeps down the valley All the surfaces of rock within reach of the ice are smoothed, polished, and striated. Such surfaces present the most unmistakable evidence of glacier-action, for they can be produced by no other known natural agency Hence, where they occur in glacier valleys, far above and beyond the present limits of the ice, they prove how greatly the ice has sunk. In regions also where there are now no glaciers, these rock-markings remain as almost imperishable witnesses that glaciers once existed By means of their evidence, for example, we can trace the march of great ice-sheets which once enveloped the whole of Scandinavia, lay deep upon nearly the whole of Britain, and moved across thousands of square miles in North America.

The river that escapes from the end of a glacier is always milky or muddy. The fine sand and mud that discolour the water are not supplied by the thawing of the clear ice, nor by the sparkling brooks that gush out of the mountain-slopes, nor by the melting of the snows among the peaks that rise on either side. This material can only come from the rocky floor of the glacier itself. It is the fine sediment ground away from the rocks and loose stones by their mutual friction under the pressure of the overlying ice. This "flour of rocks" serves thus as a kind of index or measure of the amount of material worn off the rocky bed by the grinding action of the glacier. We can readily see that as this erosion and transport are continually in progress, the amount of material removed in the course of time must be very great It has been estimated, for example, that the Justedal glacier in Norway removes annually from its bed 2,427,000 cubic feet of sediment At this rate the amount removed in a century would be enough to fill up a valley or ravine 10 miles long, 100 feet broad, and 40 feet deep.

Reference may here be made to an interesting form of erosion which takes place on the rocky floor of a glacier, not by the action

of the ice but by that of running water. The surface of a glacier thaws under the sun's rays, and streams of water are consequently produced, which course over the ice and often fall down crevasses, bearing with them the sand, gravel, and stones which they have swept off the moraine-loaded ice. When one of these cascades falls for a time on a particular part of the floor it uses the detritus to excavate a pot-hole in the rock. Such excavations are not infrequent in glaciated countries which have long been free from ice. They are known as "giants' kettles" and "moulin pot-holes" (Fig. 34).

In arctic and antarctic latitudes, where the land is buried under

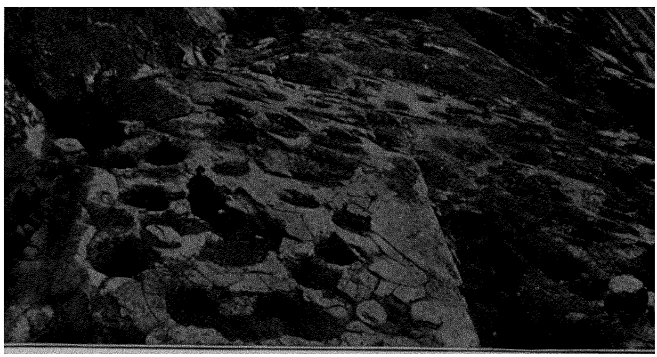


FIG. 34.—"Moulin pot-holes" in granite, High Sierra, California. Photograph by Mr. H. W. Turner, U.S. Geol. Survey.

a vast ice-sheet, which is continually creeping seaward and breaking off into huge masses that float away as icebergs, there must be a constant erosion of the terrestrial surface. Were the ice to retire from these regions, the ground would be found to wear a *glaciated* surface (Figs. 29, 32, 33); that is to say, all the bare rocks would present a characteristic ice-worn aspect, rising into smooth rounded bosses like dolphins' backs (*roches moutonnées*), and sinking into hollows that would become lake-basins. Everywhere these bare rocks would show the striæ and groovings graven upon them by the ice, radiating generally from the central high grounds, and thus indicating the direction of flow of the main streams of the ice-sheet. Piles of earth, ice-polished stones, and blocks of rock would be found strewn over the country, especially in the valleys and over the plains. These materials would still

further illustrate the movements of the ice, for they would be found to be singularly local in character, each district having supplied its own contribution of detritus. Thus from a region of red sandstone, the rubbish would be red and sandy, from one of black slate, it would be black and clayey (see Chapter XXVII.).

**Summary.**—In this chapter we have seen that Ice in various ways affects the surface of the land and leaves its mark there. Frost, as already explained in Chapter II., pulverises soil, disintegrates exposed surfaces of stone, and splits open bare rocks along their lines of natural joint. On frozen rivers and lakes, the disrupted ice wears down banks and pushes up mounds of sand, gravel, and boulders along the shores Snow lying on the surface of the land protects that surface from the action of frost and air. In the condition of avalanches, snow causes large quantities of earth, soil, and blocks of rock to be removed from the mountain-slopes and piled up on the valleys. In the form of glaciers, ice transports the debris of the mountains to lower levels, bearing along and sometimes standing masses of rock as large as cottages, which no other known natural agent could transport Moving down a valley, a glacier wears away the rocks, giving them a peculiar smoothed and striated surface which is thoroughly characteristic. By this grinding action, it erodes its bed and produces a large amount of fine sediment, which is carried away by the river that escapes at the end of the ice stream. Land-ice thus leaves thoroughly distinctive and enduring memorials of its presence in polished and grooved rocks, in masses of earth, clay, or gravel, with striated stones, and in the dispersal of erratic blocks from the principal masses of high ground. These memorials may remain for ages after the ice itself has vanished. By their evidence we know that the present glaciers of the Alps are only a shrunk remnant of the great ice-fields which once covered that region; that the Scandinavian glaciers swept across what is now the bed of the North Sea as far as the mouth of the Thames; that Scotland, Ireland, Wales, and the greater part of England were buried under great sheets of ice which crept downwards into the North Sea on the one side, and into the Atlantic on the other, and that Canada and the northern United States were overspread with ice as far south as Pennsylvania (Chapter XXVII.).

## CHAPTER VII

### THE MEMORIALS OF THE PRESENCE OF THE SEA

WE have now to inquire how the work of the Sea is registered in geological history This work is broadly of two kinds In the first place, the sea is engaged in wearing away the edges of the land, and in the second place, being the great receptacle into which all the materials, worn away from the land, are transported, it arranges these materials over its floor, ready to be raised again into land at some future time.

1. **Demolition of the Land** —In its work of destruction along the coasts of the land, the sea acts to some extent (though we do not yet know how far) by chemically dissolving the rocks and sediments which it covers Cast-iron bars, for example, have been found to be so corroded by sea-water as to lose nearly half their strength in fifty years Doubtless many minerals and rocks are liable to similar attacks.

But it is by its mechanical effects that the sea accomplishes most of its erosion The mere weight with which ocean-waves fall upon exposed coasts breaks off fragments of rock from cliffs Masses, 13 tons in weight, have been known to be quarried out of the solid rock by the force of the breakers in Shetland, at a height of 70 feet above sea-level. As a wave may fall with a blow equal to a pressure of 3 tons on the square foot, it compresses the air in every cleft and cranny of a cliff, and when it drops it allows the air instantly to expand again By this alternate compression and expansion, portions of the cliff are loosened and removed. Where there is any weaker part in the rock, a long tunnel may be excavated, which may even be drilled through to the daylight above, forming an opening at some distance inland from the edge of the cliff. During storms, the breakers rush through such a tunnel, and spout forth from the opening (or *blow-hole*) in clouds of spray (Fig. 35).

Probably the most effective part of the destructive action of the sea is to be found in the battery of gravel, shingle, and loose blocks of stone which the waves discharge against cliffs exposed to their fury. These loose materials, caught up by the advancing breakers and thrown with great force upon the rocks of a coast-line, are dragged back in the recoil of the water, but only to be again lifted and swung forward. In this loud turmoil, the loose stones are reduced in size and are ground smooth by friction against each

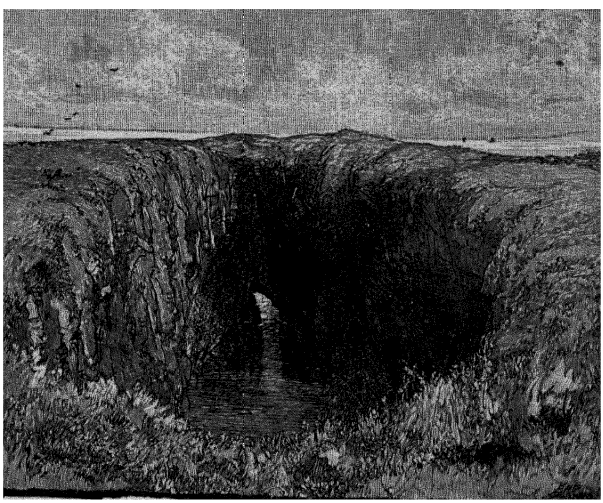


FIG. 35.—Buller of Buchan—a caldron-shaped cavity or blow-hole worn out of granite by the sea on the coast of Aberdeenshire.

other and upon the solid cliff. The well-rounded and polished aspect of the gravel on such storm-beaten shores is an eloquent testimony to the work of the waves. But still more striking, because more measurable, is the proof that the very cliffs themselves cannot resist the blows dealt upon them by the wave-borne stones. Above the ordinary limit reached by the tides, the rocks rise with a rough ragged face, bearing the scars inflicted on it by the ceaseless attacks of the air, rain, frost, and the other agencies that waste the surface of the land. But all along the base of the cliff, within reach of the waves, the rocks have been smoothed and

polished by the ceaseless grinding of the shingle upon them, while arches, tunnels, solitary pillars, half-tide skerries, creeks, and caves attest the steady advance of the sea and the gradual demolition of the shore.

Every rocky coast-line exposed to a tempestuous sea affords illustrations of these features of the work of waves. Even where the rocks are of the most durable kind, they cannot resist the ceaseless artillery of the ocean. They are slowly battered down, and every stage in their demolition may be witnessed, from the sunken reef, which at some distance from the shore marks where the coast-line once ran, up to the tunnelled cliff from which a huge mass was detached during the storms of last winter (Fig. 36). But where the materials composing the cliffs are more easily removed, the progress of the waves may be comparatively rapid. Thus on the east coast of Yorkshire, between Spurn Point and Flamborough Head, the cliffs consist of boulder-clay, and vary up to more than 100 feet in height. At high water, the tide rises against the base of these cliffs, and easily scours away the loose debris which would otherwise gather there and protect them. Hence, within historic times, a large tract of land, with its parishes, farms, villages, and sea-ports, has been washed away, the rate of loss being estimated at not less than 2¼ yards in a year. Since the Roman occupation a strip of land between 2 and 3 miles broad is believed to have disappeared.

It is evident that to carry on effectively this mechanical erosion, the sea-water must be in rapid motion But in the deeper recesses of the ocean, where there is probably no appreciable movement of the water, there can hardly be any sensible erosion. In truth, it is only in the upper parts of the sea which are liable to be affected by wind, that the conditions for marine erosion can be said to exist The space within which these conditions are to be looked for is that comprised between the lowest depth to which the influence of waves and marine currents extends, and the greatest height to which breakers are thrown upon the land. These limits, no doubt, vary considerably in different regions. In some parts of the open sea, as off the coast of Florida, the disturbing action of the waves has been supposed to reach to a depth of 600 feet, though the average limit is probably greatly less. On exposed promontories in stormy seas, such as those of the north of Scotland, breakers have been known to hurl up stones to a height of 300 feet above sea-level. But probably the zone, within which the erosive work of the sea is mainly carried on, does not as a rule exceed 300 feet in vertical range.

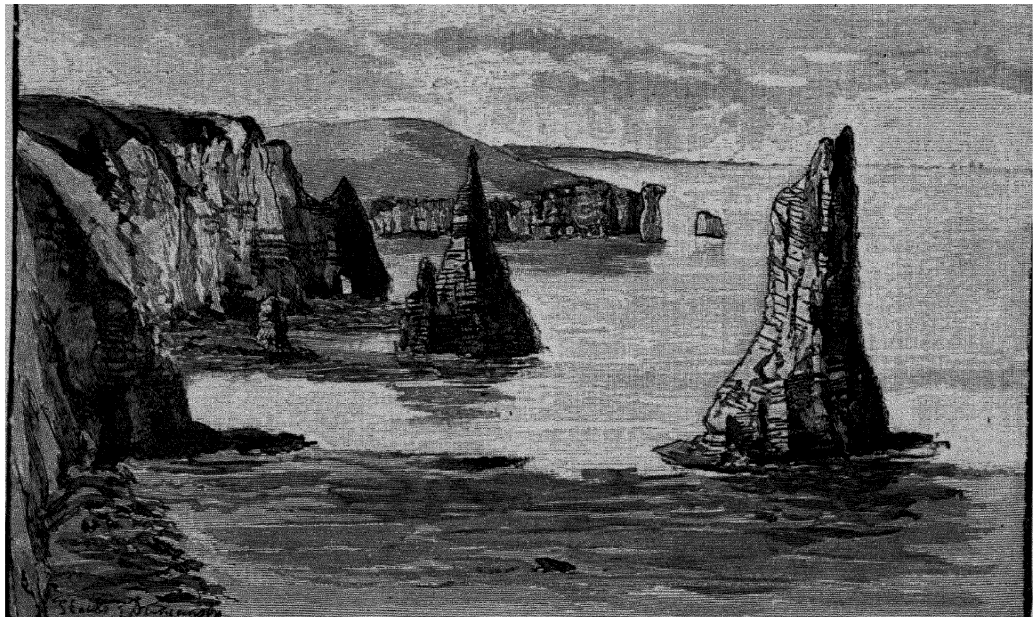


FIG. 36.—The Stacks of Duncansby, Caithness, a wave-beaten coast-line.

Within some such limits as these, the sea is engaged in gnawing away the edges of the land. A little reflection will show us that, if no counteracting operation should come into play, the prolonged erosive action of the waves would reduce the land below the sea-level If we suppose the average rate of demolition to be 10 feet in a century, then it would take not less than 52,800 years to cut away a strip one mile broad from the edge of the land But while the sea is slowly eating away the coast-line, the whole surface of the land is at the same time crumbling down, and the wasted materials are being carried away by rivers into the sea at such a rate that, long before the sea could pare away more than a mere narrow selvage, the whole land might be worn down to the sea-level by air, rain, and rivers (p 31)

There are, however, counteracting influences in nature that would probably prevent the complete demolition of the land. What these influences are will be more fully considered in a later chapter. In the meantime, it will be enough to bear in mind that while the land is constantly worn down by the forces that are acting upon

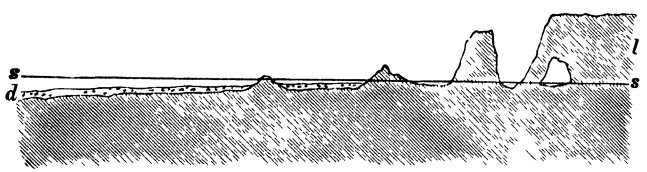



FIG. 37 Section of submarine plain *l*, l and cut into caves, tunnels, sea-stacks, reefs, and skerries by the waves, and reduced to a platform below the level of the sea (*s s*) on which the gravel, sand, and mud (*d*) produced by the waste of the coast may accumulate

its surface, it is liable from time to time to be uplifted by other forces acting from below. And the existing relation between the amount and height of land, and the extent of sea, on the face of the globe, must be looked upon as the balance between the working of both these antagonistic classes of agencies.

But without considering for the present whether the results of the erosion performed by the sea will be interrupted or arrested, we can readily perceive that their tendency is toward the reduction of the level of the land to a submarine plain (Fig. 37) As the waves cut away slice after slice from a coast-line, the portion of land which they thus overflow, and over which they drive the shingle to and fro, is worn down until it comes below the lower limit of breaker-action, where it may be covered up with sand or

mud. When the abraded land has been reduced to this level, it reaches a limit where erosion ceases, and where the sea, no longer able to wear it down further, protects it from injury by other agents of demolition. Such a lower limit of destruction on the surface of the earth has been already referred to as a base-level of erosion.

We see, then, that the goal toward which all the wear and tear of a coast-line tends, is the cutting of a more or less level shelf or platform out of the land. Yet an attentive study of the process will convince us that in the production of such a platform the sea has really had less to do than the atmospheric agents of destruction. An ordinary sea-cliff is not a vertical wall. In the great majority of cases it slopes seaward at a steep angle; but if it had been formed, and were now being cut away, mainly by the sea, it ought obviously to have receded fastest where the waves attack it—that is, at its base. In other words, if sea-cliffs retired chiefly because they are demolished by the sea, they ought to be most eroded at the bottom, and should therefore be usually overhanging precipices. That this is not the case shows that some other agency is concerned, which makes the higher parts of a cliff to recede faster than those below. This agency can be no other than that of the atmospheric forces—air, frost, rain, and springs. These cause the face of the cliff to crumble down, detaching mass after mass, which, piled up below, serve as a breakwater, and must be broken up and removed by the waves before the solid cliff behind them can be attacked.

ii. **Accumulations formed by the Sea.**—It is not its erosive action that constitutes the most important claim of the sea to the careful study of the geologist. After all, the mere marginal belt or fringe within which this action is confined forms such a small fraction of the whole terrestrial area of the globe, that its importance dwindles down when we compare it with the enormously vaster surface over which the operations of the air, rain, rivers, springs, and glaciers are displayed. But when we regard the sea as the receptacle into which all the materials worn off the land ultimately find their way, we see what a large part it must play in geological history.

During the second half of the nineteenth century great additions have been made to our knowledge of the sea-bottom all over the world. Portions of the deposits accumulating there have been dredged up even from the deepest abysses, so that it is now possible to construct charts, showing the general distribution of materials over the floor of the ocean.

Beginning at the shore, let us trace the various types of marine deposits outward to the floors of the great ocean-abysses. In many places, the sea is more or less barred back by the accumulation of sediment worn away from the land. In estuaries, for example, there is often such an amount of mud in the water that the bottom on either side is gradually raised above the level of tide-mark, and forms eventually a series of meadows which the sea can no longer overflow. At the mouths of rivers with a considerable current, a check is given to the flow of the water when it reaches the sea, and there is a consequent arrest of its detritus. Hence a bar is formed across the outflow of a river, which during floods is swept seawards, and during on-shore gales is driven again inland. Even where there is no large river, the smaller streams flowing off the surface of a country may carry down sediment enough to be arrested by the sea, and to be thrown up as a long bank or bar running parallel with the coast. Behind this bar, the drainage of the interior accumulates in long lagoons, which find an outflow through some breach in the bar, or by soaking through the porous materials of the bar itself. A large part of the eastern coast of the United States is fringed with such bars and lagoons. A space several hundred miles long on the east coast of India is similarly bordered

But the most remarkable kind of accumulation of terrestrial detritus in the sea is undoubtedly that of *river-deltas*. Where the tidal scour is not too great, the sediment brought down by a large river into a marine bay or gulf gradually sinks to the bottom, as the fresh spreads over and mingles with the salt water. During floods, coarse sediment is swept along, while during low states of the river nothing but fine mud may be transported. Alternating sheets of different kinds of sediment are thus laid down one upon another on the sea-floor, until by degrees they reach the surface, and thus gradually increase the breadth of the land. Some deltas are of enormous size and depth. That of the Ganges and Brahmaputra covers an area of between 50,000 and 60,000 square miles—that is, about as large as England and Wales. It has been bored through to a depth of 481 feet, and has been found to consist of numerous alternations of fine clays, marls, and sands or sandstones, with occasional layers of gravel. In all this great thickness of sediment, no trace of marine organisms was found, but land-plants and bones of terrestrial and fluviatile animals occurred. Lower Egypt has been formed by the growth of the delta of the Nile, whereby a wide tract of alluvial land has not only

filled up the bottom of the valley, but has advanced into the Mediterranean.

Turning now to the deposits that are more distinctively those of the sea itself, we find that ridges of coarse shingle, gravel, and sand are piled up along the extreme upper limit reached by the waves. The coarsest materials are for the most part thrown highest, especially in bays and narrow creeks where the breakers are confined within converging shores. In such situations, during heavy gales, *storm-beaches* of coarse rounded shingle are formed, sometimes several yards above ordinary high-tide mark (Fig. 38).

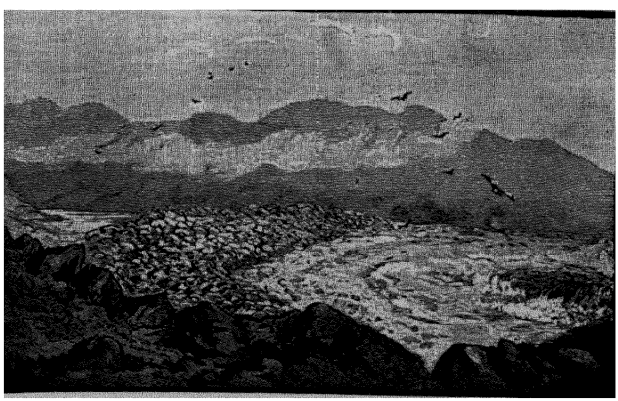


FIG. 38.—Storm-beach ponding back a stream and forming a lake; west coast of Sutherlandshire.

Where a barrier of this kind is thrown across the mouth of a brook, the fresh water may be ponded back to form a small lake, of which the outflow usually escapes by percolation through the shingle. In sheltered bays, behind headlands, or on parts of a coast-line where tidal currents meet, detritus may accumulate in spits or bars. Islands have in this way been gradually united to each other or to the mainland, while the mainland itself has gained considerably in breadth. At Romney Marsh, on the south-east coast of England, for instance, a tract of more than 80 square miles, which in Roman times was in great part covered by the sea at high water, is now dry land, having been gained partly by the natural increase of shingle thrown up by the waves, and partly by the barriers artificially erected to exclude the sea.

While the coarsest shingle usually accumulates towards the upper part of the beach, the materials generally arrange themselves according to size and weight, becoming on the whole finer as they are traced towards low-water mark. But patches of coarse gravel may be noticed on any part of a beach, and large boulders may be seen even below the limits of the lowest tides. As a rule, the deposits formed along a beach, and in the sea immediately beyond, include the coarsest kinds of marine sediment. They are also marked by frequent alternations of coarse and fine detritus, these rapid interchanges pointing to the varying action of the waves and strong shore-currents Towards the lower limit of breaker-action, fine gravel and sand are allowed to settle down, and beyond these, in quiet depths where the bottom is not disturbed, fine sand and mud washed away from the land slowly accumulate.

The distance to which the finer detritus of the land is carried by ocean-currents before it finds its way to the bottom, varies up to 300 miles or more. Within this belt of sea, the land-derived materials are distributed over the ocean-floor. Coarse and fine gravel and sand are the most common materials in the areas nearest the land. Beyond these lie tracts of fine sand and silt with occasional patches of gravel. Still farther from the land, at depths of 600 feet and upwards, fine blue and green muds are found, composed of minute particles of such minerals as form the ordinary rocks of the land. But traced out into the open ocean, these various deposits of recognisably terrestrial origin give place to thoroughly oceanic accumulations, especially to widespread sheets of exceedingly fine red and brown clay. This clay, the most generally diffused deposit of the deeper or abysmal parts of the sea, appears to be derived from the decomposition of volcanic fragments either washed away from volcanic islands or supplied by submarine eruptions. That it is accumulated with extreme slowness is shown by two curious and interesting kinds of evidence. Where it occurs farthest removed from land, great numbers of sharks' teeth, with ear-bones and other bones of whales, have been dredged up from it, some of these relics being quite fresh, others partially coated with a crust of brown peroxide of manganese, while some are wholly and thickly enveloped in this substance. The same haul of the dredge has brought up bones in all these conditions, so that they must be lying side by side on the red clay floor of the ocean abysses. The deposition of manganese is no doubt an exceedingly slow process, but it is evidently faster

than the deposition of the red clay The bones dredged up probably represent a long succession of generations of animals Yet so tardily does the red clay gather over them, that the older ones are not yet covered up by it, though they have had time to be deeply encased in oxide of manganese. The second kind of evidence of the extreme slowness of deposit in the ocean abysses is supplied by minute spherules of metallic iron, which occurring in numbers dispersed through the red clay, have been identified as portions of meteorites or falling stars. These particles no doubt fall all over the ocean, but it is only where the rate of deposition of sediment is exceedingly slow that they may be expected to be detected.

Besides the sediments now enumerated, the bottom of the sea receives abundant accumulations of the remains of shells, corals, foraminifera and other marine creatures; but these will be described in the next chapter, where an account is given of the various ways in which plants and animals, both upon the land and in the sea, inscribe their records in geological history. It must also be borne in mind that throughout all the sediments of the sea-floor, from the upper part of the beach down to the bottom of the deepest and remotest abyss, the remains of the plants, sponges, corals, shells, fishes and other organisms of the ocean may be entombed and preserved. It will suffice here to remember that various depths and regions of the sea have their own characteristic forms of life, the remains of which are preserved in the sediments accumulating there, and that although gravel, sand, and mud laid down beneath the sea may not differ in any recognisable detail from similar materials deposited in a lake or river, yet the presence of marine organisms in them would be enough to prove that they had been laid down in the sea. It is evident, also, that if the sea-floor over a wide area were raised into land, the extent of the deposits would show that they could not have been accumulated in any mere river or lake, but must bear witness to the former presence of the sea itself.

**Summary.**—The sea records its work upon the surface of the earth in a twofold way. In the first place, in co-operation with the atmospheric agents of disintegration, it eats away the margin of the land and planes it down. The final result of this process if uninterrupted would be to reduce the level of the land to that of a submarine platform, the position of the surface of which would be determined by the lower limit of effective breaker-action. In the second place, the sea gathers over its floor all the detritus

worn by every agency from the surface of the land. This material is not distributed at random; it is assorted and arranged by the waves and currents, the coarsest portions being laid down nearest the land, and the finest in stiller and deeper water. The belt of sea-floor within which this deposition takes place probably does not much exceed a breadth of 300 miles. Beyond that belt, the bottom of the ocean is covered to a large extent with a red clay, probably derived from the decomposition of volcanic material and laid down with extreme slowness. This deposit and the wide-spread layer of dead sea-organisms (to be described in next chapter) are truly oceanic accumulations, recognisably distinct from those derived from terrestrial sources within the narrow zone of deposition near the land.

# CHAPTER VIII

## HOW PLANTS AND ANIMALS INSCRIBE THEIR RECORDS IN GEOLOGICAL HISTORY

BROADLY considered, there are two distinct ways in which Plants and Animals leave their mark upon the surface of the earth. In the first place, they act directly by promoting or arresting the decay of the land, and by forming out of their own remains deposits which are sometimes thick and extensive. In the second place, their remains are transported and entombed in sedimentary accumulations of many different kinds, and furnish important evidence as to the conditions under which these accumulations were formed Each of these two kinds of memorial deserves our careful attention, for, taken together, they comprise the most generally interesting departments of geology, and those in which the history of the earth is principally discussed.[1]

1. **Direct action of living things upon the surface of the globe.**—This action is often of a destructive kind, both plants and animals taking their part in promoting the general disintegration of rocks and soils. Thus, by their decay they furnish to the soil those organic acids already referred to (pp. 17, 27) as so important in increasing the solvent power of water, and thereby promoting the waste of the land. Not only are existing rocks thus disintegrated, but new rocks are formed out of the materials removed. The iron, for example, which is abstracted from many varieties of stone and carried off in solution, is deposited at the bottom of bogs and lakes as an accumulation of iron-ore, which is sometimes profitably employed as a source of the metal (*ante*, p. 54). By thrusting their roots into crevices of cliffs, plants

[1] In the Appendix a Table of the Vegetable and Animal Kingdoms is given, from which the organic grade of the plants and animals referred to in this and subsequent chapters may be understood.

loosen and gradually wedge off pieces of rock, and by sending their roots and rootlets through the soil, they open up the subsoil to be attacked by air and descending moisture (p. 16). The action of the common earthworm in bringing up fine soil to be exposed to the influences of wind and rain was noticed in Chapter II. (p. 19). Many burrowing animals also, such as the mole and rabbit, throw up large quantities of soil and subsoil which are liable to be blown or washed away.

On the other hand, the action may be conservative, as, for instance, where, by forming a covering of turf, vegetation protects the soil underneath from being rapidly removed, or where sand-loving plants bind together the surface of dunes, and thereby arrest the progress of the sand, or where forests shield a mountain-side from the effects of heavy rains and avalanches.

(1) *Deposits formed of the remains of Plants.*—But it is chiefly by the aggregation of their own remains into more or less extensive deposits that plants and animals leave their most prominent and enduring memorials As examples of the way in which this is done by plants, reference may be made to peat-bogs, mangrove-swamps, infusorial earth, and calcareous sea-weeds.

Peat-bogs —In temperate and arctic countries, marshy vegetation accumulates in peat-bogs, from an acre or two to many square miles in extent, to a depth of sometimes 50 feet These deposits are largely due to the growth of bog-mosses and other aquatic plants which, dying in their lower parts, continue to grow upward on the same spot On flat or gently-inclined moors, in hollows between hills, on valley-bottoms, and in shallow lakes, this marshy vegetation accumulates as a wet spongy fibrous mass, the lower portions of which by degrees become a more or less compact dark brown or black pulpy substance, wherein the fibrous texture, so well seen in the upper or younger parts, in large measure disappears. A thick bed of peat sometimes reveals a succession of plant remains, one kind of vegetation having given place to another during the accumulation of the mass. Arctic plants in Scottish peat-mosses prove these deposits to date back to the Ice Age. As already mentioned (p. 4), peat-bogs often rest directly upon fresh-water marl (1 in Fig. 39), showing that the peat has accumulated on the site of shallow lakes which have been filled up and converted into morasses by the growth of marsh-plants along their edges and over their floors. The lower parts of the peat may contain remains of the reeds,

sedges, and other aquatic plants which choked up the lake (2, 3). Higher up, the peat consists almost entirely of the matted fibres of different mosses, especially of the kind known as Bog-moss or *Sphagnum* (4). The uppermost layers (5, 6) may be full of roots of different heaths which spread over the surface of the bog.

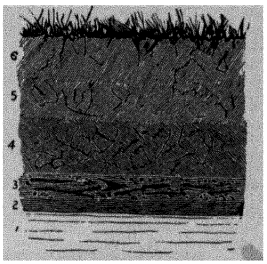


FIG. 39.—Section of a peat-bog.

The rate of growth of peat has been observed in different situations in Central Europe to vary from less than a foot to about two feet in ten years; but in more northern latitudes the growth is probably slower. Many thousand square miles of Europe and North America are covered with peat-bogs, those of Ireland being computed to occupy a seventh part of the surface of the island, or upwards of 4000 square miles.

As the aquatic plants grow from the sides toward the centre of a shallow lake, they gradually cover over the surface of the water with a spongy layer of matted vegetation. Animals, and man himself, venturing on this treacherous surface, sink through it, and may be drowned in the black peaty mire underneath. Long afterwards, when the morass has become firm ground, and openings are made in it for digging out the peat to be used as fuel, their bodies may be found in an excellent state of preservation. The peaty water so protects them from decay that the very skin and hair sometimes remain. In Ireland, numerous skeletons of the great Irish elk have been obtained from the bogs, though the animal itself has been extinct since before the beginning of the authentic history of the country.

Mangrove-swamps.—Along the flat shores of tropical lands, mangrove trees grow out into the salt water, forming a belt of jungle which runs up or completely fills the creeks and bays. So dense is the vegetation that the sand and mud, washed into the sea from the land, are arrested among the roots and radicles of the trees, and thus the sea is gradually replaced by firm ground. The coast of Florida is fringed with such mangrove-swamps for a breadth of from 5 to 20 miles. In such regions, not only does the growth of these swamps add to the breadth of the land, but the sea is barred back, and prevented from attacking the newly-formed ground inside.

Infusorial earth.—A third kind of vegetable deposit to be

referred to here is that known by the names of infusorial earth, diatom-earth, and tripoli-powder. It consists almost entirely of the minute frustules of microscopic plants called diatoms, which are found abundantly in lakes, and likewise in some regions of the ocean (Fig 40). These lowly organisms are remarkable for secreting silica in their structure. As they die, their singularly durable siliceous remains fall like a fine dust on the bottom of the water, and accumulate there as a pale grey or straw coloured deposit, which, when dry, is like flour, and in its pure varieties is made almost entirely of silica (90 to 97 per cent). Underneath the peat-bogs of Britain a layer of this material is sometimes met with One of the most famous examples is a bed, 30 feet thick,

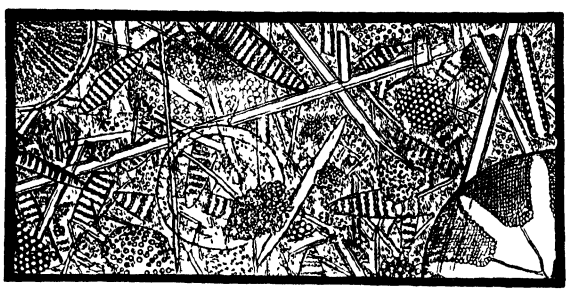


FIG. 40.—Diatom-earth from floor of Antarctic-Ocean, magnified 300 diameters (*Challenger* Expedition)

at Richmond, Virginia. At Bilin in Bohemia another important bed occurs. The bottom of some parts of the Southern Ocean is covered with a diatom-ooze made up mainly of siliceous diatoms, but containing also other siliceous organisms (radiolaria) and calcareous foraminifera (Fig. 40). The agency of mosses in forming travertine has already been cited (p 66).

Accumulations of sea-weeds.—Yet one further illustration of plant-action in the building up of solid rock may be given. As a rule the plants of the sea form no permanent accumulations, though here and there under favourable conditions, such as in bays and estuaries, they may be thrown up and buried under sand so as eventually to be compressed into a kind of peat. Some sea-weeds, however, abstract from sea-water carbonate of lime, which they secrete to such an extent as to form a hard stony structure which may grow into extensive masses. When

the common nullipore dies, its remains, thrown ashore and pounded up by the waves, form a white calcareous sand By the action of the wind, this sand is blown inland and may accumulate into dunes. But unlike ordinary sand, it is liable to be slightly dissolved by rain-water, and as the portion so dissolved is soon redeposited by the evaporation of the moisture, the little sand-grains are cemented together, and a hard crust is formed which protects the sand underneath from being blown away Meanwhile rain-water percolating through the mounds gradually solidifies them by cementing the particles of sand to each other, and thick masses of solid white stone are thus produced Changes of this kind have taken place on a great scale at Bermuda, where

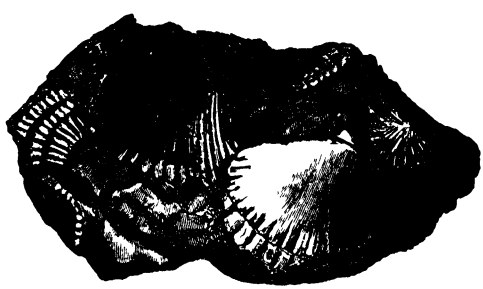


FIG 41 —Recent limestone (Common Cockle, etc , cemented in a matrix of broken shells)

all the dry land consists of limestone formed of compacted calcareous sand, mainly the detritus of sea-weeds.

(2) *Deposits formed of the remains of Animals.*—Animals are, on the whole, far more successful than plants in leaving enduring memorials of their life and work. They secrete hard outer shells and internal skeletons endowed with great durability, and capable of being piled up into thick and extensive deposits which may be solidified into compact and enduring stone. On land, we have an example of this kind of accumulation in the lacustrine marl already (pp 4, 53, 92) described as formed of the congregated remains of fresh-water shells But it is in the sea that animals, secreting carbonate of lime, build up thick masses of rock, such as shell-banks, ooze, and coral reefs (Fig 41 ; see Chapter XI., p. 174)

Shell-banks —Some molluscs, such as the oyster, live in populous communities upon submarine banks. In the course of

generations, thick accumulations of their shells are formed on these banks. By the action of currents also large quantities of broken shells are drifted to various parts of the sea-bottom not far from land. Such deposits of shells, *in situ* or transported, may be more or less mixed with or buried under sand and silt, according as the currents vary in direction and force. On the other hand, they may be gradually cemented into a solid calcareous mass, as has been observed off the coast of Florida, where they form on the sea-bottom a sheet of limestone, made up of their remains.

Ooze.—From observations made during the great expedition of the *Challenger*, it has been estimated that in a square mile of the tropical ocean down to a depth of 100 fathoms there are more

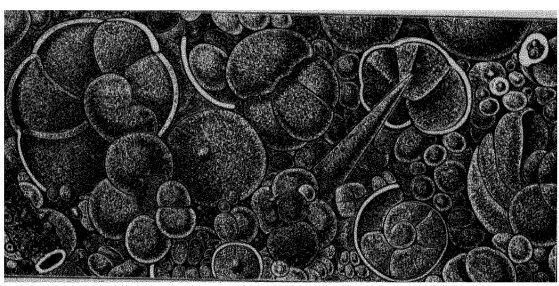


FIG. 42.—Globigerina ooze dredged up by *Challenger* Expedition from a depth of 1900 fathoms in the North Atlantic ($\frac{3}{4}$).

than 16 tons of carbonate of lime in the form of living animals. A continual rain of dead calcareous organisms is falling to the bottom, where their remains accumulate as a soft chalky *ooze*. Wide tracts of the ocean-floor are covered with a pale grey ooze of this nature, composed mainly of the remains of the shells of the foraminifer *Globigerina* (Fig. 42). In the north Atlantic this deposit probably extends not less than 1300 miles from east to west, and several hundred miles from north to south.

Here and there, especially among volcanic islands, portions of the sea-bed have been raised up into land, and masses of modern limestone have thereby been exposed to view. Though they are full of the same kind of shells as are still living in the neighbouring sea, they have been cemented into compact and even somewhat crystalline rock, which has been eaten into caverns by percolating

water, like limestones of much older date. This cementation, as above remarked, is due to water permeating the stone, dissolving from its outer parts the calcareous matter of shells, corallines, and other organic remains, and redepositing it again lower down, so as to cement the organic detritus into a compact stone.

Coral-reefs offer an impressive example of how extensive masses of solid rock may be built up entirely of the aggregated remains of animals In some of the warmer seas of the globe, and notably in the track of the great ocean-currents, where marine life is so abundant, various kinds of coral take root upon the edges and summits of submerged ridges and peaks, as well as on the shelving sea-bottom facing continents or encircling islands (1 in Fig. 43). These creatures do not appear to flourish at a greater depth than 15 or 20 fathoms, and they are killed by exposure to

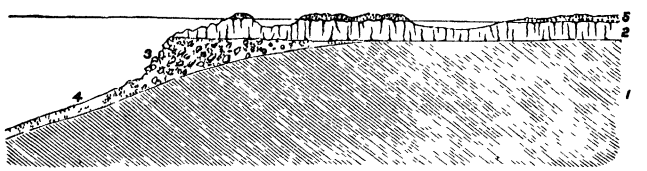



FIG 43 —Section of a coral-reef 1 Top of the submarine ridge or bank on which the corals begin to build 2 Coral-reef 3 Talus of large blocks of coral-rock on which the reef is built outward 4 Fine coral-sand and mud produced by the grinding action of the breakers on the edge of the reef 5 Coral-sand thrown up by the waves and gradually accumulating above their reach to form dry ground

sun and air The vertical space within which they live may therefore be stated broadly as about 100 feet. They grow in colonies, each composed of many individuals, but all united into one mass, which at first may be merely a little solitary clump on the sea-floor, but which, as it grows, joins other similar clumps to form what is known as a reef Each individual secretes from the sea-water a hard calcareous skeleton inside its transparent jelly-like body, and when it dies, this skeleton forms part of the platform upon which the next generation starts. Thus the reef is gradually built upward as a mass of calcareous rock (2), though only its upper surface is covered with living corals. These creatures continue to work upward until they reach low-water mark, and then their further upward progress is checked But they are still able to grow outward On the outer edges of the reef they flourish most vigorously, for there, amid the play of the breakers, they find the food that is brought to them by the ocean-currents. From time

to time fragments are torn off by breakers from the reef and roll down its steep front (3) There, partly by the chemical action of the sea-water, and partly by the fine calcareous mud and sand (4), produced by the grinding action of the waves and washed into their crevices, these loose blocks are cemented into a firm, steep slope, on the top of which the reef continues to grow outwards. Blocks of coral and quantities of coral-sand are also thrown up on the surface of the reef, where by degrees they form a belt of low land above the reach of the waves (5). On the inside of the reef, where the corals cannot find the abundant food-supply afforded by the open water outside, they dwindle and die Thus the tendency of all reefs must be to grow seawards, and to increase in breadth. Perhaps their breadth may afford some indication of their relative age.

Where a reef has started on a shelving sea-bottom near the coast of a continent, or round a volcanic island, the space of water inside is termed the *Lagoon Channel* Where the reef has been built up on some submarine ridge or peak, and there is consequently no land inside, the enclosed space of water is called a *Lagoon*, and the circular reef of coral is known as an *Atoll.* If no subsidence of the sea-bottom takes place, the maximum thickness of a reef must be limited by the space within which the corals can thrive—that is, a vertical depth of about 100 feet from the surface of the sea. But the effect of the destruction of the ocean-front of the reef, and the piling up of a slope of its fragments on the sea-bottom outside, will be to furnish a platform of the same materials on which the reef itself may grow outward, so that the united mass of calcareous rock may attain a very much greater thickness than 100 feet. On the other hand, if, as Darwin originally suggested, the sea-bottom were to sink at so slow a rate that the reef-building corals could keep pace with the subsidence, a thick mass of calcareous rock might obviously be formed by them (see p 123).

It is remarkable how rapidly and completely the structure of the coral skeleton is effaced from the coral-rock, and a more or less crystalline and compact texture is put in its place. The change is brought about partly by the action of both sea-water and rain-water in dissolving and redepositing carbonate of lime among the minute interstices of the rock, and partly also by the abundant mud and sand produced by the pounding action of the breakers on the reef, and washed into the crevices. On the portion of a reef laid dry at low water, the coral-rock looks in many places as solid and old as some of the ancient white lime-

stones and marbles of the land. There, in pools where a current or ripple of water keeps the grains of coral-sand in motion, each grain may be seen to have taken a spherical form unlike that of the ordinary irregularly rounded or angular particles. This arises because carbonate of lime in solution in the water is deposited round each grain as it moves along. A mass of such grains aggregated together is called *oolite*, from its resemblance to fish-roe. In many limestones, now forming wide tracts of richly cultivated country, this oolitic structure is strikingly exhibited. There can be no doubt that in these cases it was produced in a similar way to that now in progress on coral-reefs (see pp. 157, 171).

In the coral tracts of the Pacific Ocean there are nearly 300 coral islands, besides extensive reefs round volcanic islands. Others occur in the Indian Ocean. Coral-reefs abound in the West Indian Seas, where, on many of the islands, they have been upraised into dry land, in Cuba to a height of 1100 feet above sea-level. The Great Barrier Reef that fronts the north-eastern coast of Australia is 1250 miles long, and from 10 to 90 miles broad.

There are other ways in which the aggregation of animal remains forms more or less extensive and durable rocks. To some of these reference will be made in later chapters. Enough has been said here to show that by the accumulation of their hard parts animals leave permanent records of their presence both on land and in the sea.

11. **Preservation of remains of Plants and Animals in sedimentary deposits.**—But it is not only in rocks formed out of their remains that living things leave their enduring records. These remains may be preserved in almost every kind of deposit, under the most wonderful variety of conditions. And as it is in large measure from their occurrence in such deposits that the geologist derives the evidence that successive tribes of plants and animals have peopled the globe, and that the climate and geography of the earth have greatly varied at different periods, we shall find it useful to observe the different ways in which the remains both of plants and animals are at this moment being entombed and preserved upon the land and in the sea. With the knowledge thus gained, it will be easier to understand the lessons taught by the organic remains that lie among the various solid rocks around us.

It is evident that in the vast majority of cases, the plants and animals of the land leave no perceptible trace of their presence.

Of the forests that once covered so much of Central and Northern Europe, which is now cultivated ground, most have disappeared, and unless authentic history told that they had once flourished, we should never have known anything about them. There were also herds of wild oxen, bears, wolves, and other denizens contemporaneous with the vanished forests. But they too have passed away, and we might ransack the soil in vain for any trace of them.

If the remains of terrestrial vegetation and animals are anywhere preserved it must obviously be only locally, but the exceptionally favourable circumstances for their preservation, although not everywhere to be found, do present themselves in many places if we seek for them. The fundamental condition is that the relics should, as soon as possible after death, be so covered up as to be protected from the air and from too rapid decomposition. Where this condition is fulfilled, the more durable of them may be preserved for an indefinite series of ages.

(*a*) On the Land there are various places where the remains both of plants and animals are buried and shielded from decay. To some of these reference has already been made Thus, amid the fine silt, mud, and marl gathering on the floors of lakes, leaves, fruits, and branches, or tree-trunks, washed from the neighbouring shores, may be imbedded, together with insects, birds, fishes, lizards, frogs, field-mice, rabbits, and other inhabitants. These remains may of course often decay on the lake-bottom, but where they sink into or are quickly covered up by the sediment, they may be effectually preserved from obliteration. They undergo a change, indeed, being gradually turned into stone, as will be described in Chapter XV. But this conversion may be effected so gently as to retain the finest microscopic structures of the original organisms.

In peat-bogs also, as already stated (p. 93), animals are often engulfed, and their soft parts are occasionally preserved as well as their skeletons. The deltas of river-mouths must receive the remains of many animals swept off by floods. As the carcases float seawards, they begin to fall to pieces and the separate bones sink to the bottom, where they are soon buried in the silt. Among the first bones to separate from the rest of the skeleton are the lower jaws (pp 341, 346) We should therefore expect that in excavations made in a delta these jaw-bones would occur most frequently. The rest of the skeleton is apt to be carried farther out to sea before it can find its way to the bottom. The stalagmite floor of caverns has already been referred to

(p 65) as an admirable material for enclosing and preserving organic remains The animals that fell into these recesses, or used them as dens in which they lived or into which they dragged their prey, have left their bones on the floors, where, encased in or covered by solid stalagmite, these relics have remained for ages. Much of our knowledge of the animals which inhabited Europe at the time when man appeared, is derived from the materials disinterred from these Bone-caves. Allusion has also been made to the travertine formed by mineral-springs and to the facility with which leaves, shells, insects, and the bodies of small birds, reptiles, or mammals may be enclosed and preserved in it (p. 66). Thus, while the plants and animals of the land for the most part die and decay into mere mould, there are here and there localities where their remains are covered up from decay and preserved as memorials of the life of the time.

(*b*) On the bottom of the Sea the conditions for the preservation of organic remains are more general and favourable than on land. Among the sands and gravels of the shore, some of the stronger shells that live in the shallower waters near land may be covered up and preserved, though often only in rolled fragments. It is below tide-mark, however, and more especially beneath the limit to which the disturbing action of breakers descends, that the remains of the denizens of the sea are most likely to be buried in sediment, and to be preserved there as memorials of the life of the sea. It is evident that hard and therefore durable relics have the best chance of escaping destruction. Shells, corals, corallines, spicules of sponges, teeth, vertebræ, and ear-bones of fishes may be securely entombed in successive layers of silt or mud. But the vast crowds of marine creatures that have no hard parts must almost always perish without leaving any trace whatever of their existence And even in the case of those which possess hard shells or skeletons, it will be easily understood that the great majority of them must be decomposed upon the sea-bottom, their component elements passing back again into the sea-water from which they were originally derived. It is only where sediment is deposited fast enough to cover them up and protect them before they have time to decay, that they may be expected to be preserved

In the most favourable circumstances, therefore, only a very small proportion of the creatures living in the sea at any time leave a tangible record of their presence in the deposits of the sea-bottom. It is in the upper waters of the ocean, and especially in the neighbourhood of land, that life is most abundant. The same

region also is that in which the sediment derived from the waste of the land is chiefly distributed. Hence it is in these marginal parts of the ocean that the conditions for preserving memorials of the animals that inhabit the sea are best developed.

As we recede from the land, the rate of deposit of sediment on the sea-floor gradually diminishes, until in the central abysses it reaches that feeble stage so strikingly brought before us by the evidence of the manganese nodules (p. 88). The larger and thinner calcareous organisms are attacked by the sea-water and dissolved, apparently before they can sink to the bottom; at least their remains are comparatively rarely found there. It is such indestructible objects as sharks' teeth and the vertebræ and ear-bones of whales that form the most conspicuous organic relics in these abysmal deposits.

**Summary.**—Plants and animals leave their records in geological history, partly by forming distinct accumulations of their remains, partly by contributing their remains to be imbedded in different kinds of deposits both on land and in the sea. As examples of the first mode of chronicling their existence, we may take the growth of marsh-plants in peat-bogs, the spread of mangrove-swamps along tropical shores, the deposition of infusorial earth on the bottom of lakes and of the sea; the accumulation of nullipore sand into solid stone, the formation of extensive shell-banks in many seas, the wide diffusion of organic ooze over the floor of the sea, and the growth of coral reefs. As illustrations of the second method, we may cite the manner in which remains of terrestrial plants and animals are preserved in peat-bogs, in the deltas of rivers, in the stalagmite of caverns, and in the travertine of springs; and the way in which the hard parts of marine creatures are entombed in the sediments of the sea-floor, more especially along that belt fringing the continents and islands, where the chief deposit of sediment from the disintegration of the land takes place. Nevertheless, alike on land and sea, the proportion of organic remains thus sealed up and preserved is probably always but an insignificant part of the total population of plants and animals living at any given moment.

How the remains of plants and animals when once entombed in sediment are then hardened and petrified, so as to retain their minute structures, and to be capable of enduring for untold ages, will be treated of in Chapter XV.

# CHAPTER IX

## THE RECORDS LEFT BY VOLCANOES AND EARTHQUAKES

THE geological changes described in the foregoing chapters affect only the surface of the earth. A little reflection will convince us that they may all be referred to one common source of energy—the sun It is chiefly to the daily influence of that great centre of heat and light that we must ascribe the ceaseless movements of the atmosphere, the phenomena of evaporation and condensation, the circulation of water over the land, the waves and currents of the sea, in short the whole complex system which constitutes what has been called the Life of the Earth. Could this influence be conceivably withdrawn, the planet would become cold, dark, silent, lifeless.

But besides the continual transformations of its surface due to solar energy, our globe possesses distinct energy of its own. Its movements of rotation and revolution, for example, provide a vast store of force, whereby many of the most important geological processes are initiated or modified, as in the phenomena of day and night and the seasons, with the innumerable meteorological and other effects that flow therefrom. These movements, though slowly growing feebler, bear witness to the wonderful vigour of the earlier phases of the earth's existence. Inside the globe too lies a vast magazine of planetary energy in the form of an interior of intensely hot material. The cool outer shell is but an insignificant part of the total bulk of the globe. To this cool part the name of "crust" was given at a time when the earth was believed to consist of an inner molten nucleus enclosed within an outer solid shell or crust (p 104). The term is now used merely to denote the cool solid external part of the globe, without implying any theory as to the nature of the interior.

**Condition of the Earth's Interior.**—It is obvious that we are

not likely ever to learn by direct observation what may be the condition of the interior of our planet. The cool solid outer shell is far too thick to be pierced through by human efforts; but from various kinds of observations, more or less probable conclusions may be drawn with regard to this problem. (1) It has been ascertained that all over the world, wherever borings are made for water or in mining operations, the temperature increases in proportion to the depth pierced, the average rate of increase amounting to about one degree Fahrenheit for every 64 feet of descent. If the rise of temperature continues inward at this rate, then at a depth of not many miles it must reach a point as high as that at which the ordinary materials of the crust would melt at the surface. (2) Thermal springs in all quarters of the globe, rising sometimes with the temperature of boiling water, and occasionally even still hotter, prove that the interior of the planet must be much warmer than its exterior. (3) Volcanoes widely distributed over the earth's surface throw out steam and heated vapours, red-hot stones, and molten rock.[1]

It is inferred therefore that the interior of the globe must be intensely hot. Whether it is solid, molten, or gaseous has been the subject of prolonged discussion (p. 254). The older geologists maintained that the phenomena of volcanoes and earthquakes could not be explained, except on the supposition of a crust only a few miles thick, enclosing a vast central ocean of molten material. This view has been opposed by physicists who have shown that the globe, if this were actually its structure, could not resist the attraction of sun and moon, but would be drawn out of shape, as the ocean is in the phenomenon of the tides, and that the absence of any appreciable tidal deformation in the crust shows that the earth must be practically solid, and as rigid as a ball of glass, or of steel. A third opinion has been advanced by some geologists who, while admitting that the earth behaves on the whole as a solid rigid body, yet believe that many geological phenomena can only be explained by the existence of some liquid mass beneath the crust. Accordingly they suppose that while the nucleus is retained in the solid state by the enormous superincumbent pressure under which it lies, and the crust has become solid by cooling, there is an intermediate liquid or viscous layer which has

[1] Recent discoveries of the presence of radio-active constituents in the rocks of the crust and in the water of hot springs have revealed a hitherto unsuspected source of heat, which, when the facts are fully ascertained, will have many bearings on geological questions.

not yet cooled sufficiently to pass into the solid crust above, and does not lie under sufficient pressure to form part of the solid nucleus below. A fourth view regards the interior as gaseous (p. 254). At present, the balance of evidence seems to be in favour of the practical rigidity of the globe as a whole. But the materials of its interior probably possess temperatures far higher than those at which they would melt at the surface. They are no doubt kept rigid by the vast overlying pressure, and any change which could relieve them of this pressure would allow them to pass into the liquid form. This subject will be again alluded to in Chapter XVI. Meanwhile, let us consider how the intensely hot nucleus of the planet reacts upon its surface.

Rocks are bad conductors of heat So slowly is the heat of the interior conducted upwards by them that the temperature of the surface of the crust is not appreciably affected by that of the nucleus But the fact that the surface is not warmed from this source shows that the heat of the interior must pass off into space as fast as it arrives at the surface, and proves that our planet is gradually cooling. For many millions of years the earth has been radiating heat into space, and has consequently been losing energy. Its present store of planetary vitality therefore must be regarded as greatly less than it once was.

## VOLCANOES

Of all the manifestations of this planetary vitality, by far the most impressive are those furnished by volcanoes. The general characters of these vents of communication between the hot interior and cool surface of the planet are doubtless already familiar to the reader of these chapters—the *volcano* itself, a conical hill or mountain, formed mainly or entirely of materials ejected from below, having on its truncated summit the basin-shaped *crater*, at the bottom of which lies the *vent* or funnel from which, as well as from rents on the flanks of the cone, hot vapours, cinders, ashes, and streams of molten *lava* are discharged, till they gradually pile up the volcanic cone round the vent whence they escape.

A volcanic cone, so long as it remains, bears eloquent testimony to the nature of the causes that produced it. Even many centuries after it has ceased to be active, when no vapours rise from any part of its cold, silent, and motionless surface, its conical form, its cup-shaped crater, its slopes of loose ashes, and its black bristling lava-currents remain as unimpeachable witnesses that the volcanic

fires, now quenched, once blazed forth fiercely. The wonderful groups of volcanoes in Auvergne and the Eifel are as fresh as if they had not yet ceased to be active, but might break out again at any moment; yet they have been quiescent ever since the beginning of authentic human history.

But in the progress of the degradation which everywhere slowly changes the face of the land, it is impossible that volcanic hills should escape the waste which befalls every other kind of eminence. We can picture a time when the volcanic cones of Auvergne will have been worn away, and when all the lava-streams that descend from them will have been cut into ravines and isolated into separate masses by the streams that have even already deeply trenched the oldest of them. Where all the ordinary and familiar signs of a volcano have been removed, how can we tell that any volcano ever existed? What enduring record do volcanoes inscribe in geological history?

Now, it must be obvious that among the operations of an active volcano, many of the most striking phenomena have hardly any importance as aids in recognising the traces of long-extinct volcanic action. The earthquakes and tremors that accompany volcanic outbursts, the constant and prodigious out-rushing of steam, the abundant discharge of gases and acid vapours, though singularly impressive at the time, leave little or no lasting mark of their occurrence. It is not in phenomena, so to speak, transient in their effects, that we must seek for a guide in exploring the records of ancient volcanoes, but in those which fracture or otherwise affect the rocks below ground, and pile up heaps of material above.

Keeping this aim before us, we may obtain from an examination of what takes place at an active volcano such durable proofs of volcanic energy as will enable us to recognise the former existence of volcanoes over many tracts of the globe where human eye has never witnessed an eruption, and where, indeed, all trace of what could be called a volcano has utterly vanished. A method of observation and reasoning has been established, from the use of which we learn that in some countries, Britain for example, though there is now no sign of volcanic activity, there has been a succession of volcanoes during many protracted and widely separated periods, and that probably the interval that has passed away since the last eruptions is not so vast as that which separated these from those that preceded them. A similar story has been made out in many parts of the continent of Europe, in the United States, India,

and New Zealand, and, indeed, in most countries where the subject has been fully investigated.

A little reflection on this question will convince us that the permanent record of volcanic action must be of two kinds: first and most obvious are the piles of volcanic materials which have been spread out upon the surface of the earth, not only round the immediate vents of eruption, but often to great distances from them; secondly, the rents and other openings in the solid crust of the earth accompanying the volcanic explosions, and some of which have served as channels by which the volcanic materials have been expelled to the surface.

**Volcanic Products.**—We shall first consider those materials which are erupted from volcanic vents and are heaped up on the surface as volcanic cones or spread out as sheets. They may be conveniently divided into two groups: 1st, Lava, and 2nd, Fragmentary materials.

(1) *Lava.*—Under this name are comprised all the molten rocks of volcanoes. These rocks present many varieties in composition

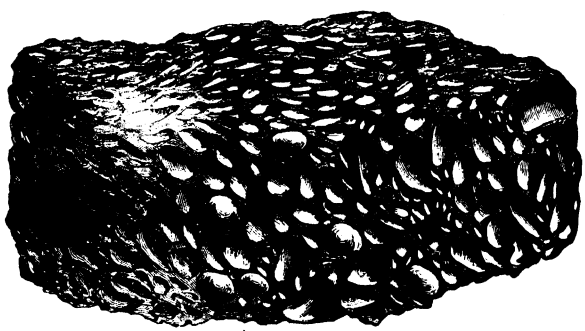


FIG. 44.—Cellular Lava with a few of the cells filled up with infiltrated mineral matter (Amygdales).

and texture, some of the more important of which will be described in Chapter XI. Most of them are crystalline—that is, are made up wholly or in greater part of crystals of two or more minerals, interlocked and felted together into a coherent mass. Some are chiefly composed of a dark brown or black glass, while others consist of a compact stony substance with abundant crystals imbedded in it. Probably most of them, when in completest fusion within the earth's crust, existed in the condition of thoroughly molten glass,

the transition from that state to a stony or lithoid one being due to a process of "devitrification" (p. 159) consequent on cooling. During this process some of the component ingredients of the glass crystallise out as separate minerals, and this crystallisation sometimes proceeds so far as to use up all the glass and to transform it into a completely crystalline substance

In many cases lavas are strikingly cellular—that is to say, they contain a large number of spherical or almond-shaped cavities somewhat like those of a sponge or of bread, formed by the expansion of the steam absorbed in the molten rock (Figs 44 and 46 and p. 161). Lavas vary much in weight and in colour. The heavier kinds are more than three times the weight of water; or, in other words, they have a specific gravity ranging up to 3 3; and are commonly dark grey to black. The lighter varieties, on the other hand, are little more than twice the weight of water, or have a specific gravity which may be as low as 2.3, while their colours are usually paler, sometimes almost white.

When lava is poured out at the surface it issues at a white heat —that is, at a temperature sometimes above that of melting copper, or more than 2204° Fahr.; but its surface rapidly darkens, cools, and hardens into a solid crust which varies in aspect according to the liquidity of the mass. Some lavas are remarkably fluid, flowing along swiftly like melted iron; others move sluggishly in a stiff viscous stream. In many pasty lavas, the surface breaks up into rough cindery blocks or scoriæ, like the slags of a foundry, which grind upon each other as the still molten stream underneath creeps forward (p 161). In general, the upper part of a lava-stream is more cellular than the central portions, no doubt because the imprisoned steam can there more easily expand. The bottom, too, is often rough and slaggy, as the lava is cooled by contact with the ground, and portions of the chilled bottom-crust are pushed along or broken up and involved in the still fluid portion above.

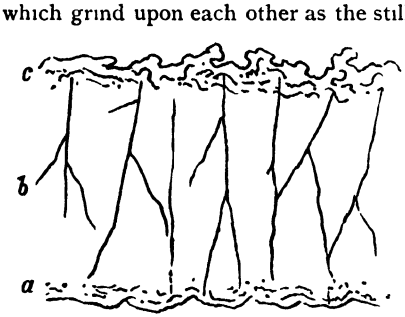


FIG 45.—Section of a lava-current

There are thus three more or less well defined zones in a solidified lava-current—a cellular or slaggy upper part (*c* in Fig. 45),

a more solid and jointed centre (*b*), embracing usually by much the largest proportion of the whole, and a cellular or slaggy bottom (*a*). A rock presenting these characters tells its story of volcanic action in quite unmistakable language. It remains as evidence of the existence of some neighbouring volcanic vent, now perhaps entirely covered up, whence it flowed. We may even be able to detect the direction in which the lava moved. The cells opened by the segregation and expansion of the steam entangled in the interstices of a mass of lava which is at rest are, on the whole, spherical. But if the rock is still moving, the cells will be drawn out and flattened into almond-shaped (amygdaloidal) vesicles, with their flat sides parallel to the surface of the lava, and their longer

FIG. 46.—Elongation of cells in direction of flow of a lava-stream.

axes ranged in one general direction, which is that of the motion of the molten stream (Fig. 46).

Near to a volcanic vent, the mass of erupted lava is generally thickest, and it thins away as its successive streams terminate on the lower grounds surrounding the cone. But sometimes a lava-current may flow for 40 miles or more from its source, and may here and there attain locally a great thickness by rolling into a valley and filling it up, as has been witnessed among the Icelandic eruptions. As a rule, where a series of ancient lava-streams is found to thicken in a certain direction, we may reasonably infer that in that direction lay the vent from which they flowed.

Again, sheets of lava that solidify on the slopes of a volcanic cone are inclined; they may congeal on declivities of as much as 30° or 40°. If a series of ancient lavas were observed to slope upward to a common centre, we might search there for some trace

of the funnel from which they were discharged. But, of course, in proportion to their antiquity, lava-streams, like every other kind of rock, have suffered from geological revolutions, among which those that involve upheaval and dislocation are especially important, so that the inclination of an ancient lava-bed must not be too hastily assumed as an indication of the slope of the cone of a volcano. It must be taken in connection with the rest of the evidence supplied by the whole district.

Where lavas reach the lower grounds beyond the foot of a volcanic cone, they may spread out in wide nearly horizontal sheets. As current succeeds current, the original features of the plain may be entirely buried under a mass of lava many feet thick. If a section could be cut through such an accumulation, it might be possible to determine the thickness of each successive lava-stream by means of the slaggy upper and lower surfaces. Here and there, too, where two eruptions were separated by an interval long enough to allow the surface of the older mass partially to crumble into soil and support some vegetation, the layer of burnt soil between the two sheets of lava would remain as a witness of this interval.

In other instances, we can understand that in the larger hollows of a lava-plain, ponds or lakes might gather, on the floor of which there might be deposited layers of fine silt full of terrestrial leaves, insect-remains, land and fresh-water shells, and other organic relics of a land-surface. If, now, a lacustrine accumulation of this kind were to be buried under a new outburst of lava, it would be sealed up and might preserve its record intact for vast ages. In any section cut through such a series of lava-beds by a river or the sea, or by man, the layers of silt, with their organic remains intercalated between the lava-streams, would prove the eruptions to have taken place on land, and to have been separated by a long interval, during which a lake was formed on the cold and decomposing surface of the earlier lava.

The conditions under which the volcanic outbursts occurred may be thus inferred, not so much from the nature of the volcanic materials themselves, as from that of the layers of sediment that may happen to have been preserved among them. Seams of red baked soil, with charred remains of terrestrial vegetation interposed between the upper and under sides of successive lavas would point to subaerial eruptions. Bands of hardened clay or marl, with leaves and fresh-water shells, would show that the lavas had invaded a lake. Beds of limestone or other rock, containing corals,

sponges, marine shells, or other traces of the life of the sea, would demonstrate that the eruptions were submarine. Examples of each of these varieties of evidence occur abundantly among the old volcanic tracts of Britain.

(2) *Fragmentary Products.*—These supply some of the most striking proofs of volcanic energy. They vary in size from huge blocks of stone, weighing many tons, down to the finest dust. The coarsest materials naturally accumulate round the vent, while the finest may be borne away by wind to distances of many hundreds of miles. On the volcano itself, the stones, ashes, and dust form beds of coarse and fine texture which, on the outside of the cone, have the usual slope of the declivity. By degrees, they become more or less consolidated, and are then known by the general name of *Tuffs*. (See p. 169.)

The materials composing a tuff are chiefly derived from lavas. The fine dust, discharged from a large volcano in such prodigious quantities as to make the sky dark as midnight for days together, is simply lava that has been blown into this finely divided condition by the explosion of the vapours and gases which exist absorbed in it while still deep down within the earth's crust. The cinder-like fragments, and scoriæ or slags, that are ejected in such numbers and fall back into the crater and upon the outer slopes of the cone, are pieces of lava frothed up by the expansion of the imprisoned steam, torn off from the column of lava in the vent, and shot whirling up into the air. Large blocks of lava, or of the rocks through which the volcanic funnel has been opened, are often broken off by the force of the explosions, and discharged with the other volcanic detritus from the vent. These various materials, descending to the ground, form successive beds that vary in dimensions according to the vigour of eruption and their distance from the vent. Around the focus of activity there may be thick accumulations of blocks, bombs, and pieces of scoriæ mixed with fine ashes and sand. A notable feature is the generally cellular character of these stones—a peculiarity which marks them as made of truly volcanic materials. An examination of the finest dust likewise discloses the presence of the glass and crystals that constitute the lava from the explosion of which the dust was derived (p 158).

From the wide area over which the fragmentary materials ejected by volcanoes are dispersed in the atmosphere before they fall to the earth, they are more likely than lavas to be preserved among contemporaneous sedimentary accumulations. They often

descend upon lakes, and must there be interstratified with the mud, marl, or other deposit in progress at the time. They are also widely diffused over the sea-floor. Recent dredgings of the ocean-basins have shown that traces of fine volcanic detritus may be detected even at remote distances from land. As active volcanoes almost always rise near the sea, as the oceans are dotted over with volcanic islands, and as, doubtless, many eruptions take place on the sea-bottom, there are obvious reasons why volcanic particles should be widely diffused over the sea-bottom. Geologists can also understand why, in the records of volcanic history in bygone ages, so large a proportion of the evidence should be of submarine eruptions.

Beds of tuff often contain traces of the plants or animals that lived on the surfaces on which the volcanic materials fell—sometimes remains of terrestrial or lacustrine vegetation and animals; but in the great majority of instances, shells and other relics of the inhabitants of the sea.

In a series of layers of tuff round a volcanic orifice, the memorials of the earliest discharges are of course preserved in the layers at the bottom. Accordingly, in such situations, abundant fragments of the rocks of the surrounding country may be noticed. We could hardly ask for more convincing evidence of the blowing out of the vent and the ejection of the rock-fragments from it, before the volcano began to discharge only volcanic materials.

Large blocks of lava ejected obliquely from the crater may descend beyond the limits of the cone. If a block thus discharged should fall into a lake-basin, it would be covered up in the silt accumulating there, and might be the only obvious record of the eruption to which it belonged. In after times, were the lake-floor laid dry, the stone might be found in its place, the layers of sediment into which it fell pressed down by the force with which it landed on them and by its weight, the later layers mounting over and covering it. Examples of this kind of evidence may be gathered in many old volcanic districts. One taken from the coast of Fife is given in Fig. 47. The lowest bed there shown (1) is a brown shaly fire-clay, about 5 inches thick, which was once a vegetable soil, for abundant rootlets can be seen branching

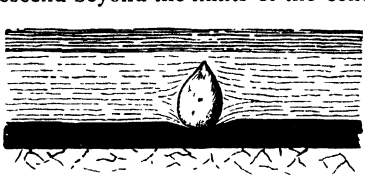



FIG. 47.—Volcanic block ejected during the deposition of strata in water.

through it. It is overlain by a seam of coal (2), 5 or 6 inches thick, representing the dense growth of vegetation that flourished upon the soil; the next layer (3) is a green crumbling fire-clay about a foot thick, covered by a dark shale with remains of plants (4). The feature of special interest in this section is the angular block of lava (diabase) weighing about six or eight pounds, which is stuck vertically in bed No. 3. There can be no doubt that this was ejected by an explosion, of which there is here no other record. It probably descended with some force, for, as shown in the drawing, the lower layers of the fire-clay are pressed down by it, and the coal itself is compressed. We see that the stone fell before the upper half of the fire-clay was formed, for the layers of that part of the bed are heaped around the stone and finally spread over it. There are layers of lava and tuff above and below the strata depicted in this section, so that there is abundant other evidence of preceding and subsequent volcanic action here (see Fig. 122)

As fine volcanic dust may be transported by wind for hundreds of miles before reaching the surface of the earth, its presence does not necessarily show that a volcano existed in the neighbourhood in which it fell. The fine ashes from the Icelandic volcanoes, for example, have been found abundantly even as far as Sweden and the Orkney Islands. But where the fragmentary materials are of coarse grain, and more especially where they contain large slags, scoriæ, and bombs, and where they are interstratified with sheets of lava, they unquestionably indicate the proximity of some volcanic vent from which the whole proceeded.

**Volcanic Vents and Fissures.**—The various materials ejected from a volcano to the surface may conceivably be in course of time entirely swept away. Nevertheless, when every sheet of lava and every bed of tuff have been removed, there will still remain the filled-up *vent*, funnel, or fissure, up which these materials rose, and out of which they were ejected. This opening in the solid crust of the earth must evidently be one of the most durable, as it is certainly one of the fundamental features in a volcano. Let us first consider the vent of an ordinary volcano.

In many instances, there is reason to believe that volcanic vents are opened along lines of fracture in the earth's crust. This seems especially to be the case where a group of volcanoes runs along one definite line, as is represented in Fig. 48. Along such a fissure, either of older date or due to the energy of the volcanic explosions themselves, there must be weaker places where the

overlying mass is less able to bear the strain of the pent-up vapours underneath. At these places, after successive shocks, openings may at length be made to the surface, whence the lavas and ashes will be emitted, and each such opening will be marked by a cone of the erupted material.

But in innumerable examples, it is found that a fissure is not necessary for the formation of a volcano. The effect of the volcanic explosions is such as to drill a pipe or funnel even through the solid unfractured crust of the earth. The volcanic energy, so far from requiring a line of fracture for its assistance, seems often to have avoided making use of such a line, even when it existed. In the volcanic plateaux of Utah, which are dotted over with little volcanic cones, and are also traversed by great

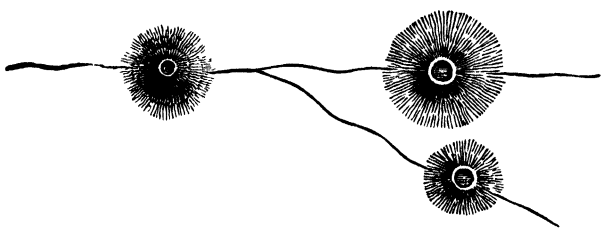


FIG. 48 —Volcanoes on lines of fissure.

dislocations, it is noticeable that the vents are not clustered along the lines of fracture. In the same region, and also along the courses of the Rhine and Moselle, volcanic vents have been opened near the brink of deep ravines rather than at the bottom. These are features of volcanic action, for which no satisfactory explanation has yet been found.

The crater of an active volcano is a hideous yawning cauldron, with rough red and black walls, at the bottom of which lie steaming pools of molten lava. Every now and then a sharp explosion tears the lava open, sending up a shower of glowing fragments and hot ashes. These pools of liquid lava lie evidently on the top of a column of melted rock which descends in the volcanic chimney to an unknown depth into the earth's interior. If the volcano were to become extinct, this lava column would cool and solidify, and even after the entire destruction and removal of the cone and crater, would remain as a stump to tell where the site of the volcano had been. Layer after layer might be stripped off

the surface of the land until hundreds or thousands of feet of rock had been removed, yet, so far as we know, the stump of the volcano would still be there. No probable amount of waste of the surface of the earth's crust could remove a vertical column of rock which descends to an unknown depth into the interior. The site of a volcanic vent can never be effaced except by being buried under masses of younger rock.

Volcanic vents, affording as they do so durable a testimony to volcanic action, deserve careful attention. At an active volcano, or even at one which, though extinct, still retains its cone of erupted materials, we cannot, of course, learn much regarding the shape and size of the funnel, for only the crater, and at most merely the upper part of the vent, are accessible. But among volcanic tracts of older date, where the cones have been destroyed, and where the filled-up funnels are laid bare, the subterranean architecture of volcanoes is revealed to us. At such places we are allowed, as it were, to descend the chimney of a volcano, and to make observations altogether impossible at a modern volcanic cone.

From researches at such favourable localities, it has been ascertained that the funnels of volcanoes are in general rudely circular or elliptical, though liable to many modifications of outline. They vary indefinitely in diameter, according to the vigour of the volcanic outbursts that produced them. The smaller vents are not more than a few yards in width; but those of the larger volcanoes which, as in Sumatra and Java, have sometimes craters comprising an area of 40 square miles, must have enormously larger funnels.

The materials that fill up a vent are sometimes only fragments of the surrounding rocks. In such cases, we may suppose that when the volcanic explosions of vapours and gases had spent their force in blowing out an opening to the surface of the ground, they were not succeeded by the uprise of any solid volcanic materials; that, in short, only the first stage in the establishment of a volcano was reached, when, owing to some failure of the subterranean energy at the place, the operations came to an end. But though the upper part of the vent might remain open, surrounded with a crater formed of the fragments into which the rocks were blown by the explosions, the lower parts would undoubtedly be filled up by the fall of fragments back again into the vent. And if all the material ejected to the surface were removed, the top of this column of fragmentary materials would remain as an unmistakable evidence of the explosions that had originated it.

But in the vast majority of cases, the operations at a volcanic vent do not end with the first explosions. Clouds of ashes and stones are ejected, and streams of molten lava are poured forth. In some instances, the chimney may be finally choked with volcanic blocks, scoriæ, cinders, and ashes, in others with consolidated lava. Examples of both kinds of infilling are found, and also others where the two forms of volcanic material occur together in the same vent.

A volcanic chimney filled up in this way with volcanic materials, and exposed by the removal of the lava or ashes thrown out to the surface, is known as a *Neck* (see Figs. 49-52, 125, and p. 233). As these materials are usually harder and more durable than the

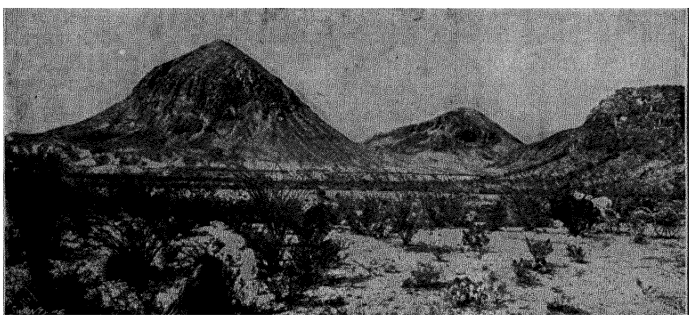


FIG. 49.—Volcanic Necks, Texas. Photograph by Mr. R. T. Hill, U.S. Geol. Survey.

surrounding rocks, they project above the general surface of the ground. The stump of the volcano is left as a protuberance, the form and prominence of which will chiefly depend upon the nature of the material; hard tough lava may rise abruptly, as a crag or hill, above the surrounding country, while consolidated ashes, scoriæ, and other fragmentary stuff will usually give a smoother and less marked outline. Remarkable examples of such denuded volcanoes have been met with in various regions of the Western and Southern United States (Fig. 49).

The origin of these features will be best understood from a series of diagrams. We may take, by way of illustration, a neck composed mainly of fragmentary ejections, but with a plug of lava reaching its summit. The usual outlines of such a neck are represented in Fig. 50. There is nothing in the general form of

this hill to suggest a volcanic origin; yet, if we examine its structure and that of the ground around it, we may find them to

FIG. 50 —Outline of a Volcanic Neck.

be as represented in Fig. 51, where the surrounding rocks are shown to consist of various sandstones, clays, limestones, and other sedimentary deposits (*a*), through which the volcanic vent (*b*, *c*) has been drilled. The neck is represented as elliptical in cross section, composed mainly of consolidated volcanic ashes and ejected blocks (*b*), but with a mass of lava (*c*) in the centre. The structure of the hill is explained in the vertical section, Fig. 52 (see also Fig. 125). We there see that the vent has been blown through the surrounding strata (*a*, *a*), and has been filled up mainly with fragmentary materials (*b*, *b*); but that through its centre there has risen a column or plug of lava (*c*), which not improbably marks the last effort of the volcano to force its ejections to the surface. The line *s*, *s* indicates the present surface of the ground, after the prolonged waste during which all the volcanic cone has been removed. But we can in imagination restore the surface, which may have been finally somewhat as shown by the dotted lines, with the position of the diminishing crater at *e*, and its crest, on either side at *d*, *d*. No trace has been left of the original volcanic cone. The present form of the ground is due to denudation, which has left the more durable volcanic rocks projecting above the surrounding strata. The continued progress of superficial degradation will remove still more of the neck, but the downward continuation of the volcanic column must remain, and will probably always project as a hill. A volcanic neck is thus one of the most enduring and unmistakable evidences of the site of a volcano (see p. 233).

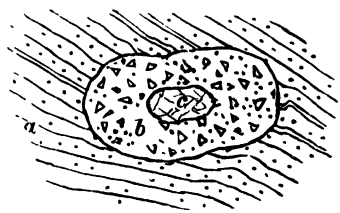



FIG. 51 —Ground-plan of the structure of the Neck shown in Fig 50.

Besides vents or funnels, other openings are made by volcanic explosions in the crust, which serve as receptacles of lava and ashes, and remain as durable memorials of volcanic action. Of these the most important are *Fissures*, which are formed in large numbers in and around a volcanic cone, but which may also arise at a distance from any actual volcano. During the convulsions of an eruption, the cone and the surrounding country are sometimes split by lines of fissure, which tend to radiate from the centre of disturbance, somewhat as cracks do in a pane of glass through which a stone is thrown. Sometimes the two sides of a fissure close together again, leaving no superficial

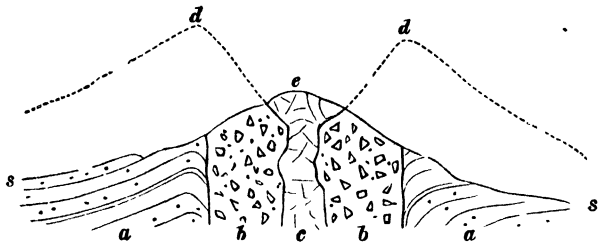



FIG 52.—Section through the same Neck as in Figs 50 and 51.

trace of the dislocation. More frequently steam and various volcanic vapours escape from the chasm, and may deposit along the walls sublimates of different minerals, such as common salt, chloride of iron, specular iron, sulphur, and sal-ammoniac. These deposited substances may even continue to grow there until they entirely fill up the space between. In such cases, the line of fissure is marked by a vertical or steeply inclined band of minerals, interposed between the ends of the rocks that have been ruptured and separated. But in most instances, the opening is filled up by the rise of lava from below. At night, the rents opened on the outside of an active volcano may be traced from afar by the glow of the white-hot lava that rises in them to within a short distance from the surface. When the lava cools and solidifies in these fissures, it forms wall-like masses, known as *Dykes* (Fig. 53). Inside many volcanic craters, the walls are traversed with dykes which, though on the whole tending to keep a vertical direction, may curve about irregularly according to the form of the rents into which the lava rose. Like the necks above described, dykes form enduring records of volcanic action. The

superficial cones and craters may disappear, but the subterranean lava-filled fissures will still remain.

In some volcanic regions, where enormous floods of lava have been poured forth, no great central cones have existed. Such regions extend as vast black plains of naked rock, mottled with shifting sand-hills, or as undulating tablelands carved by running water into valleys and ravines, between which the successive sheets of lava are exposed in terraced hills. Beyond the limits

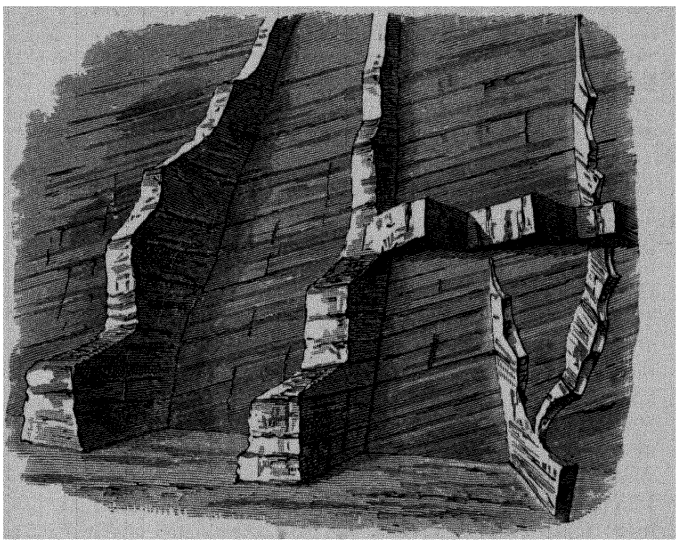


FIG. 53.—Volcanic dykes rising through the bedded tuff of a crater.

over which the lava-sheets are spread, dykes of the same kinds of lava rise in abundance to the surface. There can be no doubt that the dykes do not terminate at the edge of the lava-fields, but pass underneath them. Indeed, as they increase in number in that direction, they are probably more abundant underneath the lava than outside of the lava-fields. Sometimes sections are exposed showing how, after rising in a fissure, the lava has spread out on either side as a sheet. In these vast lava-plateaux or deserts, the molten rock, instead of issuing from one main central vent, like Etna or Vesuvius, appears to have risen in fissures opened in the shattered crust, and to have welled forth from

numerous vents on these fissures, spreading out sheet after sheet till, like a rising lake, it has not only overflowed the lower grounds, but even buried all the minor hills. Lava-eruptions of this kind have taken place in recent years in Iceland Such too appears to have been the history of vast tracts in Western North America. The area which has there been flooded with lava has been estimated to be larger than that of France and Great Britain together, and the depth of the total mass of lava erupted reaches in some places as much as 3700 feet Some rivers have cut gorges in this plain of lava, laying bare its component rocks to a depth of 700 feet or more. Along the walls of these ravines we see that the lava is arranged in parallel beds or sheets often not more than 10 or 20 feet thick, each of which, of course, represents a separate outpouring of molten rock.

Except where such deep sections have been cut through them recent lava-floods can only be examined along their surface, and we are consequently left chiefly to inference regarding their probable connection with fissures and dykes underneath. But in various parts of the world, lava-plains of much older date have been so deeply eroded as to expose not only the successive sheets of lava but the floor over which they were poured, and also the abundant dykes which no doubt served as the channels wherein the lava rose towards the surface, till it could escape at the lowest levels, or at weaker or wider parts, of the fissures. In Western Europe important examples of this structure occur, from the north of Ireland through the Inner Hebrides and the Faroe Islands to Iceland. This volcanic belt presents a succession of lava-sheets which even yet, in spite of enormous waste, are in some places more than 3000 feet thick. These sheets are nearly flat, and rise in terraces one over another into green grassy hills, or into the dark fronts of lofty sea-washed precipices Where they have been stripped off during the degradation of the land, thousands of dykes are exposed, and many of these traverse at least the lower parts of the sheets of lava. The dykes form, as it were, the subterranean roots of which these sheets were the subaerial branches ; and even where the whole of the material that reached the surface has been worn away, the dykes still remain as evidence of the reality and vigour of the volcanic forces.

## EARTHQUAKES

The rise of hot springs and the explosions of volcanoes furnish impressive testimony to the internal heat of our planet; but they are by no means the only proofs that the conditions of the materials in the interior of the globe affect the outer surface. By means of delicate instruments, it can be shown that the ground beneath our feet is subject to continual tremors which are too feeble to be perceived by the unaided senses. From these minuter vibrations, movements of increasing intensity can be detected up to the calamitous earthquake, whereby a country is shaken to its foundations, and thousands of human lives, together with much valuable property, are destroyed. We do not yet know by what different causes these various disturbances are produced. Some of the fainter tremors may arise from such influences as changes of temperature and atmospheric pressure, and the rise and fall of the tides. But the more violent must be assigned to causes working within the earth itself The collapse of the roofs of underground caverns, the sudden condensation of steam or explosion of volcanic vapours, the snap of rocks that can no longer resist the strain to which, by the cooling and consequent contraction of the inner hot nucleus, they have been subjected within the earth's crust—these and perhaps other influences may come into play to determine convulsive earthquake shocks.

Whatever may be at different times and places the origin of these shocks, the immediate cause of an earthquake is of the nature of a sudden blow, whereby a series of elastic waves is propagated outwards from the centre of disturbance through the crust, and in the case of severe shocks, through the interior of the earth As the great majority of earthquakes take place along or near mountain-chains, or below the sea in front of the margin of the land, they are most probably connected with ruptures of the crust which is there under great strain. Years may pass without any sensible yielding of the crust to the stresses to which it is subject, or there may be merely the slightest slipping, manifested by minor shakings and tremors of the ground. But eventually, when the limit of resistance is reached, the crust gives way with a sudden snap, a rupture or series of ruptures is produced which may extend for many miles, and which may even make itself visible in one or more lines of fissure or fault at the surface, and a set of undulations is set in motion through the solid earth whereby destruction is carried over thousands of square miles of the surrounding region.

Their awful suddenness and devastation have invested earthquakes with a high importance in the popular estimate of the forces by which the surface of the globe is modified. Yet if we judge of them by their permanent effects, as these have been witnessed by man, we must give them a comparatively subordinate place among these forces. After some of the most destructive earthquakes recorded in human history, hardly any trace of the calamity is to be seen, save in shattered and prostrate houses. But when these buildings have been repaired or rebuilt, no one visiting the ground might be able to detect any trace of the earthquake that shattered or overthrew them.

Yet severe earthquakes do not pass without their self-written chronicle which, though often evanescent on the face of nature, is at the time conspicuous enough. Landslips are caused, large masses of earth and blocks of rock being shaken down from higher to lower levels. As a consequence of these displacements the drainage of a region may be seriously affected. Streams are sometimes barred back by the fallen ruin so as to form lakes, which may remain for many centuries or may disappear quickly owing to the bursting of their temporary dams. Occasionally a river-channel may be so choked up with the slipped material that the stream is permanently diverted from its old course into another valley. Obviously any event which alters the drainage-system of a country acquires a high geological importance from the effects which directly and indirectly flow from it.

Another marked alteration of the surface of a country is frequently caused by the fissuring of the ground during a severe earthquake. The rents are sometimes widened and deepened afterwards by rain and runnels until they become deep chasms. Where one side of a fissure has sunk down so as to leave a vertical wall 15 or 20 feet high it produces some striking effects on any stream which it crosses. Where the face of the rent looks up-stream it ponds back the water and forms a lake. Where, on the other hand, it looks down-stream the current plunges over it in a waterfall. Unequal movements on the line of a fissure may give rise to a succession of shallow lakes along the course of a river, as took place in the great Assam earthquake of 1897.

Where an earthquake occurs along a coast-line, a good opportunity is afforded of observing any change of level of the land. Instances have been observed where the ground has been permanently uplifted a few feet; others where it has been submerged. It is obvious that unless the superficial changes wrought

by earthquakes are actually witnessed, it may in some cases be hardly possible in the end to be sure that they were actually due to that cause. Notwithstanding the havoc it may bring to the human population, even a severe earthquake does not always record itself in distinctive and enduring characters in geological history. Besides the effects that arise directly from the shock, those of an indirect kind are usually of most consequence from the importance of the changes which they bring about. Of these the most remarkable are due to the disturbance of the sea and of lakes and rivers. The great sea-waves set in motion by an earthquake roll over low lands, and may cause vastly more superficial destruction of life and property than is done by the shock of the earthquake itself.

## Upheaval and Subsidence

It is perhaps not so much by earthquakes, as by quiet, hardly perceptible movements, that the relative positions of sea and land are undergoing change at the present time. In some regions the land is gradually rising, as on the coasts of Sweden and Finland, where the maximum rate of uplift is believed to be as much as 3 feet in a century. In other places, the movement is downward, as on parts of the coast of Japan. Proofs of elevation are supplied by lines of barnacles or rock-boring shells, now standing above the reach of the highest tides; by caves that have obviously been scooped out by the sea, but now stand at a higher level than the waves can reach; by deposits of sand, gravel, and shells which were evidently accumulated on a beach, but which rise above the level where similar materials are now being accumulated (*Raised Beaches*, *Strand-lines*), and by lines of terrace, often continuous with raised beaches of sand and gravel, which have been cut by the waves out of solid rock when the land once stood at that level (*Seter*, Fig. 54). Subsidence may sometimes be inferred from trees with roots *in situ*, and beds of peat, lying below sea-level (*Submerged Forests*); but this evidence is not always reliable. The theory of Darwin (p. 98) as to the origin of atolls was formerly accepted as proof of widespread subsidence over the regions of the Pacific and Indian Oceans. But evidence has recently been accumulating to show that though this theory may hold good in some cases, it does not apply in others, and does not therefore furnish the demonstration of extensive sinking which it was supposed to do. Examples have been met with where atolls

have been associated with an upward and not a downward movement, and have evidently sprung up and grown outward on submarine banks, and have been upraised above sea-level.[1] It must obviously be more difficult to prove subsidence than elevation, for as the land sinks, its surface is carried below the waves, which soon efface the evidence of terrestrial characters.

The time within which man has been observing and recording the changes of the earth's surface forms but an insignificant fraction of the ages through which geological history has been in progress. We need not conclude that during this brief period he

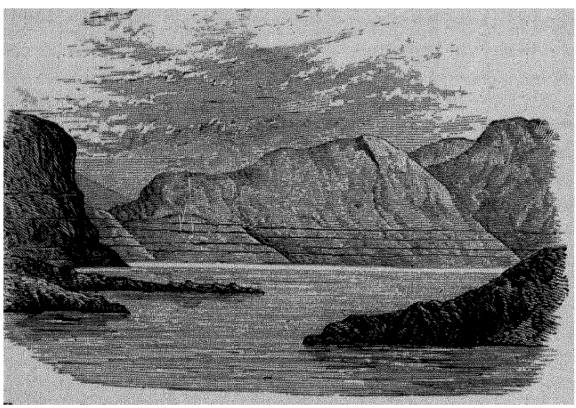


FIG. 54.—Raised marine terraces, or Strand-lines, Alten Fjord, Norway.

has had experience of every kind of geological process by which the outlines of land and sea are modified. There may be great terrestrial revolutions which happen so rarely that none has occurred since man began to take note of such things. Among these revolutions, of which he has had as yet no experience, one of the most stupendous is the formation of a mountain-chain. That the various mountain-chains of the globe are of very different ages, and that some of the most gigantic of them are, compared with others, of recent date, are facts in the history of the globe which will be more fully referred to in later pages; but so far as human history or tradition goes, man has never witnessed the uprise of a

[1] The theories as to coral reefs are stated in the *Elementary Lessons in Physical Geography*, p. 236.

range of mountains. The crust of the earth has been folded and crumpled on the most colossal scale, some parts having been pushed for miles away from their original position; it has been rent by profound fissures, on each side of which the rocks have been displaced for many thousand feet; and it has been so broken, crushed, and sheared, that its component rocks have in some places assumed a structure entirely different from what they originally possessed. But of all these colossal mutations there is no human experience. We are driven to reason regarding them from the record of them preserved among the rocks, and from the analogies that can be suggested by experiments devised to imitate as far as possible the processes of nature. To this subject we shall return in Chapter XIII.

**Summary.**—The enduring records left by volcanoes, whence their former existence in almost all regions of the world may be demonstrated, are to be sought partly in the materials which they have brought up to the surface, and partly in the vents and fissures by which they have discharged these materials. Of the former kind of evidence lava furnishes a conspicuous example; its internal crystalline or glassy structure, its steam-cavities, and the cellular slaggy upper and under parts of the sheets in which it lies, are all proofs of its former molten condition. A succession of lava-beds, piled one above another, marks a series of volcanic eruptions, and the nature of the layers of non-volcanic material intercalated between them, and more especially the remains of plants or animals preserved in these layers, may indicate the conditions under which the eruptions took place, whether on land, in lakes, or in the sea The fragmentary products consolidated into beds of tuff are likewise characteristic of volcanoes; they consist mainly of lava-dust with cinders, scoriæ, slags, and blocks; they accumulate most deeply and in coarsest material at and immediately around the volcanic vents, but their finer particles may be carried to enormous distances; they are especially liable to be intercalated with contemporaneous sedimentary deposits in lakes and on the sea-floor.

The vents through which lava and ashes are ejected to the surface form the most permanent record of volcanoes, for, being filled up with volcanic rocks to unknown depths, they cannot be destroyed by the mere denudation of the surface, and can only disappear by being buried under later accumulations. Such "necks," as they are called, consist sometimes of lava, sometimes of consolidated volcanic debris, or of both kinds of material together,

and remain as the stumps of volcanoes, where every other trace of volcanic action may have passed away. Not less enduring are the dykes or wall-like masses of lava which have risen and solidified in open fissures. Enormous sheets of lava appear to have flowed out from such fissures in regions where the volcanic energy never produced any great central cone.

Earthquakes do not impress their mark upon geological history so indelibly as might be supposed. In spite of the destruction which they cause to human life and property, it is by such direct changes as landslips, rents of the ground, and the upheaval or depression of land, and by such indirect changes as may be produced by derangements of rivers, lakes, and the sea, that earthquakes leave their chief record behind them.

Some of the most important changes of level now going on are effected quietly and almost imperceptibly, some regions being slowly elevated, and others gradually depressed. But the time within which man has been an observer and recorder of nature is too brief to have supplied him with experience of all the ways in which the internal energy of the globe affects its surface. In particular, he has never witnessed the production of a mountain-chain, nor any of the great foldings, crumplings, fractures, and displacements which the crust of the earth has undergone. Regarding these revolutions we can only reason from the records of them in the rocks, and from such laboratory experiments as may seem most closely to imitate the processes of nature that were concerned in their production.

# PART II

# ROCKS, AND HOW THEY TELL THE HISTORY OF THE EARTH

## CHAPTER X

### THE MORE IMPORTANT ELEMENTS AND MINERALS OF THE EARTH'S CRUST

IN the foregoing Part of this volume we have been engaged in considering the working of various processes by which the surface of the earth is modified at the present time, and some of the more striking ways in which the record of these changes is preserved. We have seen that, on the whole, it is by deposits of some kind, laid down in situations where they have more or less escaped destruction, that the story of geological revolution is chronicled. In one place it is the stalagmite of a cavern, in another the silt of a lake-bottom, in a third the sand and mud of the sea-floor, in a fourth the lava and ashes of a volcano. In these and countless other examples, materials are removed from one place and set down in another, and in their new position, while acquiring novel characters, they retain more or less distinctly the record of their source and of the conditions under which their transference was effected.

In these preliminary chapters, reference has intentionally been avoided, as far as possible, to details that required some knowledge of minerals and rocks, in order that the broad principles of geology, for which such knowledge is not absolutely essential, might be clearly

enforced. It is obvious, however, that as minerals and rocks form the records in which the history of the earth has been preserved, this history cannot be followed into detail until some acquaintance with these materials has been made. What now lies before the reader, therefore, in order that he may be able to apply the knowledge he has gained of geological processes to the elucidation of former geological periods, is to make himself familiar with at least the more common and important minerals and rocks. This he can only do satisfactorily by handling the objects themselves, until he acquires such an acquaintance with them as to be able to recognise them where he meets with them in nature

At first the number and variety of these objects may appear to be almost endless, and the learner may be apt to despair of ever mastering more than an insignificant portion of the wide circle of inquiry and observation which they present. But though the detailed study of this subject is more than enough to tax the whole powers of the most indefatigable student, it is not by any means an arduous labour, and assuredly a most interesting one, to acquire so much knowledge of the subject as to be able to follow intelligently the progress of geological investigation, and even to take personal part in it This accordingly is the task to which he is invited in the present and following chapters.

## Simple Elements composing the Earth's Crust

Before considering the characters presented by the various rocks that form the visible part of the earth's crust, we may find it of advantage to inquire into the general chemical composition of rocks, for by so doing we learn that though the chemist has detected about seventy substances which he has been unable to decompose, and which therefore he calls *elements*, only a small proportion of these enter largely into the composition of the outer part of the globe. In fact, there are only about seventeen elements that play an important part as constituents of rocks ; these together constitute almost the whole of the terrestrial crust. Their names, chemical symbols, and relative abundance are enumerated in the subjoined list ; the other elements probably do not make up more than one per cent of the whole, and are not here named.

| Name | Symbol | Proportion in Earth's Crust | Name | Symbol | Proportion in Earth's Crust. |
|---|---|---|---|---|---|
| Oxygen . . | O | 47.29 | Carbon . . | C | 0 22 |
| Silicon . | Si | 27 20 | Hydrogen . . | H | 0.21 |
| Aluminium | Al | 7.81 | Phosphorus | P | 0 10 |
| Iron . . | Fe | 5.46 | Manganese | Mn | 0.08 |
| Calcium . | Ca | 3 77 | Sulphur . . | S | 0 03 |
| Magnesium . | Mg | 2 68 | Barium . | Ba | 0 03 |
| Potassium | K | 2 40 | Fluorine . . | F | 0 02 |
| Sodium | Na | 2.36 | Chlorine . . | Cl | 0 01 |
| Titanium . | Ti | 0 33 | | | |
| | | | | | 100.00 |

Some of these elements occur in the free state, that is, not combined with any other element. Carbon, for instance, is found pure in the form of the diamond, and also as graphite But in the great majority of cases, they assume various combinations. Most abundant are *oxides*, or compounds of oxygen with another element. Compounds of sulphur and a metal are known as *sulphides;* and similar compounds with chlorine are *chlorides*. Some of the compounds form further combinations with one or more elements. Thus the acid-forming oxides unite with water to form what are called *acids*, which, combining with metallic oxides or *bases*, form with them compounds termed *salts*. Sulphur and oxygen, for example, uniting in certain proportions with water, constitute sulphuric acid ($H_2SO_4$) which, parting with its displaceable hydrogen and combining with the metal calcium, forms the salt known as calcium-sulphate, or sulphate of lime ($CaSO_4$).

Nearly a half of the elements named in the foregoing list are called metalloids or non-metals, viz. oxygen, silicon, carbon, hydrogen, phosphorus, sulphur, fluorine, and chlorine. Of these by far the most abundant and important is **Oxygen.** In its free state, it exists as a gas, which has been occasionally detected at active volcanic vents. But with this rare exception, it is always found mixed or combined with one or more elements. Thus, mixed with nitrogen, it constitutes the atmosphere, of which it forms about 23 per cent by weight. Water by weight consists of 88.88 per cent of oxygen and 11.12 of hydrogen, and oxygen constitutes 50 per cent of the earth's crust. At first, when the earth had an exceedingly high temperature, its oxygen probably existed

mainly or entirely in the hot gaseous atmosphere, but as soon as chemical combination became possible it would begin to combine with other elements. At that early time, under the influence of the initial heat of the planet, the chemical processes of union may have been rapid and extensive. But as the temperature fell and the atmosphere approached its present constitution, the abstraction of oxygen became comparatively slow and feeble, though still universal over the land surfaces of the globe. Thus, there is a continual removal of this element from air and water in the processes of weathering described in Chapter II. Substances which can take more of this element abstract it especially from damp air or from water. A knife or any other piece of iron, for example, will remain unchanged for an indefinite length of time if kept in dry air; but as soon as it is exposed to moisture, in which there is always some dissolved air, it begins to rust. The familiar brown rust which slowly eats into the very centre of the iron, is due to a chemical union of oxygen with the iron, forming what is called an Oxide of iron with water (see p. 143). Among the rocks of the earth's crust, a large proportion are liable to undergo a similar change. So vast has been the abstraction of oxygen from the atmosphere since the first solidification of the globe, that nearly one-half of the crust or outer accessible part consists of that element combined with metals and metalloids.

Next in importance to oxygen among the metalloids is **Silicon,** which constitutes about 27 per cent of the terrestrial crust. It is never met with in the free state. It has been artificially obtained, however, in the form of a dull brown powder. In nature, it always occurs united with oxygen, forming the familiar substance known as Silica or Silicon Dioxide ($SiO_2$), which either by itself or in combination with other substances constitutes about three-fourths of all the known part of the earth's crust. Silica is indeed the fundamental material of the crust, forming itself entire masses of rock, and entering as a principal constituent into the majority of rocks. It occurs abundantly uncombined as the mineral Quartz, the colourless transparent forms of which are known as rock-crystal (Fig. 55), and also in combination with various metallic bases as the important family of Silicates (p. 145). It is present in solution in most natural waters, both those of the land and of the sea, whence it is secreted by plants (diatoms, grasses) and animals (radiolarians, sponges, p. 94). It may be carried by percolating water into the heart of rocks, and may be deposited in their interstices and cavities. Its hardness and durability eminently

fit it for the important part it plays in binding the materials of rocks together, and enabling them better to resist the decomposing effects of air and water.

Though so large a proportion of the known terrestrial elements are metals, these are much less abundant in the earth's crust than the metalloids. The most frequent are Aluminium, Iron, Calcium, and Magnesium. The substances most familiar to us as metals, such as copper, silver, and gold, occupy an altogether subordinate part as constituents of the earth's crust.

**Aluminium** never occurs in the free state, but can be artificially

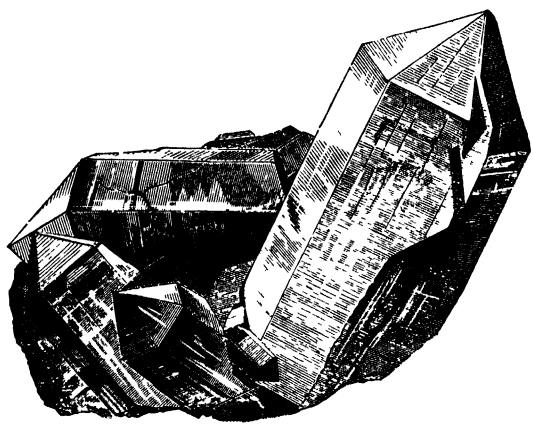


FIG 55 —Group of Quartz-crystals (Rock-crystal).

separated from its compounds, when it is seen to be a white, malleable metal, which is now extensively used on account of its lightness. It is almost always united with oxygen as the oxide or Alumina ($Al_2O_3$), which occurs crystallised as the ruby and sapphire, but is for the most part united with silica, and in this form constitutes the basis of the great family of minerals known as the Silicates of Alumina, or Aluminous Silicates. These silicates generally contain some other ingredient which is more liable to decomposition, and when they decay and their more soluble parts are removed, they pass into clay, which consists chiefly of hydrated silicate of alumina.

**Iron** is found in the free or native state in minute grains (rarely in large blocks) in some volcanic rocks, also in granules of "cosmic

dust," probably of meteoric origin (p. 89), and in fragments of various size which have undoubtedly fallen upon the earth's surface from the regions of space. There is reason to believe that much of the solid interior of the globe may consist of native iron and other metals. But it is in combination that iron is chiefly of importance in the earth's crust, of which it probably constitutes about $5\frac{1}{2}$ per cent. It has united with oxygen to form several abundant oxides (p. 143). The protoxide or ferrous oxide (FeO) contains the lowest proportion of oxygen, and being, therefore, prone to take up more, gives rise to many of the processes of decay included under the general name of Weathering (p. 11). It is readily dissolved by organic and other acids, and is then removed in solution, but on exposure rapidly oxidises and passes into the highest oxide, known as the peroxide or sesquioxide of iron or ferric oxide ($Fe_2O_3$), which, being the permanent insoluble form, is found abundantly among the rocks of the earth's crust. Iron is the great colouring matter of nature; its protoxide compounds give greenish hues to many rocks, while its peroxide colours them various shades of red which, when the peroxide is combined with water, pass into many tints of brown, orange, and yellow.

**Calcium** is not met with uncombined, but has been artificially isolated and found to be a light, yellowish metal, between gold and lead in hardness. Of the earth's crust it is computed to constitute about 3 25 per cent. It occurs in nature chiefly combined with carbonic acid as a carbonate (p. 149), and with sulphuric acid as a sulphate (p. 150), to both of which substances reference has already been made; it is also present in many silicates. Calcium-carbonate or carbonate of lime is abundant in nature; it may be found in most natural waters, which dissolve it and carry it in solution into the ocean, where its amount among the mineral constituents of sea-water is estimated to be no more than about 0.002. Its presence in rocks may be detected by a drop of any mineral acid, when the liberated carbon-dioxide escapes as a gas with brisk effervescence. Calcium-sulphate is likewise a common constituent of terrestrial waters, especially of those which in household management are called *hard;* it constitutes about 0 1395 of the salts in ordinary sea-water, and when sea-water is evaporated this sulphate (gypsum, pp. 150, 171), being least soluble, is the first to be precipitated in minute crystals resembling in shape those shown in Fig. 73.

**Magnesium** is likewise only isolated artificially, when it appears as a soft, silver-white, malleable and ductile metal. It

occurs in sea-water combined with chlorine as Magnesium-chloride, which constitutes 10 8 per cent of the total salts. The proportion of this metal in the terrestrial crust is computed to be 2.68 per cent, and in the water of the ocean 0.14 per cent. It unites with carbonic acid as a carbonate, which with carbonate of lime forms the widely diffused rock called magnesian limestone or dolomite (pp. 150, 171); it also enters into the composition of the Magnesian Silicates which are only second in importance to those of alumina.

**Potassium** and **Sodium** (alkali metals) are only obtainable in the free state by chemical processes, when they are found to be white brittle metals that float on water, and rapidly oxidise if exposed to the air. Combined with chlorine, Sodium forms the familiar chloride known as common salt, which constitutes 77.7 per cent of the salts of sea-water, is abundantly present in salt lakes, and occurs in extensive beds among the rocks of the dry land (p. 172). Potassium-chloride likewise occurs in the sea and may be obtained from the ashes of burnt sea-weed Enormous deposits of it, combined with chlorides of sodium and magnesium, have been met with in Germany (Stassfurt). Potassium also exists in the sea in combination with sulphuric acid as potassium-sulphate or sulphate of potash, which amounts to about 2.4 of the total salts of sea-water. Sulphates of potassium, sodium, magnesium, and calcium occur as thick masses of rock in the Stassfurt deposits. Potassium and sodium in combination with silica form silicates which enter largely into the composition of many rocks. The total percentage of sodium in sea-water is estimated to be 1.14, and in the crust of the earth 2.40 ; while that of potassium is, in the sea, 0.04 and in the crust 2.35. Silicates of the alkalies are readily attacked by water containing carbonic acid, giving rise to what are called carbonates of the alkalies, or alkaline carbonates, which are removed in solution. By this means, carbonate of potash is introduced into soil, where it is taken up by plants into their leaves and succulent parts. When wood is burnt, this carbonate in considerable quantity may be dissolved with water out of the ash.

**Titanium** is another of the metals not found native or pure. Combined with oxygen as a dioxide ($TiO_2$) it forms the heavy mineral rutile and one or two others ; but its most frequent occurrence is in conjunction with oxides of iron, especially with the variety known as titanic iron ($FeTi_2O_3$). In this combination it is widely diffused as a constituent of igneous rocks, though in such

minute proportions that it has often been unrecognised in chemical analyses of these rocks. It is found even in the carbonates of iron from the Carboniferous system, which are so abundantly employed as sources of that metal, the titanium being sometimes abundantly left behind in the furnace-slags. The proportion of this element in the terrestrial crust is probably not more than about one-third of one per cent.

**Carbon.**—Though much less abundant than the other metalloids already described, this element plays a singularly vital part in the life of the earth. It is found in a nearly pure state in the clear gem called Diamond, and also in the black opaque mineral Graphite. More usually it occurs mixed with various impurities, as in the different kinds of coal. Its percentage in the earth's crust is estimated to be not more than 0.20. But its chief importance arises from its being the fundamental substance made use of by both plants and animals to build up their structures, and because it serves as a bond of connection between the organic and the inorganic worlds. In union with oxygen, Carbon forms the widely-diffused gaseous compound known as Carbon-dioxide ($CO_2$), which occurs in the proportion of about three and a half parts in every ten thousand of ordinary atmospheric air. From the air it is abstracted and decomposed by living plants in presence of sunshine, the oxygen being in great measure sent back into the atmosphere, while the carbon with some oxygen, nitrogen, and hydrogen is built up into the various vegetable cells and tissues. When we look at a verdant landscape or a boundless forest, it is a striking thought that all this vegetation has been chiefly constructed out of the small proportion of invisible carbon-dioxide present in the atmosphere. The vast numbers of beds of coal imbedded in the earth's crust have, in like manner, been derived from the atmosphere through the agency of former tribes of plants. Not only in beds of coal, but still more abundantly in masses of limestone, carbon enters into the composition of rocks. Carbon-dioxide, as was pointed out in Chapter II., is abstracted by rain in passing from the clouds to the earth, and is also supplied by decomposing plants and animals in the soil. It is readily dissolved in water, and forms with it carbonic acid, $CO(OH)_2$, which has been referred to as so powerful a solvent of the substance of many rocks. This acid unites with a number of alkaline and earthy bases to form the important family of Carbonates. Of these the most abundant is calcium-carbonate, or carbonate of lime ($CaCO_3$), which consists of 44 per cent carbon-dioxide, and 56 per cent lime. This carbonate not

only occurs abundantly diffused through many rocks, but in the form of limestone builds up by itself thick mountainous masses of rock many hundreds of square miles in extent. It is abstracted by plants to form calcareous tufa (Chapter V.), but far more abundantly by animals, especially by the invertebrata, as exemplified by the familiar urchins, corallines, and shells of the sea-shore. The limestones of the earth's crust appear to have been mainly formed of the calcareous remains of animals. Hence we perceive that the two forms in which carbon has been most abundantly stored up in the earth's crust have been principally due to the action of organised life; coal being chiefly carbon that has been taken out of the atmosphere by plants, and limestone consisting of carbon-dioxide, to the extent of nearly one-half, which has been secreted from water by the agency of animals.

**Hydrogen** is a gas which has been detected in the free state at active volcanic vents, but otherwise it occurs chiefly in combination with oxygen as the oxide water ($H_2O$), of which it constitutes about one-ninth, or 11.12 per cent by weight. It is therefore chiefly stored up in the ocean. Hydrogen also enters into the composition of plant and animal substances, and forms with carbon the important group of bodies known as Hydrocarbons, of which mineral oil and coal-gas are examples. In smaller quantity, it is found united with sulphur (sulphuretted hydrogen, $H_2S$), with chlorine (hydrochloric acid, HCl), and a few other elements.

**Phosphorus**, a non-metallic element, does not occur free; it has so strong an affinity for oxygen that it rapidly oxidises on exposure to the air, and even melts and takes fire. Its most frequent combination is with oxygen and calcium, as calcium-phosphate or phosphate of lime ($Ca_3(PO_4)_2$, p. 152). Though for the most part present in minute proportions, it is widely diffused in nature. It forms only about one part in every thousand of the earth's crust. It occurs in fresh and sea water, in soil and in plants, especially in their fruits and seeds; it is supplied by plants to animals for the formation of bones, which when burnt consist almost entirely of phosphate of lime.

**Manganese** is a metal, commonly associated with iron in minute proportion in many lavas and other crystalline rocks; its oxides resemble those of iron in their modes of occurrence (pp. 132, 144). It appears to constitute no more than seven parts in every ten thousand of the earth's crust.

**Sulphur**, a metalloid, probably constitutes no more than six parts in every ten thousand of the earth's crust. It is found in the

free state, more particularly at volcanic vents, in pale yellow crystals or in shapeless masses and grains; but it chiefly occurs in combination. Some of its compounds are widely diffused among plants and animals. The blackening of a silver spoon by a boiled egg is an illustration of this diffusion, for it arises from the union of the sulphur in the egg with the metal. Combinations with a metal (Sulphides, p. 152) and combinations with a metal and oxygen (Sulphates, p. 150) are the conditions in which sulphur chiefly exists.

**Barium** and Calcium are called metals of the alkaline earths. Barium can only be obtained in a free state by artificial means, when it appears as a pale yellow very heavy metal which rapidly tarnishes. Its percentage in the composition of the earth's crust is about three parts in every ten thousand. It chiefly occurs as the sulphate, Barytes, or heavy spar ($BaSO_4$), a mineral of frequent occurrence in veins associated with metallic ores (p. 151).

**Fluorine** is a metalloid never met with uncombined; it never unites with oxygen, forming in this respect the sole exception among the elements. Its proportion in the composition of the earth's crust is perhaps about two or three parts in every ten thousand. Its most frequent combination as a rock constituent is with calcium, when it forms the mineral Fluor-spar ($CaF_2$, p. 152). Like phosphorus, it is widely diffused in minute proportions in the waters of some springs, rivers, and the sea, and in the bones of animals.

**Chlorine** is a transparent gas of a greenish-yellow colour, but except possibly at active volcanic vents, it does not occur in the free state. United with the alkali metals (potassium, sodium, and magnesium), it forms the chief salts of sea-water. The most important of these salts, Sodium-chloride, or common salt (NaCl) contains 60.61 per cent of chlorine, and forms 77.7 per cent of the salts in sea-water. The total percentage of chlorine in the earth's crust is no more than 0 01, or one part in every ten thousand. Sodium-chloride is found diffused in microscopic particles in the air, especially near the sea, and beds of it hundreds of feet thick occur in many parts of the world among the sedimentary rocks that constitute most of the dry land (pp. 152, 172).

**Nitrogen,** though present in too minute proportions to be deserving of consideration as a constituent of the earth's crust, deserves enumeration here from the important place it takes in the atmosphere, of which it constitutes four-fifths by volume

or 77 per cent by weight. It does not enter into combination so readily as the other elements above enumerated, but it is always found in the composition of plants and is a constituent of many animal tissues. It is the principal ingredient of the substance called Ammonia, which is produced when moist organic matter is decomposed in the air. In many rocks composed wholly or in great part of organic remains, such, for instance, as peat and coal, nitrogen is a constant constituent.

## Minerals of Chief Importance in the Earth's Crust

Passing now from the simple elements, we have next to note the mineral forms in which they appear as constituents of the earth's crust. A *mineral* may be defined as an inorganic substance, having theoretically a definite chemical composition, and in most cases also, a certain geometrical form. It may consist of only one element, for example, the diamond, sulphur, and the native metals, gold, silver, copper, etc. But in the vast majority of cases, minerals consist of at least two, usually more, elements in definite chemical proportions. In the following short list of the more important minerals of the earth's crust they are arranged chemically, according to the predominant element in them, or the manner in which the combinations of the elements have taken place, so that their leading features of composition may be at once perceived. The two elements, Carbon and Sulphur, in their native or uncombined state, sometimes form considerable masses of rock Some of the native metals also may be enumerated as rock constituents when they occur in sufficient quantities to be commercially important. Gold, for example, is found in grains and strings, in veins of quartz, and in irregular pieces or nuggets dispersed through gravel deposits which have been formed out of the detritus of gold-bearing quartz-veins. Omitting, however, the minerals formed of a single element, we may pass on to combinations of two or more elements, and consider first those in which oxygen is combined with some other element, forming what are commonly grouped together as Oxides. Then will come the Silicates, or combinations of silica with one or more bases, followed by the Carbonates, or combinations of carbon-dioxide with some base; the Sulphates, or compounds of sulphuric acid and a base; the Fluorides, or compounds of fluorine and a metal; the Chlorides, or compounds of chlorine and a metal; and the Sulphides, or compounds of sulphur and a metal.

For the details of the composition, form, and other characters of minerals, the learner must turn to some good treatise on Mineralogy. Only a few of the leading features of the subject can be dealt with in such a class-book as the present. But it cannot be too strongly insisted that no mere description in books will suffice to make the learner familiar with minerals and rocks. He ought to handle actual specimens of these objects and identify for himself the several characters which he finds assigned to them in books.

One of the most obvious features in a crystal of any mineral is the regular and sharply-defined edges and corners which it presents. Take a piece of rock-crystal or quartz, for example (Fig. 55), and you will find it to consist of six sides or faces, forming what is called a prism, and bevelled off at the end into a six-sided cone, called a pyramid. If you examine a large collection of similar crystals you may find no two of them exactly alike, yet they agree in presenting a six-sided figure. Again, procure a piece of the common mineral calcite, either a whole crystal (Figs. 70, 71) or a portion of a crystalline mass (Fig. 56); break it and you will find each fragment to possess the same form, that of a rhombohedron; crush one of these fragments and you will observe that each little grain of the powder preserves the same shape. The rhombohedron, therefore, is called the fundamental crystalline form of the mineral. The property so strikingly shown in calcite, of breaking along definite crystalline planes, is termed *cleavage*. So perfect is the cleavage of calcite, that the crystallised mineral can hardly be broken, except along the planes that define the rhombohedron. Many minerals cleave more or less easily in one or more directions, and break irregularly in others. The cleavage affords a guide to the proper crystalline form of a mineral.

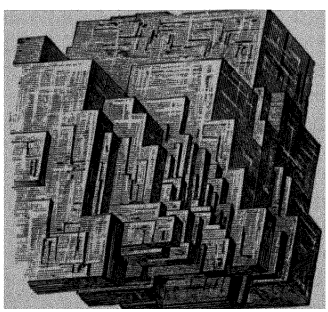


FIG. 56.—Calcite (Iceland spar), showing its characteristic rhombohedral cleavage.

Though there are many hundreds of varieties of crystalline form, they may all be reduced to six primary types or systems. These are distinguished from each other by the number and position of their *axes*, which are mathematical straight lines, intersecting

each other in the interior of a crystal, and connecting the centre of opposite flat faces of the crystal, or opposite angles or corners. The six systems, with their axes, are enumerated in the subjoined list.

I. Isometric (monometric, cubical, tesseral, regular). In this system there are three axes which are of the same length, and intersect each other at a right angle. The cube, octahedron, and dodecahedron are examples (Fig. 57). Crystals of this system are distinguished by

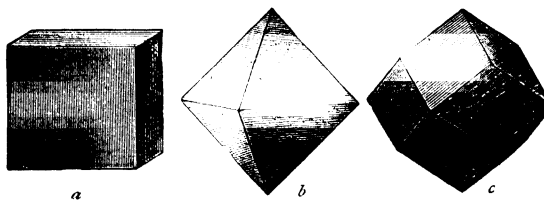



FIG. 57.—Cube (*a*), octahedron (*b*), dodecahedron (*c*).

their symmetry, their length, breadth, and thickness being equal. Common salt, fluor-spar (Fig. 74), and magnetite (Fig. 65) are illustrations.

II. Tetragonal (dimetric). The axes are three in number, and intersect each other at a right angle, but one of them, called the *vertical* axis,

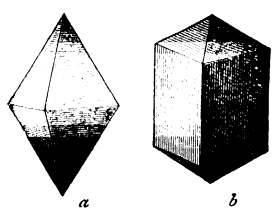



FIG. 58.—Tetragonal prism (*b*) and pyramid (*a*).

FIG. 59.—Orthorhombic prism.

is longer or shorter than the other two, which are *lateral* axes. Hence a crystal belonging to this system may either be oblong or squat (Fig. 58).

III. Orthorhombic (trimetric) has the three axes intersecting each other at a right angle, but all of unequal lengths. The rectangular and rhombic prisms and the rhombic octahedron belong to this system (Fig. 59).

IV. Hexagonal. This is the only system with four axes (Fig. 60). The lateral axes are all equal, intersect at right angles the vertical axis (which is longer or shorter than they are), and form with each other angles of 60°. Water, for instance, crystallises in this system, and the six-rayed star of a snow-flake is an illustration of the way in which

the lateral axes are placed. Quartz is an example (Fig. 55), also calcite (Figs. 56, 70, 71).

V. Monoclinic, with all the axes of unequal length. One of the lateral

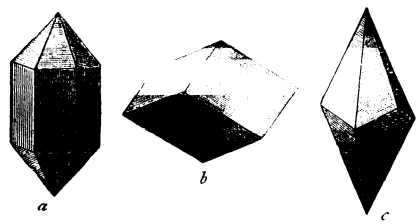



FIG. 60.—Hexagonal prism (*a*), rhombohedron (*b*), and scalenohedron (*c*).

axes cuts the vertical axis at a right angle, the other intersects the vertical axis obliquely. Augite (Fig. 61), Hornblende (Fig. 68), and Gypsum (Fig. 73) are examples.

VI. Triclinic, the most unsymmetrical of all the systems, all the axes being unequal and placed obliquely to each other (Fig. 62).

FIG. 61.—Monoclinic prism. Crystal of Augite.

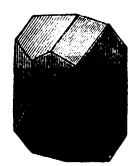


FIG. 62.—Triclinic prism Crystal of Albite felspar.

Every mineral that takes a crystalline form belongs to one or other of these six systems, and through all its varieties of external form the fundamental relations of the axes remain unchanged.

Some minerals have crystallised out of solutions in water. How this may take place can be profitably studied by dissolving salt, sugar, or alum in water, and watching how the crystals of these substances gradually shape themselves out of the concentrated solution, each according to its own crystalline pattern. Other minerals have crystallised from hot vapours (sublimation), as may be observed at the fissures of an active volcano (p. 118). Others have crystallised out of molten solutions, as in the case of lava. Thoroughly fused lava is a glassy or vitreous solution of all the mineral substances that enter into the composition of the rock

(p. 107), and when it cools, the various minerals crystallise out of it. The order of their appearance appears to depend on conditions not yet well understood; though as a rule it may be said that those which are least fusible take form first, the most fusible coming last; but a residue of non-crystalline glass sometimes remains even when the rock has solidified (p. 159). Many rocks of igneous origin show by their internal structure that they have consolidated at more than one period. The same mineral, for example, may occur in them in two series of crystals, one of which, developed during an early time, remains distinct, even after the rock has been in great measure re-melted. The crystals of the same mineral formed after this subsequent fusion, in a second consolidation, are generally much smaller and more abundant than the earlier series.

It is evident that minerals can only form perfect crystals where they have room and time to crystallise. But where they are crowded together, and where the solution in which they are dissolved dries or cools too rapidly, their regular and symmetrical growth is arrested. They then form only imperfect crystals, but their internal structure is crystalline, and if examined carefully will be found to show that in the attempt to form definite crystals each mineral has followed its own crystalline type. These characters are of much importance in the study of rocks, for rocks are only large aggregates of minerals, wherein definite complete crystals may be absent, though the structure of the whole mass is still quite crystalline (see p. 177).

But minerals also occur in various indefinite or non-crystalline shapes. Sometimes they are *fibrous* or disposed in minute fibre-like threads (Fig. 67); or *concretionary* when they have been aggregated into various irregular concretions of globular, kidney-shaped, grape-like, or other imitative shapes (Figs. 63, 64, 66, 72, 75, 76, 86); or *stalactitic* (Fig. 26) when they have been deposited in pendent forms like stalactites; or *amorphous* when they have no definite shape of any kind, as, for instance, in massive ironstone

OXIDES occur abundantly as minerals. The most important are those of Silicon (Quartz) and Iron (Hæmatite, Limonite, Magnetite, Titanic Iron).

**Quartz** (Silica, Silicon Dioxide, $SiO_2$; sp. gr. 2.65), already alluded to, is the most abundant mineral in the earth's crust. It occurs crystallised, also in various crystalline and non-crystalline varieties. In the crystallised form as common quartz it is clear and glassy when pure, but is often coloured yellow, red, purple,

green, brown, or black, from various impurities. It crystallises in the six-sided prisms and pyramids above referred to, the clear colourless varieties being rock-crystal (Fig. 55). When purple it owes its colour to the presence of oxide of manganese and is then called *amethyst;* yellow and smoke-coloured varieties, found among the Grampian Mountains of Scotland, owe their tints to iron oxide and are popularly known as Cairngorm stones. In many places, silica has been deposited from solution in water as *Chalcedony*, in translucent masses with a waxy lustre, and pale grey, blue, brown, red, or black colours. Deposits of this kind are not infrequent among the cavities and fissures of rocks. The common pebbles

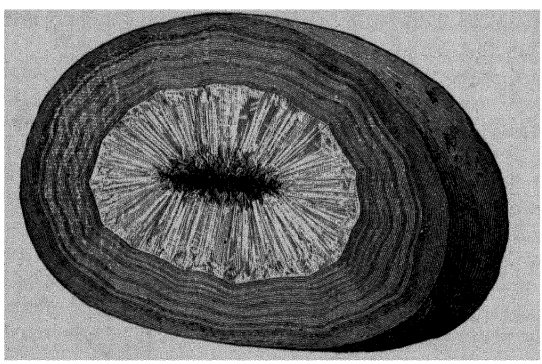


FIG. 63.—Section of a pebble of chalcedony. The outer banded layers are chalcedony, the interior being nearly filled up with crystalline quartz.

and agates with concentric bands of different colours are examples of chalcedony, and show how the successive layers have been deposited from the walls of the cavity inwards to the centre, which is often filled with crystalline quartz (Fig. 63). The dark opaque varieties are called *Jasper.*

**Opal** (sp. gr. 1.9-2.3) is a hydrated form of silica, found in many different forms of aggregation, but not crystallised. It is not quite so heavy as quartz, and is not infrequently found replacing the substance of fossil plants and animals, the minutest organic structures being replaced and exquisitely preserved. *Flint* and *Chert* are impure forms of silica, frequently associated with the remains of sponges, radiolaria, and other organisms in the rocks of the earth's crust.

Quartz can be usually recognised by its vitreous lustre and

hardness; it cannot be scratched with a knife, but easily scratches glass, and it is not soluble in the ordinary acids. It is an essential constituent of many rocks, such as granite and sandstone Silica being dissolved by natural waters, especially where organic acids or alkaline carbonates are present, is introduced by permeating water into the heart of even the most solid rocks. Hence it is found abundantly in strings and veins traversing rocks, also in cavities and replacing the forms of plants and animals imbedded in sedimentary deposits. Soluble silica is abstracted by some plants and animals, and built up into their organic structures (diatoms, radiolaria, sponges).

Four minerals composed of Oxides of Iron occur abundantly among rocks. The peroxide is found in two frequent forms, one without water (Hæmatite), the other with water (Limonite) The peroxide and protoxide combine to form Magnetite, and a mixture of the peroxide with the peroxide of the metal titanium gives Titanic Iron.

**Hæmatite** or Specular Iron ($Fe_2O_3 = Fe70O30$; sp. gr. 5.19-5·28) occurs in rhombohedral crystals that can with difficulty be scratched with a knife; but is more usually found in a massive condition with a compact, fibrous, or granular texture, and dark steel-grey or iron-black colour, which becomes bright red when the mineral is scratched or powdered The earthy kinds are red in colour, and it is in this earthy form that hæmatite plays so important a part as a colouring material in nature. Red sandstone, for example, owes its red colour to a deposit of earthy peroxide of iron round the grains of sand. Hæmatite occurs crystallised in fissures of lavas as a product of the hot vapours that escape at these places; but is more abundant in beds and concretionary masses (Fig. 64) filling veins and cavities among various rocks.

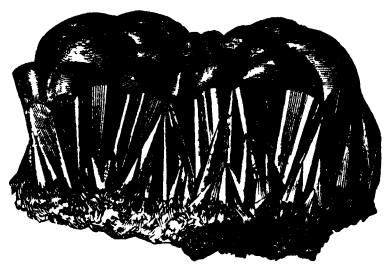


FIG 64 — Piece of hæmatite, showing the nodular external form and the internal crystalline structure

**Limonite** or Brown Iron-ore ($2Fe_2O_3, 3H_2O = Fe59.8, O25\ 7, H_2O14.5$; sp gr. 3 6-4) differs from Hæmatite in being lighter and softer, in containing more than 14 per cent of water, which

is combined with the iron to form the hydrated peroxide, in being usually massive or earthy, in presenting a dark brown to yellow colour (ochre), and in giving a yellowish-brown to dull yellow powder when scratched or bruised. It may be seen in the course of being deposited at the present time through the action of vegetation in bogs and lakes (pp. 54, 67), hence its name of Bog-iron-ore; likewise in springs and streams where the water carries much decomposing sulphate of iron. The common yellow and brown colours of sandstones and many other rocks are generally due to the presence of this mineral.

**Magnetite** ($FeOFe_2O_3 = Fe72.41$, $O27.59$; sp. gr. 4.9-5.2) occurs crystallised in isometric octahedrons and dodecahedrons of an iron-black colour, giving a black powder when scratched.

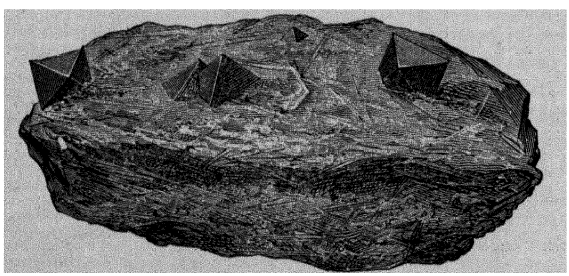


FIG. 65.—Octahedral crystals of magnetite in chlorite-schist.

It is found abundantly in many rocks (schists, lavas, etc.), sometimes in large crystals (Fig. 65), sometimes in such minute form as can only be detected with the microscope. It also forms extensive beds of a massive structure. Its presence in rocks may be detected by its influence on a magnetised needle. By pounding basalt and some other rocks down to powder, minute crystals and grains of magnetite may be extracted with a magnet.

**Titanic Iron, Ilmenite** ($FeTiO_3 = Fe36.8$, $Ti31.6$, $O31.6$; sp. gr. 4.5-5.2) occurs in iron-black crystals like those of hæmatite, from which they may be distinguished by the dark colour and metallic lustre of the surface when scratched. Though this ore is found in beds and veins in certain kinds of rock (schists, serpentine, syenite), its most generally diffused condition is in minute crystals and grains scattered through many crystalline rocks (basalt, diabase, etc.) and combined in small proportions in other iron-ores.

**Manganese Oxides** are commonly associated with those of iron in rocks. They are liable to be deposited in the form of bog-manganese, under conditions similar to those in which bog-iron is thrown down. Earthy manganese oxide (wad) not infrequently appears between the joints of fine-grained rocks in arborescent forms that look so like plants as to have been often mistaken for vegetable remains. These plant-like deposits are called *Dendrites* or dendritic markings (Fig. 66).

FIG. 66.—Dendritic markings due to arborescent deposit of earthy manganese oxide.

SILICATES. — Compounds of Silica with various bases form by far the most numerous and abundant series of minerals in the earth's crust. They may be grouped according to the chief metallic base in their composition. The most important are the Silicates of Alumina, and the Silicates of Magnesia. Of the aluminous silicates we need consider here only the Felspars, Zeolites, and Micas. Among the magnesian silicates it will be enough to note the leading characters of Hornblende, Augite, Olivine, Talc, Chlorite, and Serpentine. When the learner has made himself so familiar with these as to be able readily to recognise them, he may proceed to the examination of others, of which he will find descriptions in treatises on Mineralogy and in more advanced text-books of Geology.

**Felspars.**—This family of minerals plays an important part in the construction of the earth's crust, for it constitutes the largest part of the crystalline rocks, which, like granite and lava, have been erupted from below; is found abundantly in the great series of schists; and by decomposition has given rise to the clays, out of which so many sedimentary rocks have been formed. The

felspars are divided into two series, according to crystalline form and chemical composition.

*Orthoclase* or potash-felspar ($SiO_2$64.7, $Al_2O_3$18.4, $K_2O$16.9) crystallises in monoclinic or oblique rhombic prisms, but also occurs massive; is white, grey, or pink in colour; has a glassy lustre but is not usually clear and transparent; can with difficulty be scratched with a knife, but easily with quartz, and has a specific gravity of 2.50 to 2.60. Associated with quartz, it is an abundant ingredient of many ancient crystalline rocks (granite, felsite, gneiss, etc.). *Microcline* is a triclinic form of potash-felspar usually containing sodium and often found in granite veins.

The important series of triclinic felspars, formerly grouped under the general name of "plagioclase," are abundant ingredients of some crystalline rocks in which they appear as clear, colourless, or white turbid glassy strips, on which a fine minute parallel ruling may be detected with the naked eye, or with a lens. This striation or lamellation, due to what is called "twinning," is a character which distinguishes the crystals from the monoclinic orthoclase. These felspars occur as essential constituents of many volcanic rocks, and also among ancient eruptive masses and schists Among them are *Albite* or Soda-felspar, containing nearly 12 per cent of soda (Fig. 62); *Anorthite* or Lime-felspar, with 20 per cent of lime; *Soda-lime felspar*, *Lime-soda felspar*—a group of felspars containing variable proportions of soda, lime, and sometimes potash, of which the chief varieties are *Oligoclase* (Silica, 60-63), *Andesine* (Silica, 55-58), *Labradorite* (Silica, 50-53 per cent).

Closely related to the felspars as a rock-constituent is the mineral **Nepheline**, which is a silicate of alumina, potash and soda with a specific gravity of 2 6. It takes the place of felspar in one group of basalts, and is a conspicuous ingredient in phonolites and some forms of syenite. Another mineral which may be mentioned here as occasionally abundant in the constitution of some lavas is **Leucite.** It occurs in white, dull, 24-sided crystals, is a silicate of alumina and potash, and has a specific gravity of 2.50.

**Zeolites**, a characteristic family of minerals, composed essentially of silicates of alumina with lime, soda, and water; often marked by a peculiar pearly lustre, especially on certain planes of cleavage; usually found filling up cavities in rocks where they have been deposited from solution in water. Some of the species commonly crystallise in fine needles or silky tufts. The zeolites have obviously been formed from the decomposition of other

minerals, particularly felspars. Especially abundant in the steam-cells of old lavas in which felspars containing lime and soda prevail, they either line the walls of the cavities, shooting out in crystals or fibres towards the centre (Fig. 67), or fill the cavities up entirely (Amygdales).

Another mineral substance produced by the decomposition of Felspar is familiar under the name of Clay. The purer forms are known as *Kaolin* or China-clay.

**Micas,** a group of monoclinic minerals specially distinguished by their ready basal cleavage into thin, parallel, usually elastic silvery laminæ. They are aluminous silicates with potash (soda), or with magnesia and ferrous oxide, and always with water. They

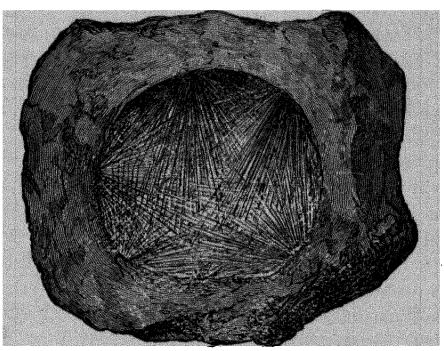


FIG. 67.—Drusy cavity in a lava, filled with zeolite which has crystallised in long slender needles.

occur as essential constituents of granite, gneiss, and many other eruptive and schistose rocks, also in worn spangles in many sedimentary strata (micaceous sandstone). Among their varieties the two most important are *Muscovite* (white mica, potash-mica) and *Biotite* (black mica, magnesia-mica). There are also *Lepidolite* (lithia mica), *Paragonite* (soda mica), *Lepidomelane* (iron mica), and others.

**Amphibole** is the name given to an important series of monoclinic minerals, divisible into two well-marked groups. (1) Varieties consisting of silicates of lime and magnesia, usually with iron, often with soda and potash, but with little or no alumina; generally white or pale green in colour, often fibrous; found more particularly among gneisses, marbles, and other metamorphic rocks.

The more frequently occurring members of this group are *Tremolite*, *Actinolite*, and *Asbestus*. (2) Composed of similar silicates but with sometimes as much as 18 per cent of alumina, and in the dark green or black varieties a considerable proportion of ferrous and ferric oxides. The commonest member of this group is *Hornblende* which occurs as a constituent of diorite, syenite, and some granites, also in many schists and gneisses as well as in thick beds among these metamorphic rocks (Hornblende-rock, Hornblende-schist)

FIG 68 —Hornblende crystal

**Pyroxene,** like Amphibole, comprises two groups of minerals composed of silicates of lime and magnesia with more or less iron. In one group wherein little or no alumina is present, the minerals are generally pale greenish grey in colour and occur in such rocks as contain the non-aluminous amphiboles. They belong to the monoclinic system of crystallisation and their specific gravity ranges from 3 to 3 5. They include *Diopside*, *Sahlite*, *Diallage*, *Hedenbergite*. The second group or aluminous pyroxenes contain sometimes upwards of 15 per cent of alumina and occasionally some alkalies. The most abundant mineral of this group is *Augite*, which includes the dark green or black varieties so abundant in many recent lavas and in ancient eruptive rocks

With the Pyroxenes may be grouped two other allied minerals of considerable consequence as constituents of rocks. *Enstatite*, a silicate of magnesia, is a characteristic ingredient of many serpentines or peridotites It occurs in orthorhombic crystals having a marked vitreous to pearly lustre *Hypersthene*, also orthorhombic but usually in foliated or massive forms, occurs associated with labradorite in some gabbros and norites and in some volcanic rocks (hypersthene-andesites).

FIG 69 —Magnified section of an olivine crystal, the light portions represent the undecomposed mineral, the shaded parts show the conversion of the olivine into serpentine

**Olivine (Peridot)** ($SiO_2$ 41 01, MgO 49 16, FeO 9.83; sp. gr. 3 2–3 5) occurs in small orthorhombic prisms and glassy grains in basalts and other lavas, of a pale yellowish-green or olive-green colour, whence its name These grains can often be readily detected on the black ground of the rock, through which they are abundantly dispersed. Olivine

is liable to alteration, and especially to conversion into serpentine by the influence of percolating water (Fig. 69).

**Serpentine** ($Mg_3Si_2O_7 + 2H_2O$) is another hydrated magnesian silicate, containing a little protoxide of iron and alumina, usually massive, dark green but often mottled with red. It occurs in thick beds among schists, is often associated with limestones, and may be looked for in all rocks that contain olivine, of the alteration of which or of some allied mineral it is the result. In many serpentines, traces of the original olivine, enstatite or other minerals can be detected.

**Chlorite** ($SiO_2$ 25-28, $Al_2O_3$ 19-23, FeO 15-29, MgO 13-25, $H_2O$ 9-12). This term includes a group of dark olive-green hydrated magnesian silicates. They are so soft as to be easily scratched with the nail, and occur in small six-sided tables, also in scaly and tufted or amorphous aggregates diffused through certain rocks. Chlorite appears generally to be the result of the alteration of some previous anhydrous magnesian silicate, such as hornblende.

**Talc** is the name given to another hydrous magnesian silicate which is readily and deeply scratched with the nail, has a pearly lustre and a soapy feel, and can be split into thin laminæ which are not elastic as those of mica are. It has resulted from the alteration of some older magnesian silicates

**Glauconite** is a dull, opaque, amorphous, greenish mineral of variable composition, but essentially a hydrous silicate of iron and potash. It is found in minute grains in some sedimentary deposits (as in the Glauconitic Marl, pp 358, 360) and has been met with in abundance as a modern deposit on the ocean floor where it is associated with the remains of foraminifera and other calcareous organisms

CARBONATES.—Though these are abundant in nature, only three of them require notice here as important constituents of the earth's crust, those of lime, magnesia and lime, and iron

**Calcite** (calcium-carbonate or carbonate of lime, $CaCO_3$, calcium 56, carbon-dioxide 44) crystallises in the hexagonal system, and has for its fundamental crystalline form the rhombohedron, as already mentioned (p. 138). When quite pure it is transparent (Iceland spar, Fig. 56), with the lustre of glass; but more usually is translucent or opaque and white Its crystals, where the chief axis is shorter than the others, sometimes take the form of flat rhombohedrons (nail-head spar, Fig. 70); where, on the other hand, that axis is elongated, they present pointed

pyramids (scalenohedrons, dog-tooth spar, Fig. 71). The mineral occurs also in fibrous, granular, and compact forms. The decomposition of lime-bearing silicates by permeating water gives rise to calcium-carbonate, which is removed in solution. Being readily soluble in water containing carbonic acid, this carbonate is found in almost all natural waters, by which it is introduced into the cavities of rocks. Some plants and many animals secrete large quantities of carbonate of lime, and their remains are aggregated into beds of limestone, which is a massive and more or less impure form of calcite (pp. 170, 174). Calcite is easily scratched with a knife, and is characterised by its abundant effervescence when acid is dropped upon it. Its specific gravity is 2.72. A less frequent and stable form of calcium-carbonate is *Aragonite*, which crystallises in orthorhombic forms, but is more usually found in globular, dendritic, coral-like, or other irregular shapes, and is rather harder and heavier than calcite.

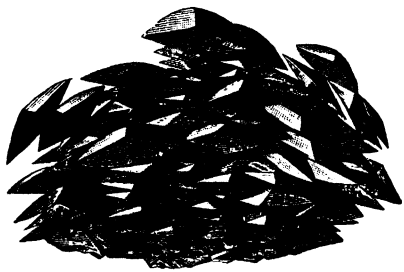


FIG. 70.—Calcite in the form of "nail-head spar."

**Dolomite** assumes a rhombohedral crystallisation, and is a compound of 54.4 of calcium-carbonate, with 45.6 of magnesium-carbonate. It has a specific gravity of 2.8–2.9, is rather harder than calcite, and does not effervesce so freely with acid. It occurs in strings and veins like calcite, but also in massive beds having a prevalent pale yellow or brown colour (owing to hydrated peroxide of iron), a granular and often cavernous texture, and a tendency to crumble down on exposure (p. 171).

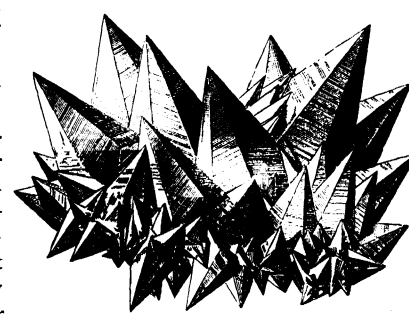


FIG. 71.—Calcite in the form of dog-tooth spar.

**Siderite** (chalybite, spathic iron, ferrous carbonate, $FeCO_3$), another rhombohedral carbonate, contains 62 per cent of ferrous oxide or protoxide of iron; specific gravity 3.83. In its crystalline form it is grey or brown, becoming much darker on exposure, as the protoxide passes into peroxide. It occurs abundantly mixed with clay in concretions and beds, frequently associated with remains of plants and animals (*Sphærosiderite*, *Clay-ironstone*, Figs. 72, 76).

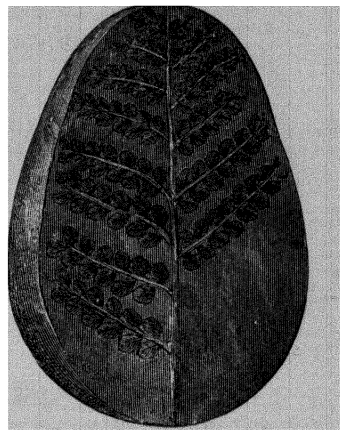


FIG. 72.—Sphærosiderite or Clay-ironstone concretion enclosing portion of a fern.

SULPHATES.—Two sulphates deserve notice for their importance among rock-masses—those of lime and baryta.

**Gypsum** (hydrous calcium-sulphate, $CaSO_4 + 2H_2O$; sp. gr. 2.2–2.4) occurs in monoclinic crystals, commonly with the form of right rhomboidal prisms (Fig. 73, *a*), which not infrequently appear as *macles* or twin-crystals (Fig. 73, *b*). When pure it is clear and colourless, with a peculiar pearly lustre (*Selenite*); it is found fibrous with a silky sheen (*Satin-spar*), also white and granular (*Alabaster*). It is so soft as to be easily cut with a knife or even scratched with the finger nails. It is readily distinguished from calcite by its crystalline form, softness, and non-effervescence with acid. When burnt it becomes an opaque white powder (plaster of Paris). Gypsum occurs in beds associated with sheets of rock-salt and dolomite (pp. 55, 171); it is soluble in water, and is found in many springs and rivers, as well as in the sea. One thousand parts of water at 32° Fahr. dissolve 2.05 parts of sulphate of lime; but the solubility of the substance is increased in the presence of common salt, a thousand parts of a saturated solution of common salt taking up as much as 8.2 parts of the sulphate.

Anhydrous calcium-sulphate or *Anhydrite* is harder and heavier than gypsum (sp. gr. 2.89), and is found extensively in beds associated with rock-salt deposits. By absorbing water, it increases in bulk and passes into gypsum.

**Barytes** (Heavy spar, barium-sulphate, $BaSO_4$; sp. gr. 4.3–

4.7), the usual form in which the metal barium is distributed over the globe, crystallises in orthorhombic prisms which are generally tabular; but most frequently it occurs in various massive forms. The purer varieties are transparent or translucent, but in general the mineral is dull yellowish or pinkish white, with a vitreous lustre, and is readily recognisable from other similar substances by its great weight; it does not effervesce with acids. Barytes is usually met with in veins traversing rocks, especially in association with metallic ores; it occurs also diffused through some sandstones.

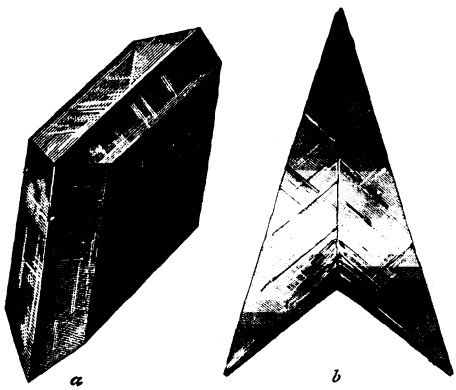


FIG. 73.—Gypsum crystals.

PHOSPHATES. — Only one of these requires to be enumerated in the present list of minerals—the phosphate of lime or Apatite.

**Apatite** (tricalcic phosphate, $3Ca_3P_2O_8 + CaF_2$ or $CaCl_2$; sp. gr. 3.1–3.2) crystallises in hexagonal prisms which, as minute colourless needles, are abundant in many crystalline rocks; it also occurs in large crystals and in amorphous beds associated with gneiss. It is soluble in water containing carbonic acid, ammoniacal salts, common salt, and other salts. Hence its introduction into the soil, and its absorption by plants, as already mentioned (p. 135).

FLUORIDES.—The only member of this family occurring conspicuously in the mineral kingdom is calcium fluoride or **Fluor-Spar** (Fluorite, $CaF_2$; Fluorine 48.9, Calcium 51.1; sp. gr. 3.1–3.2), which, in the form of colourless, but more commonly light green, purple, or yellow cubes, is found in mineral veins not infrequently accompanying lead-ores (Fig. 74).

CHLORIDES.—Reference has already been made to the only chloride which occurs plentifully as a rock-mass, the chloride of sodium, known as **Halite** or Rock-salt (NaCl, chlorine 60.64, sodium, 39.36). It crystallises in cubical forms, and is also

found massive in beds that mark the evaporation of former salt-lakes or inland seas (p. 172).

SULPHIDES.—Many combinations of sulphur with the metals occur, some of them of great commercial value; but the only one that need be mentioned here for its wide diffusion as a rock-constituent is the iron-disulphide ($FeS_2$), in which the elements are combined in the proportion of 46.7 iron and 53.3 sulphur. This substance assumes two crystalline forms: (1) **Pyrite**, which occurs in cubes and other forms of the first or monometric system, of a bronze-yellow colour and metallic lustre, so hard as to strike fire with steel, giving a brownish-black powder when scratched, and having a specific gravity of 4.9 to 5.1. This mineral is abundantly diffused in minute grains, strings, veins, concretions (Fig. 75, *c*), and crystals in many different kinds of rocks; it is usually recognisable by its colour, lustre, and hardness; (2) **Marcasite** (white pyrite) crystallises in the orthorhombic forms, is as hard as ordinary pyrites but paler in colour, not quite so heavy (sp. gr. 4.65–4.9), and much more liable to decomposition. This form, rather than pyrite, is usually associated with the remains of plants and animals imbedded among rocks. The sulphide has no doubt often been precipitated round decaying organisms by their effect in reducing sulphate of iron. By its ready decomposition, marcasite gives rise to the production of sulphuric acid and the consequent formation of sulphates. One of the most frequent indications of this decomposition is in the water of chalybeate springs (p. 67). Weathered surfaces of pyritous shale may sometimes be seen coated with crystals or an efflorescence of alum, due to the action of the sulphuric acid on the alumina and alkalies of the stone. On an exposed pyritous calcareous rock, minute groups of gypsum crystals may be detected, showing that the sulphuric acid has combined with the lime.

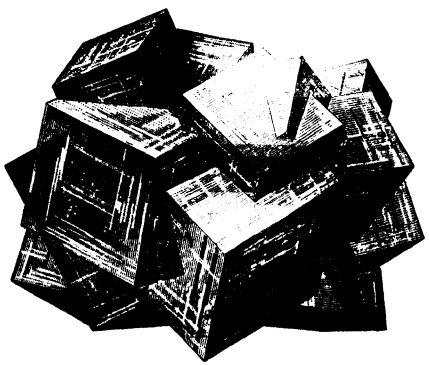


FIG. 74.—Group of flour-spar crystals.

## CHAPTER XI

### THE MORE IMPORTANT ROCKS OF THE EARTH'S CRUST

FROM the distribution of the more important elements in the earth's crust and the mineral forms which they assume, we have now to advance a stage farther and inquire how the minerals are combined and distributed so as to build up the crust. As a rule, simple minerals do not occur alone in large masses; more usually they are combined in various proportions to form what are known as Rocks. A rock may be defined as a mass of inorganic matter, composed sometimes of one but more usually of several minerals, having for the most part a variable chemical composition, with no necessarily symmetrical external form, and ranging in cohesion from loose or feebly aggregated debris up to the most solid stone. Blown sand, peat, coal, sandstone, limestone, lava, granite, though so unlike each other, are all included under the general name of Rocks.

In entering upon the study of rocks, or the division of geology known as Petrography, it is desirable to be provided with such helps as are needed for determining leading external characters; in particular, a hammer to detach fresh splinters of rock, a pocket-knife for trying the hardness of minerals, a small phial of dilute hydrochloric acid for detecting carbonate of lime, and a pocket lens. The learner, however, must bear in mind that the thorough investigation of rocks is a laborious pursuit, requiring qualifications in chemistry and mineralogy. He must not expect to be able to recognise rocks from description until he has made good progress in the study. As already stated on a previous page, he must examine the objects themselves, and for this purpose he will find much advantage in procuring a set of named specimens, and making himself familiar with such of their characters as he can himself readily observe.

[redacted]ht has been thrown upon the structure and history of [redacted] examining them with the microscope. For this purpose, [redacted]ip or slice of the rock to be studied is ground smooth [redacted]ery and water, and after being polished with flour-emery upon plate-glass, the polished side is cemented with Canada balsam to a piece of glass, and the other side is then ground down, until the specimen is so thin as to be transparent. Thin

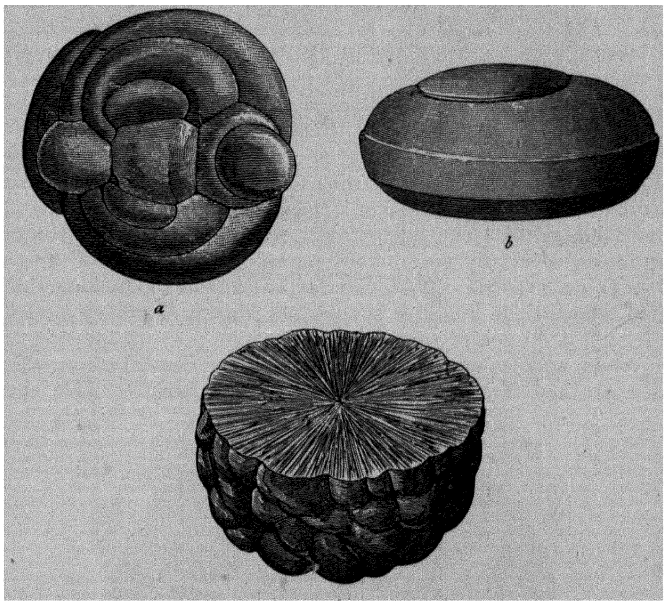



FIG. 75.—Concretions.
*a*, *b*, "Fairy stones;" *c*, Pyrite, showing internal radiated stucture.

sections of rock thus prepared (which can now be obtained from any good mineral-dealer) reveal under the microscope the minutest kinds of rock-structure. Not only can the component minerals be detected, but it is often possible to tell the order in which they have appeared, and what has been the probable origin and history of the rock. Some illustrations of this method of investigation will be given in a later part of the present chapter. It will be of advantage meanwhile to begin by taking note of

some of the more important characters of rocks, and of the names which geologists apply to them.

### *Some important Terms applied to Rocks*

*Sedimentary*—composed sediment which may be either a mechanical detritus, such as mud, sand, broken shells, or gravel; or a chemical precipitate, as rock-salt and calcareous tufa. The various deposits which are accumulated on the floors of lakes, in river-courses, and on the bed of the sea, are examples of sedimentary rocks.

*Fragmental, Clastic*—composed of fragments derived from some previous rock. All ordinary detritus is of this nature.

*Concretionary*—composed of mineral matter which has been aggregated round some centre so as to form rounded or irregularly-shaped lumps. Some minerals, particularly pyrite (Fig. 75 *c*), marcasite, siderite, and calcite, are frequently found in concretionary forms, especially round some organic relic, such as a shell or plant (Figs. 72, 76). In alluvial clay, calcareous concretions which often take curious imitative shapes, are known as "fairy stones" (Fig. 75, *a*, *b*; see p. 199).

When nodules of limestone, ironstone, or cement-stone which have cracked internally in drying or consolidating have their

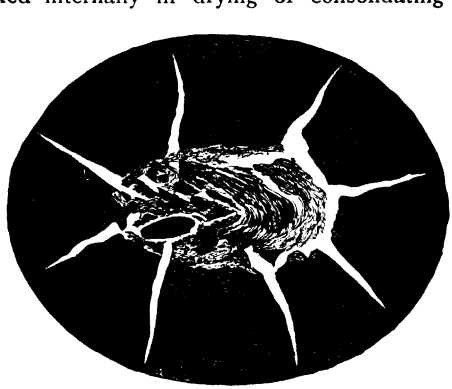


FIG. 76.—Section of a septarian nodule, with coprolite of a fish as a nucleus.

interior traversed by cracks which radiate towards, but do not reach, the outside, and are filled up with calcite or other mineral,

they are known as *Septaria* or septarian nodules (Fig. 76, and layer 13 in Fig. 91).

*Oolitic*—made up of spherical grains, each of which has been

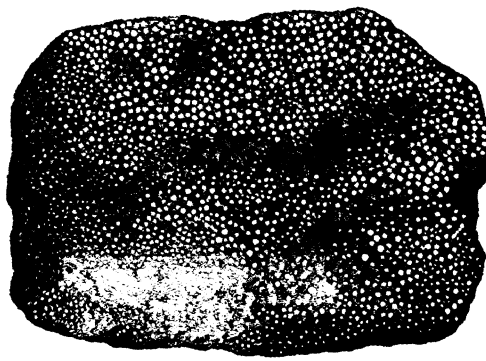


FIG. 77.—Piece of oolite.

formed by the deposition of successive coatings of mineral matter, generally round some grain of sand, fragment of shell, or other foreign particle (Fig. 77). A rock with this structure looks like

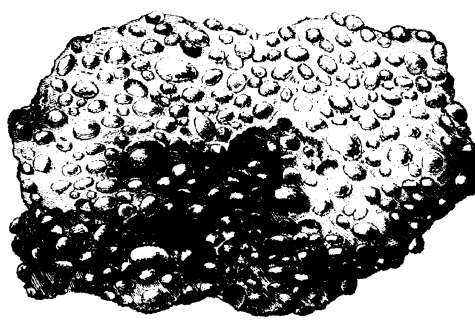


FIG. 78.—Piece of pisolite.

fish-roe, hence the name oolite or roe-stone ; but when the granules are large enough to resemble peas, the rock becomes *pisolitic* (pea-stone, Fig. 78). This peculiar structure is produced in water (springs, lakes, or enclosed parts of the sea), wherein dissolved mineral matter (usually carbonate of lime) is so abundant as to be

deposited in thin pellicles round the grains of sediment that are kept in motion by the current (p. 99)

*Stratified, Bedded*—arranged in layers, strata, or beds lying generally parallel to each other, as in ordinary sedimentary deposits (Figs 90, 91).

*Aqueous*—laid down in water, comprising nearly the whole of the sedimentary and stratified rocks.

*Unstratified, Massive*—having no arrangement in definite layers or strata. Lavas and the other eruptive rocks are examples (Chapter XIV.).

*Eruptive, Igneous*—forced upwards in a molten or plastic condition into or through the earth's crust. All lavas are Eruptive or Igneous rocks, also called *Volcanic* because erupted to the surface by volcanoes. In the same division must be classed granite and allied masses, which have been thrust through rocks at some depth within the earth's crust and may not have been directly connected with any volcanic eruption; such rocks are sometimes called *Plutonic* or *Hypogene.*

*Crystalline*—consisting wholly or chiefly of crystals or crystalline grains. Rocks of this nature may have arisen from (*a*) igneous fusion, as in the case of lavas, where the minerals have separated out of a molten glass, or what is called a *Magma*; (*b*) aqueous solution, as where crystalline calcite forms stalactite and stalagmite in a cavern; (*c*) sublimation, where the materials have crystallised out of hot vapours, as in the vents and clefts of volcanoes.

By the aid of the microscope many rocks which to the naked eye show no definite structure can be shown to be wholly or partially crystalline. Moreover, it can often be ascertained that the crystals or crystalline grains in a rock, as they were crystallising out of their solution, have enclosed various foreign bodies. Among the objects thus taken up are minute globules of gas, which are prodigiously abundant in certain minerals in some lavas; liquids, usually water, enclosed in cavities of the crystals, but not quite filling them, and leaving a minute freely-moving bubble (Fig. 79); glass, filling globular spaces, probably part of the original glassy magma of the rock; crystals and crystallites (rudimentary crystalline forms,

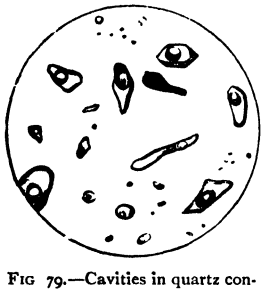


FIG 79.—Cavities in quartz containing liquids (magnified)

Fig. 80) of other minerals. Thus a crystal, which to the eye may appear quite free from impurities, may be found to be full of various kinds of enclosures. Obviously the study of these enclosures cannot but throw light on the conditions under which the minerals enclosing them were produced.

There are various types of crystalline structure which can best be examined under the microscope, as *Holocrystalline*, composed entirely of crystalline elements without any interstitial glass —one of the most characteristic types of this structure is found in granite, hence it is sometimes termed the granitic or granitoid structure; *Hemi-crystalline*, consisting partly of crystals, but with a ground-mass or base which may be partly glassy or variously devitrified; *Felsitic* or *microfelsitic*—composed of indefinite half-

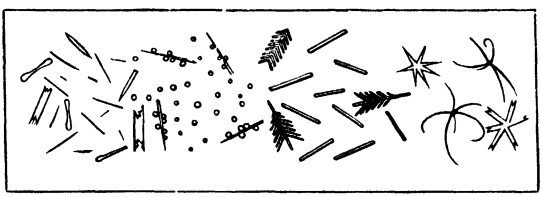


FIG. 80.—Various forms of crystallites (highly magnified).

effaced granules and filaments resulting from the devitrification of what was probably at first a glassy rock (p. 180).

*Glassy*, *Vitreous*—having a structure and aspect like that of artificial glass. Some lavas, obsidian for example, have solidified as natural glasses, and look not unlike masses of dark bottle-glass. In almost all cases, however, they contain dispersed crystals, crystallites (Fig. 80), or other enclosures. These substances have generally multiplied to such an extent in most lavas as to leave only small interstitial portions of the original glass, while in many cases the glass has entirely disappeared. When a glass has thus been converted into a dull, opaque, stony, or lithoid mass, or into a completely crystalline substance, it is said to be *devitrified*. The microscope enables us to prove many crystalline eruptive rocks to have been once molten glass which by a process of devitrification have been brought into their present more or less crystalline condition (p. 107).

*Porphyritic*—composed of a compact or crystalline base or matrix, through which are scattered conspicuous crystals, called "phenocrysts," much larger than those of the base, and frequently

of some felspar (Fig. 81). Many eruptive rocks have this structure and are sometimes spoken of as "porphyries." The large crystals existed in the rock while still in a mobile state within the earth's crust, and belong to an early phase in the history of the mass in which they occur, while the minuter crystals of the base were developed by a later process of crystallisation during the final consolidation of the rock. In the successive zones of growth which porphyritic crystals often present, we may note by the enclosed minerals some of the successive stages of crystallisation and consolidation.

When an igneous rock has caught up and enclosed the crystals

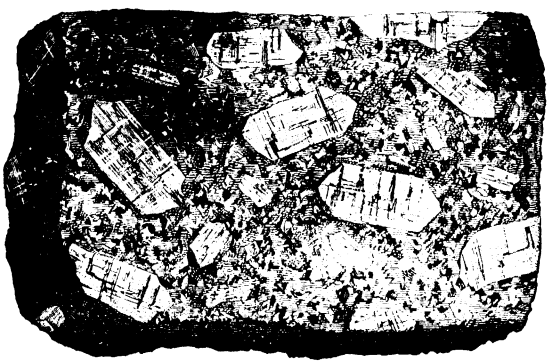


FIG. 81.—Porphyritic structure.

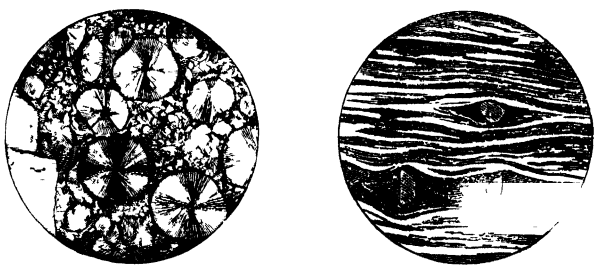
or fragments of other rocks, these inclusions, being foreign to the mass in which they lie, are known as "xenocrysts."

*Spherulitic*—composed of or containing small pea-like globular bodies (*Spherulites*) which show a minutely fibrous internal structure radiating from the centre (Fig. 82, A). This structure is particularly observable in vitreous rocks, where it appears to be one of the stages of devitrification (p. 159).

*Perlitic.*—Many vitreous rocks show a minutely fissured structure as one of the accompaniments of devitrification. In the structure termed perlitic the original glass has had a series of reticulated and globular or spiral cracks developed in it, sometimes giving rise to globules composed of successive thin shells.

*Vesicular, Cellular*—containing spheroidal or irregularly shaped cavities. In many eruptive rocks (as in modern lavas) the ex-

pansion of interstitial steam, while the mass was still in a molten condition, has produced this cellular structure (Fig. 44), the vesicles have usually remarkably smooth, even glassy walls, they may form a comparatively small part of the whole mass, or they may so increase as to make pieces of the rock capable of floating on water. Where the vesicular structure is conjoined with more solid parts, as in the irregular slags of an iron furnace, it may be called *slaggy*. Where, as in the scoriæ of a volcano, the cellular and solid parts are in about equal proportions, and the vesicles vary greatly in numbers and size within short distances, the structure may be termed *scoriaceous* The lighter and more froth-like varieties that can float on water are said to be *pumiceous*, or to have the characters of pumice (p. 180). Vesicular rocks have



A B

FIG 82 —Spherulitic and fluxion-structure. A, Spherulites, as seen under the microscope (with polarised light). B, Fluxion-structure of Obsidian, as seen under the microscope.

generally had their vesicles filled up by the deposition of various minerals from aqueous solution, especially quartz, calcite, and zeolites These substances first begin to encrust the walls of the cells, and as layer succeeds layer they gradually fill the cells up (Figs. 63, 67); as the cells have not infrequently been elongated in one direction by the motion of the rock before consolidation was completed (Fig. 46), the mineral deposits in them, taking their exact moulds, appear as oval or almond-shaped bodies. Hence rocks which have been treated in this way are called *Amygdaloids*, and the kernels filling up the cells are known as *Amygdales* (Fig. 44). An amygdaloidal rock, therefore, was originally a molten lava, rendered cellular by the expansion of its absorbed steam and gases, its vesicles having been subsequently filled up by the deposit in them of mineral matter. This change appears to have taken

place during the continuance of a volcanic period, by the infiltration of water, perhaps at a high temperature, containing the various minerals in solution.

*Flow-structure, Fluxion-structure* — an arrangement of the ground-mass, crystallites, crystals, or particles of a rock in streaky lines, the minuter forms being grouped round the larger, indicative of the internal movement of the mass previous to its consolidation. The lines are those in which the particles flowed past each other, the larger crystals giving rise to obstructions and eddies in the movement of the smaller objects past them. This structure is characteristic of many once molten rocks; it is well seen in

FIG. 83.—Schistose structure.

obsidian (Fig. 82, B). But it is also found in rocks which, by enormous stresses within the earth's crust, have been crushed and made to undergo an interstitial movement like that of the flow of liquids. The most solid gneisses and granites have in this way been so sheared and squeezed that their component minerals have been crushed into a fine compact mass, through which the streaky lines of flow are sometimes displayed with singular clearness.

*Mylonitic*—a name sometimes applied to rocks which by terrestrial movement have had their original structure entirely obliterated, their substance having been crushed to powder so as to present now only a dull, compact, often streaky mass, sometimes partially or completely recrystallised.

*Schistose, Foliated*—consisting of minerals that have crystallised

in approximately parallel, wavy, and irregular laminæ, layers, or folia (Fig. 83). Such rocks are called generally schists. They have, in large measure, been formed by the alteration or metamorphism of other rocks of various kinds during the vast terrestrial movements referred to in the foregoing paragraphs (see Chapter XIII.).

## CLASSIFICATION OF ROCKS

Various schemes of classification of rocks are in use among geologists, some based on mode of origin, others on mineral composition or structure. For the purpose of the learner, perhaps the most instructive and useful arrangement is one which as far as possible combines the advantages of both these systems. Accordingly, in the following account of the more important rocks which enter into the structure of the earth's crust, a threefold subdivision will be adopted into: (i) sedimentary rocks; (ii) eruptive rocks; (iii) schistose rocks.

### I. Sedimentary Rocks

This division includes the largest number, and to the geologist the most important, of the rocks accessible to our notice It comprises the various deposits that arise from the decay of the surface of the land and are laid down on the land or over the bed of the sea, together with all those directly or indirectly due to the growth of plants and animals. It thus embraces those which constitute the main mass of the earth's crust so far as known to us, and which contain the evidence whence the geological history of the earth is chiefly worked out. It is, therefore, worthy of the earliest and closest attention of the student.

Sedimentary rocks, being due to the deposition of some kind of sediment or detritus, are obviously not original or primitive rocks. They have all been derived from some source, the nature of which, if not its actual site, can usually be determined. In no case, therefore, can sedimentary rocks carry us back to the beginning of things; they are themselves derivative, and presuppose the existence of some older material from which they could be derived.

One of their most obvious characters is that, as a rule, they are *stratified*. They have been deposited, usually in water, some-

times in air, layer above layer, and bed above bed, each of the strata marking a particular interval in the progress of deposition (Chapter XII ). As regards their mode of origin, they may be subdivided into three great sections: (1) fragmental or clastic, composed of fragments of pre-existing rocks; (2) chemically precipitated, as in the deposits from mineral springs; and (3) formed of the remains of organisms, as in peat and coral-rock.

### (1) *Fragmental or Clastic Rocks*

These are masses of mechanically-formed sediment, derived from the destruction of older rocks; they vary in coherence from loose sand or mud up to the most compact sandstone or conglomerate; they are accumulating abundantly at the present time in the beds of rivers and lakes, and on the floor of the sea, and they have been formed in a similar way all over the globe from the earliest periods of known geological history. Some of the more frequent kinds are the following:—

**Cliff-Debris**—coarse angular rubbish, including large blocks of stone, disengaged by the weather from cliffs and other bare faces of rock. This kind of detritus is formed in regions with a great range of temperature (p. 13), or where the action of frost is severe; it slides down the slopes (*screes*, p 20), and accumulates at their foot, unless washed away by torrents. In glacier-valleys it descends to the ice, where, gathering into moraines (Chapter VI.), it is transported to lower levels The perched blocks of such valleys are some of the larger fragments of this cliff-debris left stranded by the ice, and from around which the smaller detritus has been washed away (Figs. 29, 30, and 33).

**Soil, Subsoil,** described in Chapter II., represent the result of the subaerial decomposition of the surface of the land A gradation can be traced from solid rock into subsoil, which consists of the broken-up and more or less decomposed rock, and again from subsoil upwards into soil, which represents a further stage of decay, where the rotted stone is mingled with humus, resulting from the decomposition of the remains of plants and animals (Figs. 2 and 3).

**Breccia**—a rock composed of angular fragments. Such a rock usually shows that its materials have not travelled far; otherwise, they would have lost their edges, and would have been more or less rounded. Ordinary cliff-debris may consolidate into a breccia, more especially where it falls into water and is allowed to gather

on the bottom. The angular fragments shot out of a volcano often accumulate into volcanic breccia (Fig. 84). A rock containing abundant angular fragments, or which has been broken up into angular pieces that have been cemented together, is said to be *brecciated.*

**Gravel**—loose rounded water-worn detritus, in which the pebbles range in average size between that of a small pea and that of a walnut ; where they are larger they form Shingle. They may consist of fragments of any kind of rock, though as they have resulted from more or less violent water-action, pieces of the more durable stones usually predominate in them. Quartz and other

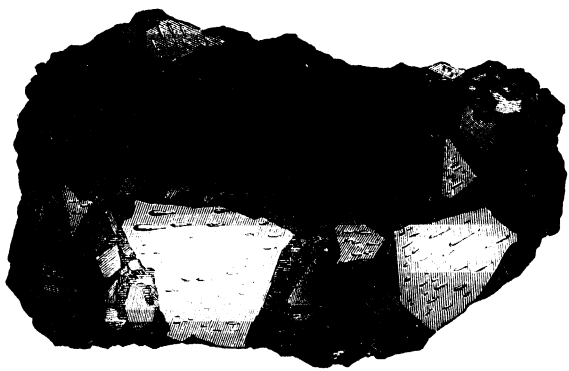


FIG. 84.—Brecciated structure—volcanic breccia, a rock composed of angular fragments of lava (lapilli), in a paste of finer volcanic debris.

siliceous materials, from their great hardness, are better able to withstand the grinding to which the detritus on an exposed seashore, or in the bed of a rapid stream, is subjected. Hence siliceous pebbles are the most frequent constituents of gravel and shingle.

**Conglomerate**—a name given to gravel and shingle when they have been consolidated into stone, the pebbles being bound together by some kind of paste or cementing material, which may be fine hardened sand, clay, or some calcareous, siliceous, or ferruginous cement (Fig. 85). As above remarked with regard to gravel, the component materials of conglomerate may have been derived from any kind of rock, but siliceous pebbles are of most common occurrence. Different names are given to conglomerates,

according to the nature of the pebbles, as quartz-conglomerate, flint-conglomerate, limestone-conglomerate, basalt-conglomerate.

**Sand**—a name given to fine kinds of detritus, the grains of which may vary from the size of a small pea down to minute particles that can only be detected with a lens. These grains are generally rounded, like water-worn pebbles, but when extremely small, so as to be carried along in suspension in water, they remain angular. For the reason already assigned in the case of gravel, the component grains of sand are commonly of quartz or of some other durable material. Examined with a good magnifying glass, they are seen to be usually rounded, water-worn, but sometimes angular, unworn particles of indefinite shapes which, except in

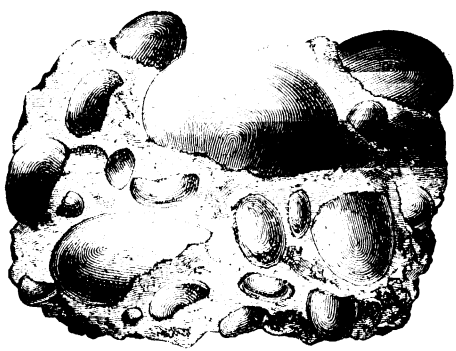


FIG. 85.—Conglomerate.

their smaller size, resemble those of gravel-stones. Angular sand may be formed by the disintegration of the surface of rocks exposed to the weather, more especially in dry climates, where there is a great difference between the temperature of day and night (p. 13). The loosened particles are blown away by the wind, and may be heaped up into great sand-wastes, as in the tracts known as Deserts. On a sea-coast, where a sandy beach is liable to be laid bare and exposed to be dried between tides by breezes blowing from the sea, the sand-particles are generally more or less rounded, and those at the surface are lifted up by the wind and borne away landward, to be piled up into dunes (p. 21). In some places the particles are derived mainly from the remains of calcareous sea-weeds, shells, corallines, and other calcareous organisms exposed to the pounding action of the surf. A sand composed of such

calcareous material may harden into a more or less coherent and even compact limestone, for rain falling on it dissolves some carbonate of lime which, being deposited again, as the moisture evaporates, coats the grains of sand and cements them together. At Bermuda, as already stated, all the rock exposed above sea-level has been formed in this way, and some of it is hard enough to make a good building-stone (p. 95). Ordinary siliceous or quartzose sand remains loose, unless its grains are made to cohere by some kind of cement, or by pressure, when it becomes sandstone

**Sandstone**—consolidated sand. The grains are chiefly quartz, but may include particles of any other mineral or rock; they are usually bound together by some cement which has either been laid down with them at the time of their deposition, or has subsequently been introduced by water permeating the sand. The cementing material may be *argillaceous*—that is, some kind of clay; or *calcareous*, consisting of carbonate of lime; or *ferruginous*, composed mainly of peroxide of iron; or *siliceous*, where silica has been deposited in the interstices of the mass. The colours of sandstone vary chiefly with the nature of this cementing material. The hydrous peroxide of iron colours them shades of yellow and brown; the anhydrous peroxide of iron gives them different hues of red; the mineral glauconite tints them a greenish hue. Some varieties of sandstone are named after a conspicuous component or structure; thus *micaceous* sandstone is distinguished by abundant spangles of mica deposited along the bedding planes, whereby the rock can be split up into thin layers; *freestone*—a thick-bedded sandstone (the word is sometimes applied to limestone) that does not tend to split up in any one direction, and can therefore be cut into blocks of any size and form; *glauconitic* sandstone (green sand), containing green grains and kernels of glauconite; *quartzose* sandstone, conspicuously composed of quartz-grains; *grit*—a sandstone formed of coarse or sharp, somewhat angular grains of quartz.

**Greywacke**—a greyish, compact, granular rock, composed of rounded or subangular grains of quartz and other minerals or rocks, cemented together in a compact paste; it differs from sandstone chiefly in its darker colour, and in the proportion of other grains than those of quartz.

The rocks above enumerated represent the coarser and more durable kinds of detritus derived from the weathering of the surface of the land; but during the progress of the decomposition from which these materials are derived some of the component

ingredients of the rocks decay into clay, or what is called *argillaceous* sediment. This more particularly occurs in the case of felspars and other aluminous silicates, the decomposition of which produces minute particles capable of being lifted up and carried a great distance by running water. Hence argillaceous sediment, being finer in grain, travels farther, on the whole, than quartzose sediment; and beds of clay denote, generally, deeper and stiller water than beds of sand.

**Clay**—a fine-grained argillaceous substance, derived from the decay and hydration of aluminous silicates, white when pure, but usually mixed with impurities, which impart to it various shades of grey, green, brown, red, purple, or blue; it usually contains interstitial water, and when wet can be kneaded between the fingers; when dry it is soft and friable, and adheres to the tongue. Shaken with water it becomes *Mud;* even a small quantity will make a glass of water turbid, so fine are the particles of which it is composed. As has already been mentioned, the white purer forms of clay, resulting from the decomposition of the felspars of granite or similar rocks, are known as *Kaolin* or *China-clay*, and are largely used in the manufacture of porcelain (p 147).

**Fire-clay**—a white, grey, yellow, or black clay, nearly free from alkalies and iron, and capable of standing a great heat without fusing; it is abundantly found underneath coal-seams, where it represents the ancient soil on which the plants grew that have been converted into coal (pp. 194, 298).

**Brick-clay**—a name commonly applied to any clay, loam, or earth from which bricks can be made. Such deposits are always more or less sandy and impure clays; in the south of England brick-earths have largely arisen from the prolonged subaerial waste of the Cretaceous and Tertiary formations (p 407).

**Mudstone**—a compact solidified clay or clay-rock, having little or no tendency to split into thin laminæ.

**Shale**—clay that has become hard and splits into thin laminæ which lie parallel with the planes of deposit (p. 193). A thoroughly fissile shale can be subdivided into leaves as thin as fine cardboard. This is the common form which the clays of the older geological formations have assumed. Whether the lamination be due to intermittent deposition, or to a kind of cleavage-structure induced by superincumbent pressure (p. 216), cannot always be definitely ascertained. Gradations may be traced from shale into other sedimentary rocks; thus, by additions of sand into fissile sandstones, of calcareous cement into limestone, of carbonate of iron

into iron-stone, of carbonaceous matter into coal These passages are interesting as indications of the conditions under which the rocks were formed. Where, for example, shale shades up into coral-limestone, we see that mud gathered over the sea-floor, while afterwards, when the water had cleared, corals flourished and built up a limestone out of their remains (p. 200).

**Loess**—a pale somewhat calcareous and sandy clay, found in regions where it has probably been accumulated by the drifting action of the wind. It is sufficiently coherent to be capable of excavation into tunnels and passages, and in China is even dug out into houses and subterranean villages. It occupies parts of the valleys of the Rhine, Danube, Mississippi, and other large rivers, but also crosses watersheds (p. 409).

Fragmental rocks of volcanic origin may be enumerated here. They consist partly of materials ejected in fragmentary form from volcanic vents, and partly of the detritus derived from the disintegration of volcanic rocks already erupted to the surface. They are comprised under the general name of *Tuff* (p 111)

**Bombs**—round, elliptical or discoidal pieces of lava which have been ejected in a molten state from an active vent, and have acquired their form from rapid rotation in the air during ascent and descent They are often very cellular or even quite empty inside Where the large ejected stones are of irregular forms, and appear to have been thrown out in an already solidified condition, as from the consolidated crust of the lava-plug, or from the sides of the funnel or crater, they are called *Volcanic Blocks* (p 112).

**Lapilli**—ejected pieces of lava, usually vesicular or porous, from the size of a pea to that of a walnut (Fig. 84)

**Volcanic Ash**—the fine dust produced by the explosion of the superheated steam absorbed in molten lava. Under the microscope, it is often found to consist of minute grains of glass, and in such cases, shows that the lava from which it was derived, rose from below in the condition of a liquid glassy magma. In other instances, it is made up of the crystallites and crystals that arose during the devitrification of the glass. It consolidates into a more or less coherent mass, which is known as *Tuff*, and which may receive some distinctive name according to the nature of the lava that has supplied it, as *Basalt-tuff* and *Trachyte-tuff*. Most tuffs contain angular and vesicular pieces of lava, and sometimes pass into coarse breccias (*Volcanic Breccia*, Fig. 84). In many cases, they

enclose the remains of plants and animals which, if of terrestrial kinds, indicate that the eruptions took place on land; if of marine species, that the volcanoes were probably submarine (pp 111-113).

**Agglomerate**—a coarse, usually unstratified accumulation of blocks of lava and other rocks, not infrequently filling up the chimney or neck of a volcanic vent.

### (2) *Rocks formed by Chemical Precipitation*

In Chapter V. it was pointed out that all natural waters contain in solution invisible mineral matter which they have dissolved out of the rocks of the earth's crust, and that the quantity of this material is sometimes so great that it is precipitated into visible form as the water evaporates. The substance most abundantly dissolved and deposited is Carbonate of lime. Others of frequent occurrence are Sulphate of lime, Chloride of sodium, Silica, Carbonate of magnesia, and various salts of iron. Among the rocks of the earth's crust, considerable masses of these substances have been piled up by chemical precipitation.

**Limestone**—compact or crystalline calcium-carbonate (carbonate of lime), which may be nearly pure, or may contain sand, clay, or other impurity, and may consequently pass into sandstone, shale, or other sedimentary rock. Probably the great majority of the limestones in the earth's crust have been formed by the agency of animals, as more particularly referred to at p 174. We are here concerned only with those which have been deposited from chemical solution. The most familiar example of this kind of limestone is afforded by stalactites and stalagmite, which have already been described (Chap V. and Figs. 25, 26) Large masses of it have been deposited by calcareous springs and streams (p. 65). At first, it is a fine white milky precipitate, but gradually crystals of calcite shape themselves and grow out of it, with their vertical axes usually at right angles to the surface of deposit. In a vertical stalactite, consequently, the prisms radiate horizontally from the centre outwards; on a horizontal surface of stalagmite they diverge perpendicular to the floor. A mass of limestone, not originally crystalline, may thus acquire a thoroughly crystalline internal structure by the action of infiltrating water in dissolving the carbonate of lime and redepositing it in a crystalline condition.

Limestones vary greatly in texture and purity. Some are snow-white and distinctly crystalline; others are grey, blue, yellow, or brown, dull and compact, and full of various impurities.

They may usually be detected by the ease with which they can be scratched, and their copious effervescence when a drop of weak acid is put on the scratched surface Pure limestone dissolves entirely in hydrochloric acid, so that the amount of residue is an indication of the proportion of insoluble impurity. Among the varieties of chemically-formed limestone are:—*Oolite*, a limestone composed of minute spherical grains like the roe of a fish, each grain being composed of concentrically deposited layers or shells of calcite (Fig. 77); *Pisolite*, a similar rock, where the grains are as large as peas (Fig. 78); *Travertine* or calcareous tufa, a white porous crumbling rock which, by infiltration of carbonate of lime, may acquire a compact texture, and become suitable for building stone (p. 65); *Hydraulic limestone*, containing 10 to 30 per cent of fine sand or clay, and having the property, after being burnt, of hardening under water into a firm compact mortar.

**Dolomite, Magnesian Limestone**—this substance has been already referred to as a mineral (p. 150); but it also occurs in large masses as a white or yellowish crystalline or compact rock. The white varieties look like marble. The yellow and brown kinds contain various impurities, and are coloured by iron-oxide Dolomite differs from limestone in its greater hardness and feebler solubility in acid, in its frequently cellular or cavernous texture, in its tendency to assume spherical, grape-shaped, or other irregular concretionary forms (Fig. 86), and in its proneness to crumble down into loose crystals. It occurs in beds, not uncommonly associated with gypsum and rock-salt, and in such conditions it may have been deposited first as limestone which, by the chemical action of the magnesian salts in the saline water, had its carbonate of lime partially replaced by carbonate of magnesia. It is also found in irregular bands traversing limestone which, probably by the influence of percolating water containing carbonate of magnesia in solution, has been changed into dolomite.

**Gypsum** is not only a mineral (p 150) but also a rock, white, grey, brown, or reddish in colour, granular to compact, sometimes fibrous or coarsely crystalline in texture. It consists of sulphate of lime, is easily scratched with the nail, and is not affected by acids, being thus readily distinguishable from limestone. It is found in beds or veins, especially associated with layers of red clay and rock-salt, and in these cases has evidently resulted from the evaporation of water containing it in solution,

such as that of the sea. The lime-sulphate being less soluble than the other constituents is precipitated first. Hence in a thick series of alternations of beds of gypsum (or anhydrite) and rock-salt, each layer of sulphate of lime indicates a new supply of water into the natural reservoirs where the evaporation took place. The overlying bed of salt, usually much thicker than the gypsum, points to the condensation of the water into a strong brine, from which the salt was ultimately precipitated. And the next sheet

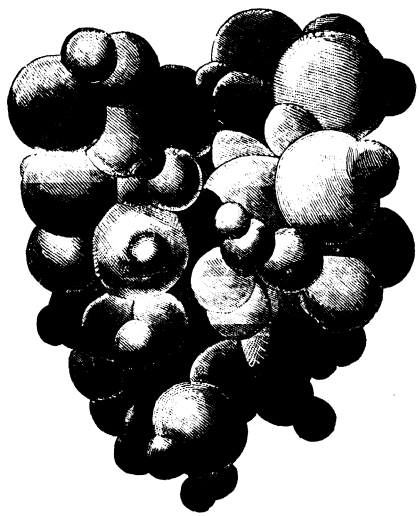


FIG. 86.—Concretionary forms assumed by Dolomite, Magnesian Limestone, Durham.

of sulphate of lime tells how, by the breaking down of the barrier, renewed supplies of salt water were poured into the basin (pp. 55, 151).

**Rock-salt** occurs in beds or layers, from less than an inch to hundreds or even thousands of feet in thickness. One mass of salt in Galicia is more than 4600 feet thick, and a still thicker mass occurs near Berlin. When quite pure, rock-salt is clear and colourless, but it is usually more or less mixed with impurities, particularly with red clay, and in association with beds of gypsum, as above remarked. It has been formed in inland salt lakes or basins by the evaporation and concentration of the saline water

It is being deposited at the present time in the Dead Sea, the Great Salt Lake, and the salt lakes so frequent in the desert regions of continents, where the drainage does not flow outwards to the sea (p. 54).

**Ironstone.**—Various minerals are included under this name as large rock-masses. One of the most important of them is *Hæmatite* (p 143), which occurs in large beds and veins, as well as filling up caverns in limestone. *Limonite* or bog-iron ore is formed in lakes and marshy places (p. 143), and occurs in beds among other sedimentary accumulations. *Magnetite* (p. 144) is found in beds and huge wedge-shaped masses among various crystalline rocks, as in Scandinavia, where it sometimes forms an entire mountain. *Carbonate of iron* (Siderite, Sphærosiderite, Clay-ironstone) occurs in concretions and beds among argillaceous deposits (Figs. 72, 76, and p. 150). In the Coal-measures, for example, it is largely developed, much of the iron of Britain being obtained from this source. As many ironstones are largely due to the influence of plants and animals, the rock is alluded to again on p. 175

**Siliceous Sinter**—a white powdery to compact and flinty deposit from the hot water of springs in volcanic districts, consisting of 84 to 91 per cent of silica, with small proportions of alumina, peroxide of iron, lime, magnesia, and alkali, and from 5 to 8 per cent of water. It accumulates in basin-shaped cavities round the mouths of hot springs and geysers, and sometimes forms extensive terraces and mounds, as at the geyser regions of Iceland, Wyoming, and New Zealand.

**Vein-quartz**—a massive form of quartz, which occurs in thin veins and in broad dyke-like reefs, traversing especially the older rocks.

### (3) *Rocks formed of the Remains of Plants or Animals*

In Chapter VIII. an account was given of the manner in which extensive accumulations are now being formed of the remains of plants and animals. Similar deposits have constantly been accumulated from an early period in the history of the earth. Regarding them with reference to their mode of origin, we observe that in some cases they have been piled up by the unremitting growth and decay of organisms upon the same site. In a thick coral-reef, for example, the living corals now building at the surface are the descendants of those whose skeletons form

the coral-rock underneath (p. 97). In other cases, the remains of the organisms are broken up and carried along by moving water, which deposits them elsewhere as a sediment. Strictly speaking, these last deposits are fragmental, and might be classed with those described at p. 164; they pass into ordinary sand, sandstone, clay, or shale. But it will be more convenient to class together all the rocks which consist mainly of organic remains, whether they have been directly built up by the organisms, or have only been formed out of their detrital remains.

**Limestone.**—As carbonate of lime is so largely secreted by animals in their hard parts which are more or less durable, it is naturally the most common substance among rocks of organic origin. The limestones that form so large a proportion of the stratified rocks of the earth's crust have been, for the most part, formed out of the remains of marine animals The following are some of the more important or interesting varieties of this rock — *Shell-marl*, a soft white earthy crumbling deposit formed chiefly of fresh-water shells (pp 53, 92); by subsequent infiltration or by pressure it may be hardened into a compact stone, when it is known as fresh-water limestone; *Calcareous sand*—a mass of broken-up shells, calcareous algæ, and other calcareous organisms (p. 95), often cemented by percolating water into solid stone; *Coral rock*—a limestone formed by the continuous growth of corals and cemented into a solid compact and even crystalline rock by the washing of calcareous mud into its interstices and the permeation of sea-water and rain-water through it, whereby crystalline calcite is deposited within it (p 98); *Chalk*—a soft, white rock, soiling the fingers, formed of a fine calcareous powder of remains of foraminifera, shells, etc (see *Ooze*, p 96); *Crinoidal limestone*—composed chiefly of the calcareous joints of the marine creatures known as crinoids, with foraminifera, shells, corals, and other organisms (Fig 87)

A limestone composed in great part of organic remains may show little trace of its origin on a fresh fracture of the stone; but a weathered surface will often reveal its true nature, the fossils being better able to withstand the action of the atmosphere than the surrounding matrix which is accordingly removed, leaving them standing out in relief (Fig. 87).

**Peat**—a yellow, brown, or black fibrous mass of compressed and somewhat altered vegetation. It occurs in boggy places in temperate latitudes, where it largely consists of bog-mosses and other marshy plants (p. 92). Its upper parts are loose and full

of the roots of living plants, while the bottom portions may be compact and black like clay, and with little obvious trace of intercalated vegetable structure.

**Lignite** or Brown Coal is a more compressed and chemically changed condition of vegetation than peat It varies in colour from yellow to deep brown or black, and may be regarded as an intermediate stage between peat and coal. Like coal it occurs in beds between layers of shale, clay, and sandstone.

**Coal**—a compact, brittle, black, or dark brown stone, formed of mineralised vegetation, and found in beds or seams usually resting on clay, and covered with sandstone, shale, etc. (see Figs. 90 and 154). There are many varieties of coal, differing from

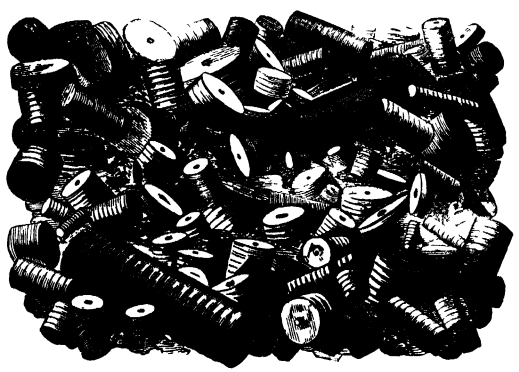


FIG. 87 —Weathered surface of a limestone composed of the broken stems of encrinites

each other in the relative proportions of their constituents. *Caking-coal*, such as is ordinarily used for domestic purposes in England, contains from 75 to 80 per cent of carbon, 5 or 6 per cent of hydrogen, and 10 or 12 per cent of oxygen, with some sulphur and other impurities *Anthracite*, the most thoroughly mineralised condition of vegetation, is a hard, brittle, lustrous substance, from which the hydrogen and oxygen have been in great measure driven away, leaving 90 per cent or more of carbon

**Ironstone.**—Reference was made at pp 54, 67, and 173 to ironstone precipitated from chemical solution. This precipitation is often caused through the medium of decomposing organic matter. Organic acids, produced by the decay of plants in marshy places and shallow lakes, attack the salts of iron contained in the rocks

or detritus of the bottom, and remove the iron in solution. On exposure, the iron oxidises and is thrown down as a yellow or brown precipitate of *limonite* or bog-iron-ore (pp 143, 173), which is found in layers and concretions. *Clay-ironstone*, composed of a mixture of carbonate of iron, with clay and carbonaceous matter, occurs abundantly both as nodules and in layers, with remains of plants, shells, fishes, etc., in the Coal-measures (Figs. 72, 76, and bed 13 in Fig. 91). It has, no doubt, been also formed through the agency of organic acids which, passing into carbonic acid, have given rise to the solution and subsequent deposit of the iron as carbonate mingled with mud and with entombed plants and animals (p. 54).

**Flint.**—Some siliceous deposits, due to organic agency, have been already referred to at p. 94. Besides these, mention may be made of *Flint*, which occurs as dark lumps and irregular nodular sheets in chalk and other limestones, frequently enclosing sponges, radiolaria, urchins, shells, and other organisms, which are converted into flint. Its mode of origin is not yet thoroughly understood, but there is reason to regard it as due to the abstraction of silica from sea-water, either by living animals, such as sponges, or by the decomposition of animal remains *Chert* is a more impure siliceous aggregate found under similar conditions, especially among the older limestones.

**Guano**—a brown, light, powdery deposit, formed of the droppings of sea-birds in rainless tracts of the west coasts of South America and Africa. Containing much phosphate of lime as well as ammoniacal salts, it has great commercial value as an important manure.

**Bone-beds**—deposits composed of fragmentary or entire bones of fish, reptiles, or higher animals, as in the bone-bed of the English Rhætic series (p. 330). The floors of some caverns are covered with stalagmite, so full of pieces of the bones of cave-bears, hyænas, and other extinct and living species, as to be called *Bone-breccia.* Layers of stone, full of the *coprolites* (fossil excrement, Fig. 76) or of the rolled bones of various vertebrate animals, have, in recent years, been largely worked as sources of phosphate of lime for the manufacture of artificial manures.

## II. Eruptive or Igneous Rocks

Under this division are grouped all the massive rocks which have been erupted from underneath into the crust or to the

surface of the earth. They are composed chiefly of silicates of alumina, magnesia, lime, potash, and soda, with different proportions of free silica, magnetic or other oxide of iron, and phosphate of lime. The principal silicate is generally some felspar, the number of eruptive rocks without felspar being comparatively small. The felspar is, in different rocks, conjoined with mica, hornblende, augite, magnetite, or other minerals.

No perfectly satisfactory classification of the eruptive rocks has yet been devised; they have been grouped according to their presumed mode of origin, some being classed as *plutonic* or *hypogene*, from their supposed origin, deep within the earth's crust, others as *volcanic*, from having been ejected by volcanoes. They have likewise been arranged according to their chemical composition, and also with reference to their internal structure. In the following enumeration of some of the more abundant and important varieties, they are grouped according to the relative proportion of silica, in three sections: 1st, Acid Rocks, in which the silica varies from 66 to 76 per cent and is often visible to the naked eye as free quartz; 2nd, Intermediate Rocks, in which the silica ranges between 56 and 66 per cent; and 3rd, Basic Rocks, with a silica percentage which in some of the series rises above 50 and in others falls below 40.

Each of these sections may be further subdivided, according to internal structure. At the one end there is usually a thoroughly crystalline (holocrystalline) or granitic type, in which all the constituent minerals have assumed a crystalline character, either with definite crystallographic forms (*idiomorphic*) or bounded irregularly against each other (*allotriomorphic*). From this extreme, gradations may be traced wherein, between the crystalline ingredients, a variable proportion of a *ground-mass* or *base* may be observed, which is sometimes wholly devitrified and is seen, in thin sections under the microscope, to consist of microlites, crystallites, or other irregular and incipient forms of crystals (p. 159). This ground-mass is the residue of the original molten magma after the recognisable minerals had crystallised out of it. At the other extreme of the series are rocks that consist wholly or almost wholly of glass, which solidified without the development of so large a proportion of microlites or crystals as to obscure its true vitreous character. As far as possible this is the arrangement in the following description, each section having its holocrystalline types placed at the beginning and its glassy types at the end.

### (1) *Acid Rocks*

In this section the prevalent silicate is Orthoclase, either in its common dull, white, or pink form, or in the glassy condition (sanidine). Other frequent felspars in these rocks are Microcline, Oligoclase, and Albite. In many of the rocks, free quartz occurs either in irregular crystalline blebs, or in definite crystals which frequently take the form of double pyramids. Among other minerals, hornblende, white and black mica, and apatite are of common occurrence. The rocks of this division are the most acid of the eruptive series, inasmuch as they contain the largest

FIG. 88.—Group of crystals of felspar, quartz, and mica, from a cavity in the Mourne Mountain granite.

proportion of silica or silicic acid. Some of them (granite) are only found as masses that have consolidated deep beneath the surface; others (rhyolite, obsidian) are abundant as superficial volcanic products.

**Granite**—a thoroughly crystalline (holocrystalline) rock, the individual minerals being large enough to be distinctly recognised by the naked eye. The felspars (potash and also soda varieties) are the most abundant constituents. After them come quartz (generally full of minute cavities containing liquid and a movable bubble), white mica (muscovite), black mica (biotite), sometimes hornblende, and occasionally augite. These minerals have crystallised in an allotriomorphic form, but occasionally, where

cavities occur in the rock (miarolitic structure), these are lined or nearly filled with well terminated crystals. Fig. 88, for example, shows a group of the ordinary crystals of this rock which have crystallised in a cavity of the granite of the Mourne Mountains, Ireland. It is in such cavities also that the rarer minerals of this rock, such as topaz and beryl, may be looked for.

Of the constituents of granite the ferro-magnesian minerals (hornblende, mica) crystallised first, then came the felspars, and lastly the quartz. This order is shown by the way in which the ingredients enclose each other. The name *Granitite* (Biotite-granite) has been given to an abundant type of granite where the only mica present is biotite. Where hornblende is conspicuous the rock becomes *Hornblende-granite*. Much less frequent are the granites with augite. Numerous cases have now been recorded where the outer border of a granite mass has a highly basic composition, passing even into serpentine, though the main body of the rock is acid.

Granite occurs in large eruptive masses which have been intruded into many different kinds of rocks, also in smaller bosses and veins. Round the outside of a mass of granite there frequently diverge from it dykes and veins (Fig. 119) which, where of great width, may show the usual granitic structure; but which, when of small dimensions, are apt to become exceedingly close-grained (*Aplite*). There can be no doubt that such fine-grained veins are actually portions of the same mass of rock as the granite, so that granite and aplite or quartz-porphyry are only different conditions of the same substance, the differences being probably due to variations in the circumstances under which the cooling and consolidation took place.

*Pegmatite* is a name given to coarse varieties of granite, often with a peculiar structure known as *graphic*, where the quartz and felspar have crystallised in simultaneous intergrowths.

*Granophyre* is a granitic rock in which the quartz and felspar have crystallised in minute (micrographic) intergrowth. It occurs in the deeper-seated portions of volcanic centres.

**Quartz-Porphyry** (Eurite)—a minutely crystalline (micro-granitic) rock composed of the same constituents as granite, with phenocrysts of quartz or of felspar or both (Fig. 81). It occurs in dykes, veins, and other intrusive forms, sometimes directly connected with masses of granite. Some of the more compact eurites have been classed as *Felsites*, but this term has also been applied to devitrified forms of rhyolitic lava. The quartz phenocrysts are

sometimes idiomorphic, being well crystallised in double pyramids, in other cases they have been left only as granules which have been corroded by the surrounding magma.

**Rhyolite** (Liparite)—under this name are included the more acid lavas. They range from a coarse texture to a true glass. They often display streaky lines or bands of flow-structure (Fig. 82, B), glassy layers or patches being intercalated among devitrified parts. They consist of sanidine, sometimes with quartz in double pyramids or corroded grains, and with subordinate proportions of augite, hornblende, magnetite, and a few other minerals. Many rhyolites display well-marked perlitic structure or are markedly spherulitic (Fig. 82, A).

By devitrification, rhyolite passes from the glassy condition through various stages until it assumes a "felsitic" texture Many of the felsites in Palæozoic and later formations are probably devitrified rhyolites.

The glassy form of rhyolite is known as *Obsidian*, which is a black, brown, or greenish (sometimes yellow, blue, or red) glass, breaking with a shell-like or *conchoidal* fracture and into sharp splinters, which are translucent at the edges Examined in a thin section under the microscope, the rock is found to owe its usual blackness to the presence of minute opaque crystallites (Fig. 80) which are crowded through it, not infrequently drawn out into streaky lines and curving round any larger crystal that may be embedded in the mass (Fig. 82 B). This flow-structure (p. 162) has evidently been caused by the movement of the rock while still in a fused state, the crystallites and other objects being borne onward by the currents of molten glass. In some obsidians, little spherulites of a dull grey enamel-like substance have made their appearance as stages in the devitrification of the rock (Fig. 82 A); but the mass has consolidated before the stony condition could be completed. In other instances, the whole glass has passed into the condition of ordinary rhyolite, showing both lines of flow and perlitic structure (*pearlstone*, p. 160). Where a still molten rhyolite has been frothed up by the expansion of steam or gas through it, so as to become a spongy cellular substance which will float on water, it is called *pumice*. The glassy forms of rhyolite occur in many volcanic regions, sometimes as streams of lava which have been poured forth at the surface, sometimes in dykes and veins, and often in fragments ejected with the other detritus that now forms tuffs.

**Pitchstone** (Retinite) is a general term now applied to the

glassy (vitrophyric) condition of igneous rocks, especially to those of former geological periods, when owing to the development of crystallites in the glassy base, the rock has assumed a resinous lustre. Thus rhyolite, trachyte, andesite, and basalt have their pitchstone phases. Pitchstone is most frequent in veins and dykes, but it also occurs in lava-streams, as in the famous example that forms the Scuir of Eigg, off the west coast of Scotland.

### (2) *Intermediate Rocks*

In this section also the rocks may be so arranged as to present holocrystalline granitoid varieties at the one end and glassy forms at the other. Free quartz is generally absent.

**Syenite**—a thoroughly crystalline or granitoid rock, consisting essentially of orthoclase with alkali-felspars and hornblende. It is distinguished from granite by the absence or small amount of quartz. Sometimes biotite takes the place of hornblende and occasionally augite becomes conspicuous. The name nepheline-syenite or elæolite-syenite is given to a variety which contains nepheline besides the felspar.

Syenite is much less abundant than granite. It is found in intrusive bosses and veins among the older rocks.

**Orthophyre** (Orthoclase-porphyry)—a compact, close-grained rock which stands to syenite in the same relation as quartz-porphyry does to granite. It has generally a minutely holocrystalline (microgranitic) ground mass with porphyritic crystals of orthoclase or plagioclase. It occurs intrusively in bosses and dykes.

**Lamprophyre**—a group of rocks of frequent occurrence in dykes and veins among the older formations. They are close-grained and vary considerably in chemical composition. From the prevalence of mica in many of them they have been called "mica-traps." Those in which orthoclase is the predominant felspar have been termed *Minette;* those composed mainly of plagioclase, *Kersantite.* Where the mica of Minette is replaced by augite or hornblende the rock is called *Vogesite;* and where this replacement occurs in Kersantite the rock becomes *Camptonite.*

**Diorite**—a crystalline aggregate of plagioclase (oligoclase, andesine or labradorite) and hornblende, usually with magnetite and apatite, sometimes with augite and mica, and in some varieties with quartz. The hornblende is dark brown or green, and often more or less decomposed, giving rise to a greenish chloritic discoloration of the felspar. From its prevalent green colour, usually

arising from the alteration of its ferro-magnesian constituents, the rock was formerly known as "greenstone."

The Quartz-diorites have a granitoid texture and a percentage of silica ranging up to above 65 per cent. They occur, like the other members of this group, as intrusive masses which have consolidated beneath the surface. *Quartz-mica-diorite* or *Tonalite* contains dark biotite, and resembles a grey granite in outward aspect; it is sometimes found in the peripheral parts of a granite boss and passing into the true granite. *Mica-diorite* contains no quartz; while another quartzless variety, where the dark silicate is hornblende, is termed *Hornblende-diorite.* Occasional examples of *Augite-diorite* are met with.

**Trachyte**—a compact porphyritic rock, consisting mainly of orthoclase (sanidine), with some plagioclase, and usually with a little biotite, augite, or with hornblende, magnetite, sphene, apatite, or zircon. It possesses a peculiar matrix which, under the microscope, is found to consist mainly of minute lath-shaped felspar-crystallites. Large crystals of orthoclase (sanidine) are frequent, and also scales of dark mica. This rock is found abundantly among some of the younger volcanic regions of the world, where it occurs in lava-streams, and also in intrusive sheets and dykes. It is likewise met with in singularly fresh and typical forms as sheets of lava intercalated in the Lower Carboniferous system of Scotland, also as bosses or necks connected with these lavas.

*Phonolite* is a trachyte in which occur minute six-sided prisms of nepheline, sometimes with sphene, and with nosean and leucite. It is found in Tertiary and much older volcanic series. Some of the bosses in the Lower Carboniferous formations of Scotland consist of phonolite.

**Andesite**—a large group of volcanic rocks, consisting essentially of a characteristic ground-mass of minute lath-shaped crystals of a soda-lime felspar which are arranged in a "felted" structure Through this matrix are usually dispersed abundant conspicuous phenocrysts of some plagioclase felspar (generally andesine or labradorite), less plentifully of certain ferro-magnesian minerals. According to the prominence of these darker constituents the rocks are divided into Hornblende-andesites, Mica-andesites, Augite-andesites, Hypersthene-andesites, etc.

The chemical composition of these rocks varies from an almost acid character to a basic type that links them with the third great section of the igneous rocks. The more acid forms are called *Dacite.*

The andesites occur abundantly among rocks of all ages both as lavas that have been poured out at the surface and as dykes, veins, and bosses. They form the great mass of the lavas in the volcanic chain of the Andes, from which their name was taken. The older andesites have often undergone more or less oxidation and decomposition, and hence appear as dull reddish or purplish rocks to which, from their usual porphyritic structure, the name *Porphyrite* was formerly given. They are frequently amygdaloidal, the cavities being filled with calcite, chalcedony, zeolites, chlorite, or other minerals.

### (3) *Basic Rocks*

The rocks grouped in this division likewise present a wide range in chemical composition and in structure In a few of them free quartz may be observed, but for the most part the silica percentage is low, sinking in some cases below 40.

**Gabbro.**—This rock represents the granitoid phase of the more basic rocks. It consists of a holocrystalline aggregate of a plagioclase (lime-soda felspar) and a pyroxene. The name Gabbro is generally restricted to those types which contain diallage or augite. Those in which the pyroxene is a rhombic form are called *Norite* or *Hyperite*. Where free silica appears, the rocks become *Quartz-gabbro* or *Quartz-norite*. Olivine is a frequent constituent, and, where conspicuous, it gives the name of *Olivine-gabbro*. The gabbros are eruptive masses which have consolidated at some depth beneath the surface.

**Basalt-Rocks**—a group of rocks consisting of plagioclase (mostly labradorite), augite, and magnetite or titaniferous iron, to which olivine, apatite, and other minerals are frequently added. These rocks range in texture from a black glass up to a coarsely crystalline mass wherein the component minerals are distinctly visible to the naked eye. Different names are employed for these varieties. Two series may be distinguished, one with, the other without, olivine. *Basalt-glass* (*Tachylyte*, *Hyalomelan*) is a general epithet to denote the vitreous varieties. These are particularly to be observed along the edges of dykes and other intrusive masses, where they represent the outer surface of the basalt that was suddenly chilled and consolidated by coming in contact with the cold walls of the vent or fissure into which it was injected, and where they no doubt show what was the original state of the whole basalt before devitrification converted the rock into its present

crystalline structure (pp. 107, 159, 177). *Basalt*—a black, compact, heavy, homogeneous rock, breaking with a conchoidal fracture, showing sometimes porphyritic crystals of plagioclase, augite or olivine, but too fine-grained for the component minerals of the base to be determined except with the microscope. Most basalts contain olivine, sometimes in great abundance; but there is also an olivine-free section. The ground-mass usually presents more or less of a glassy residue. The coarser varieties, where the minerals can be recognised with the naked eye, are known as *Dolerite*, of which there is also an olivine-bearing and olivine-free sub-group The dolerites are holocrystalline rocks, wherein the glass of the original magma has disappeared.

The basalt-rocks are pre-eminently volcanic lavas, occurring both as intrusive masses that consolidated underground, and as sheets that were poured out in successive streams at the surface. The black, compact kinds (true basalt) are particularly prone to assume columnar forms (Fig. 89), whence columnar rocks are sometimes spoken of as *basaltic*. In some varieties of basalt the felspathoid mineral leucite takes the part of the plagioclase; and in others this is done by nepheline.

**Diabase** — This term has been so variously applied that it has been discarded by some petrographers. It has been made to include old altered forms of dolerite, basalt, and andesite. By some writers it is used to embrace a group of intrusive rocks having a holocrystalline structure in which the plagioclase felspar has crystallised before the augite.

**Limburgite** is a highly basic lava containing little or no felspar, and consisting mainly of olivine, augite, and magnetite. This rock connects the basic with what has been called the *ultra-basic* section of the Igneous rocks, which includes the following species.

**Peridotites** —a small subdivision of rocks which consist principally of olivine, and which by gradual alteration pass into serpentine (Fig. 69). They are liable to remarkably rapid changes of texture and composition. In some places they are mainly made up of olivine, with augite, enstatite, bronzite, hornblende, magnetite, or brown mica, but some of these minerals may disappear and some felspar may take their place. Peridotites are intrusive masses which appear to have been generally injected into the crust in connection with volcanic eruptions, rather than to have been poured out at the surface in true lava-streams.

*Picrite* is a name given to some varieties which contain augite (augite-picrite), hornblende (hornblende-picrite), enstatite

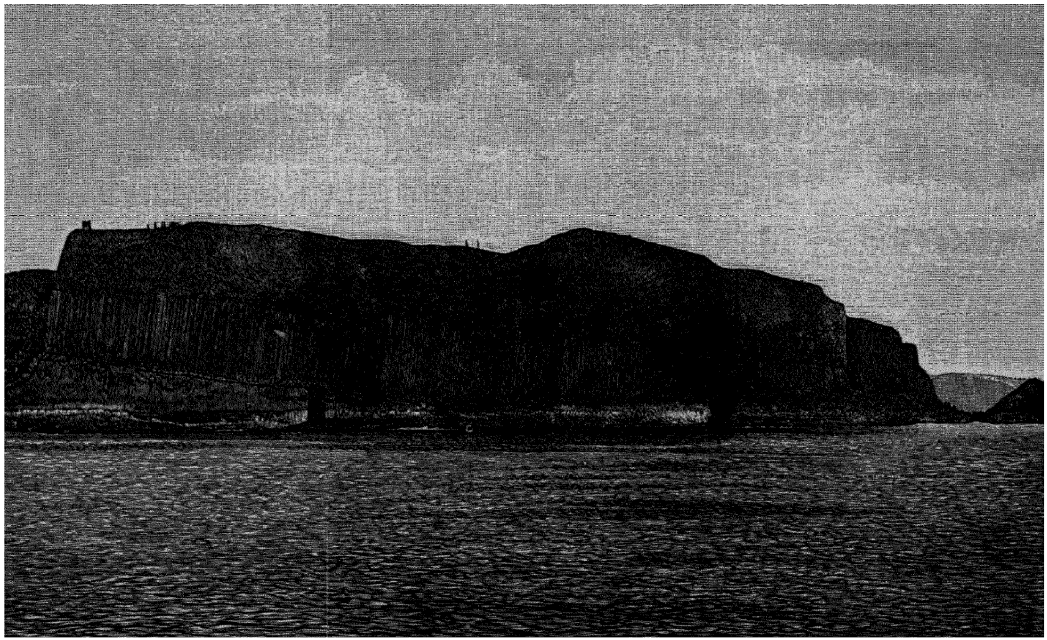


FIG. 89.—Columnar basalts of the Isle of Staffa, resting upon tuff (to the right is Fingal's Cave).

(enstatite-picrite), mica (mica-picrite). A little felspar is generally present.

*Dunite* is the last type of this subdivision, consisting entirely of olivine, with only a few subordinate minerals. The alteration of peridotites leads into serpentine.

**Serpentine**—a compact, dull, or faintly glimmering rock, dirty green, purple or red in colour, variously mottled, greasy to the touch, easily scratched, and giving a white powder which does not effervesce with acids. It has resulted from the alteration of the magnesian silicates of the peridotites, and sometimes contains more or less distinct traces of the original constituent minerals of these rocks. Thus it presents disseminated crystals of bronzite, enstatite, and chromic iron, which are characteristic of the peridotites. It is often traversed with veins of the delicately fibrous silky variety of serpentine known as chrysotile. Serpentine occurs in bosses, dykes, and veins, evidently of eruptive origin; it is also found in thick beds associated with limestones and crystalline schists.

## III. Metamorphic Rocks

Originally, some of these rocks were igneous, others aqueous or sedimentary, but they have all undergone alteration by heat, pressure, crushing, or other cause so as to have acquired new structures and often a modified composition. In a large section of them the leading character is the possession of a schistose or foliated structure (Fig. 83). They are, in their most typical varieties, distinctly crystalline. Some of them shade off into ordinary fragmental rocks, such as shale and sandstone; others agree in chemical and mineral composition with some of the eruptive rocks already enumerated, into which they may often be traced by imperceptible gradations.

In Chapter XIII. some further account of the schists will be given, with special reference to their probable origin, and to the grounds on which they have been regarded as *metamorphic* or altered rocks. For the present, in taking notice of their composition and structure, it will be enough to state that in many cases they can be shown to be more or less altered and crystalline transformations of what were originally sedimentary rocks; and that in other instances they represent original crystalline eruptive masses, which have been subjected to such enormous pressure and shearing, that a foliated structure and recrystallisation of

minerals have been superinduced in them. The essential feature which unites masses of such different origin is the possession of that common evidence of having undergone alteration from having all been subjected to the processes of metamorphism.

Round many intrusive masses the encircling rocks have undergone more or less alteration. This *contact-metamorphism* ranges from mere hardening through stages of increasing change until the rock becomes entirely crystalline. Thus in such circumstances, greywacke may be traced in successive phases of alteration until it becomes a thoroughly schistose rock, such as mica-schist or gneiss.

**Indurated Sandstone**—a sandstone which has been so affected by contact with an eruptive igneous rock as to acquire a compact structure, and even to pass into the species known as quartzite. Sometimes the minute fluid cavities in the quartz of the sandstone have been emptied, while the matrix in which the quartz-grains are imbedded has here and there been actually fused.

**Baked Shale** (Porcellanite, Lydian-stone)—a shale which has undergone intense induration from the intrusion of molten material in contact with it. The fissile structure of the original stone is destroyed and is replaced by a compact flinty or horny texture, the rock breaking with a splintery or even conchoidal fracture. Microscopic examination shows that the material of the shale has sometimes been fused wholly or in part, and that minute microlites have been developed in it.

**Clay-slate**—a hard fissile clay-rock, through which minute scales of mica and crystals or crystallites of other minerals have been developed; generally bluish-grey to purple or green, and splitting into thin parallel leaves. As this rock sometimes contains remains of marine animals and plants, and is interstratified with bands of sandstone, grit, conglomerate, and limestone, it was undoubtedly at first in the condition of soft mud on the sea-bottom Sometimes the organic remains in it are curiously elongated or distorted in one general direction, showing that the rock has been drawn out by intense pressure and shearing (Figs. 110, 116, 117). The planes along which clay-slate splits are most frequently independent of the original surfaces of deposit, even crossing these at a right angle. They have been superinduced by mechanical movements (Cleavage), as explained in Chapter XIII.

Different varieties of clay-slate have received special names. *Roofing slate* is the fine compact durable kind, employed for roofing purposes and also for the manufacture of cisterns, chimneypieces,

and writing-slates; *Alum-slate*—dark, carbonaceous, and pyritous, the iron-disulphide oxidising into sulphuric acid, and giving rise to an efflorescence of alum; *Whet-slate*, *Honestone* (see Hornfels)—exceedingly hard, fine-grained, and suitable for making hones; sometimes owing its hardness to the presence of microscopic crystals of garnet; *Spotted or Knotted* slate—a slate in which numerous brown or black spots, knots, or patches have been developed owing to the gathering together, in separate centres, of the materials that go to form definite minerals. These knots are in fact incipient crystals, and gradations can be followed from them into crystals of andalusite or other minerals. *Andalusite-slate*, *Chiastolite-slate*, *Staurolite-slate*—containing disseminated crystals of andalusite, chiastolite, or staurolite; found especially round eruptive bosses of granite, but also extensively developed in regions where little or no eruptive rock is visible at the surface. Spilosite, Fruchtschiefer, Fleckschiefer, Garbenschiefer are further names for varieties of slate. By the development of abundant minute flakes of mica, a clay-slate passes into a *Phyllite*, which has a more silvery sheen, and represents a further stage of metamorphism. Phyllite, by further increase of the mica, becomes *Mica-slate*, so that a transition may be traced from sedimentary fossiliferous rocks through clay-slate and phyllite into thoroughly crystalline schist. The different varieties of slate occur extensively among the older geological formations in all parts of the world.

**Hornfels**—an exceedingly close-grained rock, often of a reddish-brown colour, which on microscopic examination is found to consist of an intimate aggregate of quartz, mica (especially biotite), ferruginous minerals, and sometimes garnets. Rocks of this type have not infrequently been produced by the alteration of fine sedimentary strata around eruptive bosses. Where the sediment has been partly calcareous, *Calc-silicate hornfels* or *Lime-silicate-rock* has been produced in which various lime-bearing silicates have been developed (pyroxene, wollastonite, etc.).

**Altered Limestone, Marble**—a crystalline granular aggregate of calcite, having the texture of loaf-sugar, white when pure, but passing into various colours according to the nature of the impurities. It occurs in beds among the schists, and is no doubt a limestone, originally formed either by chemical precipitation or by organic agency, which has been metamorphosed by heat and pressure into its present thoroughly crystalline character. Some of the fossiliferous limestones through which the Christiania granite rises have been changed into crystalline marble, but their original

corals and shells have not been wholly effaced (see Chapter XIV.). Not only limestone but dolomite is liable to undergo this kind of metamorphism. The mineral impurities in these rocks (clay, mud, sand, etc.) have been entirely altered and are now found in the form of various lime-silicate minerals (tremolite, actinolite, zoisite, wollastonite, lime-felspars, pyroxenes, etc.). The *Cipollino* of Italy is a marble marked with layers of white and green micas. *Ophicalcite* is a mixture of altered limestone or dolomite and serpentine.

**Quartzite**—originally more or less pure quartz-sandstone which has been changed into a hard, compact, granular material composed of adherent quartz-grains which have sometimes been re-crystallised, so that the rock breaks with a characteristic lustrous fracture. It occurs in beds and thick masses, not infrequently associated with slates, mica-schists, and limestones; it sometimes contains organic remains. In some cases a form of quartzite has been produced by the infiltration of silica into a quartz-sand, and the deposit of this material upon the quartz-grains so as to bind the rock into an exceedingly compact mass. Not infrequently the secondary quartz, in optical continuity with that of the sand-grains, has restored to the latter idiomorphic contours.

**Quartz-schist**—a schistose form of quartzite, probably representing an original shaly sandstone, now composed of quartzite, with layers of mica or other minerals.

**Schistose Grit and Conglomerate.**—Interstratified with clay-slates and mica-schists there are sometimes found beds of grit and conglomerate, the grains and pebbles of which consist of quartz or other durable material, imbedded in slate or schist. The original fragmental character of such rocks admits of no doubt; they were obviously at one time sheets of fine and coarse gravel, mixed with sandy mud; and their presence among schistose rocks furnishes additional corroborative evidence of the original sedimentary character of some of these rocks. The clay or mud which formed the matrix has been metamorphosed into a more or less thoroughly crystalline micaceous substance, while in many cases the pebbles have been flattened and pulled out of shape. Hence these rocks afford important evidence as to the nature of the processes whereby the schists have been produced.

**Mica-schist (Mica-slate)**—a schistose aggregate of quartz and mica, the two minerals being arranged in irregular but nearly parallel wavy folia. The rock splits along the laminæ of mica, so that its flat surfaces have a bright silvery sheen, and the quartz is not well seen except on the cross fracture, where only the thin

edges of the mica-plates present themselves. Mica-schist is often remarkably crumpled or puckered—a structure bearing witness to the intense compression it has undergone (Fig. 128). It abounds in most regions where schists are extensively developed (Chapter XVI.). Some mica-schists contain fossil shells and corals (Bergen), and must thus represent what were originally sedimentary deposits; others may be highly deformed eruptive rocks. *Sericite-schist* is a variety where the mica (sericite) is diffused in minute scales giving a silky sheen to the rock. Where this rock contains a marked proportion of calcareous admixture it becomes *Calc-sericite schist.*

**Chlorite-schist**—a scaly, schistose aggregate of greenish chlorite with quartz, and often with felspar, mica, and octahedra of magnetite (Fig. 65). It occurs in beds associated with gneiss and other schists. Some chloritic schists may represent old lavas or other erupted rocks which have been crushed down and become schistose; others, especially where they contain pebbles of quartz, etc., and are banded with quartzites and schistose conglomerates, not improbably mark where fine basic volcanic ashes fell over a sea-bottom, and were then mingled and interstratified with the ordinary sediment that happened to be accumulating at the time.

**Talc-schist** is the name given to an infrequent member of the metamorphic series where the magnesian silicate is chiefly pale greenish or white talc.

**Amphibolites**—rocks composed mainly of amphibole, but with quartz, orthoclase, and other minerals in minor proportions; sometimes they are massive and granular (*Hornblende-rock*), and in this condition doubtless represent eruptive rocks. Gradations can be followed from such rocks (originally diorite, gabbro, diabase, etc.) into perfect schist (*Hornblende-schist, Actinolite-schist*), so that the successive stages in the development of the schistose structure can be traced out of rocks as structureless as any amorphous eruptive mass can be Amphibolites occur among the crystalline schists in most parts of the world as occasional bands or bosses, which probably mark zones of basic igneous rock, either intruded into the accompanying masses, or contemporaneously erupted with them. Some hornblendic rocks in a metamorphic region have evidently resulted from the alteration of gabbro, dolerite, basalt, or other igneous rock, the pyroxene having been converted into hornblende. Such rocks are known as *Epidiorite.* Occasionally the magnesian silicate has undergone the serpentinous

change and there results a schistose serpentine, or serpentine-schist.

**Granulite**—a fine-grained crystalline admixture of quartz, felspars, and garnet, with sometimes pyroxene or other minerals, marked by the even granular mosaic which its constituents display when viewed under the microscope. This rock is known as Leptynite among French geologists.

**Eclogite**—a somewhat rare rock, consisting of omphacite and garnet, with sometimes quartz, amphibole, biotite, kyanite, zoisite, and other minerals.

**Gneiss**—a schistose aggregate of orthoclase, quartz, and mica, varying in texture from a fine-grained rock up to a coarse crystalline mass which, in hand specimens, may not be distinguishable from granite There is no difference, indeed, as regards composition between gneiss and granite; gneiss may be called a foliated granite. There is good reason to believe that many gneisses have been made out of granite or allied rocks, by the process of shearing above referred to (see p. 221). Gneiss occurs abundantly among the oldest known rocks of the earth's crust, and may be found in most large regions of crystalline schists (Chapter XVI.).

# PART III

# THE STRUCTURE OF THE CRUST OF THE EARTH

## CHAPTER XII

### SEDIMENTARY ROCKS—THEIR ORIGINAL STRUCTURES

HAVING in the two foregoing chapters considered the more important elementary substances of which the earth's crust is composed and their combinations in minerals and rocks, we have to inquire how these minerals and rocks have been put together so as to build up the crust. A very little examination will suffice to show us that the upper or outer part of the solid globe consists chiefly of sedimentary rocks. All over the plains and low grounds of the earth's surface, which cover so large a proportion of the whole area of the land, some kind of sediment underlies the soil—clay, sand, gravel, limestone. It is chiefly in hilly or mountainous regions that anything has been pushed up from below, so as to indicate the nature of the materials underneath. But everywhere we encounter proofs that the sedimentary rocks of the land do not remain as they were deposited. In the first place, most of them were laid down on the sea-floor, and they have been upraised into land. In the next place, not only have they been upheaved, they have not infrequently been bent, broken, and crushed, until sometimes their original condition can no longer be determined. Moreover they have been invaded by masses of lava and other eruptive rocks, which have been thrust in among them and have often burst through them to form volcanoes at the surface. We must now endeavour to form as clear a conception

as possible of what, after all these changes, the present structure of the crust actually is. In this chapter, therefore, we may examine some of the leading characters of sedimentary rocks in the architecture of the crust, more particularly those which have been determined by the conditions under which the rocks were formed. In the next chapter we shall consider some of the more important characters which have been superinduced upon these rocks since their formation.

**Stratification.**—It has been shown (p. 163) that one of the most distinctive features in sedimentary rocks is that they are stratified—that is, are arranged in layers one above another. As those at the bottom must have been deposited before those at the top (p. 3), a succession of layers of stratified rocks forms a record of deposition, in which the early stages are chronicled by the lower, and the later stages by the upper layers. An illustration of this kind of record has already been given in the introductory chapter. As a further example, the accompanying section (Fig. 90) may be taken. At the bottom lies a bed (*a*) of dark shale or clay with fragments of crinoids, corals, shells, and other marine organisms. Such a bed unmistakably points to a former muddy sea-floor, on which the creatures lived whose remains have been preserved in the hardened mud or shale. The next bed (*b*) is one of limestone full of similar organic remains; it shows that the supply of mud, which had previously made the water turbid and had been slowly gathering in successive layers on the bottom, now ceased The water became clear and much better fitted for the life of the crinoids, corals, and shells. These creatures accordingly flourished abundantly, living and dying on the spot generation after generation, until their accumulated remains had built up a solid sheet of limestone several feet thick. But once more muddy currents spread over the place, and from the cloud of suspended mud there slowly settled down the layer of blue clay (*c*) which overlies the limestone. As hardly any remains of organisms are to be seen in it, we may infer that the inroad of mud killed them off. Next,

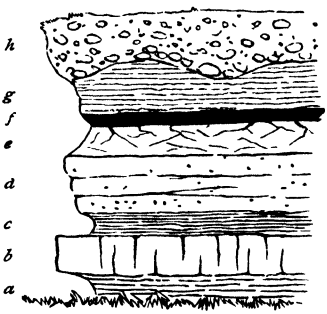


FIG 90.—Section of stratified rocks.

owing to some new shifting of the currents, a quantity of sand was brought in and spread out over the mud, forming the sandstone beds (*d*). The sea in which these various strata were deposited was probably shallow; or its floor may have been gradually rising. At all events, the last layers of sand could have been only slightly below the surface of the water, for they are immediately covered by a hardened silt or fire-clay (*e*) which, from the abundant roots and rootlets that run through it in all directions, was clearly once a soil whereon plants grew. It was probably part of a mud-flat, on which vegetation spread seaward from the land where the water shallowed, as happens at the present day among tropical mangrove-swamps (p. 93). The plants that grew on this soil have formed the coal-seam (*f*), no doubt representing the growth of a long period of time. But the existence of the coal-jungle came to an end, probably by a sinking of the ground beneath the water. Mud, once more carried hither from the neighbouring land, settled down upon the submerged vegetation and formed the clay (*g*). But that land plants still abounded in the immediate neighbourhood, is shown by their numerous remains in this clay. We notice too that the salts of iron dissolved in the water were eliminated by the decaying plants and animals and were precipitated in the form of carbonate, so as to form concretions of clay-ironstone round occasional dead shells, fishes, fern-fronds, and seed-cones. What were the immediately succeeding events in this ancient history we cannot tell; the layer next in order is a coarse conglomerate (*h*), originally gravel, which must have been swept along by a swift current that tore away the upper part of the clay-beds (*g*) and any strata which may once have overlain them.

The whole stratified part of the earth's crust is composed of materials which may be made more or less completely to tell their story. In forcing them to yield up their records of the ancient changes of which they are memorials, scope is afforded for the most accurate and laborious investigation, and for the closest reasoning from the facts collected. At the same time, it is obvious that the pursuit is one which constantly exercises the imagination, and that, indeed, it cannot be adequately followed unless, by the proper use of the imagination, the former conditions of the earth's surface are vividly realised.

The thinnest layers of a stratified rock form *laminæ*, such as the thin paper-like leaves into which shale can be split. A number of laminæ may be united in a *stratum* or *bed* which may

vary from less than an inch to several feet or yards in thickness. It is only the finer kinds of sedimentary rock that, as a rule, are *laminated.* In other cases a stratum or bed is the thinnest subdivision; it can usually be separated easily from those above and below it, and it may generally be regarded as marking one continued phase of deposit, while the break between it and the next bed above or below probably denotes an interruption of the deposit. The study of the relations of strata to each other is called *Stratigraphy.*

Layers of deposit usually lie parallel with each other, their flat surfaces marking the general floor of the water at the time of their formation (Figs 90, 91) But sometimes a series of layers may be found inclined at various angles to what was obviously the original general plane of deposition. In Fig. 92, for example, a series of strata is presented, which are distinguished by a diagonal lamination. This is known as *False bedding* or *Current-bedding* As explained in Chapter III (p. 42), it has been caused by the pushing of layers of sediment over the advancing front of a stratum, and may be compared to the oblique bedding often to be seen in an earthwork, such as a railway embankment, the upper surface of which may be in a general sense parallel with the flat bottom of the surrounding valley or plain, while the successive layers of which the mound is made are inclined at angles of 30° or more. False bedding is interesting as affording some indication of the nature and direction of the currents by which sediment has been transported.

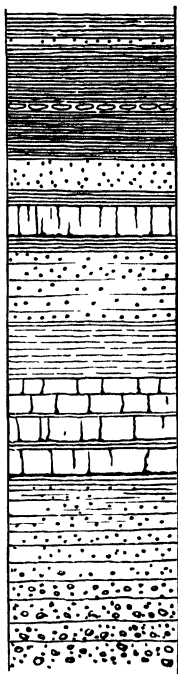



FIG 91 —Section showing alternation of beds.

15. Shale 14 Seam of sandstone. 13 Shale with septarian nodules 12 Sandstone. 11 Mudstone. 10. Limestone 9. Clay 8 Sandstones. 7 Sandy clays. 6 Limestone with parting of shale 5 Shale 4 Limestone. 3. Shale with cement-stone passing down into sandstone (2), which graduates into fine conglomerate (1)

**Proofs of former Shores.** — Along the margin of the sea, of lakes, and of rivers, several interesting kinds of markings may be seen impressed on surfaces of sand or mud from which the water has retired. Every one who has walked

on a tidal sea-beach is familiar with the *Ripple-marks* left by the retreating tide upon the bare sands. They are produced by the oscillation of the water driven into movement by wind playing over its surface. They are usually effaced by the next advancing tide; hence, out of the same sand new sets of ripple-marks are made by each tide. But we can understand that now and then, under peculiarly favourable conditions, the markings may not be destroyed. If, for instance, they were made in a kind of muddy sand, which, in the interval between two tides and under a strong sun, could become hard and coherent on the surface, and if the next tide advanced so quietly as not to disturb them, but to lay

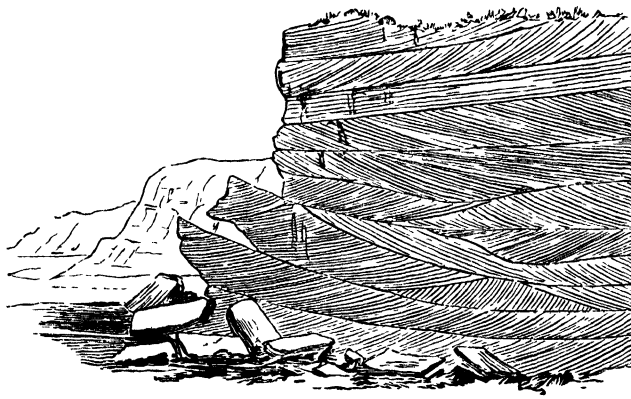


FIG. 92.—False-bedded sandstone.

down upon them a fresh layer of sand or mud, they might be covered up and preserved. They would then remain as a memorial of the shallow rippling water and bare sandy shore where they had been formed.

Now evidence of this kind regarding the conditions of deposition occur abundantly among sedimentary rocks (Fig. 93). Ripple-marked surfaces may be traced one over another for many hundred feet in a thick series of sandstones. They bring clearly to the mind that the strata on which they lie were accumulated in shallow water, or along beaches that were often laid dry.

**Land-Surfaces.**—Other traces of exposure to the air may be noticed, where ripple-mark is abundant, in what are termed *Sun-cracks*, *Foot-prints*, and *Rain-prints*. Those who have observed

what takes place in muddy places during dry weather will remember that, as the mud dries and contracts, it splits up into a network of cracks; and that, on its hardened surface, it retains impressions of the feet of birds or large insects that may have walked over it while still soft. The geological history recorded at such places cannot be mistaken; first, the rainy period, with the rush of muddy water down the slopes and the formation of pools in which the mud is allowed to settle; then the season of warm weather when the pools gradually dry up and birds seek the edges of the water to drink. If by any means a

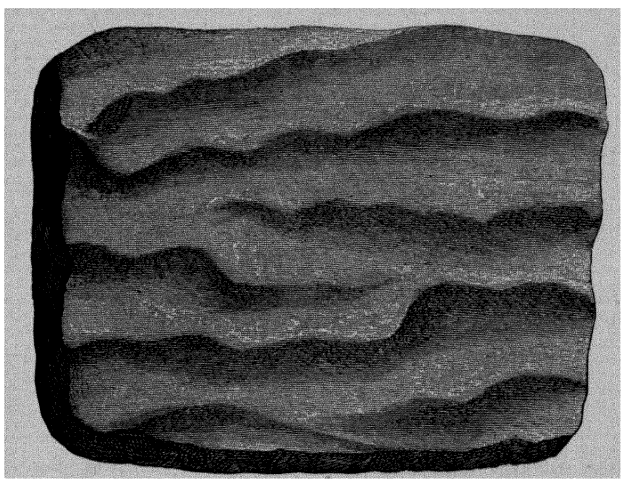


FIG. 93.—Ripple-marked surface of sandstone.

layer of sediment could be laid down upon one of these desiccated basins so gently as not to efface its peculiar markings, the cracked surface of mud, with its footprints, would contain a perfectly intelligible record of the events which it had witnessed (Fig. 94).

Now surfaces of this kind abound among the sedimentary rocks of the earth's crust. They are found upon strata which, from the presence of marine organic remains in them, were certainly deposited under the sea. But these strata cannot have accumulated in deep water; they were probably formed along flat shores, where the sheets of sand and mud were liable

from time to time to be laid bare to the sun and wind, where animals of various kinds left their footmarks or trails on the still soft sediment, where the evaporation and desiccation were so rapid as to cause the exposed mud to harden on the surface and to crack up into irregular polygonal cakes, and where the next succeeding layers of sediment were deposited so quietly as to cover up and preserve the sun-cracked surfaces.

One further piece of evidence that indicates land-surfaces, or, at least, shore-surfaces, in a series of aqueous sedimentary strata, is that furnished by Rain-prints. A brief shower of rain leaves upon a smooth surface of fine sand or mud a series of small pits,

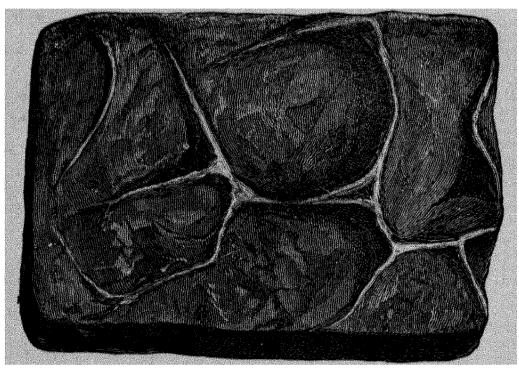


FIG. 94.—Cast of a sun-cracked surface preserved in the next succeeding layer of sediment.

each of which is the imprint of a descending raindrop (Fig. 95). Where this takes place along the edge of a muddy pool which is rapidly being dried up, the prints of the drops may remain quite distinct on the hardened surface of mud. And here, again, we can suppose that if another layer of mud were gently deposited above this surface, the rain-prints would be sealed up and preserved. We might even be able to tell from what quarter the wind blew that brought the rain-cloud. If, for example, the rain-prints were ridged up on one side in one general direction, this would show that the shower fell aslant and with some force, and that the side on which the mud round the imprints was forced up was that towards which the rain was driven. Such indications of ancient weather may here and there be detected among stratified rocks.

**Concretions.**—Another original characteristic of many sedimentary rocks is a concretionary structure, particularly observable in clays, limestones, and ironstones. In many cases, the concretions have gathered round some fragment of a plant or an animal. Clay-ironstone and impure limestone have been aggregated into spherical or elliptical forms (septaria), which are of frequent occurrence in clay or shale (Figs. 72, 76). Flint has also gathered round some organic nucleus, which it has often entirely replaced. But many concretions may be found where no organic fragment as a starting-point can be detected. Some of the most curious are the so-called Fairy-stones (Fig. 75), found

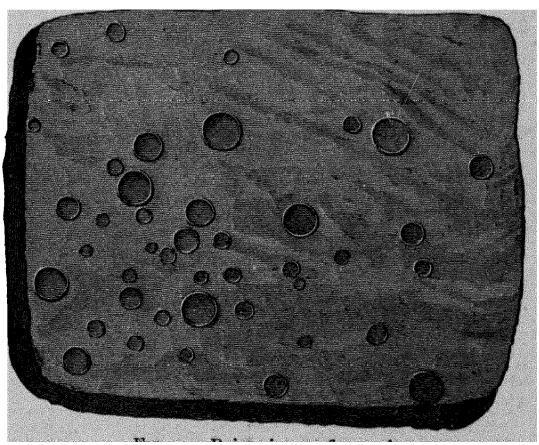


FIG. 95.—Rain-prints on fine mud.

in alluvial clays, with so many imitative shapes, which have been popularly supposed to be works of human or even preternatural construction. They have probably been produced by the irregular cementing of clay, owing to the spread of carbonate of lime through it, carried down by permeating water. Some of the most extraordinary concretionary masses are to be seen in certain magnesian limestones, which appear to be built up of petrified lumps of coral, bunches of grapes, cannon-balls, and other objects (Fig. 86). In reality, all these diversified figures are due to the irregularly varied way in which a concretionary structure has been developed in the dolomite.

**Association and Alternation of Strata.**—Certain kinds

of sedimentary rocks are apt to occur together to the exclusion of others. This association depends on the circumstances of deposition. Ironstone concretions, for example, are much more frequent among clays or shales than in any other strata, because it was during the deposit of fine mud with abundant decomposing organic matter that the most favourable conditions were supplied for the precipitation of carbonate of iron. Clays and limestones

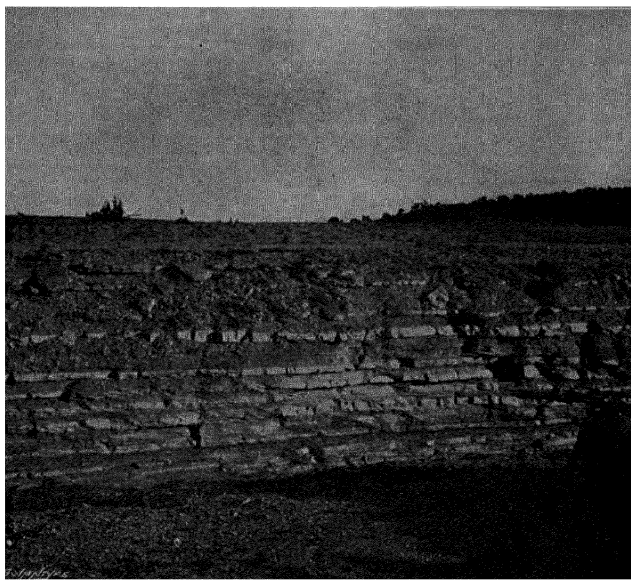


FIG. 96.—Regular alternation of Limestone and Shale, Greenhorn formation (Cretaceous), Colorado. Photograph by Mr. G. K. Gilbert, U.S. Geol. Survey.

frequently alternate, as also do sandstones and conglomerates, because the circumstances of deposition were somewhat alike (see Figs. 91 and 96). But we need not expect to encounter a bed of coarse conglomerate regularly intercalated in a group of fine clays, for the current that was strong enough to sweep along the stones of the conglomerate was too powerful to allow the fine silt to lie undisturbed. For a similar reason, we should be surprised to meet with a layer of well-stratified shale in a mass of con-

glomerate. The agitated water in which these coarse materials were heaped up would have swept away any fine sediment and prevented it from being deposited. In all cases, the manner in which the different kinds of sediment are associated with each other leads us back directly to the original conditions of deposit, and is only intelligible in proportion as these conditions are clearly realised.

**Relative Areas of Stratified Rocks.**—Moreover, some kinds of sedimentary material must obviously spread over wider areas than others. The coarse gravel and shingle of the present beach do not extend far seawards; they are confined to the margin of the land. Sand covers the sea-floor over a wider area; and beyond the limits of the sand, in the deeper and stiller water, mud is allowed to accumulate. Roughly speaking, therefore, the area of the distribution of sediment is in inverse proportion to the coarseness of the materials. The same law has regulated the accumulation of detritus from early geological time. Coarse conglomerates, which represent ancient shingles and gravels, thicken and thin out rapidly, and do not usually cover a large area, though they may sometimes be traced for long distances in the direction probably of the original coast or line of heaping up of the shingle. They pass laterally and vertically into grits and sandstones which have a much wider distribution, and these again shade off into clays and shales that range also over large areas.

**Chronological Value of Strata.**—No clue has yet been found to determine the length of time required for the accumulation of a stratum or group of strata; but some indications are afforded of relative lapse of time. Here and there, for instance, vertical trunks of trees are met with standing in their positions of growth, but imbedded in solid sandstone (Fig. 97). These stems, sometimes 20 feet or more in height, prove that a mass of sand of that depth must have been accumulated around them before they had time to decay. We know little about the durability of the submerged trees; but they probably could not have lasted long unless covered up in sediment; so that the mass of strata in which they are enclosed may be supposed to have been accumulated within not many years. The nature of the material composing sedimentary rocks may likewise furnish indications of the relative rate of deposition. Thus finely laminated clays were evidently deposited with comparative slowness. Beds of limestone, composed of the crowded remains of successive generations of marine creatures, must also have required prolonged periods of time for

their growth. On the other hand, thick beds of sandstone presenting great uniformity of characters may not improbably have been laid down with comparative rapidity.

No reliable inference can be drawn from the mere thicknesses of strata as to the lapse of time which they represent A mass of sandstone 20 feet thick may have accumulated round a submerged tree in a few years. On the other hand, a corresponding depth of fine laminated clay may have required tenfold more time

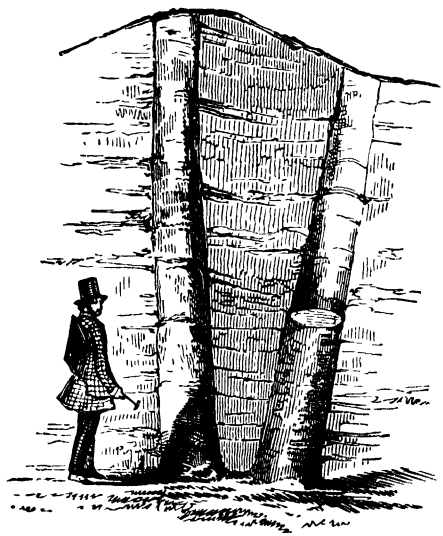


FIG. 97 —Vertical trees (*Sigillaria*) in sandstone, Swansea (Logan)

for its deposition. But the same thickness of rock composed of alternations of shale and limestone might represent a still longer period For it is obvious that the change from one kind of sediment to another must often have been brought about by an extremely gradual modification of the geography of the region from which the supply of sediment was derived. Hence the interval between two beds or groups of beds, differing much from each other in mineral composition, may have been considerably longer than the time required for the actual deposition of the strata of either or both beds or groups of beds.

On any probable estimate, the deposition of sedimentary rocks to a depth of many thousand feet and over areas many thousands of square miles in extent, must have demanded enormous periods of time. Side by side with the growth of mechanical sediments, there must have been a corresponding wasting of land. Every bed of conglomerate, sand, or mud represents at least an equivalent amount of rock worn away from the land and transported as sediment to the floor of the sea. During such prolonged ages as these changes required, there was ample time for the outburst of many successive volcanoes, for the passage of many earthquake-shocks, and for the subsidence or upheaval of many parts of the earth's crust.

**Proof of Subsidence.**—A mass of sedimentary material of great thickness which, from the remains of sun-cracks and other

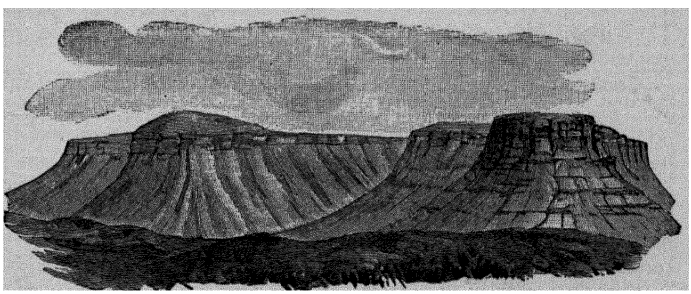


FIG. 98.—Hills formed out of horizontal sedimentary rocks (compare Fig. 7).

evidence, was obviously deposited in shallow water near land can only have been accumulated on an area that was gradually sinking. Suppose, for instance, that a hill formed out of horizontal strata rises a thousand feet above the valley at its foot (Fig. 98), and that proofs of deposition in shallow water can be detected from the lowest beds all the way up to the highest. The lowest beds having once been close to the surface, as shown by the sun-cracks and other evidence, could only be covered with hundreds of feet of similar strata by a gradual sinking of the ground, during which fresh sediment was poured in, so that, although the original bottom sank a thousand feet, the water may never have become sensibly deeper, the rate of deposit of sediment having, on the whole, kept pace with that of the subsidence.

**Overlap.**—During such tranquil movements, as the area of land

lessens and that of the sea increases, the later sedimentary accumulations must needs extend beyond the limits of the older ones. Suppose, for instance, that such a sloping land-surface as that represented in the section (*x*, Fig. 99) were slowly to subside beneath the sea, the first-formed strata (*a*) will be covered and

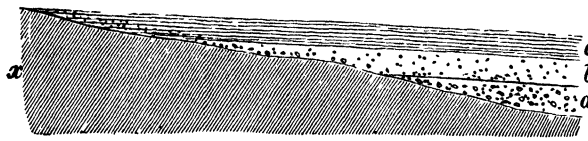



FIG. 99.—Section of overlap.

overlapped by the next series (*b*), and these in turn, as the sea-floor sinks, will be similarly concealed by the following group (*c*). This structure, termed *Overlap*, may usually be regarded as evidence of a gentle subsidence of the area of deposit.

**Conformability, Unconformability.**—When stratified deposits are laid down regularly and continuously upon each other, with no interruption of their generally level position, they are said to be *conformable*. In the section Fig. 91, for instance, the series of sediments there represented has evidently been deposited under the same general conditions. The nature of the sediment has of course varied from time to time; limestones, shales, and sandstones have alternated with each other; but there has been no marked interruption or disturbance in their sequence. Suppose, however, that owing to subterranean movements, a series of rocks

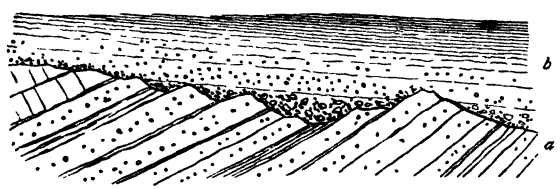



FIG 100.—Unconformability.

(*a* in Fig. 100) is shifted from its original position, and after being uplifted, is exposed to the wearing action of the sea, rivers, air, rain, frosts, and the other agents concerned in the degradation of the surface of the land. If a new series of deposits (*b*) is laid down upon the denuded edges of these rocks, the bedding of the

whole will not be continuous. The younger strata will rest successively upon different parts of the older group, or, in other words, will be *unconformable.* Such a relation or *unconformability* (unconformity) implies a terrestrial disturbance, and usually also the lapse of a long interval of time between the respective periods of the older and younger rocks, during which denudation of the older strata took place. It serves to mark one of the breaks or gaps in geological history. Unconformabilities differ much from each other in regard to the length of interval which they denote. In some cases, the blank may be of comparatively slight moment; in others, it is so vast as to include the greater part of the time represented by the stratified rocks of the earth's crust.

By means of unconformabilities the different ages of mountain-chains are determined. If, for example, a mountain showed the structure represented in Fig. 100, its upheaval must obviously have taken place between the deposition of the two series of rocks. Suppose the series *a* to represent Lower Silurian, and *b* Carboniferous rocks, the date of the mountain would be between the Lower Silurian and Carboniferous periods (see p. 257) If, in another mountain, series *b* were unconformably overlain by a younger series, say of Jurassic age, this mountain would thereby be shown to have undergone a subsequent uplift in the long interval between the Carboniferous and the Jurassic periods.

**Summary.**—In this Lesson some of the more characteristic original features of sedimentary rocks have been considered. Of these features, one of the most distinctive is the arrangement into layers or beds, each of which is the record of a portion of geological history, the oldest being below and the youngest above. The smallest subdivision of these records is a lamina or thin leaf, such as those into which shales may be split. A stratum or bed, which may contain many laminæ or none, is a thicker layer separable with more or less ease from those below and above it. Though strata lie on the whole parallel with each other, they often show oblique current-bedding, especially in sandstones. Traces of shore-lines and of surfaces laid bare by the retirement of the water in which they were deposited, are found in sun-cracks, rain-pittings, and footprints. Not infrequently, instead of being evenly spread out in layers, the sedimentary material has been aggregated into variously-shaped concretions. Certain kinds of sedimentary rocks are apt to occur together, such as clays and limestones, clay-ironstones and shales, coals and fire-clays, conglomerates and sandstones; because the conditions under which they were

respectively deposited were on the whole similar. As a rule, the finer the detritus, the wider the area over which it is spread; hence clays generally cover wider tracts than conglomerates. No inference can safely be drawn from the relative thickness of strata as to the length of time which they respectively represent; they must vary widely in this respect, and it is quite conceivable that, in many cases, the interval of time between the deposition of two successive beds of very different character and composition may have been actually longer than the period required for the deposition of the two beds. A thick series of sedimentary deposits usually indicates that the sea-bottom on which it was laid down was slowly sinking. In subsiding, the later deposits spread beyond the limits of the earlier ones, and thus present what is called an overlap. Where they have been laid down continuously one upon another, they are said to be conformable; where one group has been deposited on the disturbed and worn edges of an older series, the two are unconformable to each other

# CHAPTER XIII

## SEDIMENTARY ROCKS—STRUCTURES SUPERINDUCED IN THEM AFTER THEIR FORMATION

AFTER their deposition sedimentary materials have undergone various changes before assuming the aspect which they now wear.

**Consolidation.**—The most obvious of these changes is that, instead of consisting of loose materials, such as gravel, sand, and mud, they are now hard stone. This consolidation has sometimes been the result of mere pressure. As bed was piled over bed, those at the bottom would gradually be more and more compressed by the increasing weight of those that were laid down upon them, the water would be squeezed out, and any tendency which the particles might have to cohere would promote the consolidation of the mass. Mud, for example, might in this way be converted into clay, and clay in turn might be pressed into mudstone or shale. But besides cohesion from the pressure of overlying masses, sedimentary matter has often been bound together by some kind of cement, either originally deposited with it or subsequently introduced by permeating water. Among natural cements, the most common are silica, carbonate of lime, and peroxide of iron. In a red sandstone, for example, the quartz-grains may be observed to be coated over with earthy iron-peroxide, which serves to unite them together into a more or less coherent stone. The effect of weathering is not infrequently to remove the binding cement, and thereby to allow the stone to return to its original condition of loose sediment.

**Joints** —Next to their consolidation into stone, the most common change which has affected sedimentary rocks is the production in them of a series of divisional planes or fractures termed *Joints*. Except in loose incoherent materials, this structure is hardly ever absent. In any ordinary quarry of sandstone, limestone, or other

sedimentary rock, or along a natural cliff of the same materials, a little attentive observation will show that the bare wall of rock forming the back of the quarry or the face of the cliff has been determined by one or more natural fissures in the stone, and that there are other fissures running parallel with it through every outstanding buttress of rock. Moreover, we may observe that these vertical or highly inclined lines of fissure are cut across by others, more or less nearly at a right angle, and that the sides of the buttresses have been defined by these transverse lines, just as the main face of rock has been formed by the

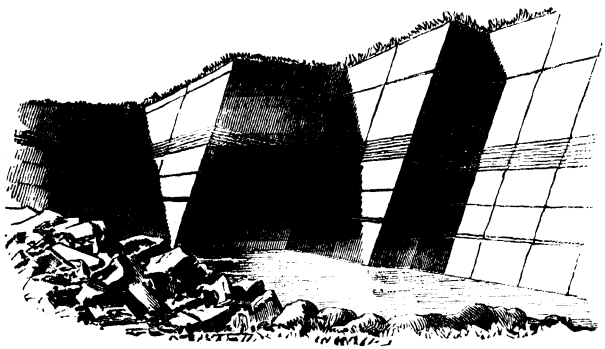


FIG. 101.—Joints in a stratified rock.

first set. Such lines of division are Joints. In close-grained stone they may be imperceptible until it is quarried or broken, when they reveal themselves as sharply defined, nearly vertical fractures, along which the stone splits. There are usually at least two series of joints crossing each other at right angles or obliquely, whereby a rock is divided into quadrangular blocks. In the accompanying diagram (Fig. 101) a group of stratified rocks is seen to be traversed by two sets of joints, one of which (*dip-joints*, "cutters" of the quarrymen) defines the faces that are in shadow, the other (*strike-joints*, "backs" of the quarrymen) those that are in light. By help of these divisional planes, it is possible to obtain large blocks of stone for building purposes. The art of the quarryman, indeed, largely consists in taking advantage of these natural lines of fracture, so as to obtain his materials with the least expenditure of time and labour, and in large masses.

In nature, also, the existence of joints is a fact of the highest importance. Reference has already been made to the way in which they afford a passage for the descent of water from the surface. It is in great measure along joints that the underground circulation of water is conducted. At the surface, too, where rocks yield to the decomposing influence of the weather, it is by their joints that they are chiefly split up. Along these convenient planes of division, rain-water trickles and freezes; the walls of the joints are separated, and the space between them is slowly widened, until in the end it opens into yawning rents, and portions of a cliff are overbalanced and fall, while detached pinnacles are here and there isolated. The picturesqueness of the scenery of stratified rock is, in great measure, dependent upon the influence of joints in promoting their dislocation and disintegration by air, rain, and frost.

In many cases, joints may be due to contraction. A mass of sand or mud, as it loses water and as its particles are more firmly united to each other, gradually occupies less room than at first. In consequence of the contraction strains are set up in the stone, and relief from these is eventually found in a system of cracks or fissures In other instances, joints have been produced by the compression or torsion to which large masses of rock have been exposed during movements of the earth's crust.

**Original Horizontality.**—As laid down upon the margin or floor of the sea, on the bottoms of lakes, and on the beds or alluvial plains of rivers, sedimentary accumulations are in general nearly flat They slope gently, indeed, seawards from a shelving shore, and they gather at steeper angles on slopes of debris at the foot of cliffs, or down the sides of mountains. But, taken as a whole, and over wide areas, their original position is not far removed from the horizontal. It we turn, however, to the sedimentary rocks that form so much of the dry land, we find that although at first deposited for the most part horizontally over the sea-bottom, they are now inclined at all angles, and even sometimes stand on end. Such situations, in which their deposition could never have taken place, show that they have been disturbed Not only have they been upraised into land, but they have been tilted unequally, some parts rising or sinking much more than others.

**Dip.**—The inclination of bedded rocks from the horizon is called their *Dip*. The amount of dip is reckoned from the plane of the horizon. A face of rock standing up vertically above that plane is said to be at 90°, while midway between that position and

horizontality it lies at an inclination of 45°. The angle of dip is accurately measured with an instrument called a *Clinometer*, of which there are various forms. One of the simplest kinds is a brass half-circle, graduated into 90° on each side of the vertical, on which a pendulum is hung, as in Fig. 103. The instrument is held between the eye and the angle to be measured, and the upper

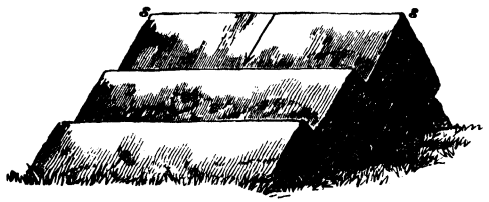



FIG. 102.—Dip and Strike. The arrow shows the direction of dip; the line *s s* marks the strike.

edge is made to coincide with the line of the inclined rock. The pendulum, remaining vertical, points to the angle of inclination from the horizon. A little practice, however, enables an observer to estimate the amount of dip by the eye with sufficient accuracy for most purposes. The direction of dip is the point of the compass toward which a stratum is inclined (shown by the arrow in Fig. 102), and is best ascertained with a magnetic compass. But

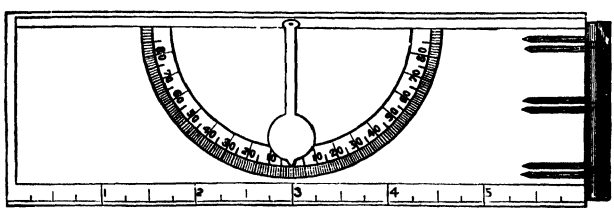



FIG. 103.—Clinometer.

here again a little experience in judging of the quarters of the sky, without an instrument, will usually enable us to tell the direction of dip with as much precision as may be required.

**Strike.**—A mathematical line running at a right angle to the direction of dip is called the *Strike* (*s s* in Figs. 102, 104). Where a series of strata dips due north or due south, no matter at what angle of inclination, the strike is east and west. But the

direction of strike changes with that of the dip. Suppose, for example, that certain strata dip due east, then veer round by south-east to south, and so on by west and north, back to east again. The strike following this change would describe a circle In fact, the beds would be included in a basin-shaped or dome-shaped arrangement and the strike would be the lip of the basin or rim of the truncated dome. Though the direction of dip may slightly vary from place to place, still, if it remains with the same general trend along the line of certain strata, their strike is on the whole uniform Obviously the amount of dip, in other words, the angle of inclination, may vary indefinitely up to verticality

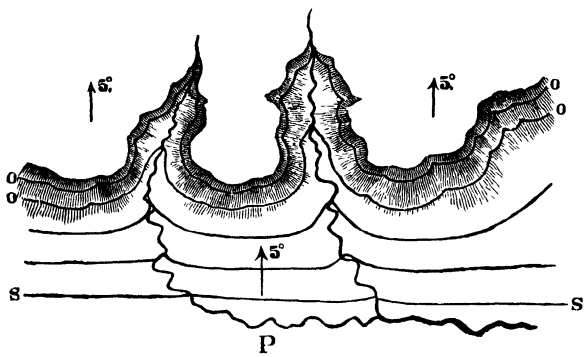



FIG. 104 —Dip, Strike, and Outcrop.

without affecting the strike, so long as the direction in which the strata are inclined remains constant.

**Outcrop.**—The actual edge presented by a stratum at the surface of the ground is called its *Outcrop*. On a perfectly level surface, strike and outcrop must coincide ; but as ground is seldom quite level they usually diverge from each other, and do so the more in proportion to the lowness of angle of dip and the inequalities of the ground. This may be illustrated by a diagram such as that given in Fig 104, which represents a portion of the edge of a table-land, deeply trenched by two valleys that discharge their waters into the plain (P) The arrows point out that the strata dip due N. at 5°. On the level plain, the outcrop and the strike (S S) of the beds are coincident and run due E. and W. But as the surface rises towards the high ground and the deep valleys,

the outcrop (o o) is observed to depart more and more from the strike till in some places the two lines are at right angles ; yet, as the direction of dip remains the same, the strike is likewise unchanged, the sinuosities of the outcrop being entirely due to the irregularities of the surface of the ground.

**Curvature.**—It requires no long observation to perceive that in being tilted from their original more or less level positions, stratified rocks have been thrown into curves. Suppose, for

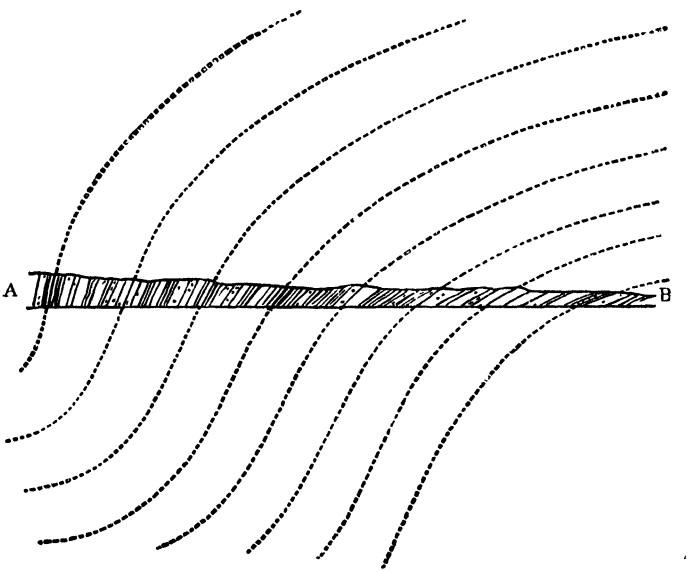



FIG 105.—Inclined strata shown to be parts of curves.

instance, that in walking along a mile of coast-line, where all the successive strata of a thick series are exposed to view, we should observe such a section as is drawn in Fig. 105. Beginning at A, we find the beds tilted up at angles of 70° or more, which gradually lessen, till at B they have sunk to 15°. As there is no break in the series, it is evident that the lines of bedding must be prolonged downward, and must once have been continued upward in some such way as is expressed by the dotted lines. The visible portion

which is here shaded must thus form part of a great curvature of the rocks.

But the actual curvature may often be seen on coast-cliffs, ravines, or hillsides. In Fig. 106, for example, a simple arch is shown from the Berwickshire coast, wherein hard beds of greywacke and shale have been folded. Again, in Fig 107, the reverse structure is exhibited, beds of grit and slate being there curved into a trough. Where rocks dip away from a central line of axis the structure is known as an *Anticline;* where, on the other hand,

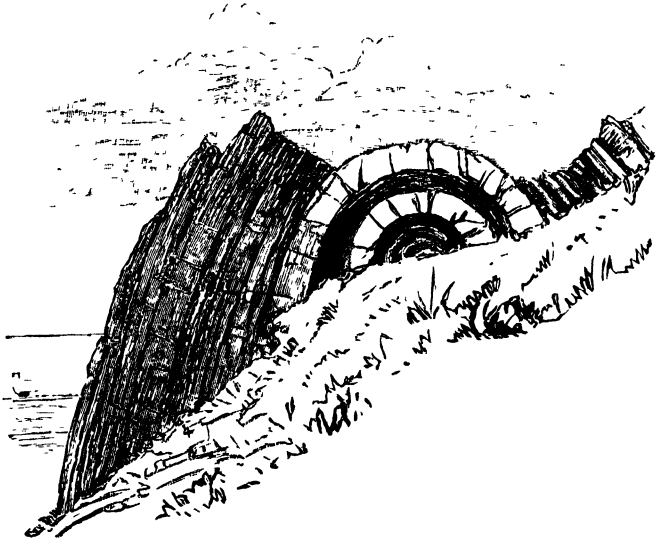


FIG. 106.—Curved strata (anticlinal fold), near St. Abb's Head.

they dip towards an axis it is called a *Syncline.* In Figs. 106 and 107 these two structures are presented on so small a scale as to be visible in a single section. More usually, however, it is only by observing the upturned edges of strata that anticlines and synclines can be detected. The part of Fig. 108, below the dotted lines, represents all that can be actually seen; but the angles and direction of dip leave no doubt that if we could restore the amount of rock which has here been worn away from the surface of the land, the present truncated ends of the strata would be prolonged upward in some such way as is indicated by the dotted

lines. By observations of this truncation of strata, some of the most interesting and important evidence is obtained of the enormous extent to which the land has been reduced by the removal of solid material from its surface.

**Plication, Shearing.**—From such simple curvatures as those depicted in the foregoing diagrams, we may advance to more complex foldings, wherein the solid strata have been doubled up and crumpled together, as if they had been mere layers of carpet. So far is this plication sometimes carried, that the lowest rocks

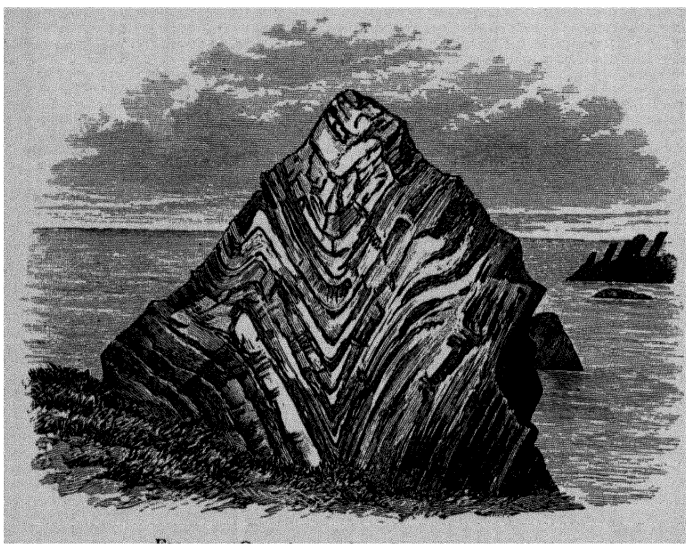


FIG. 107.—Curved strata (synclinal fold) near Banff.

are brought up and thrown over the highest, the more yielding materials being squeezed into the most intricate frillings and puckerings. It is in mountainous regions, where the crust of the earth has been subjected to the most intense corrugation, that these structures are best seen. We can form some idea of the gigantic energy of the earth-movements that produced them, when we see a whole mountain-range made up of solid limestones or sandstones which have been bent, twisted, crumpled, and inverted, as we might crush up sheets of paper (Fig. 109).

So enormous has been the compression produced by important

movements of the earth's crust, that the solid rocks have actually been squeezed out of shape or have undergone a process of shearing. The amount of distortion may sometimes be measured by the

FIG 108 —Anticlines (*a a*) and Synclines (*b b*)

extent to which shells or other organic remains are pulled out in the direction of movement. In Fig 110 the proper shape of a trilobite (*Angelina Sedgwicki*) is given, and alongside of it is a view of the same organism which has been elongated by the distortion of the mass of rock in which it lies. Further results of shearing will be immediately referred to in connection with the cleavage and metamorphism of rocks.

**Cleavage.**—One of the most important structures developed by

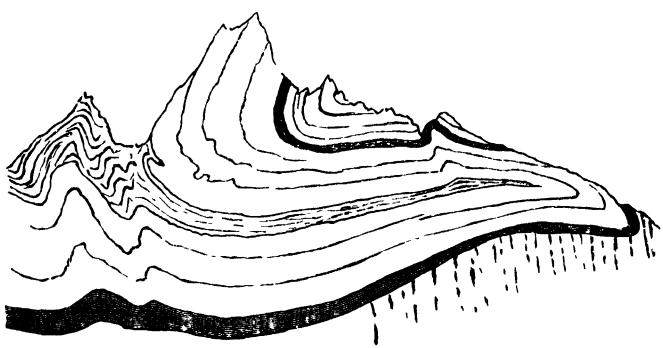
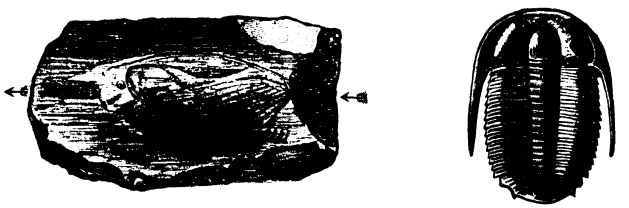


FIG 109 —Section of the Grosse Windgalle (10,482 feet), Canton Uri, Switzerland, showing crumpled and inverted strata thrown into a flat fold (after Heim)

the great compression to which the rocks of the earth's crust have been exposed is known as *Cleavage.* The minute particles of rocks, being usually of irregular shapes, have been compelled to arrange themselves with their long axes perpendicular to the direction of pressure, during the interstitial movements consequent upon intense subterranean compression. Hence, a fissile tendency

has been imparted to a rock, which will now split into leaves along the planes of rearrangement of the particles. This superinduced tendency to split into parallel leaves, irrespective of what may have been the original structure of the rock, constitutes cleavage. It is well developed in ordinary roofing-slate. Though the leaves or plates into which a slate splits resemble those in a shale, they have no necessary relation to the layers of deposition but may cross them at any angle. In Fig. 111, for instance, the original bedding is quite distinct and shows that the strata have been folded by a force acting from the right and left of the section; the parallel highly inclined lines traversing the folds of the bedding represent the planes of cleavage. Where the material is of exceedingly fine grain, such as fine consolidated mud, the original bedding may be entirely effaced by the cleavage, and the rock



*a* *b*

FIG. 110.—Distortion of fossils by the shearing of rocks; (*a*), a Trilobite (*Angelina Sedgwickii*) distorted by shearing, the direction of movement indicated by the arrows; (*b*), the same fossil in its natural form.

will only split along the cleavage-planes. Indeed, the finer the grain of a rock, the more perfect may be its cleavage, so that where alternations of coarser and finer sediment have been subjected to the same amount of compression, cleavage may be perfect in the one and rudely developed in the other, as is indicated in Fig. 111. It is possible that the lamination of fine argillaceous sediments parallel to the stratification, in ancient and once deeply buried formations, may sometimes be a cleavage structure that has been superinduced by the enormous superincumbent pressure of the vast mass of rock that has been worn away (p. 168).

Cleavage may be regarded as one of the first stages in the mechanical deformation of a rock, and in the production of schistose metamorphism (p. 186). Besides being compressed and having its component particles rearranged in definite planes, the rock may likewise reveal under the microscope that new minerals, such

for example as crystallites or minute flakes of some mica, have been developed out of the general matrix, as may be seen in common roofing-slate. By increasing stages of crystallisation we trace gradations into phyllites and mica-schists.

**Dislocation.**—Another important structure produced in rocks after their formation is *Dislocation*. Not only have they been folded by the great movements to which the crust of the earth has been subjected, but the strain upon them has often been so great that they have snapped across. Such ruptures of continuity pre-

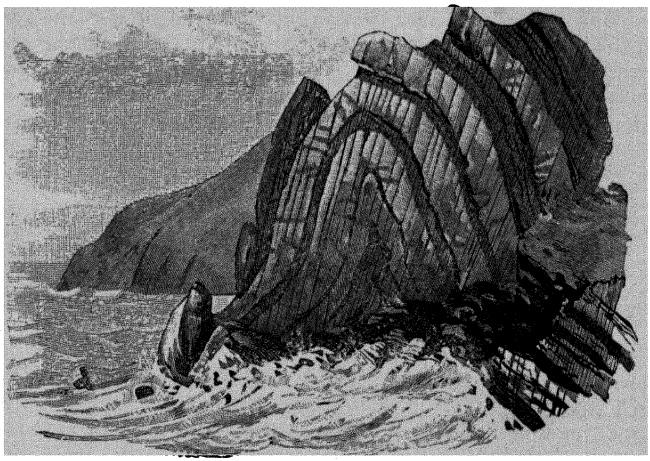


FIG. 111.—Curved and cleaved rocks. Coast of Wigtonshire. The fine parallel oblique lines indicate the cleavage, which is finer in the dark shales and coarser in the thicker sandy beds.

sent an infinite variety in the position of the rocks on the two sides. Sometimes a mere fissure has been caused, the rocks being simply cracked across, but remaining otherwise unchanged in their relative situations. But, in the great majority of instances, one or both of the walls of a fissure have moved, producing what is termed a **Fault.** Where the displacement has been small, a fault may appear as if the strata had been sharply sliced through, shifted, and firmly pressed together again (*a* in Fig. 112). Usually, however, they have not only been cut, but bent or crushed on one or both sides (*b*); while not infrequently the line of fracture is represented by a band of broken and crushed material (*Fault-rock*, *c*).

The fracture is seldom quite vertical; almost always it is inclined at angles varying up to 70° or more from the vertical. In by far the largest number of faults, the inclination of the plane of the fissure, or what is called the *Hade* of the fault, is away from the side which has risen or toward that which has sunk. In the examples given in Fig. 112, *a*, *b*, this relation is expressed; but in nature it often happens that the beds on two sides of a fault are entirely different (*c*), and consequently that the side of upthrow or downthrow cannot be determined by the identification of the two severed positions of the same bed But if the hade of the fault can be seen, we may usually be confident that the strata on the upper or hanging side belong to a higher part of the series than those on the lower side. Faults that follow this rule (*normal* faults) are by far the most frequent. They occur universally, and are probably for the most part caused by subsidence in the earth's crust. In adjusting themselves to the new position into which a

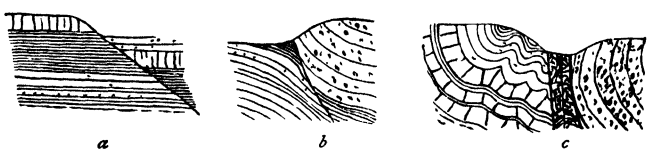



FIG 112.—Examples of normal Faults

downward movement brings them, rocks must often be subject to such strains that their limit of elasticity is reached, and they break across, one portion settling down farther than the part next to it. In a normal fault, the same bed can never be cut twice by a vertical line.

In mountainous districts, however, and generally where the rocks of the earth's crust have been disrupted and pushed over each other, what are termed *reversed* faults occur. In these, the hade slopes in the direction of upthrow, and a vertical line may cut the same beds twice on opposite sides of the fracture (Fig. 113, *c*). Such faults may be observed more particularly where strata have been much folded. A fold may be seen to have snapped asunder, the whole being pushed over, and the upper side being driven forward over the lower (Fig. 113).

The amount of vertical displacement between the two fractured ends of a bed is called the *Throw* of a fault. In Fig. 114, for example, where bed *a* has been shifted from *b* to *d*, a vertical line dropped from the end of the bed at *b* to the level of the corre-

sponding part of the bed at *e* will give the amount of the subsidence of *d*, which is the throw. Faults may be seen with a throw of less than an inch—mere local cracks and trifling subsidences in a mass of rock; in others the throw may be several thousand feet. Large faults often bring rocks of entirely different characters together, as, for instance, shales against limestones or sandstones,

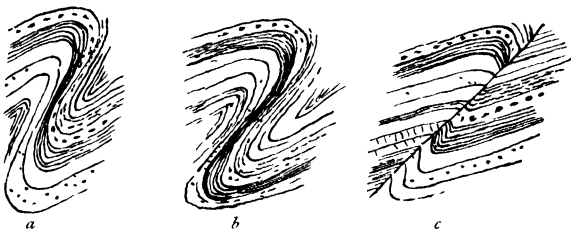



FIG 113.—Sections to show the relations of Plications (*a*, *b*) to reversed Faults (*c*)

or sedimentary against eruptive rocks. Consequently they are not infrequently marked at the surface by the difference between the form of ground produced in the two kinds of rock through the influence of denudation. One side, perhaps, rises into a hilly or undulating region, while the other side may be a plain. Comparatively seldom does a fault make itself visible as a line of ravine

FIG 114.—Throw of a Fault.

or valley. Where it does so, the surface feature may usually be traced to the effects of denudation, which has been more effective on the broken and crushed rocks along the line of fault than on the solid surrounding masses. In actual fact, most faults cut across valleys or only coincide with them here and there. They run in straight or wavy lines which, where the amount of displacement is great, may be traced for many miles. The Scottish Highlands, for example, are bounded along their southern margin by a great fault which places a thick series of

sandstones and conglomerates on end against the flanks of the mountains. This fault may be traced across the island from sea to sea—a distance of fully 120 miles, and by bringing two distinct kinds of rocks next each other, along a nearly straight line, it has given rise to the boundary between Highland and Lowland scenery which, in some places, is so singularly abrupt.

In regions of the most intense terrestrial disturbance, tracts of rock many square miles in area and hundreds or thousands of feet in thickness, have been torn away and pushed upward and forward, sometimes for long distances, until they have come to rest on rocks originally much higher in geological position. Such displaced cakes or slices of the earth's crust sometimes rest upon an almost horizontal or gently inclined platform of undis-

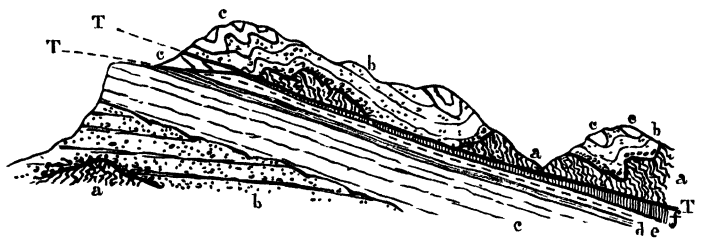



FIG 115.—Section showing thrust-planes, Loch Maree, Scotland *aa*, Archæan gneiss; *bb*, Pre-Cambrian (Torridon) Sandstone; *cc*, Quartzite (Cambrian), *d*, Dolomitic shales with *Olenellus*-zone, *e*, Serpulite grit, *f*, Dolomite; TT, Thrust-planes.

turbed materials. Vertical or contorted strata are thus placed above others which may be flat or but little inclined The plane of separation between the moved and unmoved masses is really a dislocation, but to distinguish it from faults, which are generally placed at steep angles, it is called a *Thrust-plane.* Structures of this kind on a colossal scale are traceable for about 100 miles in the north-west of Scotland. An example of this structure is given in Fig. 115. It will be seen that the oldest rock there represented is the ancient gneiss (*a*), which is unconformably overlain by pre-Cambrian sandstones and conglomerates (*b*), which in turn are separated by an important unconformability from the Cambrian system (*c*, *d*, *e*, *f*) which overlies them (see p. 257). The upper part of the dolomite (*f*) is abruptly cut off and a portion of the oldest rocks has been thrust over it. First comes the gneiss, then its overlying sandstones. These masses have been thrown into folds, in

the cavities of which lie basins of the Cambrian strata (*c*), the whole of these upturn masses having been driven forward over a sole or thrust-plane (T). Not infrequently the structure is much more complicated than here represented, successive minor thrust-planes being over-ridden by others of greater force.

In the Alps, in recent years, many remarkable and gigantic illustrations of similar structures have been observed Thus on the northern side of the valley of the Rhine above Chur, the formations follow each other in regular order until towards the top of the higher mountain, where a portion of the most ancient rock (gneiss) of the district has been torn up from below and pushed for a long distance upon a thrust-plane so as to overlie the youngest strata in the section. The strata have sometimes been violently plicated, and the gneiss overrides them on the great thrust-plane. In consequence of enormous denudation, the originally continuous cake of gneiss has been so much worn away that only outliers of it are left capping the summits. It has now been ascertained, through the labours of Bertrand, Rothpletz, and the Swiss geologists, that thrust-planes, as well as plication, play a large part in the internal or tectonic arrangement of the rocks of the Alpine chain. There is reason to believe that the same structure will be found to characterise the greater mountain ranges of the globe, and that the amount of horizontal displacement has often exceeded distances of many miles.

**Regional Metamorphism.**—The last structure which will be mentioned in this chapter as having been superinduced upon rocks is connected with the movements to which plication, cleavage, and reversed faults are due. So enormous has been the energy with which these movements have been carried on, that not only have the rocks been crumpled, ruptured, and pushed over each other, but they have undergone such intense crushing and shearing that their original structure has been partially or wholly effaced. They have been so crushed that their component particles have been reduced, as it were, to powder (mylonite), and have assumed new crystalline arrangements along the shearing-planes or surfaces of movement. A sandstone, for example, which in its ordinary state shows, when magnified, such a structure as is represented in Fig. 116, when it has come within the influence of this crushing process has its grains of quartz, felspar, and other materials flattened and squeezed against each other in one general direction, as in cleavage, while out of the crushed debris a good deal of new mica has been developed.

This change may be intensified until the component grains are hardly, if at all, recognisable. Simultaneous with this mechanical movement, or following closely on it, comes a chemical rearrangement of the constituents of the rock New combinations are formed, and a more or less completely crystalline structure is superinduced. In particular, mica is specially apt to be developed and the rock passes into a mica-schist. Other minerals, such as garnet, felspars and others, likewise make their appearance, until the rock assumes a wholly new crystalline character Such an alteration of the internal structure of a rock is known as *Metamorphism.* Where the change arises from mechanical movements combined with chemical rearrangement, it usually affects a wide district, and is then spoken of as *regional metamorphism*, as

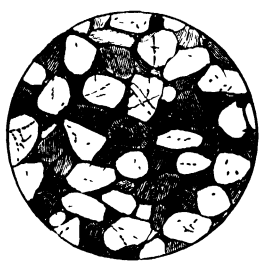


FIG 116 —Ordinary unaltered red sandstone, Keeshorn, Ross-shire (magnified)

FIG 117 —Sheared red sandstone forming now a micaceous schist, Keeshorn, Ross-shire (magnified)

distinguished from the more local alteration, effected round the margins of intrusive rocks, which is known as *contact-metamorphism* (p. 227).

There are wide regions of the earth's surface where schists of various kinds form the prevailing rock. Whether they have all been produced by the shearing and alteration of previously-formed rocks has not yet been determined. But that a large number of schists are truly altered or *metamorphosed* rocks admits of no doubt. Sandstones, shales, limestones, quartzites, diorites, syenites, granites, in short, any rock that has come within the crushing and shearing movements here referred to, has been converted into schist. The gradation between the unaltered and the metamorphic condition can often be clearly traced Granite, by crushing, passes into gneiss, diorite into hornblende-schist, sandstone into

quartz-schist or mica-schist, and so on. Even where it is no longer possible to tell what the original nature of the metamorphosed material may have been, there is usually abundant evidence that the rock has undergone great compression (see pp. 186-189).

**Summary.**—In this chapter attention has been directed to new structures produced in sedimentary rocks after their formation. Beginning with the simplest and most universal of these, we find that sediments have been consolidated into stone, partly by pressure, and partly by some kind of cement, such as silica or carbonate of lime. In the process of consolidation and contraction, they have been traversed by systems of joints, or have had these subsequently produced by the torsion accompanying movements of the crust. Though at first nearly flat, they have, by these movements, been thrown into various inclined positions, and more especially into undulating folds, or more complicated plication and puckering. So great has been the compression under which they have been moved, that a cleavage has been developed in them. They have also been everywhere more or less fractured, the dislocations being due either to their gradual subsidence or to excessive plication. The most gigantic displacements are seen where vast slices of the terrestrial crust have been wrenched off and pushed bodily, sometimes for many miles, over younger formations. The most complete alteration of rocks is seen in metamorphism, where, under the influence of intense shearing, their original structure has been more or less completely effaced, and a new crystalline rearrangement has been developed in them, converting them into schists.

## CHAPTER XIV

### ERUPTIVE ROCKS AND MINERAL VEINS IN THE ARCHITECTURE OF THE EARTH'S CRUST

NOT only have sedimentary formations since their deposition been hardened, plicated, fractured, and sometimes even turned into crystalline schists, but into the rents opened in them new masses of mineral matter have been introduced which, in many regions, have entirely changed the structure of the crust below and the appearance of the surface above. Broadly speaking, there are two ways in which these new masses have been wedged into their places. First of all, eruptive material in a molten, or at least in a viscous or plastic condition, has been thrust upward into the cool and consolidated crust of the earth ; and in the next place, various ores and minerals have been deposited from solution in cracks and fissures, which they have entirely filled up. To each of these two kinds of later rocks attention will be given in this chapter.

### Eruptive Rocks

The rise of eruptive matter, thrust upwards from lower depths within the planet, is one of the causes by which the structure of the crust has been most seriously affected. In Chapter IX. reference was made to some of the features connected with the protrusion of molten rocks in the production of volcanoes, and more particularly to those subterranean changes which, when all the outer and ordinary tokens of a volcano have been swept away, remain as evidence of former volcanic action, even in districts where every symptom of volcanic activity has long vanished. We have now to inquire, generally, in what forms eruptive matter has been built into the earth's crust, and what

changes it has produced there, apart from those superficial manifestations which are the visible signs of volcanic action.

When a mass of lava is forced upwards from the heated interior into the solid crust of the earth, the form which it finally takes, and in which it cools and solidifies, must depend upon the shape of the rent or cavity into which it has been thrust. We may compare such a mass to a quantity of melted iron escaping from a blast-furnace. The shape taken by the iron will, of course, be fixed by that of the mould into which it is allowed to run. The crust of the earth, as was pointed out in the previous chapter, has undergone extensive movements, whereby its rocks have been crumpled and broken. It consequently presents in different parts very various degrees of resistance to any force acting upon it from below. The eruptive materials have sometimes risen in the fissures, sometimes have forced their way between the beds and joints of the strata. According to the form of the mould in which they have solidified, we may classify the eruptive rocks of the crust into (1) bosses; (2) sheets or sills; (3) veins and dykes; and (4) necks.

**Bosses.**—These are circular, elliptical, or irregularly shaped masses of rock which, while still in a liquid or viscous state, have been ejected into irregular rents of the earth's crust and have solidified there They consist of various crystalline rocks, more especially granite, syenite, quartz-porphyry, trachyte, gabbro, diorite, diabase, and basalt-rocks, and vary in width from a few yards to several miles. Being generally harder than the surrounding rocks, they commonly stand up as prominent knobs, hills, or ridges. Their presence at the surface, however, is due, not to their original protrusion there, as in a volcanic cone, but to the removal of the overlying part of the original crust under which they cooled and consolidated. Every boss is thus a witness of the extensive wearing away of the surface of the land (Fig. 118).

In some large bosses there may have been a complex system of fissures in which the eruptive material rose. Forced upwards into these, the molten rock would no doubt envelope separated masses of the crust, and might bear them along with it in its ascent. We may even conceive it to have melted down such enveloped masses. Pushing the rocks aside and thrusting itself into every available crack in them, the eruptive mass would work its way across the crust. Where it succeeded in opening a passage to the surface, ordinary volcanic phenomena might take place, such as disruption of the ground, ejection of stones and

ashes, and outflow of lava. But, no doubt, in a vast number of cases no such communication was ever effected. The eruptive material paused in its upward passage and consolidated below ground.

Where a body of eruptive material has pushed the rocks upward into a dome-shaped form, and has collected beneath into a thick lenticular mass, it forms what is known as a *Laccolite*. This structure connects the Bosses with the Sills. It is not infrequent in old volcanic districts. The admirable examples of it, by which the name was suggested, were described by Mr. G. K. Gilbert from the Henry Mountains in Southern Utah.

No rock affords more interesting bosses than granite. Two

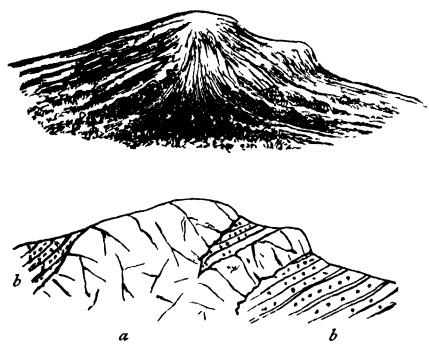



FIG. 118.—Outline and section of a Boss (*a*) traversing stratified rocks (*b b*).

features are especially well displayed by it—the marginal veins or dykes, and the surrounding ring of metamorphism produced in the rocks through which granite has risen. Granite has invaded many different kinds of rocks, and has effected various kinds of change in them. Round its margin, large numbers of veins or dykes of granite, aplite, quartz-porphyry or porphyrite, often strike out from it into the surrounding rocks. There can be no doubt that these are portions of the granite material, squeezed or injected into cracks that opened in the crust around it during its ascent. More important is the change that can be observed to have taken place in the rocks immediately surrounding the boss. The granite at the time of its protrusion was probably in a molten or pasty condition, and impregnated with hot water or steam and vapours. For a distance varying from a few feet up to two or three miles,

according chiefly to the size of the granite mass, the rocks next to it have undergone alteration, the nature and amount of which appear to have been in great measure dependent on their permeability and chemical and mineralogical composition (Fig. 119). This kind of metamorphism may sometimes consist in mere induration, but more commonly it is accompanied by the development of new minerals, or a new crystalline structure, even out of non-crystalline sedimentary materials The very same rock, which is elsewhere a dark limestone full of shells, corals, or other organic remains, may become a white crystalline marble next the granite, with no trace of any organisms, and so unlike its usual condition that no one would readily believe it to be the same rock. Again, a dark shaly sandstone or greywacke traced towards the granite begins

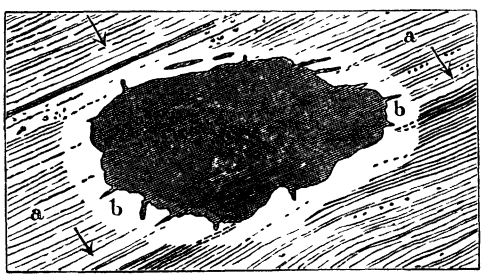



FIG 119 — Ground-plan of Granite-boss with ring of Contact-Metamorphism. (*a*), Sandstones, shales, etc , dipping at high angles in the direction of the arrows , (*b*), zone or ring within which these rocks are metamorphosed , (*c*), granite, sending out veins into *b*.

to show an increasing amount of mica, which has been developed among the original sedimentary grains. Other new minerals likewise make their appearance, particularly garnets, until the rock entirely loses its sedimentary structure and becomes a hornfels or a garnetiferous mica-schist. Shales and slates, as they approach the granite, likewise present a remarkable development of fine mica-plates, and may pass into phyllites, with crystals of chiastolite or other minerals developed in them. The alteration of rocks round eruptive masses is called *contact-metamorphism.*

What the cause may be of this remarkable alteration has not yet been satisfactorily made out The mere heat of large masses of eruptive material was probably sufficient to produce change. There must often have been also a copious discharge of hot vapours and water bearing mineralising agents, which would powerfully

affect the adjacent rocks. Silica and other substances might then be introduced, leading to induration and new chemical rearrangements of the constituents. The protrusion of enormous bodies of granite may also have given rise to mechanical movements in the earth's crust, like those which have produced the shearing and schistose structure, seen in regional metamorphism (p. 221).

**Sills, Intrusive Sheets.**—Sometimes the easiest passage for the erupted material from below has lain between the bedding-planes of strata. The molten rock, after ascending some fissure or pipe, has found its farther progress barred, and has escaped by forcing up the overlying beds and thrusting itself in below them. On cooling and consolidating, it appears as a sheet or bed intercalated between older rocks. This structure is represented in Fig. 120. Any one examining such a section on the ground, might naturally regard the sheet *s* as a bed of lava erupted at the surface, after the

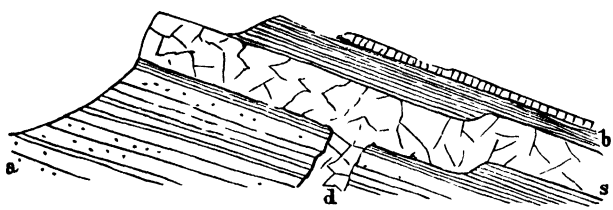



FIG. 120.—Sill or Intrusive Sheet.

formation of the strata *a* and before that of *b*. But various features, characteristic of intrusive or subsequently injected sheets, enable us to distinguish them from those which have been poured out during the deposition of the strata among which they lie. For example, sills break across the strata (as shown in Fig. 120) and send veins into them. They are commonly most close-grained along their edges; sometimes, indeed, these edges have consolidated as a natural glass, showing that the rock at the time of its intrusion was a molten vitreous mass which subsequently assumed a more or less completely crystalline structure, except where it was suddenly chilled by contact with the cool rocks between which it was injected. True lava-streams, on the other hand, being erupted above ground are generally most slaggy and scoriform on their upper and under surfaces (p. 108). Lastly, sills have generally hardened and otherwise altered the rocks above and below them, sometimes baking or even fusing them (p. 187). Where these

characters are present, we may confidently infer that, though a sheet of crystalline rock, so far as visible at the surface, may seem to be regularly interstratified between sedimentary beds, as if it had been contemporaneously poured forth among them, it has

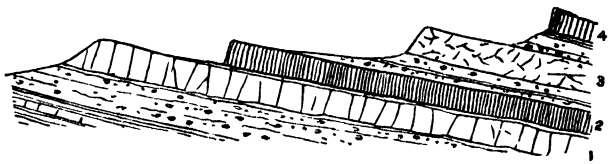



FIG. 121.—Interstratified or contemporaneous Sheets.

nevertheless been thrust in between them and may be of much younger date.

**Contemporaneous Sheets or Interstratified Lavas.**—A truly contemporaneous sheet or group of sheets, marking the actual outpouring of lava-streams at the surface, during the deposition of the strata among which they now lie, may be recognised by equally distinctive characters. Thus a sheet having this origin does not break across nor send veins into the overlying or underlying strata, while its upper and under-surfaces, as above stated, are usually the most open cellular portions, though it is often more or less vesicular or amygdaloidal throughout. In Fig. 121 the beds marked 1, 2, 3, and 4 are sheets of different lavas interstratified contemporaneously in the series of sandstones, shales, limestones, and other strata among which they lie. Fragments of them are not infrequently to be detected in the overlying sediments, which are thus shown to be of later origin, and bands of tuff are commonly associated with them, just as showers of ashes accompany the lava-streams of living volcanoes. As an illustration of the way in which the evidence of ancient volcanic action may be gathered, the section in Fig. 122 may be taken supplementary to the data given already in

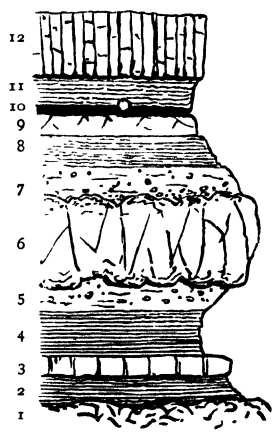



FIG. 122.—Section to illustrate evidence of contemporaneous volcanic action.

Chapter IX. At the bottom of the section we stand on the slaggy upper surface of a lava-stream (1) which was poured out under water, for directly above it comes a seam of dark shale (2) representing fine mud that was deposited from suspension in water. That volcanic explosions still continued after the outflow of the lava, is indicated by the abundant bits of slaggy lava and volcanic detritus scattered through the shale, and that the scene of these operations was the sea-floor is conclusively proved by the numerous shells, crinoids, and other marine remains that lie in some bands of the shale. The bottom must at that time have been muddy, and therefore not so well suited as it afterwards became for the support of life. Above the shale come two feet of limestone (3), entirely made up of fragments of marine organisms, and showing that the water had at last become clear, so that these sea-creatures continued to flourish abundantly until their congregated remains formed a bed of solid stone. But from some change in the geography of the region, currents bearing dark mud once more invaded this part of the sea, and threw down the material that now forms the band of shale (4). The absence of organic remains in this band probably indicates that the inroad of mud destroyed the life previously so prolific. When this condition of things had been brought about, renewed volcanic explosions took place in the neighbourhood. First came showers of dust, ashes, and stones, which fell over the sea, and are now represented by the band of tuff (5). Then followed the outpouring of a stream of lava (6), with its characteristic cellular structure. But this did not quite exhaust the vigour of the volcano, for the band of tuff (7) points to renewed showers of dust and stones. When the explosions ceased, the deposition of dark mud, which had been interrupted by the volcanic episode, was resumed, and the band of shale (8) was laid down. From the fragments of ferns and other plants in this shale, it is clear that land was not far off. The sea had evidently been gradually shallowing by the infilling of sediment and volcanic materials, and at last, on the muddy flat, represented by the layer of fire-clay (9), marshy vegetation sprang up into a thick jungle, like the mangrove-swamps of tropical shores at the present day. After growing long enough to form the bed of matted vegetable matter now represented by the coal-seam (10), the verdant jungle was invaded by the sea, and sank under the muddy water that threw down upon its submerged surface the grey shale (11). In this shale we detect interesting traces of the renewal of volcanic activity, more especially in occasional large

blocks of lava, which have evidently been ejected by volcanic explosions in the near neighbourhood, as in the example already cited on p. 112 (Fig. 47). A more vigorous volcanic outburst

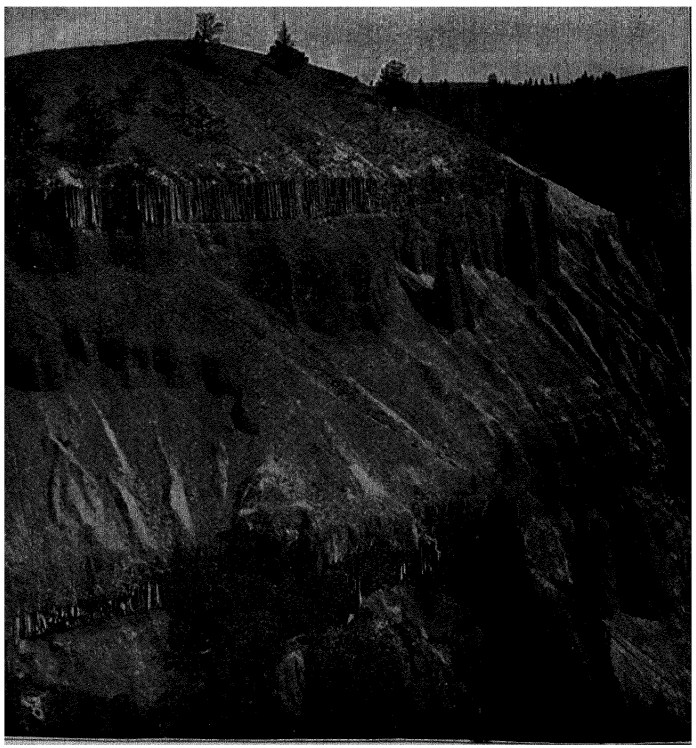


FIG. 123.—Succession of lava-sheets and volcanic conglomerates, Cañon of Yellowstone River, Yellowstone Natural Park. Photograph by Mr. C. D. Walcott, U.S. Geol. Survey.

poured out the stream of columnar lava (12) which buried the whole and forms the top of the section.

In regions where volcanic activity has long ceased, and where the erupted rocks have been for ages exposed to the universal denudation that affects the dry land, the alternation of hard massive lavas with softer tuffs and other fragmental materials has given

rise to many striking topographical features. In Britain and the Faroe Isles the lavas of Tertiary time have been dissected by the sea and have been cut into stupendous precipices and isolated sea-stacks. In Western America similar results have been achieved by the erosive action of rivers combined with the other processes of weathering (Fig. 123).

**Veins** and **Dykes.**—These have already been referred to in Chapter IX. as part of the evidence for volcanic action. We have here to consider how they occur in connection with the protrusion of eruptive material within the crust of the earth. Where the material so erupted has solidified in a vertical or nearly vertical fissure so as to form a wall-like mass, it is called a *dyke* (Fig. 53 and *d* in Fig 120). Otherwise the portions of erupted rock that have consolidated in irregular rents are known as *veins.*

Veins are of common occurrence round bosses of granite, where they can be traced into the parent mass from which they have proceeded (Fig 119). They may likewise be observed in connection with intrusive sheets and bosses of basalt, andesite, trachyte, diorite, and other rocks from which they ramify outwards into the surrounding parts of the earth's crust. Their occurrence there is one of the proofs of the intrusive character and subsequent date of such masses (pp. 226, 228).

Dykes vary from less than a foot to 100 feet or more in breadth, and often run in nearly straight courses, sometimes for many miles. They consist most usually of diabase, andesite, basalt, or some allied rock. Sometimes they have risen along lines of fault; but in hundreds of instances in Great Britain, they do not appear to be connected with any faults, but actually cross some of the largest faults in the country without being deflected. The remarkable way in which dykes have risen through a complicated series of rocks and faults, and have preserved their courses, is exemplified in Fig. 124.

Like intrusive sheets, but in a less degree, dykes harden or otherwise alter the rocks on either side of them; they likewise present a similar closeness of grain or even a glassy texture along their margins, where the molten rock was most rapidly chilled by coming in contact with the cold walls of the fissure. Not infrequently, indeed, their sides are coated with a thin crust of black glass, as if they had been painted with tar (see Basalt-glass, p. 183), as has been already remarked with regard to many sills. No doubt the whole material of such dykes, at the time when it rose from below and filled up the space between the two walls of its

opened fissure, was a molten glass. The portions that were at once chilled by contact with the walls adhered as a layer of glass. But inside this layer, the molten rock had more time to cool. In cooling, its various minerals crystallised, and the present crystalline

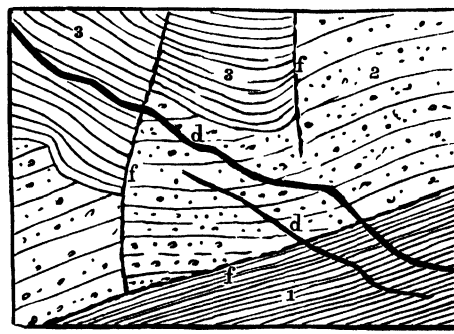



FIG. 124.—Map of Dykes near Muirkirk, Ayrshire 1, Silurian rocks, 2, Lower Old Red Sandstone; 3, Carboniferous rocks; *f*, *f*, *f*, Faults; *d*, *d*, Dykes

structure was developed. But even yet, though most of the rock is formed of crystalline minerals, portions of the original glass may not infrequently be detected between them, when thin sections are placed under the microscope (p. 159).

**Necks.**—These are the filled-up pipes or funnels of former

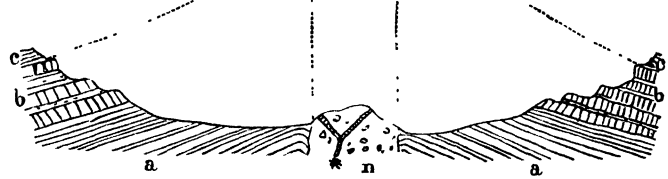



FIG 125.—Section of a volcanic neck The dotted lines suggest the original form of the volcano.

volcanic vents. Their connection with volcanic action has been already alluded to on p. 116. They are circular or elliptical in ground-plan, and vary in diameter from a few yards up to a mile or more (see Figs. 49-52). They consist of some form of lava (quartz-porphyry, andesite, trachyte, diorite, basalt, etc.) or of the fragmentary materials which, after being ejected from the volcanic

chimney, fell back into it and consolidated there. They occur more particularly in districts where beds of lava and tuff are interstratified with other rocks. The necks, in fact, represent vents from which these volcanic materials were ejected. In Fig. 125, for example, the beds of lava and tuff (*b b*) interstratified between the strata *a a* and *c c* have been folded into an anticline. In the centre of the arch rises the neck (*n*), which has probably been the chimney that supplied these volcanic sheets, and which has been filled up with coarse tuff. and traversed with dykes and veins of basalt (*). The dotted lines, suggestive of the outline of the original volcano, may serve to indicate the connection between the neck and its volcanic sheets, and also the effects of denudation

Necks are frequently traversed by dykes (* in Fig 125), as we know also to be the case with the craters of modern volcanoes. The rocks surrounding a neck are sometimes bent down round it, as if they had been dragged down by the subsidence of the material filling up the vent; they are also frequently much hardened and baked When we reflect upon the great heat of molten lava and of the escaping gases and vapours, we may well expect the walls of a volcanic vent to bear witness to the effects of this heat. Sandstones, for instance, as already remarked, have been indurated into quartzite, and shales have been baked into a porcelain-like substance (p 187).

## Mineral Veins

Into the fissures opened in the earth's crust there have been introduced various simple minerals and ores which, solidifying there, have taken the form of *Mineral Veins*. These materials are to be distinguished from the eruptive veins and dykes above described. A true mineral vein consists of one or more minerals filling up a fissure which may be vertical, but is usually more or less inclined, and may vary in width from less than an inch up to 150 feet or more. The commonest minerals (or *veinstones*) found in these veins are quartz, calcite, barytes, and fluor-spar. The metalliferous portions (or *ores*) are sometimes native metals (gold and copper, for example), but are more usually metallic oxides, silicates, carbonates, sulphides, chlorides, or other combinations. These materials are commonly arranged in parallel layers, and it may often be noticed that they have been deposited in duplicate on each side of a vein. In Fig 126, for instance, we see that each wall (w w) is coated with a band of quartz (1, 1), followed

successively by one of blende (sulphide of zinc, 2, 2), galena (sulphide of lead, 3, 3), barytes (4, 4), and quartz (5, 5). The central portion of the vein (6) is sometimes empty or may be filled up with some veinstone or ore Remarkable variations in breadth characterise most mineral veins. Sometimes the two walls come together and thereafter retire from each other far enough to allow a thick mass of mineral matter to have been deposited between them. Great differences may also be observed in the breadth of the several bands composing a vein. One of these bands may swell out so as to occupy the whole breadth of the vein, and then rapidly dwindle down. The ores are more especially liable to

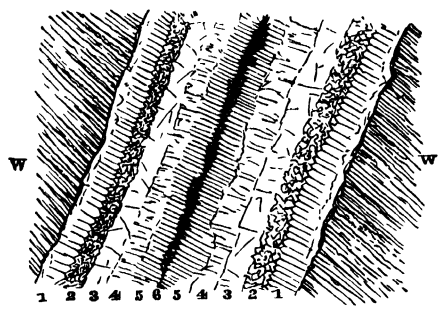



FIG. 126.—Section of a Mineral vein.

such variations. A solid mass of ore may be found many feet in breadth and of great value ; but when followed along the course of the vein, it may die away into mere strings or threads through the veinstones.

The duplication of the layers in mineral veins shows that the deposition proceeded from the walls inwards to the centre. In the diagram (Fig. 126) it is evident that the walls of the open fissure were first coated with quartz. The next substance introduced into the vein was sulphide of zinc, a layer of which was deposited on the quartz. Then came sulphide of lead, and lastly, quartz again. The way in which the quartz-crystals project from the two sides shows that the space between them was free, and, as above stated, it has sometimes remained unfilled up.

There appears to be no reason to doubt that the substances deposited in mineral veins were mainly introduced dissolved in water. Not improbably heated waters rose in the

fissures, and as they cooled in their ascent, they coated the walls with the minerals which they held in solution. These minerals may sometimes have been abstracted from the surrounding rocks by the permeating water; more usually perhaps they have been carried up from some deeper source within the crust. During the process of infilling, or after it was completed, a fissure has sometimes reopened, and a new deposition of veinstones or ores has taken place. Now and then, too, land-shells and pebbles are found far down in mineral veins, showing that during the time when the layers of mineral matter were being deposited, the fissures sometimes communicated with the surface.

**Summary.**—In this chapter it has been shown that, in many cases, rents and cavities in the earth's crust have been filled up with mineral matter introduced into them, either (i) in the molten state, or (ii) in solution in water.

(i) The forms assumed by the masses of eruptive rock injected into the crust of the earth have depended upon the shape of the openings into which the melted matter has been poured, as the form of a body of cast-iron is regulated by that of the mould into which the melted metal is allowed to run. Taking this principle of arrangement, we find that eruptive rocks may be grouped into (1) Bosses, or irregularly-shaped masses, which have risen through and solidified in fissures or orifices, and now, owing to the removal of the rock under which they lay, form hills or ridges. The eruptive material sends out veins into the surrounding rocks which are sometimes considerably altered, forming a metamorphic ring round the eruptive rock. (2) Sills or sheets which have been thrust between the bedding-planes of strata. These resemble truly interstratified beds, but the difference between the two kinds of structure can be readily appreciated. Interstratified lavas and tuffs mark the occurrence of volcanic phenomena at the surface, during the time of the formation of the strata among which they occur. Intrusive sheets, on the other hand, are always subsequent in date to the rocks between which they lie. (3) Veins and dykes, consisting of eruptive rock which has been thrust between the walls of irregular rents or straight fissures. (4) Necks, or the filled-up pipes of former volcanic vents.

(ii) Mineral veins are masses of mineral matter which has been deposited, probably in most cases from aqueous solution, between the walls of fissures in the earth's crust, and consists of bands of veinstones (quartz, calcite, barytes, etc.) and ores (native metals, or oxides, sulphides, etc., of metals).

## CHAPTER XV

### HOW FOSSILS HAVE BEEN ENTOMBED AND PRESERVED, AND HOW THEY ARE USED IN INVESTIGATING THE STRUCTURE OF THE EARTH'S CRUST, AND IN STUDYING GEOLOGICAL HISTORY

IN an earlier part of this volume (Chapter VIII.) attention was called to the various circumstances under which the remains of plants and animals may be entombed and preserved in sedimentary accumulations. When these remains have thus been buried they are known as *Fossils*.

**Nature and use of Fossils.**—The word "fossil," meaning literally "dug up," was originally applied to all kinds of mineral substances taken out of the earth; but it is now exclusively used for the remains or traces of plants and animals imbedded by natural causes in any kind of rock, whether loose and incoherent, like blown sand, or solid, like the most compact limestone. It includes not only the actual remains of the organisms. The empty mould of a shell which has decayed out of the stone that once enveloped it, or the cast of the shell which has been entirely replaced by inorganic sand, mud, calcite, silica, etc., are fossils. The very impressions left by organisms, such as the burrow or trail of a worm in hardened mud, and the footprints of birds and quadrupeds upon what is now sandstone, are undoubted fossils. In short, under this general term is included whatever bears traces of the form, structure, or presence of organisms preserved in the sedimentary accumulations of the surface, or in the rocks underneath.

In geological history fossils are of fundamental importance. They enable us to investigate conditions of geography, of climate, and of life in ancient times, when these conditions were very

different from those which now prevail on the earth's surface. They likewise furnish the ground on which the several epochs of geological history can be determined, and on which the stages of that history in one country can be compared with those in another. So valuable and varied is the evidence supplied by fossils to the geologist, that he regards them as among the most precious documents accessible to him for unravelling the past history of the earth. Some knowledge of the structure and classification of plants and animals is essential for an intelligent appreciation of the use of fossils in geological inquiry. To aid the learner, a synopsis of the Vegetable and Animal Kingdoms is given in the Appendix, with especial reference to the fossil forms; but it must be understood that for adequate information on this subjects recourse should be had to text-books of Botany and Zoology.

**Conditions for the preservation of Organic Remains.**—It is obvious that all kinds of plants and animals have not the same chances of being preserved as fossils. In the first place, only those, as a rule, are likely to become fossils whose remains can be kept from decay and dissolution by being entombed in some kind of deposit. Hence land-animals and plants have, on the whole, less chance of preservation than those living in the sea, because deposits capable of receiving and securing their remains are exceptional on land, but are generally distributed over the floor of the sea (pp. 100, 101). Moreover, the ocean covers now, and probably always has covered, a far larger area of the earth's surface than the land. We should expect, therefore, that among the records of past time, traces of marine should largely preponderate over traces of terrestrial life. Now this is everywhere the case. We know relatively little of the assemblages of plants and animals which in successive epochs have lived upon the dry land, but we have a comparatively large amount of information regarding those which have tenanted the sea. For this reason, marine fossils are more valuable than terrestrial, in comparing the records of the successive epochs of geological history in different parts of the globe.

In the second place, from their own chemical composition and structure, plants and animals present extraordinary differences in their aptitude for preservation as fossils. Where they possess no hard parts, and are liable to speedy decay, we can hardly expect that they should leave behind them any enduring relic of their existence. Hence a large proportion, both of the vegetable and

animal kingdoms, may at once be excluded as inherently unlikely to occur in the fossil condition. Of course, under exceptional circumstances, traces of almost any organism may be preserved, and therefore we should probably not be justified in saying that by no chance might some recognisable vestige of it be found fossil. Nothing seems more perishable than the tiny gnats and other forms of insect life that fill the air on a summer evening. Yet many of these short-lived flies have been sealed up within the resin of trees (amber), and their structure has been admirably preserved. Even moulds of jelly-fish have been found in Cambrian strata (p. 271). Such exceptional instances, however, only bring out more distinctly how large a proportion of organisms must perish without leaving any recognisable record of their ever having existed.

But, where there are hard parts in an organism, and especially where, from their chemical composition, they can for some time resist decay, they may, under favourable conditions, be buried in sedimentary deposits, and may remain for indefinite ages locked up there. It is obvious, therefore, that animals possessing hard parts are much the most likely to leave permanent relics of their presence, and ought to occur most frequently as fossils. It is these animals whose remains are preserved in peat-mosses, river-gravels, lake-marls, and on the sea-floor at the present time. Yet, if we were to judge of the extent of the whole existing animal kingdom solely from the fragmentary remains so preserved, what an utterly inadequate conception of it we should form! So, too, if we estimate the variety of the living creatures of past time merely from the evidence of the fossils that have chanced to be preserved among the rocks, we shall probably arrive at quite as erroneous a conclusion. There can be no doubt that from the earliest time only an insignificant fraction of the varied life of each period has been preserved in the fossil state, as is unquestionably the case at the present day.

**Durable parts of Plants.**—The essential parts of the solid framework of plants consist of the substances known as cellulose and vasculose, which, when kept in dry air, or when water-logged and buried in stiff mud, may remain undecomposed for long periods. The timber beams in the roofs and floors of old buildings are evidence that, under favourable conditions, wood may last for many centuries. Some plants eliminate carbonate of lime from solution in water, and form with it a solid substance which requires no further treatment to enable it to endure for an indefinite period, when screened from the action of water. Still more durable are

the remains of those plants which abstract silica and build it up into their framework, such as the diatoms of which the frustules become remarkably permanent fossils, in the form of diatom-earth or tripoli-powder, which is made up of them (p. 94).

**Durable parts of Animals** —The hard parts of animals may be preserved with little or no chemical change, and remain as durable relics The hard horny integuments of insects, arachnids, crustacea, and some other animals, are composed essentially of the substance called *chitin*, which can long resist decomposition, and which may therefore be looked for in the sedimentary deposits of the present time, as well as of former periods The chitin of some fossil scorpions, admirably preserved among the Carboniferous rocks of Scotland, can hardly be distinguished from that of the living scorpion. Many of the lower forms of animal life secrete silica, and their hard parts are consequently easily preserved, as in the case of radiolaria and sponges. In the great majority of instances, however, the hard parts of invertebrates consist mainly of carbonate of lime, and are readily preserved among sedimentary deposits. The skeletons of corals, the plates of echinoderms, and the shells of molluscs, are examples of the abundance of calcareous organisms, and the frequency of their remains in the fossil state shows how well fitted they are for preservation. Among vertebrates the hard part consists chiefly of phosphate of lime. In some forms (ganoid fishes and crocodiles, for example) this substance is partly disposed outside the body (exo-skeleton) in the form of scales, scutes, or bony plates. But more usually it is confined to the internal skeleton (endo-skeleton). It is mainly by their bones and teeth that the higher vertebrates can be recognised in the fossil state. Sometimes the excrement has been preserved (*Coprolites*), and may furnish information regarding the food of the animals, portions of undigested scales, teeth, and bones being traceable in it (Fig. 76).

**Fossilisation** —The process by which the remains of a plant or animal are entombed and preserved in the fossil state is termed Fossilisation. It varies greatly in details, but all these may be reduced to three leading types.

1. *Entire or partial preservation of the original substance.*— In rare instances, the entire animal or plant has been preserved, of which the most remarkable examples are those where carcases of the extinct mammoth have been sealed up in the frozen mud and peat of Siberia, and have thus been preserved in ice. Insects, as above mentioned, have been involved in the resin of trees, and

may now be seen, embalmed like mummies, in amber. More usually, however, a variable proportion of the organic matter has passed away, and its more durable parts have been left, as in the carbonisation of plants (peat, lignite, coal) and the disappearance of the organic matter from shells and bones, which then become dry and brittle and adhere to the tongue.

2. *Entire removal of the original substance and internal structure, only the external form being preserved.*—When a dead animal or plant has been entombed, the mineral matter in which it lies hardens round it and takes a mould of its form. This may be accomplished with great perfection if the material is sufficiently fine-grained and solidifies before the object within has time to

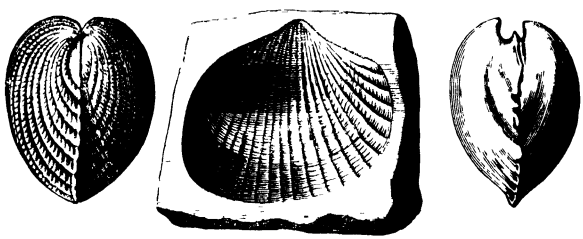



FIG. 127.—Common Cockle (*Cardium edule*); (*a*), side view of both valves, (*b*), mould of the external form of one valve taken in plaster of Paris, (*c*), side view of cast in plaster of Paris of interior of the united valves.

decay. Carbonate of lime and silica are specially well adapted for taking the moulds of organisms, but fine mud, marl, and sand are also effective. The organism may then entirely decay, and its substance may be gradually removed by percolating water, leaving a hollow empty space or mould of its form. Such moulds are of frequent occurrence among fossiliferous rocks, and are specially characteristic of molluscs, the shells of which are so abundant, and occur imbedded in so many different kinds of material. Sometimes it is the external form of the shell that has been taken, the shell itself having entirely disappeared; in other cases a cast of the interior of the shell has been preserved. How different these two representations of the same shell may be is shown in Fig 127, wherein *a* represents a side view of the common cockle, while *c* is a cast of the interior of the shell in plaster of Paris. The contrast between a mould of the outside and inside of the

same shell is shown by the difference between *b* and *c*, which are both impressions taken in plaster.

After the decay and removal of the substance of the enclosed organisms, the moulds may be filled up with mineral matter, which is sometimes different from the surrounding rock. The empty cavities have formed convenient receptacles for any deposit which permeating water might introduce. Hence we find casts of organisms in sand, clay, ironstone, silica, limestone, pyrites, and other mineral substances. Of course, in such cases, though the external form of the original organism is preserved, there is no trace of internal structure. No single particle of the cast may ever have formed part of the plant or animal.

3. *Partial or entire petrifaction of organic structure by molecular replacement.*—Plants and animals which have undergone this change have had their substance gradually removed and replaced, particle by particle, with mineral matter. This transformation has been effected by percolating water containing mineral solutions, and has proceeded so tranquilly, that sometimes not a delicate tissue in the internal structure of a plant has been displaced, and yet so rapidly, that the plant had not time to rot before the conversion was completed. Accordingly, in true *petrifactions*, that is, plants or animals of which the structure has been more or less perfectly preserved in stone, the petrifying material is always such as may have been deposited from water. The most common substance employed by nature in the process of petrifaction is carbonate of lime, which, as we have seen, is almost always present in the water of springs and rivers. Organic structures replaced by this substance are said to be *calcified*. Frequently the carbonate of lime has assumed, more or less completely, a crystalline structure after its deposition, and in so doing has generally injured or destroyed the organic structure which it originally replaced. Where the calcareous matter of an organism has been removed by percolating water, as often happens in sands, gravels, or other porous deposits, the fossil is said to be *decalcified*. Another abundant petrifying medium in nature is silica, which, in its soluble form, is generally diffused in terrestrial waters, where humous acids or organic matter are present in solution. The replacement of organic structures by silica, called *silicification*, furnishes the most perfect form of petrifaction. The interchange of mineral matter has been so complete that even the finest microscopic structures have been faithfully preserved. Silicified wood is an excellent example of this perfect replacement. Sulphides,

which are often produced by the reducing action of decaying organic matter upon sulphates, occur also as petrifying media, the most common being the iron sulphide, usually in the less stable form of marcasite, but sometimes as pyrite. Carbonate of iron likewise frequently replaces organic structures ; the clay-ironstones of the Carboniferous system abound with the remains of plants, shells, fishes, and other organisms which have been converted into siderite (Figs. 72, 76).

The chief value of fossils in geology is to be found in the light which they cast upon former conditions of geography and climate, in the clue which they furnish as to the relative ages of different geological formations, and in the materials which they supply for a history of the evolution of organised existence upon the earth.

1. **How Fossils indicate former changes in Geography.**— Terrestrial plants and animals obviously point to the existence of land. If their remains are found in strata wherein most of the fossils are marine, they usually show that the deposits were laid down upon the sea-floor not far from land. But where they occur in the positions in which they lived and died, they prove that their site was formerly a land-surface. The stumps of trees remaining in their positions of growth, with their roots branching out freely from them in the clay or loam underneath undoubtedly mark the position of an ancient woodland. If, besides these remains, there are associated in the same strata leaves, fruits, or seeds, together with wing-cases of beetles, bones of birds and of land-animals, additional corroborative evidence is thereby obtained as to the existence of the ancient land. More usually, however, it is by deposits left on lake-bottoms that the land of former periods of geological history is known. As already pointed out (Chapter IV.), the fine mud and marl of lakes receive and preserve abundant relics of the vegetation and animal life of the surrounding regions. As illustrations of lacustrine formations, from which most of our knowledge of the contemporary terrestrial life is obtained, reference may be made to the Molasse of Switzerland, the limestones and marls of the Limagne d'Auvergne, in Central France, and the vast depth of strata from which so rich an assemblage of plant and animal remains has been obtained in the Western Territories of the United States (see Chapter XXV.). Alternations of buried forests or peat-mosses, with lake deposits, show how lakes have successively increased and diminished in volume. The frequent occurrence of a bed of lacustrine marl at the bottom of a peat-bog

proves how commonly shallow lakes have been filled up and displaced by the growth of marshy vegetation (pp. 4, 92).

Remains of marine plants and animals almost invariably demonstrate that the locality in which they are found was once covered by the sea Exceptions to this rule are so few as hardly to be worthy of special notice, as, for instance, when molluscs, crustaceans, and other forms of marine life are carried up by sea-birds to considerable elevations, where, after their soft parts have been eaten, their hard shells and crusts may be preserved in truly terrestrial deposits, or when sea-shells, tossed up by breakers above the tide-line, are swept inland by wind.

Rolled fragments of shells, mingled in well-rounded gravel and sand, point to some former shore where these materials were ground down by beach-waves. Fine muddy sediment, containing unbroken shells, echinoderms, crustaceans, and other relics of the sea, indicate deeper water beyond the scour of waves, tides, and currents. Beds of limestone, full of corals and crinoids, mark the site of a clear sea, in which these organisms were allowed to flourish undisturbed for many generations It may often be observed that the fossils, which are abundant and large in a limestone, become few in number and small in size in an overlying bed of shale or clay ; or that they wholly disappear in the argillaceous rock. The meaning of this can hardly be mistaken. The clear water in which the marine creatures were able to build up the limestone was at last invaded by some current carrying mud. Consequently, while the more delicate forms perished, others continued to live on in diminished numbers and dwarfed development, until at last the muddy sediment settled down so thickly that the animals, whose hard parts might have been preserved, were killed off upon that area of the sea-bottom.

2. **How Fossils indicate former conditions of Climate.**— The remains of plants or animals characteristic of tropical countries may be taken to bear witness to a tropical climate at the time which they represent. If, for example, a deposit were found containing leaves of palms and bones of tigers, lions, and elephants, we should infer that it was formed in tropical conditions, such as are now presented by the warmer parts of Africa or Asia. On the other hand, were a stratum to yield leaves of a small birch and willow, with bones of reindeer, musk-ox, and lemming, we would regard it as evidence of a cold climate. Such inferences, however, must be based either upon the occurrence of the very same species as are now living, and the characteristic climate of

which is known, or upon assemblages of plants or animals which may be compared with corresponding assemblages now living. We may be tolerably confident that the existing reindeer has always been restricted to a cold climate, and that the living elephants have as characteristically been confined to warm climates. But it would be rash to assume that all deer prefer cold and all elephants choose heat. The bones of an extinct variety of elephant and one of rhinoceros, have long been known as occurring even up within the Arctic regions, and when these remains were first found the conclusion was naturally drawn that they proved the former existence of a warm climate in the far north. But the subsequent discovery of entire carcases of the animals covered with a thick mat of woolly hair, showed that they were adapted for life in a cold climate, and their occurrence in association with the remains of animals which still live in the Arctic regions, proved beyond doubt that the original inference regarding them was erroneous In drawing conclusions as to climate from fossil evidence, it is always desirable to base them upon the concurrent testimony of as large a variety of organisms as possible, and to remember that they become less and less reliable in proportion as the organisms on which they are founded depart from the species now living.

3. **How Fossils indicate Geological Chronology.**—As the result of careful observations all over the world, it has been ascertained that in the youngest strata the organic remains are nearly or quite the same as species now living, but that, as we proceed into older strata, the number of existing species diminishes, and the number of extinct species increases, until at last no living species is to be found. Moreover, the extinct species found in younger strata disappear as we trace them back into older rocks, and their places are taken by other extinct species. Every great series of fossiliferous rocks is thus characterised by its own peculiar assemblage of species. Not only do the species change; the genera, too, disappear one by one as we follow them into older rocks, until among the earliest strata only a few of the living genera are represented. Whole families and orders of animals which once flourished have utterly vanished from the living world, and we only know of their existence from the remains of them preserved among the rocks.

A certain definite order of succession has been observed among the organic remains imbedded in the stratified rocks of the earth's crust, and this order has been found to be broadly alike all over

the world. The fossils of the oldest fossiliferous rocks of Europe, for instance, are like those of the oldest fossiliferous rocks of Asia, Africa, America, and Australasia, and those of each succeeding series of rocks follow the same general sequence. It is obvious, therefore, that fossils supply us with an invaluable means of fixing the relative position of rocks in the series of geological formations. Whether or not the same type of fossils was always contemporaneous over the whole planet cannot be determined; but it generally occupied the same place in the procession of life. Hence stratified formations, which may be quite unlike each other in regard to the nature of their component materials, if they contain similar organic remains, may be compared with each other, and classed under the same name.

Fossils characteristic of particular subdivisions of the series of geological formations (see Table, p. 256) are of great service as guides to the relative age of the rocks that contain them. Of these the following are examples :—

Lepidodendra and Sigillariæ, characteristic of Old Red Sandstone and Carboniferous rocks (pp 288, 306).
Cycads, characteristic of Mesozoic rocks (pp 318, 323, 325, 332, 350).
Graptolites, characteristic of Silurian rocks (pp 270, 279, 292)
Trilobites ,, Cambrian to Carboniferous rocks (pp. 271, 281, 293, 307).
Cystideans, characteristic of Silurian rocks (Fig 137).
Blastoids ,, Carboniferous rocks (Fig 165).
Hippurites ,, Cretaceous rocks (p 353)
Orthoceratites ,, Palæozoic rocks (Figs. 144, 172).
Ammonites ,, Mesozoic rocks (Figs. 182, 191, 205).
Cephalaspids ,, Silurian, Old Red Sandstone (pp 284, 290).
Ichthyosaurus and Plesiosaurus—Mesozoic rocks (Figs 328, 338, 356).
Iguanodon—Cretaceous rocks (p 356)
Toothed birds—Jurassic and Cretaceous rocks (pp. 341, 357)
Nummulites, Palæotherium, Anoplotherium, Deinocerata, characteristic of older Tertiary rocks (pp 368, 370, 371, 372, 377)
Mastodon, Elephas, Equus, Cervus, Hyæna, Apes, characteristic of younger Tertiary and Recent rocks (pp. 382, 387, 388, 390, 400, 408).

By attentive study and comparison, the fossiliferous rocks in different countries have been subdivided into sections, each characterised by its own facies or type of organic remains. Consequently, beginning with the oldest and proceeding upward to the youngest, we advance through natural chronicles of the successive tribes of plants and animals which have lived on the earth's surface. These chronicles, consisting of sandstones, shales, limestones, and the other kinds of stratified deposits, form what is

called the Geological Record. In order to establish their true sequence in time, their *Order of Superposition* (p. 3) must first be determined; that is, it is requisite to know which lie at the bottom, and must have been formed first, and in what order the others succeed them. When this fundamental question has once been settled, then the fossils characteristic of each group of strata serve as a guide for recognising that group wherever it may be found.

While fossils enable us to divide the Geological Record into chapters, they also show how strikingly imperfect this record is as a history of the plants and animals that have lived on the surface of the earth, and of the revolutions which that surface has undergone. We may be sure that the progress of life, from its earliest appearance in lowly forms of plant or animal, has been continuous up to the present condition of things. But in the Geological Record there occur numerous gaps. The fossils of one group of rocks may be succeeded by a more or less completely different series in the next group. At one time it was supposed that such breaks in the continuity of the record marked terrestrial convulsions which caused the destruction of the plants and animals of the time, and were followed by the creation of new tribes of living things. But evidence has every year been augmenting to indicate that no such general destruction and fresh creation ever took place. The gaps in the record mark no real interruption of the life of the globe They are rather to be looked upon as chapters that have been torn out of the annals, or which never were written. We have already learned in Chapter VIII. how many chances there must be against the preservation of anything like a complete record of the life of the globe at any particular time. It is also clear that even where the chronicle may have been comparatively full, it is exposed to many dangers afterwards. The rocks containing it may be hidden beneath the sea, or raised up into land and entirely worn away, or entombed beneath volcanic ejections, or so crushed and crumpled as to become no longer legible.

Taking fossils as a guide, geologists have partitioned the fossiliferous rocks into what are called *stratigraphical* subdivisions as follows:—A bed, or limited number of beds, in which one or more distinctive species of fossils occur, is called a *zone* or *horizon*, and may be named after its most typical fossil. Thus in the Lias, the zone in which the ammonite known as *Ammonites Jamesoni* occurs, is spoken of as the "zone of *Ammonites Jamesoni*," or "*Jamesoni*-zone." Two or more zones, united by the

occurrence in them of a number of the same characteristic species or genera, form what are known as *Beds* or an *Assise*. Two or more of such beds or assises may be termed a *Group* or *Stage*. Where the number of assises in a stage is large they may be subdivided into *Sub-stages* or *Sub-groups*. The stage or group will then consist of several sub-stages, and each sub-stage or sub-group of several assises. A number of groups or stages is combined into a *Series*, *Section*, or *Formation*, and a number of series, sections, or formations constitute a *System*. A number of systems are connected together to form each of the great divisions of the Geological Record. This classification will be best understood if placed in tabular form, as in the subjoined subdivisions, which occur in the Cretaceous System.[1]

| Stratigraphical Components | | Descriptive Names | Examples from the Cretaceous System of Europe. |
|---|---|---|---|
| A stratum, layer, seam, or bed, or a number of such minor subdivisions, characterised by some distinctive fossil | = | one or horizon . . | Zone of *Pecten asper* |
| Two or more zones | = | Beds or an assise . . | Warminster beds |
| Two or more sets of connected beds or assises | = | Group or stage, which may be subdivided into sub-groups or sub-stages | Cenomanian stage, comprising the Rothomagian and Carentonian sub-stages |
| Two or more groups or stages | = | Series, section, or formation | Neocomian formation. |
| Several related formations | = | System . | Cretaceous System |

The names by which the larger subdivisions of the Geological Record are known have been adopted at various times and on no regular system. Some of them are purely lithological; that is, they refer to the mere mineral nature of the strata, apart altogether from their fossils, such as Coal-measures, Chalk, Greensand, Oolite. These names belong to the early years of the progress of geology, before the nature and value of organic remains had been definitely realised. Other epithets have been suggested by localities where the strata were first noticed, as Bath

[1] For an account of the Cretaceous System, see Chapter XXIV.

Oolite (Bathonian), Oxford Clay (Oxfordian), Portland Stone (Portlandian). The more recent names for the larger divisions have, in general, been chosen from districts where the formations are typically developed, or where they were first critically studied, *e.g.* Silurian, Devonian, Permian, Jurassic. In some cases, the larger subdivisions have received names from some distinguishing feature in their fossil contents, as Eocene, Miocene, Pliocene [1] But it is mainly to the minor sections that the characters of the fossil contents have supplied names.

The designation of any particular group of strata has gradually come to acquire a chronological meaning. Thus the term Carboniferous formations or system was originally applied to a series of strata in which the occurrence of coal and carbonaceous shales is a distinctive feature. It includes a thick series of limestones, clays, sandstones, and other strata, replete with organic remains, and containing the records of a long interval of geological time, which were first observed in Europe, but of which representatives have since been found all over the globe. Though it does not always contain coal, yet the name Carboniferous is retained for any group of strata that includes some of the typical fossils of the system. We also speak of the Carboniferous period —a phrase which, in the strict grammatical use of the word, is of course incorrect, but which conveniently designates the period of geological time during which the great series of Carboniferous strata was deposited, and when the abundant life of which they contain the remains flourished on the surface of the earth. This chronological meaning has indeed come to be the more usual sense in which the names of the major subdivisions of the Geological Record are generally employed. Such adjectives as Devonian and Jurassic do not so much suggest to the mind of the geologist Devonshire and the Jura Mountains, from which they were taken, nor even the rocks to which they are applied, as the great sections of the earth's history of which these rocks contain the memorials. He compares the Jurassic or Devonian rocks of one country with those of another, studies the organic remains contained in them, and then obtains materials for forming some conception of what were the conditions of geography and climate, and what was the general character of the vegetable and animal life of the globe, during the periods which he classes as Jurassic and Devonian.

[1] For the meanings of these names see Chapter XXV p 367

**Summary.**—Fossils are the remains or traces of plants and animals which have been imbedded in the rocks of the earth's crust. From the exceptional nature of the circumstances in which these remains have been entombed and preserved, only a comparatively small proportion of the various tribes of plants and animals living at any time upon the earth is likely to be fossilised. Those organisms which contain hard parts are best fitted for becoming fossils. The original substance of the organism may, in rare cases, be preserved; more usually the organic matter is partially or wholly removed. Sometimes a mere cast of the plant or animal in amorphous mineral matter retains the outward form without any trace of the internal structure. In other instances, true petrifaction has taken place, the organic structure being reproduced in calcite, silica, or other mineral by molecular replacement.

Fossils are of the utmost value in geology, inasmuch as they indicate (1) former changes in geography, such as the existence of ancient land-surfaces, lakes, and rivers, the former extension of the sea over what is now dry land, and changes in the currents of the ocean; (2) former conditions of climate, such as an Arctic state of things as far south as Central France, where bones of reindeer and other Arctic animals have been found; (3) the chronological sequence of geological formations, and, consequently, the succession of events in geological history, each great group of strata being characterised by its distinctive fossils. This is the most important use of fossils in geology. Having ascertained the order of superposition of fossiliferous rocks, that is, the order in which they were successively deposited, and having found what are the characteristic fossils of each subdivision, we obtain a guide by which to identify the various rock-groups from district to district, and from country to country. By means of the evidence of fossils the stratified rocks of the Geological Record have been divided into sections and sub-sections, to which names are applied that have now come to designate not merely the rocks and their fossils, but the period of geological time during which these rocks were accumulated and these fossils actually lived. Fossils are of the utmost importance as memorials of the successive stages through which plants and animals have passed since organic life first appeared upon the earth. They are thus indispensable in the study of the genetic relations of the various types in the living vegetable and animal worlds.

# PART IV

# THE GEOLOGICAL RECORD OF THE HISTORY OF THE EARTH

## CHAPTER XVI

### THE EARLIEST CONDITIONS OF THE GLOBE—THE ARCHÆAN PERIODS

THE foregoing chapters have dealt chiefly with the materials of which the crust of the earth consists, with the processes whereby these materials are produced or modified, and with the methods pursued by geologists in making their study of these materials and processes subservient to the elucidation of the History of the Earth. The soils, rocks, and minerals beneath our feet, like the inscriptions and sculptures of a long-lost race of people, are in themselves full of interest, apart from the story which they chronicle; but it is when they are made to reveal the history of land and sea, and of life upon the earth, that they are put to their noblest use. The investigation of the various processes whereby geological changes are carried on at the present day is undoubtedly full of fascination for the student of nature; yet he is conscious that it gains enormously in interest when he reflects that in watching the geological operations of the present day he is brought face to face with the same instruments whereby the very framework of the continents has been piled up and sculptured into the present outlines of mountain, valley, and plain.

The highest aim of the geologist is to trace the history of the earth. All his researches, remote though they may seem from this

aim, are linked together in the one great task of unravelling the successive mutations through which each area of the earth's surface has passed, and of discovering what successive races of plants and animals have appeared upon the globe. The investigation of facts and processes, to which the previous pages have been devoted, must accordingly be regarded as in one sense introductory to the highest branch of geological inquiry. We have now to apply the methods and principles already discussed to the elucidation of the history of our planet and its inhabitants. Within the limits of this volume only a mere outline of what has been ascertained regarding this history can be given. I shall arrange in chronological order the main phases through which the globe seems to have passed, and present such a general summary of the more important facts regarding each of them as may, I hope, convey an adequate outline of what is at present known regarding the successive periods of geological history.

As the primitive stages of mankind upon the earth and the early progress of every race fade into the obscurities of mythology and archæology, so the story of the primeval condition of our globe is lost in the dim light of remote ages, regarding which almost all that is known or can be surmised is furnished by the calculations and speculations of the astronomer. If the earth's history could only be traced out from evidence supplied by the planet itself, it could be followed no further back than the oldest portions of the earth now accessible to us Yet there can be no doubt that the planet must have had a long history before the appearance of any of the solid portions now to be seen That such was the case is made almost certain by the traces of a gradual evolution or development which astronomers have been led to recognise among the heavenly bodies. Our earth being only one of a number of planets revolving round the sun, the earliest stages of its separate existence must be studied in reference to the whole planetary system of which it forms a part. Thus, in compiling the earliest chapter of the history of the earth, the geologist turns for evidence to the researches of the astronomer among stars and nebulæ.

In recent years, more precise methods of inquiry, and, in particular, the application of the spectroscope to the study of the stars, have lent support to the Nebular Hypothesis of Laplace. According to this speculation, the orderly related series of heavenly bodies, which we call the Solar System, existed at one time, enormously remote from the present, as a Nebula—that is, a cloudy mass of matter, like one of those nebulous, faintly luminous

clouds which can be seen in the heavens. This nebula probably extended at least as far as the outermost planetary member of the system is now removed from the sun. It may have consisted entirely of incandescent gases or vapours, or of clouds of stones in rapid movement, like the stones that from time to time fall through our atmosphere as meteorites, and reach the surface of the earth. The collision of these stones moving with planetary velocity would dissipate them into vapour, as is perhaps the case in the faint luminous tails of comets. At all events, the materials of the nebula began to condense, and in so doing threw off, or left behind, successive rings (like those around the planet Saturn), which, in obedience to the rotation of the parent nebula, began to rotate in one general plane around the gradually shrinking nucleus. As the process of condensation proceeded, these rings broke up, and their fragments rushed together with such force as not improbably to generate heat enough to dissipate them again into vapour. They eventually condensed into planets, sometimes with a further formation of rings, or with a disruption of these secondary rings, and the consequent formation of moons or satellites round the planets The outer planets would thus be the oldest, and, on the whole, the coolest and least dense. Towards the centre of the nebula the heaviest elements might be expected to condense, and there the high temperature would longest continue. The sun is the remaining intensely hot nucleus of the original nebula, from which heat is still radiated to the furthest part of the system.

When a planetary ring broke up, and by the heat thereby generated was probably reduced to the state of vapour, its materials, as they cooled, would tend to arrange themselves in accordance with their respective densities, the heaviest in the centre, and the lightest outside. In process of time, as cooling and contraction advanced, the outer layers might grow quite cold, while the inner nucleus of the planet might still be intensely hot. Such, in brief, is the well-known Nebular Hypothesis.

Now the present condition of our earth is very much what, according to this hypothesis or theory, it might be expected to be. On the outside comes the lightest layer or shell in the form of an Atmosphere, consisting of gases and vapours. Below this gaseous envelope which entirely surrounds the globe lies an inner envelope of water, the Ocean or hydrosphere, which covers about two-thirds of the earth's surface, and is likewise composed mainly of gases in a liquid form. Underneath this watery covering, and

rising above it in dry land, rests the solid part of the globe (lithosphere) which, so far as accessible to us, is composed of rocks twice or thrice the weight of pure water. But observations with the pendulum at various heights above the sea show that the attraction of the earth as a whole indicates that the globe probably has a density about five and a half times that of water. Hence its inner nucleus has been supposed to consist of heavy, possibly metallic, materials.

Again, the outside of the earth is now quite cool; but abundant proof exists that at no great distance below the surface the temperature is high (p. 104). Volcanoes, hot springs, and artificial borings all over the world testify to the abundant store of heat within the earth. By far the largest part of the planet may be hotter than molten iron. We may admit it to be probable that the earth was formerly in the state of incandescent vapour, and that it has ever since that time been cooling and contracting. Some physicists, indeed, believe that the central mass of the planet still remains in a gaseous condition at an enormously high temperature and under vast pressure; that, as it slowly cools, it condenses on the outside into a layer or shell of molten material, and that this thin shell by cooling becomes solid, and thus increases the depth of the crust, which may be 25 miles thick. The flattening at the poles and bulging at the equator, or what is called the oblately spheroidal figure of the planet, is just the shape which a plastic mass would have assumed in obedience to the influence of the movement of rotation, imparted to it when detached from the parent nebula.

At present a complete rotation is performed by the earth in twenty-four hours. But calculations have been made with the result of showing that originally the rate of rotation was much greater. Fifty-seven millions of years ago it was about four times faster, the length of the day being only six and three-quarter hours. The moon at that time was only about 35,000 miles distant from the earth, instead of 239,000 miles as at present. Since these early times the rate of rotation has gradually been diminishing, and the figure of the earth has been slowly tending to become more spherical, by sinking in the equatorial and rising in the polar regions.

Of the first hard crust that formed upon the surface of the earth no trace has yet been found. Indeed, there is reason to suppose that this original crust would break up and sink into the molten mass beneath, and that not until after many such formations

and submergences did a crust establish itself of sufficient strength to form a permanent solid surface. Even though solid, the surface may still have been at a glowing red-heat, like so much molten iron. Over this burning nucleus lay the original atmosphere, consisting not merely of the gases in the present atmosphere, but of the hot vapours which subsequently condensed into the ocean, or were absorbed into the crust. It was a hot, vaporous envelope, under the pressure of which the first layers of water that condensed from it may have had the temperature of molten lead.

Regarding these early ages in the earth's history we can only surmise, for no direct record of them has been preserved. They are sometimes spoken of as pre-geological; but geology really embraces the whole history of the planet, no matter from what sources the evidence may be obtained. Deposits from this original hot ocean have been supposed to be recognisable in the very oldest crystalline schists; but for this supposition there does not appear to be any good ground. The early history of our planet, like that of man himself, is lost in the dimness of antiquity, and we can only speculate about it on more or less plausible suppositions.

When we come to the solid framework of the earth we stand on firmer footing in the investigation of geological history. The terrestrial crust, or that portion of the globe which is accessible to human observation, has been found to consist of successive layers of rock, which, though far from constant in their occurrence, and though often broken and crumpled by subsequent disturbance, have been recognised over a large part of the globe. They contain the earth's own chronicle of its history, which has already been referred to as the Geological Record, and the subdivision of which into larger and minor sections, according mainly to the evidence of fossils, was explained in the preceding chapter.

Had the successive layers of rock that constitute the Geological Record remained in their original positions, only the uppermost, and therefore most recent, of them would have been visible, and nothing more could have been learnt regarding the underlying layers, except in so far as it might have been possible to explore them by boring into them. But the deepest mines do not reach greater depths than between 3000 and 4000 feet from the surface. Owing, however, to the way in which the crust of the earth has been plicated and fractured, portions of the bottom layers have been pushed up to the surface, and those that lay above them have been thrown into vertical or inclined positions, so that we

can walk over their upturned edges and examine them, bed by bed. Instead of being restricted to merely the uppermost few hundred feet of the crust, we are enabled to examine many thousand feet of its rocks. The total mean thickness of the accessible fossiliferous rocks of Europe has been estimated at 75,000 feet, or upwards of 14 miles. This vast depth of rock has been laid bare to observation by successive disturbances of the crust.

The main divisions of the Geological Record and, we may also say, of geological time, are five: (1) Archæan, embracing the periods of the earliest rocks, wherein few or no traces of organic life occur; (2) Palæozoic (ancient life) or Primary, including the long succession of ages during which the earliest types of life existed; (3) Mesozoic (middle life) or Secondary, comprising a series of periods when more advanced types of life flourished; (4) Cainozoic (recent life) or Tertiary, embracing the ages when the existing types of life appeared, but excluding man; and (5) Quaternary or Post-tertiary and Recent, including the time since man appeared upon the earth. It must not be supposed that each of these five divisions was of the same duration. The Palæozoic ages were probably vastly more prolonged than those of any later division; while the Quaternary periods doubtless comprise a very much briefer time than any of the other four groups.

Each of these main sections is further subdivided into systems or periods, and each system into formations as already explained. Arranged in their order of sequence, the various divisions of the Geological Record may be placed as in the accompanying Table Though the broad outlines of the sequence of living things has been the same all over the world, many local diversities may be traced in the nature and grouping of the sedimentary materials in which these outlines have been preserved. The subdivisions in Europe and in North America are here shown.

## THE GEOLOGICAL RECORD

or, Order of Succession of the Stratified Formations of the Earth's Crust

| | Europe | North America. |
|---|---|---|
| Post-tertiary or Quaternary | Recent and Prehistoric.<br>Pleistocene or Glacial. | Recent.<br>Pleistocene or Glacial. |

| | Europe. | North America. |
|---|---|---|
| Cainozoic or Tertiary | Pliocene<br>Miocene<br>Oligocene<br>Eocene. | Pliocene<br>Miocene<br>Oligocene<br>Eocene |
| Mesozoic or Secondary | Cretaceous.<br>Jurassic.<br>Triassic. | Cretaceous<br>Jurassic.<br>Triassic. |
| Palæozoic or Primary. | Permian.<br><br>Carboniferous.<br>Coal-measures.<br>Millstone Grit.<br>Carboniferous Limestone series<br><br>Devonian and Old Red Sandstone.<br>Upper (Famennian, Frasnian)<br>Middle (Givetian, Eifelian).<br>Lower (Coblentzian, Gedinnian).<br><br>Silurian.<br>Upper (Ludlow, Wenlock, Llandovery groups)<br>Lower [Ordovician] (Caradoc or Bala, Llandeilo and Arenig groups)<br><br>Cambrian or Primordial<br>Upper or Olenidian series<br>Middle or Paradoxidian series.<br>Lower or Olenellus series. | Permian or Permo-Carboniferous.<br>Carboniferous<br>Coal-measures (Upper Carboniferous, Pennsylvanian)<br>Sub Carboniferous (Lower Carboniferous, Mississippian).<br><br>Devonian<br>Upper (Catskill, Chemung, Portage and Genesee groups)<br>Middle (Hamilton, Marcellus groups)<br>Lower (Corniferous, Onondaga, Oriskany groups)<br><br>Silurian.<br>Upper (Lower Helderberg, Water-lime, Niagara, Clinton, and Medina groups).<br>Lower (Cincinnati, Utica, Trenton, Chazy and Calciferous groups).<br><br>Cambrian or Primordial.<br>Potsdam (Olenidian series).<br>Acadian (Paradoxidian series)<br>Georgian (Olenellus series) |
| Pre-Cambrian. | Longmyndian, Uriconian — England and Wales<br>[Dalradian], Torridonian — Scotland.<br><br>Archæan. — Lewisian (Fundamental gneiss of Scandinavia, etc). | Algonkian. — Keweenawan. Upper Huronian (Animikean) Lower Huronian.<br><br>Archæan. — "Fundamental Complex" of gneiss, granite, etc., invading limestones, quartzites, etc. (Laurentian) |

## The Pre-Cambrian Periods

Owing to the revolutions which the crust of the earth has undergone, there have been pushed up to the surface, from underneath the oldest fossiliferous strata, certain very ancient crystalline rocks which form what is termed the Archæan system. As already mentioned, these rocks have by some geologists been supposed to be a part of the primeval crust of the planet, which solidified from fusion. By others they have been thought to have been formed in the boiling ocean, which first condensed upon the still hot surface of the globe. But we are still ignorant as to the conditions under which they arose, and have hardly any means of ascertaining in what order they were formed. We know no method of determining whether those of one region belong to the same period as those of another. Nor can we always be sure that masses which have been called Archæan may not belong to a much later part of the Geological Record, their peculiar crystalline structure having been superinduced upon them by some of those subterranean movements described in Chapter XIII.

It has been observed that in all parts of the world, wherever the most ancient mineral masses appear at the surface, they present a remarkable sameness of character. They consist for the most part of thoroughly crystalline rocks, which range from acid amorphous granites to the most basic and finely foliated silky schists. They are generally characterised by a schistose structure. The most universally abundant of them may be classed as gneisses, which pass into granites, syenites and diorites, and often include interstratified bands of various hornblendic, pyroxenic, and garnetiferous rocks. These various materials are usually more or less distinctly bedded; but the beds are for the most part inconstant, swelling out into thick zones, and then rapidly diminishing and dying out. As this bedding somewhat resembles that of sedimentary rocks, the inference has been drawn that the Archæan crystalline series was really deposited on the floor of the primeval ocean, as chemical precipitates or mechanical sediments which have since been more or less crystallised and disturbed. But from what has been brought forward in Chapter XIII. regarding the totally new structures which have been developed in rocks by subterranean movement, it is evident that a bedded arrangement and a crystalline texture,

like those of the Archæan system, have sometimes been induced in rocks by excessive crumpling, fracture, and shearing. The apparent bedding of the Archæan gneisses is most probably never their original structure, but has been superinduced on them by subsequent movements of the terrestrial crust

The alternations of gneiss and other crystalline masses form bands which are usually placed on end or at high angles, and are often intensely crumpled and puckered, having evidently undergone enormous crushing (Fig. 128). Attempts have been made to subdivide them into groups or series, according to their apparent order of succession and lithological characters. But such subdivisions are probably entirely without any solid basis. We

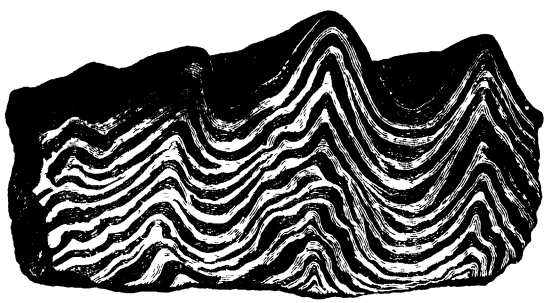


FIG. 128.—Fragment of crumpled Schist

have no evidence that the banding of the gneisses has any stratigraphical value.

So far as these rocks can be compared with any of the later portions of the earth's crust they find their nearest analogies in the structure of the larger bosses of eruptive material which have been intruded into the various geological formations. It seems at present most probable that they are really of igneous origin, and that they represent deep-seated portions of very ancient protrusions of molten material from the interior, their upward prolongations having long ago been removed by denudation. Their alternations of different mineral composition may have arisen like the banding which is found in great bosses of gabbro; their schistose character points to much compression and shearing, and their complicated puckerings and folds show how intense must have been the movements to which their original bands and their foliation-layers must have been subsequently exposed.

Nevertheless, even amidst these relics of what were probably intrusions of acid and basic material into the early terrestrial crust, there are indications that, in some regions, this crust already included sedimentary formations. Masses of limestone, graphite-schist, mica-schist, and quartzite have been crushed and involved among the gneisses; and though the relations of the two groups of rocks have been greatly obscured, it may be conjectured that the metamorphic series represents a group of sedimentary formations into which the gneisses were intruded.

No unquestionable relic of organic existence has been met with among Archæan rocks. Some of the Archæan limestones of Canada have yielded a peculiar mixture of serpentine and calcite, with a structure which has been regarded by some able naturalists as that of a reef-building foraminifer. It occurs in masses, and was supposed by these writers to have grown in large, thick sheets or reefs over the sea-bottom. By most observers, however, this supposed organism (to which the name of *Eozoon* has been given) is now regarded as merely a mineral segregation, and various undoubted mineral structures are pointed to in illustration and confirmation of this view.

Pre-Cambrian rocks cover a large area in Europe. Among the Hebrides and along the north-west coast of the Scottish Highlands, where they are largely developed, they consist of a very ancient group of rocks, of which the most conspicuous are various forms of gneiss to which the name of Lewisian has been given, from its abundant and characteristic development in the Island of Lewis. These rocks consist of a complicated series of what have probably been deep-seated igneous masses successively intruded into the terrestrial crust. They include a succession of basic and acid dykes which in many respects resemble those of much more recent geological periods. At different times all these rocks have undergone intense mechanical crushing and deformation, and they now present a strikingly banded and foliated structure. At one or two places, in the west of the counties of Ross and Inverness, certain mica-schists, graphitic schists, and limestones have been found apparently involved among the gneisses. They are probably metamorphosed sediments, and they may represent sedimentary rocks of the crust into which the gneisses and dykes were intruded.

The Lewisian gneiss of North-West Scotland gives rise to a singular type of scenery. Over much of that region it forms hummocky bosses of naked rock, with tarns and peat-bogs lying

in the hollows, seldom rising into mountains, but forming the platform which supports the singular group of red sandstone mountains mentioned below. Here and there it mounts up into solitary hills or groups of hills. The highest point it reaches on the mainland is among the mountains on the east side of Loch Maree, in Ross-shire, where it attains an elevation of 3000 feet. Some of its masses in that region were mountains at the time of the deposition of the overlying Torridon sandstone, which when removed by denudation reveals a system of hills and valleys—the oldest topography that has been preserved in Europe. In the Island of Harris the gneiss sweeps upwards into rugged mountainous ground, of which the highest summits rise more than 2600 feet out of the Atlantic, and are visible far and wide as a notable landmark. Rocks of similar character appear likewise in Ireland; while in Anglesey, and possibly in the south-west of England, other scattered bosses of them rise to the surface.

Much later than the Lewisian, and lying upon it with a violent unconformability, comes a remarkable group of red sandstones with some dark shales and calcareous bands, to which the name of Torridonian has been given from its great development at Loch Torridon in the west of Ross-shire. This group reaches a thickness of 8000 or 10,000 feet, and is almost entirely confined to the west of the counties of Sutherland and Ross It there forms a remarkable group of pyramidal mountains, to which their nearly horizontal stratification gives a characteristic architectural aspect. No unquestionable relics of plant or animal life have yet been found in this thick mass of sedimentary material. But certain phosphatic nodules which are found in the shales are not improbably of organic origin, and may indicate the presence of crustacea or of horny brachiopods in the waters in which the strata were deposited. The great antiquity of these Torridonian sediments is proved by the fact that they are unconformably overlain by the base of the Cambrian system in which the Olenellus zone is well represented.

The term "Dalradian" has been applied to a thick series of metamorphosed sedimentary and igneous rocks forming the Central and Southern Highlands of Scotland. They must be of great thickness, but their true geological position is not yet ascertained. They may possibly contain altered representatives of the Lewisian gneiss, Torridon sandstone and Cambrian quartzites and limestones of the north-west, and, probably, even of Silurian (Arenig) formations.

On the borders of Wales and Shropshire a thick series of sedimentary rocks (Longmyndian) forms the Longmynd country It appears to be pre-Cambrian, and may be partly the equivalent of the Torridonian Sandstone of the north-west. It is underlain by a group of felsitic lavas and tuffs named Uriconian.

On the continent of Europe, pre-Cambrian rocks have their greatest extension in Scandinavia, where they evidently belong to the same ancient land as that of which the Hebrides and Scottish Highlands are fragments. They include a fundamental gneiss and other crystalline rocks like those included in the Lewisian series of Scotland. This ancient group is overlain by various younger schists and gneisses, the geological equivalents of which in other countries have not been satisfactorily determined, though they are classed by some Scandinavian geologists with the Algonkian series of North America. That some of these rocks are of Silurian age is proved by the occurrence of corals, graptolites, and other fossils (probably Upper Silurian forms) in mica-schists and limestones not far from Bergen.

Pre-Cambrian rocks range widely across Finland into Russia, appearing in the centre of the chain of the Ural Mountains. They form likewise the nucleus of the Carpathians and the Alps, and appear in detached areas in Bavaria, Bohemia, France, and the Pyrenees.

Rocks belonging to pre-Cambrian time attain an enormous development on the western side of the Atlantic, where they are estimated to cover a region more than 2,000,000 square miles in extent, which stretches from the great lakes northwards into the Arctic regions. They have been divided into two great sections which appear to correspond, on the whole, with those recognised in Europe. At the base lies the Archæan gneiss —a vast mass of foliated and unfoliated granites, gneisses, syenites, gabbros, schists, and peridotites, which resemble deep-seated eruptive rocks, but contain no certain trace of sedimentary origin. Above this most ancient or fundamental formation lies the great series known as Algonkian, which is classed in three divisions. Of these the lowest (1) Lower Huronian, about 5000 feet thick, consists of conglomerates, quartzites, dolomites, and slates with important iron-ores. This great succession of sediments must be vastly younger than the Archæan rocks, for it rests upon them with a violent unconformability. On the other hand, it is seen to be much older than the next group (2) Upper Huronian, which lies upon its upturned and denuded

edges. This middle group is said to reach a thickness of 12,000 feet. It consists of various sedimentary formations, often more or less metamorphosed, together with included masses of eruptive rocks. The third group (3), known as Keweenawan, is stated to be sometimes 50,000 feet thick. It is made up mainly of volcanic accumulations, with sedimentary deposits intercalated in and overlying them. It is surmounted by the Cambrian system, and is thus certainly pre-Cambrian.

In Newfoundland and in the Grand Cañon region of the Colorado, thick sedimentary formations underlying Cambrian strata have yielded a number of shells and other organisms which comprise all the pre-Cambrian fossils yet discovered, and have a special interest as being the oldest forms of life that have yet been found.

It will be observed that both in the Old and New World the pre-Cambrian rocks are chiefly exposed in the northern tracts of the continents. The areas which they there overspread were probably land at an early geological period, and it was the waste of this land that mainly supplied the original materials out of which enormous masses of stratified rocks were formed.

In the southern hemisphere, also, ancient gneisses and other schists rise from under the oldest fossiliferous formations. In Australia and in New Zealand they cover large tracts of country, and appear in the heart of the mountain ranges.

## CHAPTER XVII

### THE PALÆOZOIC PERIODS—CAMBRIAN

THE portion of geological history which embraces those ages in which the earliest known types of plants and animals lived has been termed Palæozoic (Ancient Life). Of the first appearance of organic life upon our planet we know nothing. Whether plants or animals came first, and in what forms they came, are questions to which as yet no satisfactory answer can be given. The oldest discovered fossils are assuredly not vestiges of the first living things that peopled the globe. There is every reason, indeed, to hope that as researches in all parts of the world are pushed into the pre-Cambrian sedimentary formations, more numerous and more ancient organisms than those yet found may be discovered. But it is in the highest degree improbable that any trace of the earliest beginnings of life will ever be detected. The first plants and the first animals were probably of a lowly kind, with no hard parts capable of preservation in the fossil state. Moreover, the sedimentary rocks which may have chronicled the first advent of organised existence are hardly likely to have escaped the varied revolutions to which all parts of the crust of the earth have been exposed. They have more probably been buried out of sight, or have been so crushed, broken, and metamorphosed, that their original condition, together with any fossils they may have enclosed, is no longer to be recognised. The first chapters have been, as it were, torn out from the chronicle of the earth's history.

The Palæozoic rocks, which, leaving out of account the somewhat scanty and obscure organic remains obtained from pre-Cambrian sediments, contain the earliest record of plant and animal life, consist mainly of the hardened mud, sand, and gravel of the sea-bottom. Here and there they include beds, or thick groups of beds, of limestone composed of marine shells, crinoids, corals, and

other denizens of salt water. They are thus essentially the chronicles of the sea. But they also contain occasional vestiges of shores, and even of the jungles and swamps of the land, with a few rare glimpses into the terrestrial life of the time. Everywhere they abound in evidence of shallow water, for though chiefly marine, they appear to have been generally accumulated not far from land. We may believe that in the earliest periods, as at the present day, the sediment washed away from the land has been deposited on the sea-floor, for the most part at no great distance from the coast.

The land from the waste of which the Palæozoic rocks were formed lay, in Europe and North America, chiefly towards the north. It no doubt consisted of such pre-Cambrian rocks as still rise out from under the oldest Palæozoic formations. As already mentioned, the north-west Highlands of Scotland, part of the table-land of Scandinavia, and most of North America to the north of the great lakes, are probably portions of that earliest land, which, after being deeply buried under later geological accumulations, have once more been laid bare to the winds and waves. We can form some conception of the bulk of the primeval northern land by noting the thickness of sedimentary rocks that were formed out of its detritus during the Palæozoic periods. The older half of the Palæozoic rocks in the British Islands, for example, is at least 16,000 feet or 3 miles thick, and covers an area of not less than 60,000 square miles. This material, derived from the waste of pre-Cambrian rocks, would make a table-land larger than Spain, with an average height of 5000 feet, or a mountain chain 1800 miles long, with an average elevation of 16,000 feet. Of the general form and height of the northern land that supplied this vast mass of sedimentary matter nothing is known. Perhaps it was lofty; but it may have been slowly uplifted, so that its rise compensated for the ceaseless degradation of its surface.

Among the pre-Cambrian formations of Europe and of North America abundant evidence has been obtained that, even in the primeval period which they represent, volcanic action was in full vigour, and that sheets of lava and showers of ashes formed thick accumulations on the sea-floor. Volcanic energy continued all through Palæozoic time, and heaped up huge piles of lavas and tuffs. We find also many indications of upward and downward movements of the crust of the earth. The mere fact of the superposition of many thousands of feet of shallow-water strata, one above another, is proof of a gradual sinking of the sea-floor. For

it is evident that the accumulation of such a thickness of sediment, and the continuance of a shallow sea over the area of deposition, could only take place during a progressive subsidence (see p. 203).

The vegetable and animal life of the Palæozoic periods, so far as known from the fossils which have been obtained from the rocks, appears to have been far more uniform over the whole globe than at any subsequent epoch in geological history. For instance, the same species of fossils are found in corresponding rocks in Britain, Russia, United States, China, and Australia. The climate of the globe at that ancient date was doubtless more uniform than it afterwards became, and was probably also generally warmer. Palæozoic fossils, obtained from high northern latitudes, are precisely similar to those that abound in England, whence it may be inferred that not only was there a greater uniformity of climate, but that the great cold which now characterises the Arctic regions did not then exist.

In the earlier Palæozoic periods, the animal life of the globe appears to have been entirely invertebrate, the highest known types being chambered shells, of which our living nautilus is a representative. In the middle periods vertebrate life appeared. The earliest known vertebrate forms are fishes akin to some modern sharks and to the sturgeon, the polypterus of the Nile, and the gar-pike of American lakes. The most highly organised forms of existence upon the earth's surface in the later Palæozoic periods were amphibians—a class of animals represented at the present day by frogs, toads, newts, and salamanders. It is evident, however, that the number and kinds of animal remains preserved in Palæozoic rocks afford only an imperfect record of the animal life of these early ages. Whole tribes of creatures no doubt existed of which no trace whatever has yet been recovered. An accidental discovery may at any moment reveal the former presence of some of these vanished forms. For example, the examination of a fossil tree-trunk imbedded among the coal-strata of Nova Scotia led to the finding of the first and as yet almost the only traces of Palæozoic land-shells, though thousands of species of marine shells, belonging to the same period, had long been known. Every year is enlarging our knowledge in these respects; but from the very nature of the circumstances in which the records of the rocks were formed, we cannot expect this knowledge ever to be more than fragmentary.

The Palæozoic rocks are divided into five systems which in the

order of their age have been named: (1) Cambrian; (2) Silurian; (3) Devonian; (4) Carboniferous; (5) Permian.

## CAMBRIAN

The strata containing the earliest organic remains were formerly known as Greywacke, from the rock which is specially abundant among them. They were also termed Transition, from the supposition that they were deposited during a transitional period, between the time when no organic life was possible on the earth's surface and the time when plant and animal life abounded. But Murchison, who first explored them, showed that they contain a series of formations, each characterised by its own assemblage of organic remains. He called them the Silurian system, after the name of the old British tribe—the Silures, who lived on the borders of England and Wales, where these rocks are especially well developed. This name soon passed into use all over the world as the designation of those stratified formations which contain the same or similar organic remains to those found in the typical region described by Murchison.

While the succession of the rocks and fossils was established by that geologist in South Wales, and in the border counties of Wales and England, Sedgwick was at work among similar rocks in North Wales. These were at first believed to be all older than those called Silurian, and were accordingly named CAMBRIAN, after the old name for Wales, Cambria. In the end, however, it was found that throughout a large part of them, the same fossils occurred as in the Silurian series, and they were accordingly claimed as Silurian. Much controversy has since been carried on regarding the limits and names to be assigned to these rocks, and geologists are not yet agreed upon the nomenclature that should be followed. Murchison and his followers claimed the Cambrian as the lowest portion of the Silurian system, while Sedgwick and his disciples maintained that the lower half of the Silurian system should be included in his Cambrian series. There can be no doubt that the first succession of organic remains established among these ancient members of the great Palæozoic series of formations was that worked out by Murchison and named by him Silurian. But it has been found convenient to retain the name Cambrian for the oldest group of Palæozoic fossiliferous formations. It may be well to repeat that these words, like all those adopted by geologists to distinguish the successive rock-

groups of the earth's crust, have acquired a chronological meaning. We speak, not only of Cambrian and Silurian strata and Cambrian and Silurian fossils, but of Cambrian and Silurian time. The terms are used to denote those particular periods in the history of the earth when Cambrian and Silurian strata were respectively deposited, and when Cambrian and Silurian fossils were the living denizens of sea and land.

The rocks of which the Cambrian system is composed, like those of the whole of the Lower Palæozoic formations, present considerable uniformity over the whole globe. They consist of grey and reddish grits, sandstones, greywackes, quartzites, and conglomerates, with thick groups of shale, slate, or phyllite, and, in some regions, of limestone. These sedimentary accumulations occasionally attain a great thickness. In Wales they have been estimated by some observers to be at least 20,000 feet in depth. Their ripple-marks, pebble-beds, and frequent alternations of coarse and fine sediment, point to their having probably been laid down in comparatively shallow water, during a period of prolonged subsidence of the sea-bottom. They include tuffs and basic lavas which indicate contemporaneous submarine eruptions.

With regard to the occurrence of fossils among the older Palæozoic formations, and indeed among stratified rocks in general, it is worthy of notice that they are far from being equally distributed; that, on the contrary, they occur by preference in certain kinds of material rather than in others. Grits and sandstones, for instance, are comparatively unfossiliferous, while fine shales, slates, and limestones are often crowded with fossils. It is not that life was probably on the whole more abundant at the time of the deposition of some kinds of strata, but that the local conditions for its growth and for the subsequent entombment and preservation of its remains were then more favourable. At the present time, for example, dredging operations show the most remarkable variations between different and even adjacent parts of the sea-bottom, as regards the abundance of marine life. Some tracts are almost lifeless, while others are crowded with a varied and prolific fauna. We can easily understand that if, from the nature of the bottom, plants and smaller animals cannot flourish on a particular tract, the larger kinds that feed on them will also desert it. Even if organisms live and die in some numbers over a part of the sea-bed, the conditions may not be suitable there for the preservation of their remains. The rate of deposit of sediment, for instance, may be so slow that the remains may decay before there is time

for them to be covered up; or the sediment may be unfitted for effectually preserving them, even when they are buried in it. We must not lose sight of these facts in our explorations of the Geological Record. A relation has generally existed between the abundance or absence of fossils in a sedimentary rock and the circumstances under which the rock was originally formed

The Cambrian or Primordial group of sedimentary formations contains a remarkable assemblage of animal remains, which, being nearly the earliest known traces of the animal life of the globe, might have been anticipated to belong to the very lowest tribes of the animal kingdom. But they are by no means of such humble organisation. On the contrary, they include no representatives of many of the groups of simpler invertebrates, which we may be sure were nevertheless living at the same time. Not only so, but some of the fossils belong to comparatively high grades in the scale of invertebrate life, such as chambered molluscs. From this incompleteness, and from the wide differences in the organic grade of the forms actually preserved in the rocks, we may reasonably infer that only a most meagre representation of the life of the time has come down to us in the fossil state. Some of the fossils, moreover, have been so indistinctly preserved that considerable difficulty is experienced in deciding to what sections of the animal or vegetable kingdoms they should be assigned

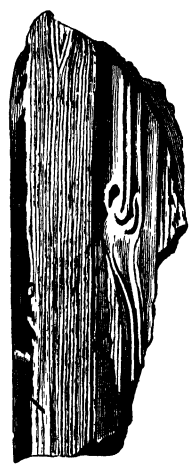


FIG 129 —Fucoid-like impression (*Eophyton Linneanum*) from Cambrian rocks (½) [1]

Among the markings which have given rise to much discussion allusion may be made to plant-like impressions, some of which, like *Eophyton* (Fig. 129), have been claimed as sea-weeds. These and others, however, may only be irregular wrinklings of the surfaces of deposit, and of no organic origin at all (see p. 277). Another puzzling impression is that called *Oldhamia* (Fig. 130), which has been variously referred to the Hydrozoa, the Sertularia, the Polyzoa, and the calcareous Algae.

[1] The fractional numbers inserted within parentheses in the titles of the figures of fossils indicate how much the figures have been reduced or magnified. Thus ½ = reduced one-third; 2 = magnified four times.

Some of the most characteristic older Palæozoic organisms belong to the Hydrozoa, and are embraced under the general

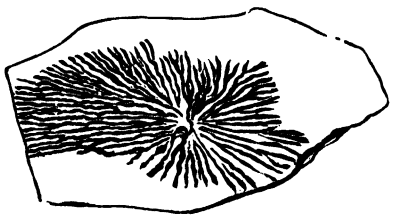


FIG. 130.—*Oldhamia radiata* (natural size), Ireland.

title of Graptolites—a name given to them from their fancied resemblance to quill-pens. They were composed of a horny or chitinous substance, and hence they commonly present themselves

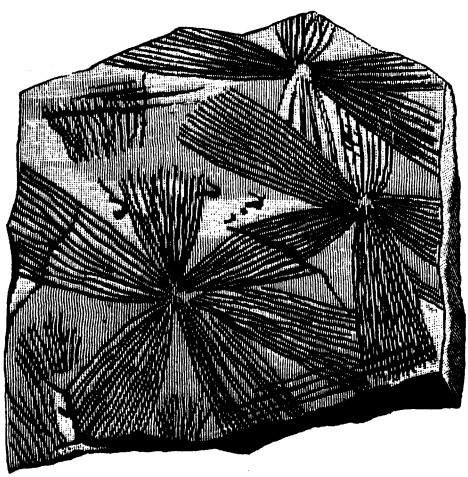


FIG. 131.—Hydrozoon from the Cambrian rocks (*Dictyograptus* (*Dictyonema*) *sociale*), natural size.

merely as black streaks upon the stone. Each graptolite was a colony, comprising many individuals which occupied each its own cell. The cells are in some kinds placed in a row on one side of a supporting rod or axis ; in other kinds there is a row of cells on both sides (see Fig. 135). Some varieties are straight, others

curved or spiral. Some are single stalks, others are composed of two or more branches, while in certain types a large number of separate branches is united in one common centre One of the most ancient hydrozoa is *Dictyograptus* (*Dictyonema*, Fig 131)—a characteristic fossil of the Cambrian rocks of Scandinavia. The graptolites are more especially characteristic of the Silurian system (p 279). In Scandinavia and in Alabama well-preserved casts of medusæ have been found in the Cambrian sediments. The Cambrian limestones have yielded various ancient types of corals (*Archæocyathus*, etc ).

The Echinodermata had their representatives in Cambrian time, though the remains of these are few and infrequent. The great tribe of the Crinoids or sea-lilies (p 280) had already established itself on the floor of the Cambrian sea, where also there were representatives of Cystideans and star-fishes (see p. 280)

Numerous kinds of sea-worms (Annelids) crawled over the sandy and muddy bottom and shores of the Cambrian ocean. These creatures have left no trace of their bodies, which, like those of their representatives in the present ocean, were soft and unfitted for preservation. But the burrows they made in wet sand or mud, and the trails they left upon the soft surfaces over which they moved, have been abundantly preserved (*Arenicolites*, etc., see Fig. 138). These markings, like the casts of medusæ, afford unquestionable proof of the presence of creatures which have otherwise utterly disappeared.

Among the most abundant and characteristic fossils of the older stratified rocks of the earth's crust are those to which the general name of Trilobites has been given. These long-extinct animals were crustaceans, having a more or less distinctly three-lobed body, at one end of which was the head or cephalic shield, usually with a pair of fixed compound eyes; at the other end the caudal shield or tail; while between the two shields was the ringed or jointed body, the rings of which were movable, so that the animal could bring the two shields together or coil itself up. The different genera represented in Figs. 132, 139, and 150 show how varied were the forms which in course of time they assumed. In the shapes and relative sizes of the shield and segmented body, in the number of the body-rings, in the development of spines, and in other features, the most wonderful variety is traceable among the trilobites even of the oldest fossiliferous strata. Some of the earliest genera were also the largest; *Paradoxides* sometimes reaching a length of nearly two feet. Yet contemporaneous with

this large creature were some diminutive forms. A few genera (among them *Agnostus*) were blind; but most possessed eyes furnished with facets The peculiar crescent-shaped eye on each side of the head is well shown in some of the forms represented in Figs 132 and 139 The trilobites appear to have particularly swarmed on sandy and muddy bottoms, for their remains are abundant in many sandstones and shales.

Another form of crustacean life represented in the early

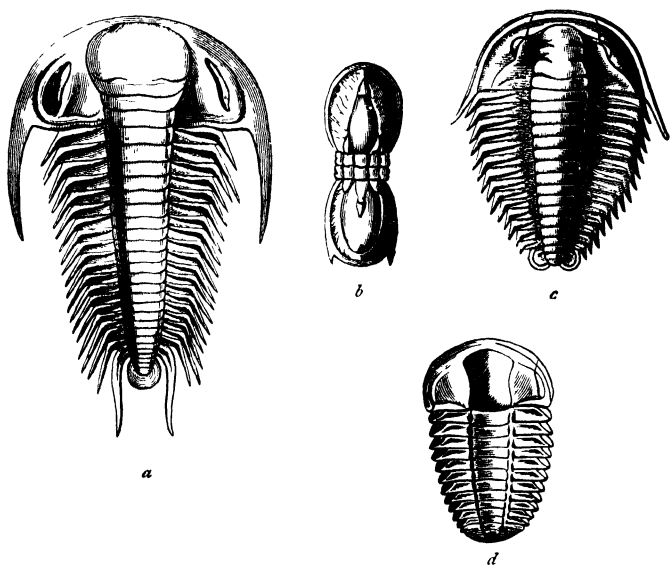



FIG. 132.—Cambrian Trilobites (*a*), *Paradoxides bohemicus* (natural size); (*b*), *Agnostus princeps* (½), (*c*), *Olenus micrurus* (natural size), (*d*), *Ellipsocephalus Hoffi* (natural size).

Palæozoic ocean was that of the Phyllocarida—animals furnished with bivalve shell-like carapaces, which protected the head and upper part of the body, while the jointed tail projected beyond it. Most of them were of small size (see Fig. 140) The characteristic Cambrian genus is *Hymenocaris*.

Of all the divisions of the animal kingdom none is so important to the geologist as that of the Mollusca When one walks along the shores of the sea at the present time, by far the

most abundant remains of the marine organisms to be there observed are shells. They occur in all stages of freshness and decay, and we may trace even their comminuted fragments forming much of the white sand of the beach. So in the geological formations, which represent the shores and shallow sea-bottoms of former periods, it is mainly remains of the marine shells that have been preserved. From their abundance and wide diffusion, they supply us with a basis for the comparison of the strata of different ages and countries, such as no other kind of organic remains can afford.

It is interesting and important to find that among the fossils of the oldest fossiliferous rocks the remains of molluscan shells occur, and that they are of kinds which can be satisfactorily referred to their place in the great series of the Mollusca. The most abundant of them are representatives of the Brachiopods or Lamp-shells. Among these are species of the genera *Lingulella* (Fig 133), *Obolus*, *Acrotreta*, and *Discinopsis*. Some of these types seem to have persisted with but little change during the whole of geological time, from the early Palæozoic periods downwards, for their living representatives do not appear to indicate any marked divergence from them. They possessed horny shells not hinged together by teeth. A more highly organised order of brachiopods possessed two hard calcareous shells articulated by teeth on the hinge-line (*Kutorgina*, *Orthis*, etc.). These forms in the end vastly outnumbered the horny lingulids and discinids. So abundant are they, both in individuals and in genera and species, among the older Palæozoic rocks, that the period to which these rocks belong is sometimes spoken of as the "Age of Brachiopods."

FIG. 133.—Cambrian Brachiopod (*Lingulella Davisii*, natural size)

The ordinary bivalve shells or Lamellibranchs had their representatives even in Cambrian times. From that early period they have gradually increased in numbers, till they have attained their maximum at the present time. Among the known Cambrian genera are *Ctenodonta* allied to the living "ark-shells," and *Modiolopsis*, probably representing some of the modern mussels.

The Gasteropods or common univalve shells, now so abundant in the ocean, are represented among the Cambrian formations by the earliest type of limpets (*Scenella*), also by the genera *Ophileta*, *Maclurea*, *Pleurotomaria*, etc.

The highest division of the molluscs, the Cephalopods, to which the living nautilus and cuttle-fish belong, is but poorly represented at the present time. But during the Palæozoic and Secondary periods it flourished exuberantly, both as regards number of individuals and variety of forms. It is divisible into two great orders. In one of these, the shell is usually internal and sometimes chambered; in the other, the shell is chambered and external, the chambers being connected by a tube or siphuncle. The former order includes all the living cuttle-fishes, squids, and the paper-nautilus; the latter comprises only one living representative—the pearly nautilus. It is to the family of chambered cephalopods that the Palæozoic forms are all referable. In some the shell was straight, in others it was variously curved. Only scanty traces of cephalopodan life have yet been found among the Cambrian rocks. But occasional examples of the important genera *Orthoceras* (see Fig. 144) and *Cyrtoceras* show that this great division of the molluscs had even in the earliest Palæozoic ages appeared upon the earth.

Taking advantage of the observed distribution of the trilobites in the Cambrian strata, geologists have classed these rocks in three great divisions: (1), Lower or Olenellus group, in which the genus *Olenellus* is specially characteristic; (2), Middle or Paradoxidian, distinguished by the prevalence of the genus *Paradoxides;* and (3), Upper or Olenidian, wherein the characteristic trilobite genus is *Olenus*.

As the term Cambrian denotes, the rocks to which this name is applied are well developed in Wales. There, and in the border English counties, they attain a depth of perhaps more than 12,000 feet. They are found also in the east of Ireland, while in the north-west of Scotland they are well represented by a group of quartzites full of annelid burrows, surmounted by dolomitic shales, containing *Olenellus* and other forms, and then by a group (1500 feet thick) of dolomites and limestones, which contain a large and varied assemblage of fossils, having a general affinity with those of Canada and the United States rather than with those of Wales.

The following Table gives the commonly accepted subdivisions of the Cambrian rocks in Britain.

| | |
|---|---|
| UPPER or OLENIDIAN ZONE. | Tremadoc group—dark grey slates, with *Olenus, Asaphus, Angelina, Ogygia,* etc<br>Lingula Flags—bluish and black slates, flags, and sandstones, with *Lingulella, Discina, Obolella, Kutorgina, Hyolithes, Olenus, Conocoryphe, Dikelocephalus, Hymenocaris,* etc. |

| | |
|---|---|
| MIDDLE or PARADOXIDIAN ZONE | Menevian group—sandstones, shales, slates, and grits, with *Paradoxides, Agnostus, Anopolenus, Conocoryphe, Protospongia, Lingulella, Obolella*, etc |
| | Solva group of St David's, with *Paradoxides, Plutonides, Agnostus, Conocoryphe, Microdiscus, Arenicolites*, etc |
| LOWER or OLENELLUS ZONE | Harlech and Llanberis group of purple, red, and grey flags, sandstones, slates, conglomerates, and volcanic rocks In Shropshire *Olenellus, Ellipsocephalus, Kutorgina*, and other fossils have been obtained from the lowest Cambrian strata |

The characteristic Cambrian or Primordial fauna has a world-wide distribution In Europe it has been detected at intervals from Scandinavia through Belgium, France, Spain, the Thuringer Wald and Bohemia to Sardinia and eastwards into Russia, whence it ranges into Asia even as far as China. It has been met with in the Salt Range of India, in Southern Australia and Tasmania, and in South America. Nowhere has it been found with so varied an assemblage of organic remains as in North America, where in the United States and the British Possessions it runs along the margins of the pre-Cambrian rocks and presents the threefold grouping of the Old World as shown in the subjoined Table

| | |
|---|---|
| UPPER or POTSDAM (OLFNIDIAN). | Seen on the north and east sides of the Adirondack Mountains of New York, and stretching into Canada by New Brunswick and Cape Breton into Newfoundland ; in the upper Mississippi valley, South Dakotah, Wyoming, Montana and Colorado, North Arizona, and Nevada. |
| MIDDLE or ACADIAN (PARADOXIDIAN) | Developed in Eastern Massachusetts, New Brunswick, and Eastern Newfoundland ; also in New York, Tennessee, Alabama, Central Nevada, and British Columbia. |
| LOWER or GEORGIAN (OLENELLUS FAUNA). | Typically displayed in Vermont ; seen also on west side of Green Mountains, and Appalachian chain in Pennsylvania, Virginia, Tennessee, Georgia, Alabama ; likewise in the eastern region by S Massachusetts, New Brunswick, and Newfoundland into Labrador. It has been recognised in the Wahsatch Mountains and in British Columbia. |

# CHAPTER XVIII

## SILURIAN

THE origin and use of the term SILURIAN have already been given (p. 267) The rocks embraced under this term form a mass of strata which in some countries (Wales and Scotland) must be many thousand feet thick. Like the Cambrian system below, into which they graduate downward, they consist mainly of greywackes, sandstones, shales, or slates; but they are marked by the occasional occurrence of bands of limestone—a rock which from this part of the geological record appears in increasing quantity onwards to recent times. Some highly characteristic bands of dark carbonaceous shale are in some countries persistent for long distances, and contain abundant graptolites. Not infrequently these dark shales are full of pyritous impregnations, which, when the rock weathers, give rise to an efflorescence of alum or the formation of chalybeate springs; such bands are sometimes called *alum-slates*. In Wales, the Lake District of the north of England, and in the south of Scotland, remains of submarine volcanic eruptions of Silurian time appear as intercalated sheets of tuff and different lavas

In certain regions (Russia, New York) Silurian rocks have undergone little change since the time of their deposition; but, as a rule, they have been more or less indurated, plicated, and dislocated (Wales, Lake District, etc.), while in some districts (parts of Norway and Scotland) they have been so crushed and metamorphosed as to have assumed the character of schistose rocks (phyllites, mica-schists, etc.)

Murchison subdivided his Silurian system into two great sections, Lower and Upper. This arrangement still holds, though the limits and nomenclature of the several component groups have not been exactly maintained. It has been proposed to separate

the lower division as a distinct system under the name of "Ordovician," restricting the name Silurian to the upper division only, and this classification has been adopted by many writers. In justice, however, to the great pioneer by whom these ancient rocks were first worked out, his terminology, which is still perfectly applicable, ought to be maintained. The arrangement of the various subdivisions, as followed in Britain and North America, is shown in the tables on p. 286.

Taking the fossils of the Silurian system as a whole, we find that they prolong and amplify the peculiar type of life found to characterise the Cambrian system. They include both plants and animals. The flora, however, is exceedingly meagre It consists almost entirely of sea-weeds, which occur usually in the form of fucoid-like impressions. But, as already remarked in reference to the so-called plants of the Cambrian rocks, many of the supposed vegetable remains are almost certainly not such (see p. 269). Some of them may be hydrozoa, others are possibly tracks left upon soft mud or sand by worms, crustaceans, or other marine creeping or crawling creatures, some may be casts of hollows made by trickling water or yielding sediment; while others seem to be the result of some peculiar crumpling or puckering of the strata. A fossil which was described by Salter as an Upper Silurian sea-weed (Fig 134) is somewhat similar to one which has been claimed as a dendroid graptolite. Among the Upper Silurian strata traces of land-vegetation have been detected in the form of stems of cryptogamous plants Lycopods or club-mosses and ferns appear to have been the chief types in the earliest terrestrial floras; at least, it is remains referable to them that chiefly occur in the older Palæozoic rocks. They reached a great development in the Carboniferous period, in the account of which a fuller description of them will be given. We can dimly picture the Silurian land with its waving thickets of fern, above which lycopod trees raised their fluted and scarred stems, threw out their scaly moss-like branches, and shed their spiky cones.

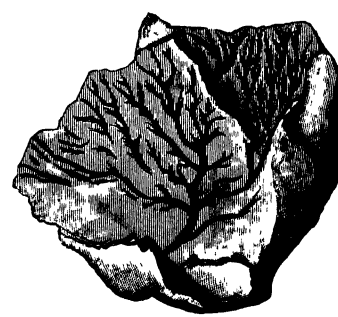


FIG. 134.—*Chondrites verisimilis*, natural size.

The fauna of the Silurian period has been more abundantly preserved than that of the Cambrian, and appears to have been more varied and advanced Among its simpler forms were Foraminifera, Radiolaria, and sponges A foraminifer (of which there were no doubt representatives in Cambrian times, and there are still many living types in the present ocean, see Fig 42) is generally a minute animal, composed of a jelly-like substance which, possessing no definite organs, has in some kinds the power of secreting a hard calcareous or horny shell, through openings or pores (*foramina*) in which filaments from the jelly-like mass are protruded. By other kinds, grains of sand are cemented together

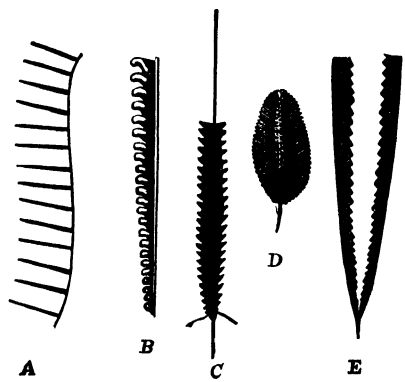



FIG 135 —Graptolites from Silurian rocks A, *Rastrites Linnæi*; B, *Monograptus priodon*, C, *Diplograptus pristis*; D, *Phyllograptus typus*, E, *Didymograptus Murchisoni* (all natural size).

to form a protecting shell. It is these calcareous and sandy coverings which occur in the fossil state, and prove the presence of foraminifera in the older oceans of the globe The siliceous skeletons of radiolaria are often found aggregated in nodules of chert or flint, as in the Silurian series of the South of Scotland. Sponges are known to have existed in the Cambrian and Silurian seas, and their remains have been met with in all later parts of the Geological Record A sponge is a mass of soft, transparent, jelly-like substance, perforated by tubes or canals, and supported on an internal network of minute calcareous or siliceous spicules, or of interlacing horny fibres. Most fossil sponges are calcareous or siliceous, and their hard parts, being durable, have been preserved sometimes in

prodigious numbers and in wonderful perfection. The common sponge of domestic use is an example of the horny type.

The Hydrozoa were abundantly represented in the Silurian seas by graptolites (see p 270), of which there were many kinds Some of the more characteristic of these are shown in Fig 135. They abound in certain bands of shale, both in the Lower and Upper Silurian series, the double forms (such as C, Fig. 135) being more characteristic of the Lower division, while the single forms run throughout the system

Corals abound in some parts of the Silurian seas. Their remains chiefly occur in the limestones, doubtless because these rocks were formed in comparatively clear water, in

FIG. 136.—Silurian Corals (*a*), Rugose Coral (*Omphyma turbinatum*, ½), (*b*), Alcyonarian Coral (*Heliolites interstinctus*, natural size)

which the corals could flourish. But they differed in structure from the familiar reef-building corals of the present day. The great majority of them belonged to the Rugose corals, now only sparingly represented in the waters of the present ocean. As their name denotes, they were particularly marked by their thick rugged walls Many of them were single independent individuals; some lived together in colonies; while others were sometimes solitary, sometimes gregarious. A typical example of these rugose forms is *Omphyma*, shown in Fig. 136 (*a*). Other genera were *Cyathaxonia*, *Cyathophyllum*, and *Zaphrentis*. There were likewise less numerous and more delicate compound forms belonging to what are known as the Tabulate corals (*Favosites*, *Halysites*), while another type (*Heliolites*, Fig. 136, *b*) represented in ancient times the Alcyonarian corals (*Heliopora*) of the present time.

Crinoids or stone-lilies played an important part in the earlier seas of the globe. In some regions they lived in such abundance on the sea-floor that their aggregated remains formed solid beds of limestone, hundreds of feet thick and covering thousands of square miles. As their name denotes, crinoids are lily-shaped animals, having a calcareous, jointed flexible stalk fixed to the bottom, and supporting at its upper end the body, which is composed of calcareous plates furnished with branched calcareous arms (see Figs 164, 180, 188) It is these hard calcareous parts which have been so abundantly preserved in the fossil state.

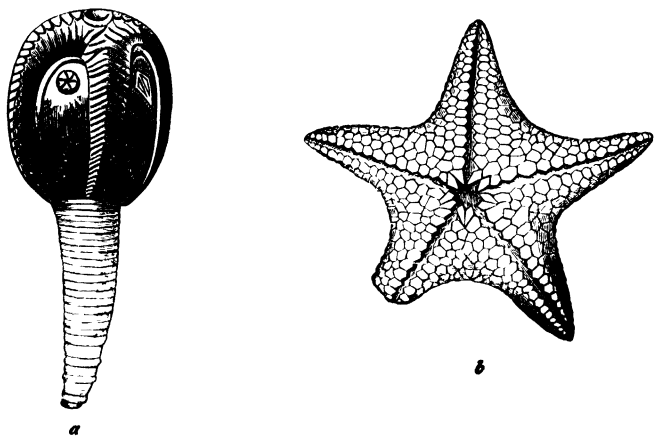



FIG. 137.—Silurian Echinoderms. (*a*), Cystidean (*Pseudocrinites quadrifasciatus*, natural size); (*b*), Star-fish (*Palæasterina stellata*, 3½)

Remains of crinoids are found in various parts of the Silurian system (*Dendrocrinus*, *Glyptocrinus*), chiefly in the limestones, but not in such abundance and variety as in later portions of the Palæozoic formations (compare pp. 293, 306, and Figs 164, 180, and 188) Allied to the crinoids were the Cystideans, a curious order of echinoderms, with rounded or oval bodies enclosed in calcareous plates, possessing only rudimentary arms, and a comparatively small and short jointed stalk. They first appeared in the Cambrian period (*Protocystites*), but attained their chief development during Silurian time, thereafter diminishing in numbers. They are thus characteristically Silurian types

of life. One of them is represented in Fig. 137 (*a*). Star-fishes and brittle-stars likewise occur as fossils among the Silurian rocks. These marine creatures, still represented in our present seas, possess hard calcareous plates and spines, which, being imbedded in a tough leathery integument, have not infrequently been preserved in their natural position as fossils. Some of the genera of star-fishes found in the Silurian system are *Palæaster*, *Palæasterina* (Fig. 137, *b*), *Palæochoma*. Brittle-stars were represented by *Protaster*.

In the Silurian system are found many tracks and burrows like those of the Cambrian rocks, indicative of the presence of different kinds of sea-worms. Throughout great thicknesses of strata, indeed, these markings are sometimes the only or chief fossils to be found. Names have been given to the different kinds of burrows (*Arenicolites*, *Scolithus*, *Lumbricaria*, Fig 138), and of trails (*Palæochorda*, *Palæophycus*). There were likewise representatives of the familiar *Serpula*, which is found so abundantly on the present sea-bottom, encrusting shells and stones with a calcareous protecting tube, inside of which the annelide lives. This tube has been preserved in the fossil state in rocks of all ages.

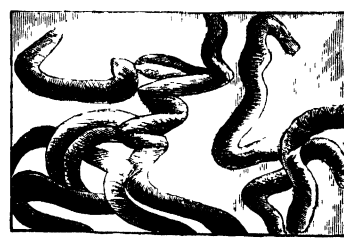


FIG. 138.—Filled-up Burrows or Trails left by a sea-worm on the bed of the Silurian sea (*Lumbricaria antiqua*, ½).

The Trilobites, which had already appeared in Cambrian time, attained their maximum development during the Silurian period. A few of the primordial or Cambrian types continued to live into this period, but many new genera appeared. In the Lower Silurian series some of the more abundant genera are *Asaphus*, *Ampyx*, *Ogygia*, and *Trinucleus*; in the Upper Silurian division characteristic genera are *Calymene*, *Phacops*, *Encrinurus*, *Illænus*, and *Homalonotus* (Fig. 139). Trilobites continued to flourish, but in gradually diminishing variety, during the Devonian and Carboniferous periods, after which they seem to have died out They are thus a distinctively Palæozoic type of life, each great division of the Palæozoic rocks being characterised by its own varieties of the type.

Phyllocarid crustaceans likewise attained to greater variety

during the Silurian period; some of the more frequent genera are *Ceratiocaris* (Fig. 140), *Discinocaris*, and *Caryocaris*

The Mollusca are far more abundant and varied in the Silurian

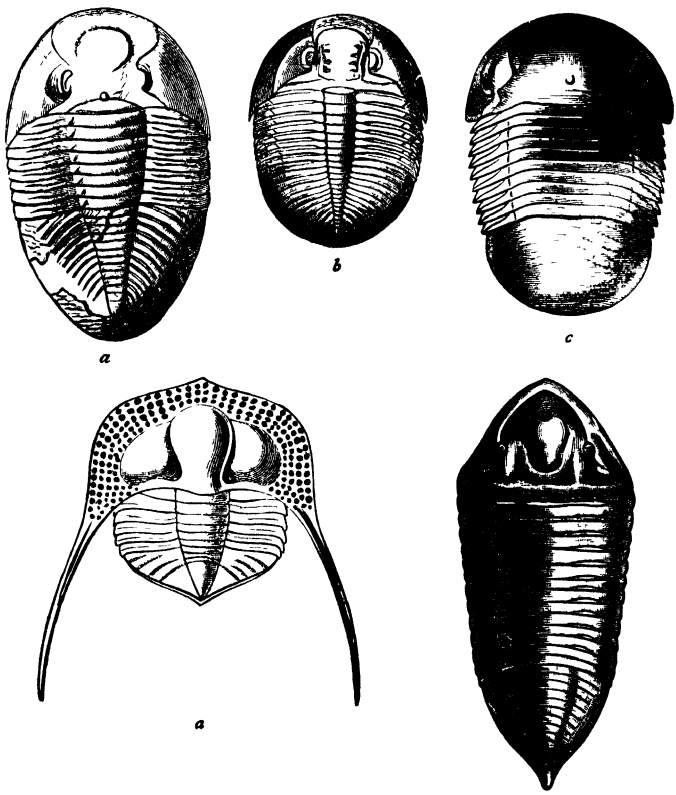



FIG. 139.—Lower and Upper Silurian Trilobites (*a*), *Asaphus tyrannus* (½); (*b*), *Ogygia Buchii* (½), (*c*), *Illænus barriensis* (½), (*d*), *Trinucleus concentricus* (natural size), (*e*), *Homalonotus delphinocephalus* (½)

than in the Cambrian rocks. Among the more characteristic Silurian genera of Brachiopods are *Atrypa*, *Leptæna*, *Orthis*, *Pentamerus*, *Rhynchonella*, and *Strophomena* (Fig. 141). Among the Lamellibranchs we find the Cambrian genera *Ctenodonta* and

*Modioloides*, with new forms such as *Orthonota* (Fig 142), *Cleidophorus* and *Ambonychia*

The Gasteropods played an important part in the fauna of the Silurian sea, for upwards of 1300 species of them have been found in Silurian rocks. Among the more frequent genera are *Bellerophon* (Fig. 143), *Ophileta*, *Holopea*, *Murchisonia*, *Platyschisma*.

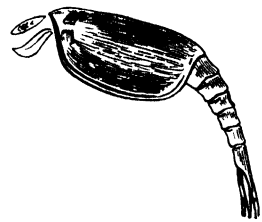


Fig. 140.—Silurian Phyllocarid Crustacean (*Ceratiocaris papilio*)

Numerous representatives of the chambered Cephalopods have been found in the Silurian rocks, especially in the upper division. Among the more frequent genera are *Orthoceras* (straight, Fig 144 *a*), *Cyrtoceras* (curved), *Ascoceras* (globular or pear-shaped), *Lituites* (coiled, Fig. 144 *b*), and also *Nautilus*, a genus which

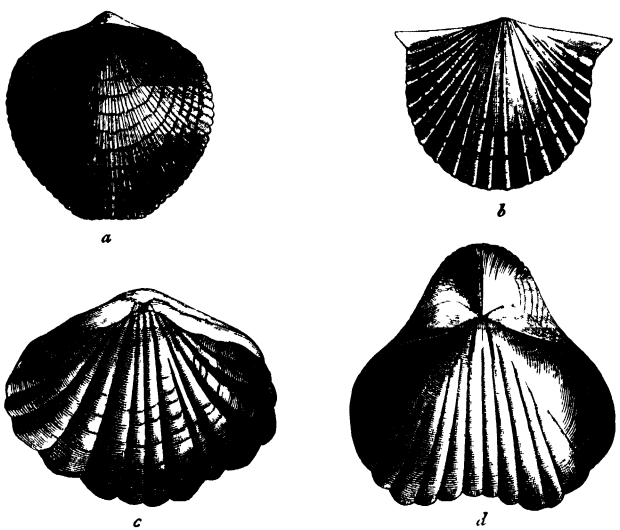


Fig. 141.—Silurian Brachiopods (*a*), *Atrypa reticularis* (natural size), Caradoc beds to Lower Devonian; (*b*), *Orthis actoniæ* (natural size), (*c*), *Rhynchonella borealis* (natural size); (*d*), *Pentamerus galeatus* (natural size)

has persisted through the greater part of geological time to the

present day, and now remains the only representative of the chambered cephalopods formerly so abundant.

Remains of Ostracoderms and fishes detected in the Upper Silurian rocks are the earliest traces of vertebrate life yet known. They consist partly of plates which are regarded as portions of the bony covering of certain "placoderms"[1] or bone-plated forms (*Pteraspis*, *Cephalaspis*, Fig. 148, *Auchenaspis*); partly of curved spines and shagreen-like fragments The creatures of which these are relics appeared as forerunners of the remarkable assemblage of organisms which characterised the next geological period (see p 289). All the animal remains hitherto enumerated are relics of the inhabitants of the sea. Of the land-animals of the time nothing was known until the year 1884, when, by a

FIG 142 —Silurian Lamellibranch (*Orthonota semisulcata*, natural size).

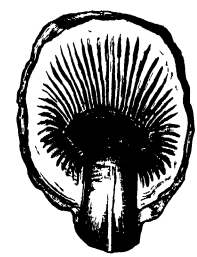


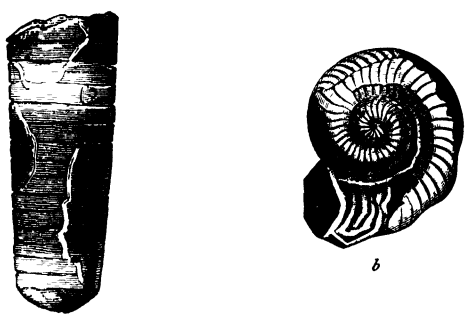
FIG 143 —Silurian Gasteropod (*Bellerophon dilatatus*, ½).

curious coincidence, the discovery was made of the remains of scorpions in the Silurian rocks of Sweden, Scotland, and the United States (compare Fig 157), and of an insect allied to the living cockroach (*Palæoblattina*) in those of France. If scorpions and insects existed during this ancient period we may be sure that other forms of terrestrial life were also present. A new interest is thus given to the prosecution of the search for fossils among the older formations

Putting together the evidence furnished by the rocks and fossils of the Silurian system, we get a glimpse of the aspect of the globe during the early geological period which they represent. The rocks bring before us the sand, mud, and gravel of the bottom of the sea, and tell of some old land from which these

[1] The organisms called "placoderms" and hitherto regarded as fishes, are now believed by some palæontologists not to have been true fishes, and they are placed by these authors in the sub-class Ostracodermi.

materials were worn away. The detritus carried out from the shores of that land was laid down upon the sea-bottom, just as similar materials are being disposed of at the present day. The area occupied by Silurian rocks marks out the tracts then covered by the sea. Following these upon a map we perceive that vast regions of the existing continents were then parts of the ocean-floor. In Europe, for example, Silurian rocks underlie the greater part of the British Islands, whence they stretch northwards across a large part of Scandinavia and the basin of the Baltic. They rise to the surface in many places on the continent from Spain to the Ural Mountains. They have yielded an extraordinary abundance and variety of organic forms in Bohemia. In the New



*a* *b*

FIG. 144.—Silurian Cephalopods (*a*), *Orthoceras emeritum* (⅓); (*b*), *Trochoceras* (*Lituites*) *cornu-arietis* (⅓)

World also they are well developed over Canada and the adjacent portions of the United States. They are found forming parts of some of the great mountain-chains of the globe, as, for instance, in the Cordilleras of South America, in the Rocky and Wahsatch Mountains, in the Alps, and in the Himalayas. Even at the antipodes they are met with as thick masses in Australia and New Zealand It is evident that the geography of the globe in Silurian times was utterly unlike what it is now. A large part of the present land was then covered with shallow seas, in which the Silurian sedimentary rocks were laid down. There would seem to have been extensive masses of land in the boreal part of the northern hemisphere, connecting the European, Asiatic, and American continents Along the coast-line of the northern land, and across the shallow seas lying to the south of it, the same

species of marine organisms migrated freely between the Old and the New Worlds.

The Silurian system of Britain has a total thickness of nearly 20,000 feet, and has been classified into the subdivisions shown in the following Table :—

| | |
|---|---|
| Upper Silurian. | Ludlow group (mudstone and Aymestry Limestone)—Kirkby Moor and Bannisdale Flags and Slates<br>Wenlock group (shales and limestones)—Denbighshire and Coniston Grits and Flags<br>Llandovery group—May Hill Sandstones, Tarannon Shales. |
| Lower Silurian [Ordovician]. | Bala and Caradoc group—sandstones, slates, and grits, with Bala (Coniston) Limestone<br>Llandeilo group—dark argillaceous and sometimes calcareous flagstones and shales<br>Arenig group—dark slates, flags, and sandstones. |

In the United States and Canada the Silurian system is arranged as follows.—

| | |
|---|---|
| Upper Silurian. | Lower Helderberg group (see p. 295), comprising—<br>(3) Upper Pentamerus Limestone.<br>(2) Delthyris (Shaly or Catskill) Limestone<br>(1) Lower Pentamerus Limestone<br>Onondaga, Water-lime (a hydraulic magnesian limestone), and Salina (reddish marls, dolomite, gypsum, and rock-salt) group<br>Niagara Shale and Limestone, full of corals (like Wenlock Limestone)<br>Clinton group : may be paralleled with the Tarannon Shales of Wales.<br>Medina group of sandstones with the Oneida conglomerate below |
| Lower Silurian [Ordovician] | Hudson River Shales and Cincinnati Limestones and Shales.<br>Utica Shales<br>Trenton group, composed mostly of dark carbonaceous limestone (Trenton Limestone, Black River Limestone, Bird's-eye Limestone)<br>Chazy Limestone (dolomite, with *Maclurea*, *Orthoceras*, *Illænus*), etc<br>Calciferous group of arenaceous cherty, magnesian limestones, with rare fossils corresponding to those of the Welsh Arenig rocks. |

# CHAPTER XIX

## DEVONIAN AND OLD RED SANDSTONE

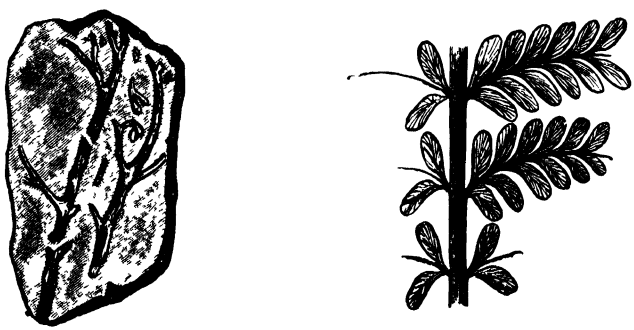
THE DEVONIAN system, which comes next in order, was named by Sedgwick and Murchison after the county of Devon, where they studied its details. In Europe, and likewise in the eastern part of North America, it occurs in two distinct types, which bring before us the records of two very different conditions in the geography of these regions during the time when the rocks composing the system were being deposited. The ordinary type, which occurs all over the world, represents the tracts that were covered by the sea, and has preserved the remains of many forms of the marine life of the period. It is that to which the name DEVONIAN is more particularly applicable. The less frequent type is characterised by thick accumulations of red sandstones, flagstones, and conglomerates which appear to have been laid down in lakes and inland seas. They contain a distinct assemblage of land and probably fresh-water fossils. This lacustrine type is known by the name of OLD RED SANDSTONE.

In general lithological characters the Devonian rocks resemble those of the Silurian system underneath. In Central Europe, where they attain a thickness of many thousand feet, their lower division consists mainly of sandstones, grits, greywackes, slates, and phyllites. The central zone contains thick masses of limestone, often full of corals and shells, while the upper portions comprise thin-bedded sandstones, shales, and limestones. These various strata represent the sediments intermittently laid down upon the bottom of the sea which then covered the greater part of Europe. Here and there, they include bands of diabase and tuff, which show that submarine volcanic eruptions took place during their deposition.

In the north-west of Europe, however, the floor of the Silurian

sea was irregularly ridged up into land, and large water-basins were formed, more or less completely shut off from the sea, into which rivers from the ancient northern continent poured enormous quantities of gravel, sand, and silt. The sites of these inland seas or lakes can be traced in Scotland, the north of England, and Ireland. Similar evidence of land and lake-waters is found in New Brunswick and Nova Scotia. That some of the larger basins were marked by lines of active volcanoes is well shown in Central Scotland, where the piles of lava and ashes left by the eruptions are more than 6000 feet thick.

The occurrence of both marine and lacustrine deposits is of the highest interest, for, on the one hand, we learn what kinds of



*a* *b*

FIG 145 —Plants of the Devonian period (*a*), *Psilophyton* (¼); (*b*), *Palæopteris* (¼)

animals lived in the sea in succession to those that peopled the Silurian waters, and, on the other hand, we meet with the first abundant remains of the vegetation that covered the land, and of the fishes that inhabited the inland waters. The terrestrial flora of the Devonian period has been only sparingly preserved in the marine strata; but occasional drifted specimens occur to show that land was not very distant from the tracts on which these strata were laid down. In the lacustrine series or Old Red Sandstone of Britain more abundant remains have been met with; but the chief sources of information regarding this flora are to be sought in New Brunswick and Gaspé, where upwards of 100 species of plants have been discovered. Both in Europe and in North America, the Devonian vegetation was characterised by the predominance of ferns, lycopods (*Lepidodendron*, etc.), and

calamites. It was essentially acrogenous—that is, it consisted mainly of flowerless plants like our modern ferns, club-mosses, and horse-tail reeds. One of the most characteristic plants, called *Psilophyton*, is represented in Fig 145. Traces of coniferous plants show that on the upland of the time ancient types of pine-trees grew, the stems of which were now and then swept down by floods into the lakes or the sea.

While the general aspect of the flora was uniformly green and somewhat monotonous, the fauna had now become increasingly varied. We know that these early woodlands were not without insect life, for neuropterous and orthopterous wings have been preserved in the strata of New Brunswick. Some of these remains indicate the existence of ancient forms of ephemera or May-fly, one of which was so large as to have a spread of wing measuring 5 inches across. In the Lower Old Red Sandstone of Scotland traces have been found of millipedes, which fed on the decayed wood of the forests. Relics of land-snails too have been detected among the fossil vegetation in the New Brunswick deposits. It is evident, however, that the plant and animal life of the land has only been sparingly preserved; and though our knowledge of it has in recent years been largely increased, we shall probably never discover more than a mere fragmentary representation of what the original terrestrial flora and fauna really were.

The water-basins of the Old Red Sandstone have yielded large numbers of remains of the fishes of the time. These are members of the remarkable order of Ganoids—the earliest known type of fishes—which, though so abundant in early geological time, is represented at the present day by only a few widely scattered species, such as the sturgeon, the polypterus of the Nile, and the bony pike or garpike of the American lakes. These modern forms are denizens of fresh water, and there is reason to believe that their early ancestors were also inhabitants of lakes and rivers, though many of them may also have been able to pass out to the sea. The ganoids are so named from the enamelled scales and plates of bone in which they are encased. In some of the fossil forms, this defensive armour consisted of accurately fitting and overlapping scales (Figs. 146, 147). Some of the most characteristic scale-covered genera are *Osteolepis* (Fig. 147, *a*), *Diplopterus*, *Glyptolæmus*, *Holoptychius*. The acanthodians (Fig. 147, *b*), an order of elasmobranchs, distinguished by the thorn-like spines supporting their fins, reached their greatest development during the Devonian period. Of the plate-covered "placoderms" some of

the most characteristic were the curious *Cephalaspis* (Fig. 148, *a*), with its head-buckler shaped like a saddler's awl, the *Pteraspis*, which, with *Cephalaspis*, had already appeared in the Silurian period, and the *Pterichthys* (Fig. 148, *b*). The true affinities of these forms, however, are doubtful, and some authors do not regard them as true fishes.

FIG. 146.—Overlapping scales of an Old Red Sandstone fish (*Holoptychius Andersoni*, natural size).

One of the fishes of the Old Red Sandstone, named *Dipterus*, has been found to have a singular modern representative in the barramunda or mud-fish (*Ceratodus*) of the Queensland rivers in Australia. *Dipterus* resembled the ganoids in its external enamel and strong bony helmet, but its jaws present the characteristic teeth, and its scales have the rounded or "cycloid" form of *Ceratodus*. The curious genus *Coccosteus*, which is found in the Old Red Sandstone, may also

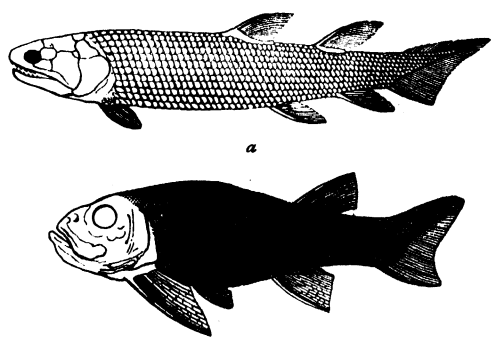


FIG. 147 —Scale-covered Old Red Sandstone fishes. (*a*), *Osteolepis*; (*b*), *Acanthodes* (both reduced).

have Dipnoan affinities. Its head and body were armoured with bony plates. Some of its American allies were of large size, one of which, the *Dinichthys*, found in Ohio, had a head-buckler 3 feet long armed with formidable teeth, while another, the *Titanichthys*, is said to have reached a length of 25 feet.

Some of the fishes swarmed in the waters of the Old Red Sandstone, as is shown by the prodigious numbers of their remains occasionally preserved in the sandstones and flagstones. Their bodies lie piled on each other in such numbers, and often so well preserved, as to show that probably the animals were suddenly killed, and were covered up with sediment before their remains had time to decay and to be dispersed by the currents of water Perhaps earthquake shocks, or the copious discharge of mephitic gases, or other sudden baneful influence, may have been the cause of the extensive destruction of life in these ancient waters.

That some of the fishes found their way to the sea, as our

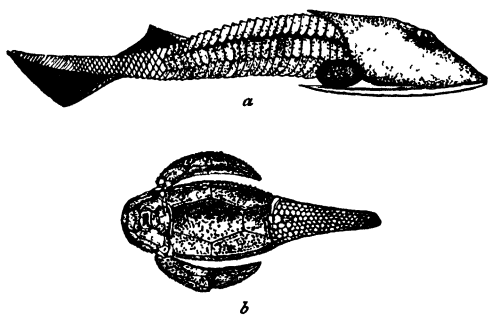


FIG. 148.—Old Red Sandstone Placoderms (*a*), *Cephalaspis*; (*b*), *Pterichthys* (both reduced).

modern salmon does, may be indicated by the occasional occurrence of their remains among those of the truly marine fauna of the Devonian rocks. But the rarity of their presence there, compared with their prodigious abundance in some parts of the Old Red Sandstone, probably serves to show that they were essentially inhabitants of the inland waters of the time.

Among the animals that appear to have been migratory between the outer sea and the inland basins, were the curious forms known as Eurypterids, which, though generally classed with the crustaceans, possibly had affinities with the arachnids or scorpions One of the most remarkable of these creatures was the *Pterygotus*, of which the general form is shown in Fig 149 Most of the species are small, though one of them found in Scotland must have attained a length of 5 or 6 feet.

But it is the marine or Devonian fauna which is most widely

spread over the globe, and from its extensive distribution is of most importance to the geologist. Taken as a whole, it presents a general resemblance to that of the Silurian period, which it succeeded Some of the Silurian species survived in it, and new species of the old genera made their appearance. But important differences are to be observed between the faunas of the two systems, showing the long lapse of time, and the changes that were gradually brought about in the life of the globe.

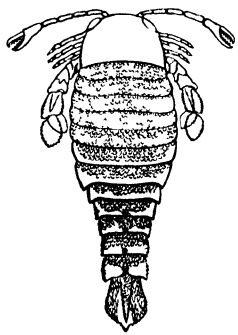


FIG. 149.—Devonian Eurypterid Crustacean (*Pterygotus*, reduced)

It is specially interesting to mark how some of the characteristic Silurian types dwindle and finally die out in the Devonian system. One of the best examples of this survival and disappearance is supplied by the Graptolites. It will be remembered how prodigiously abundant these creatures were in the Silurian seas. They are met with also in scattered specimens in the lower division of the Devonian system, but their rarity there affords a

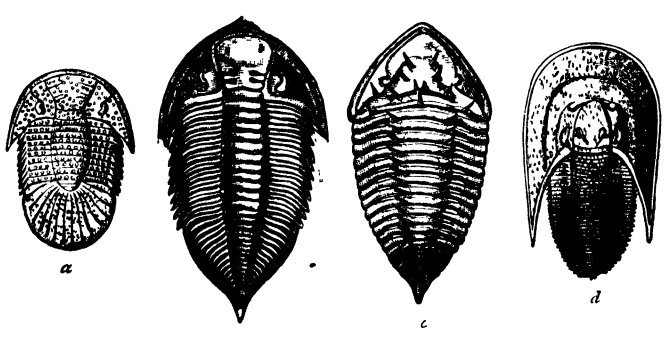



FIG. 150.—Devonian Trilobites (*a*), *Bronteus flabellifer* (½), (*b*), *Dalmania rugosa* (½), (*c*), *Homalonotus armatus* (½), (*d*), *Harpes macrocephalus* (½)

striking contrast to their profusion among the Silurian strata, and they seem to have entirely died out before the end of the Devonian period, for no traces of them occur in the higher parts of the

system, and they have never been met with in any later geological formation.

Again, Trilobites, which form such a predominant and striking feature of the Silurian fauna, occur in greatly diminished number and variety among the Devonian rocks. Most of the Silurian genera are absent. Among the most frequent Devonian types are species of *Phacops*, *Cryphæus*, *Homalonotus*, *Dalmania*, and *Bronteus* (Fig. 150). We shall find that this peculiarly Palæozoic type of crustacea finally died out in the next or Carboniferous period. But while the trilobites were waning, the eurypterids, already referred to, appeared and attained a great development.

In the clearer parts of the sea vast numbers of rugose corals flourished, and, with other calcareous organisms, built up solid masses of limestone. Some of the characteristic genera were

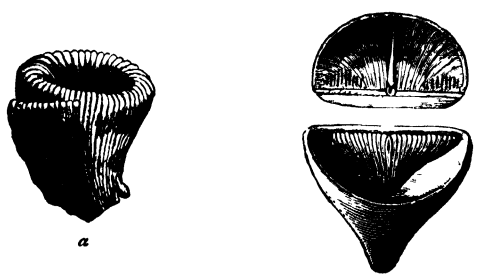



FIG. 151.—Devonian Corals. (*a*), *Cyathophyllum ceratites* (½), (*b*), *Calceola sandalina* (⅓)

*Cyathophyllum* (Fig 151), *Acervularia*, *Cystiphyllum*, and the curious *Calceola* which, after being successively placed among the lamellibranchs and the brachiopods, is now regarded as a rugose coral with an opercular lid With these were likewise associated vast numbers of crinoids, of which the genera *Cyathocrinus* and *Cupressocrinus* were especially characteristic.

The Brachiopods reached their maximum of development in the Devonian seas, upwards of 60 genera and 1100 species having been described from Devonian rocks Comparing them with those of the Silurian system, we notice that some of the most characteristic Silurian types, such as forms of *Orthis* and *Strophomena*, became fewer in number, while forms of *Productus* and *Chonetes* increased. The most abundant families were those of the Spirifers (*Uncites*, *Cyrtia*, *Athyris*, *Atrypa*) and Rhynchonellids (Fig. 152). Two distinctly Devonian brachiopods were

*Stringocephalus* and *Rensselena*, allied to the still living *Tere-*

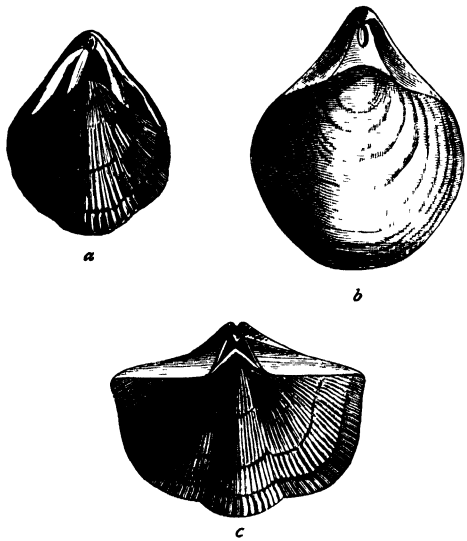



FIG. 152.—Devonian Brachiopods (*a*), *Uncites gryphus* (⅓); (*b*), *Stringocephalus Burtini* (⅓), (*c*), *Spirifera Verneuilli* (*disjuncta*) (½)

*bratula*. The former is especially characteristic of one of the Middle limestones (see Table on p. 295)

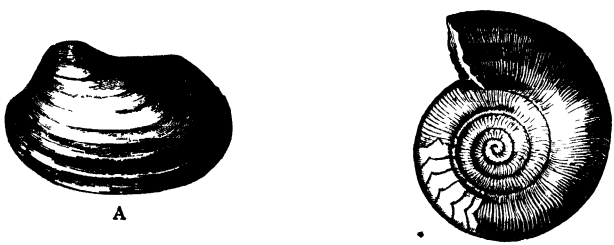



FIG 153.—A, Devonian Lamellibranch (*Cucullæa Hardingii*, ⅔), B, Devonian Cephalopod (*Clymenia Sedgwickii*, ⅔)

The Mollusca appear to have been well represented in the Devonian seas. Of the lamellibranchs, *Pterinea* is particularly

abundant in the lower part of the system, *Cucullæa* (Fig. 153, A) in the upper part. The Devonian cephalopods included many species of the genera *Orthoceras*, *Cyrtoceras*, *Clymenia*, *Goniatites*, and *Bactrites* (Fig. 153, B)

The Devonian system in Europe is subdivided as in the subjoined Table :—

| | |
|---|---|
| Upper | Pilton and Pickwell-Down Group of England—Upper Old Red Sandstone of Scotland, Famennian and Frasnian sandstones, shales, and limestones of the north of France and Belgium, Psammites de Condroz, Cypridina shales, Spirifer sandstone, *Rhynchonella cuboides* beds of Germany |
| Middle | Ilfracombe and Plymouth Limestones, grits, and conglomerates of Devonshire, Limestone of Givet, and Calceola shales of north of France, Stringocephalus limestone (Givetian), Calceola group (Eifelian) of Germany |
| Lower | Linton Slates and sandstones of Devon and Cornwall—Lower Old Red Sandstone of Scotland and Wales, Coblenzian and Gedinnian rocks of the Ardennes and the Rhine district |

In North America the following subdivisions have been made.—

| | |
|---|---|
| Upper | Catskill Red Sandstone and conglomerate, 6000 feet thick (Upper Old Red Sandstone)<br>Chemung group, 3300 feet thick in Pennsylvania (*Spirifera Verneuilli*)<br>Portage group of shales and shaly sandstones (*Goniatites*, *Cardiola*, *Clymenia*)<br>Genesee group of dark shales (with a *Rhynchonella* like *R cuboides*) |
| Middle | Hamilton group of shaly sandstone, shales, and thin limestones (*Phacops*, *Homalonotus*, etc ).<br>Marcellus group of soft dark shales with a thin limestone at the bottom containing *Goniatites.* |
| Lower | Corniferous Limestone with abundant masses of chert or flint and numerous corals which sometimes assume the form of reefs (*Spirifera acuminata*, *Dalmania*, etc.), Schoharie grit, Caudagalli grit. — Upper Helderberg group<br>Oriskany Sandstone (*Spirifera arenosa*, *Rensseleria ovoides*) connected with the Lower Helderberg group (p 286) in stratigraphical relations but containing Devonian fossils. |

# CHAPTER XX

## CARBONIFEROUS

THE next great division of the Geological Record has received the name of CARBONIFEROUS, from the beds of coal (Latin *Carbo*) which form one of its most conspicuous features. The rocks of which it consists reach sometimes a thickness of fully 20,000 feet, and contain the chronicle of a remarkable series of geographical changes which succeeded the Devonian period. They include limestones made up in great part of corals, crinoids, polyzoa, brachiopods, and other calcareous organisms which swarmed in the clearer parts of the sea, sandstones often full of coaly streaks and remains of terrestrial plants; dark shales not infrequently charged with vegetation, and containing nodules and seams of clay-ironstone, and seams of coal varying from less than an inch to several feet or yards in thickness, and frequently resting on beds of fire-clay

These various strata are disposed in such a way as to afford clear evidence of the physical geography of large areas of the earth's surface during the Carboniferous period. The limestones attain a thickness of sometimes several thousand feet, with hardly any intermixture of inorganic sedimentary material. They consist partly of aggregated masses of calcareous algæ, corals, and coralloid animals, which grew on the sea-floor, somewhat like modern coral-reefs; partly of aggregated stems and joints of crinoids, which must have flourished in prodigious numbers on the bottom, mixed with fragments of other organisms, the whole being aggregated into sheets of solid stone. Thus, in Europe, the Carboniferous or Mountain Limestone, which forms the lower part of the Carboniferous system, stretches from the west of Ireland eastwards for a distance of 750 miles, across England, Wales, Belgium, and Rhineland into Westphalia. In the basin of the Meuse it is not less than 2500 feet thick, and in Lancashire, where it attains its maximum development, it exceeds 6000 feet. Such an enormous

accumulation of organic remains shows that, during the time of its deposition, a wide and clear sea extended into the centre of Europe. But as the limestone is traced northwards, it is found to diminish in thickness. Beds of sandstone, shale, and coal begin to make their appearance in it, and rapidly increase in importance, as they are followed away from the chief limestone area; while the limestone itself is at last reduced in Scotland to a few beds, each only a yard or two in thickness. From this change in the character of the rocks, the inference may be drawn that, while the sea extended from the west of Ireland eastwards into Westphalia, land lying to the north supplied sand, mud, and drifted plants, which, being scattered over the sea-floor, prevented the calcareous organisms of the thick limestone from extending continuously northwards. These detrital materials now form the masses of sandstone and shale that take the place of the limestone in the north of England and in Scotland The northward extension of a few limestone beds full of marine organisms serves to show that during longer or shorter intervals, the water cleared, sand and mud ceased to be carried so far southward, and the calcareous algæ, corals, crinoids, shells, and other limestone-building organisms could spread themselves farther over the sea-floor. But the thinness of such intercalated limestones also indicates that the intervals favourable for their formation were comparatively short, the sandy and muddy silt being once again borne southward from the land, killing off or driving away the limestone-builders, and spreading new sheets of sand and mud upon the bottom of the sea.

There can be no doubt that, while these changes were in progress, the whole wide area of deposition in Western and Central Europe was undergoing a gradual depression The sea-bottom was sinking, but so slowly that the growth of limestone and the deposit of sediment probably on the whole kept pace with it. The actual depth of the water may not have varied greatly even during a subsidence of several thousand feet. That this was the case may be inferred from the structure of the limestone itself. We have seen that this rock sometimes exceeds 6000 feet in thickness. Had there been no subsidence of the sea-floor during the accumulation of so thick a mass of organic debris, it is evident that the first beds of limestone must have been begun at a depth of at least 6000 feet below the surface of the sea, and that, by the gradual increase of calcareous matter, the sea was eventually filled up to that amount, if it was not filled up entirely. But we can hardly suppose that the same kinds of

organisms could live at a depth of 6000 feet and also at or near the surface. We should expect to find the organic contents of the lower parts of the limestone strikingly different from those in the upper parts. But though there are differences sufficient to admit of the limestone being separated into stages, each marked by its own distinctive assemblage of fossils, the general character or facies of the organisms remains so uniform and persistent throughout, as to make it quite certain that the conditions under which the creatures lived on the bottom and built up the limestone continued with but little change during the whole time when the 6000 feet of rock were being deposited. As this could not have been the case had there been a gulf of 6000 feet to fill up, we are led to conclude that the bottom slowly subsided until its original level, on which the limestone began to form, had sunk at least 6000 feet.

This conclusion is borne out by many other considerations. Thus the sedimentary strata that replace the limestone on its northern margin are also several thousand feet thick. But from bottom to top they abound with evidence of shallow-water conditions of deposition. Their repeated alternations of sandstone, grit (even conglomerate), and shale; the presence in them of constant current-bedding; the frequent occurrence of ripple-marked and sun-cracked surfaces; the preservation of abundant remains of terrestrial vegetation—much of it evidently in its position of growth—prove that the mass of sediment was not laid down in a deep hollow of the sea-bottom, but on the sinking floor of shallow waters not far from the margin of the land.

But probably the most interesting evidence of long-continued subsidence during the Carboniferous period is furnished by the history of the coal-seams. Coal is composed of compressed and mineralised vegetation. In most coal-fields each layer of coal is usually underlain by a bed of fire-clay, or at least of shale, through which roots and rootlets, descending from the under surface of the coal-seam, branch freely. There can be little doubt that each bed of fire-clay is an old soil, while the coal lying upon it represents the matted growth of vegetation which that soil supported. Hence the association of a fire-clay and a coal-seam furnishes distinct evidence of a terrestrial surface.[1]

[1] In some coal-fields there is evidence that coal has likewise been formed out of matted vegetation which has been swept down by floods and been buried under sand, gravel, and other sediment. In such circumstances, there is no usual accompaniment of an underclay below each coal-seam.

In many regions the Carboniferous system comprises a series of sandstones, shales, and other strata, many thousands of feet in thickness, throughout which, on successive platforms, there lie hundreds of seams of coal (Fig. 154). If each of these seams marks a former surface of terrestrial vegetation, how is this succession of buried land-surfaces to be accounted for? There is obviously but one solution of the problem. The area over which the coal-seams extend must have been slowly sinking. During this subsidence, sand, mud, and silt were transported from the neighbouring land, and in such quantity as to fill up the shallow waters. On the muddy flats thus formed, the vegetation of the flat marshy swamps spread seaward There may not improbably have been pauses in the downward movement, during which the maritime jungles and forests continued to flourish and to form a thick matted mass of vegetable matter. When the subsidence recommenced, this mass of living and dead vegetation was carried down beneath the water and buried under fresh deposits of sand and mud. As the weight of sediment increased, the vegetable matter would be gradually compressed and would slowly pass into coal. But eventually another interval of rest or of slower subsidence would allow the shallow sea once more to be silted up. Again the marsh-loving plants from the neighbouring swampy shores would creep outward and cover the tract with a new mantle of vegetation, which, on the renewal of the downward movement, would be submerged and buried.

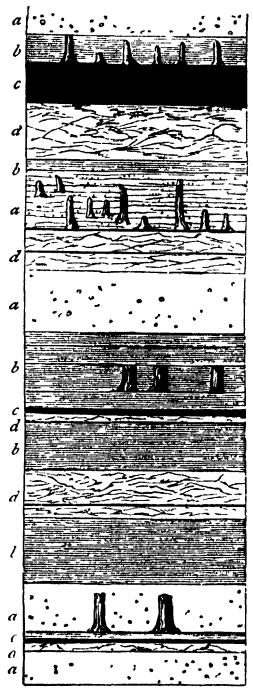



FIG 154.—Section of part of the Cape Breton coal-field, showing a succession of buried trees and land surfaces (*a*), sandstones; (*b*), shales; (*c*), coal-seams; (*d*), under-clays or soils.

In the successive strata of a coal-field, therefore, we are presented with the records of a prolonged period of subsidence, probably marked by longer or shorter intervals of rest. These

more stationary periods are indicated by the coal-seams, and perhaps their relative duration may be inferred from the thickness of the coal. A thick coal-bed not improbably marks a time of rest, when the vegetation was allowed to flourish unchecked, or when at least the sinking was so imperceptible that the successive generations of plants, springing up on the remains of their predecessors, contrived to keep themselves above the level of the water.

In the present world there is no vegetable growth now in progress quite like that of the coal-seams of the Carboniferous period. Perhaps the nearest analogy is supplied by the mangrove-swamps already described (pp 93, 194) In these tracts, the mangrove trees grow seaward, dropping their roots and radicles into

FIG 155.—Carboniferous Ferns (*a*), *Neuropteris macrophylla* (¼), (*b*), *Eremopteris* (*Sphenopteris*) *artemisiæfolia* (¼), (*c*), *Alethopteris* (*Pecopteris*) *lonchitica* (¼).

the shallow waters, and gradually forming a belt of swampy jungle several miles broad. That the coal-jungles extended into the sea is shown by the occurrence of marine shells and other organisms in the coal itself But there were probably also wide swamps wherein the water was brackish or fresh. A single coal-seam may sometimes be traced over an area of more than 1000 square miles, showing how widespread and uniform were the conditions in which it was formed.

During the subterranean movements that marked the Carboniferous period, the Devonian physical geography was entirely remodelled The lake-basins of the Old Red Sandstone were effaced, and the sea of the Carboniferous limestone spread over their site. Much of the Devonian marine area was upridged into land, and the rocks eventually underwent that intense compres-

sion and plication which have given them their cleaved, crumpled, and metamorphic aspect, and in connection with which they were invaded by granite and intersected with mineral veins It is deserving of remark that volcanic action, which played so notable a part in Devonian time, was continued, but with diminished vigour, in the Carboniferous period During the earlier half of the period, volcanic outbursts were frequent in different parts of Britain, particularly in Derbyshire, the Isle of Man, central and southern Scotland, and the south-west of Ireland. The lava and ashes ejected in some of these areas during the time of the Carboniferous Limestone now form conspicuous groups of hills.

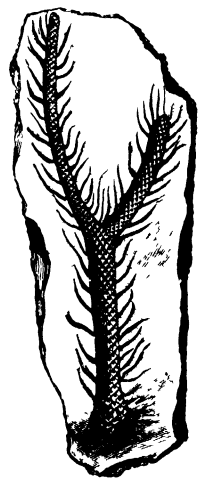


Fig. 156 — Carboniferous Lycopod (*Lepidodendron Sternbergii*, ¼).

Of the plant and animal life of the Carboniferous period much is known from the abundant remains which have been preserved of the terrestrial surfaces and sea-floors of the time. The flora includes calcareous sea-weeds, which often form great part of the limestone. The terrestrial plants present a general resemblance to those of the Devonian period. Many of the genera of the older time survived in the Carboniferous jungles; but other forms appeared in vast profusion, which have not been met with in any Devonian or Old Red Sandstone strata. The Carboniferous flora, like that which preceded it, must have been singularly monotonous, consisting as it did almost entirely of flowerless plants Not only so, but the very same species and genera appear to have then ranged over the whole world, for their remains are found in Carboniferous strata from the Equator to the Arctic Circle Ferns, lycopods, and equisetaceæ, constituted the main mass of the vegetation The ferns recall not a few of their modern allies, some of the more abundant kinds being *Calymmatotheca*, *Sphenopteris*, *Neuropteris*, and *Pecopteris* (Fig. 155). Among the lycopods the most common genus is *Lepidodendron*, so named from the scale-like leaf-scars that wind round its stem (Fig. 156) Its smaller branches, closely covered with small pointed leaves, and bearing at their ends little cones or spikes (*Lepidostrobus*), remind one of the club-mosses of our moors and mountains; but instead of being low-growing or creeping plants, like their modern

representatives, they shot up into trees, sometimes 50 feet or more in height. Equisetaceæ abounded in the Carboniferous

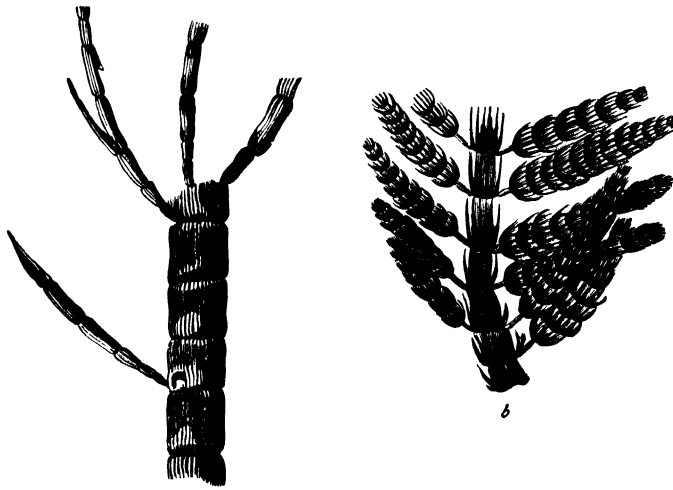



FIG. 157.—Carboniferous Equisetaceous Plants (*a*), *Calamites Lindleyi* (=*C. Mougeoti*, *Lindl.*, ¼); (*b*), *Asterophyllites densifolius* (⅛)

swamps, the most frequent genus being *Calamites*, the jointed and finely-ribbed stems of which are frequent fossils in the sand-

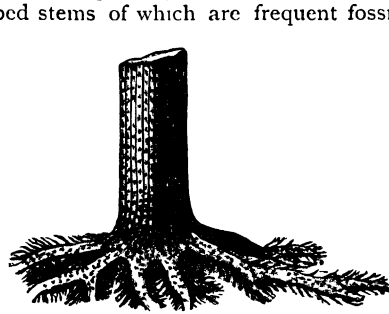


FIG 158.—*Sigillaria* with *Stigmaria* roots (much reduced)

stones and shales (Fig. 157, *a*). This plant probably grew in dense thickets in the sandy and muddy lagoons, and bore as its

foliage slim branches, with whorls of pointed leaves set round the joints (*Asterophyllites*, Fig 157, *b*). The Sigillarioids were among the most abundant, and, at the same time, most puzzling members of the Carboniferous flora. They do not appear to have any close modern allies, and their place in the botanical scale has been a subject of much controversy. The stem of these trees, sometimes reaching a height of 50 feet or more, was fluted, each of the parallel ribs being marked by a row of leaf-scars, hence the name *Sigillaria*, from the seal-like impressions of the scars (Fig 158) These surface-markings disappeared as the tree grew, and in the lower part of the trunk they passed down into the pitted and tubercular surface characteristic of the roots (*Stigmaria*), still so

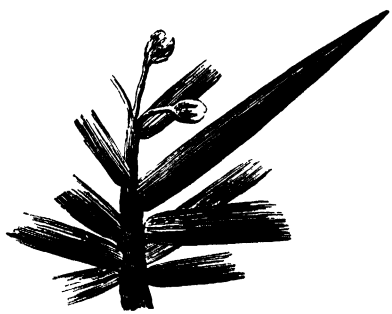


FIG. 159.—*Cordaites alloidius* (½) with *Carpolithes* attached.

abundant in their position of growth in fire-clay, and also as drifted broken specimens in sandstones and shales Another plant that took a prominent part in the Carboniferous flora was that named *Cordaites* (Fig. 159). Its true botanical place is still matter of dispute; some writers placing it with the lycopods, others with the cycads, or even among the conifers. It bore parallel-veined leaves somewhat like those of a yucca, which, when they fell off, left prominent scars on the stem, and it also carried spikes or buds (*Carpolithes*, Fig. 159) All the plants now enumerated probably flourished on the lower grounds and swamps But on the higher and drier tracts of the interior there grew araucarian pines (*Dadoxylon*, *Araucarioxylon*), the trunks of which, swept down by floods, were imbedded in some of the sands of the time and now appear petrified in the sandstones.

While the terrestrial vegetation of the Carboniferous period has

been so abundantly entombed, the fauna of the land has been but scantily preserved. That air-breathers existed, however, has been made known by the finding of specimens of scorpions, myriapods, true insects, and amphibians. Vast numbers of the remains of scorpions have been discovered in the Carboniferous rocks of Scotland. These ancient forms (*Eoscorpius*, Fig. 160) presented a remarkably close resemblance to the living scorpion, and so well have they been preserved among the shales that even the minutest parts of their structure can be recognised. They possessed stings like their modern descendants, whence we may infer the presence of other forms of life which they killed. The Carboniferous woodlands had plant-eating millipedes, and their silence was broken by the hum of insect-life ; for ancestral forms of dragon-flies (*Libellulæ*), May-flies (*Ephemeridæ*), stone-flies (*Perlidæ*), white-ants (*Termidæ*), cockroaches (*Blattidæ*), spectre-insects (*Phasmidæ*), crickets (*Gryllidæ*), locusts (*Acrydiidæ*), and curious transitional forms between modern types that are quite distinct, have been detected, chiefly among the shales and coals of the Coal-measures. Some of these insects attained a great size ; a single wing of one of them (*Megaptilus*) must have measured between 7 and 8 inches in length. While detached wings and more or less complete bodies have been found as rare and precious discoveries in many coal-fields in Europe and America, it is at Commentry in France that remains of insects have been met with in largest numbers—no fewer than 1300 specimens having there been disinterred, most of them admirably preserved. In the interior of decaying trees early forms of land-snails lived, having a striking resemblance to some kinds that are still to be found in our present woodlands (*Pupa*).

FIG. 160.—Carboniferous Scorpion (*Eoscorpius glaber*).

The lagoons in which the coal-growths flourished were tenanted by numerous forms of animal life. Among these were various mussel-like molluscs (*Anthracomya*, Fig. 169, *Anthracosia*), which were possibly restricted to fresh water. But wherever the sea-

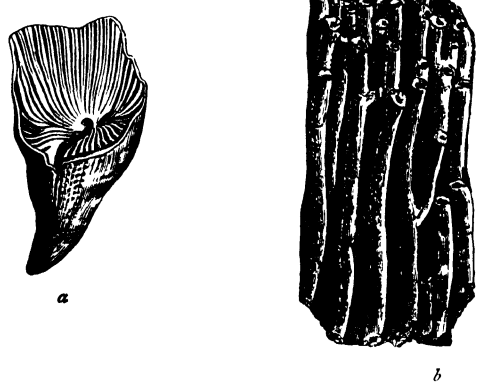
water penetrated, it carried some of its characteristic life with it, particularly *Lingula*, *Discina*, *Aviculopecten*, *Goniatites*, and other marine shells The fishes of the lagoons were chiefly ganoids (*Megalichthys*, *Rhizodus*, Fig 173, *a*, *Cheirodus*, *Strepsodus*, etc.) But some of the rays and sharks from the sea made their way into these waters, for their teeth and spines are occasionally found among the coal-seams and shales (*Gyracanthus*, *Pleuracanthus*, Fig 173, *b*, *c*). That the larger fishes lived upon the smaller ones is shown by a curious and interesting piece of evidence. Many of the shales are full of small oblong bodies which contain in their interior the broken and undigested scales and bones of small fishes. From their contents, their peculiar external form and markings, and their phosphatic composition, these bodies (*coprolites*) are recognised as the excrement of some of the larger fishes, and the teeth and scales within them serve to show what were the smaller forms on which these fishes fed (see Fig 76).

During the Carboniferous period, and indeed throughout the later parts of the Palæozoic ages, the most highly organised creatures living on the globe, so far as we at present know, belonged to the Amphibia—the great class which includes our modern frogs, toads, and salamanders. They belonged, however, to an older that has long been entirely extinct—the Labyrinthodonts, so named from the labyrinthine folds of the internal substance of their teeth. They were somewhat like the existing salamander in form, with weak limbs and a long tail. Their skulls were encased in strong plates of bone, and they likewise carried protective bony scutes on the under sides of their bodies. Those found in Carboniferous rocks are mostly small in size, but some of them, measuring perhaps 7 or 8 feet in length, must have been the monsters of the lagoons, in which they lived. Some of the leading genera are *Archegosaurus*, *Anthracosaurus*, *Loxomma*, *Dendrerpeton*, *Baphetes*.

The marine life of the Carboniferous period has been extensively preserved in the Carboniferous Limestone, which, as already stated, consists of little else than aggregated remains of organisms. In walking over the surface of the beds of this limestone, one treads upon the floor of the sea in Carboniferous times, with its calcareous algæ, corals, crinoids, and shells crowded upon each other. Beginning with the most lowly forms of animal life, we find abundant remains of foraminifera, which in some portions of the limestone constitute the greater part of the rock. One of their most characteristic forms, named *Fusulina* (Fig. 161), enters largely into the structure of the limestone across the Old World

from Russia to China and Japan, and likewise in North America. Another, called *Sacammina*, abounds as aggregates of little globular bodies in some parts of the limestone of Britain Corals have been preserved in prodigious numbers; indeed, some parts of the limestone are almost entirely made up of them and of calcareous algæ Most are rugose, characteristic genera being *Zaphrentis*, *Lithostrotion* (Fig. 162), *Clisiophyllum*, *Lonsdaleia*. With these there occur also tabulate forms, including *Chætetes*, *Alveolites*, *Favosites*, etc. Of the sea-urchins, the plates and spines of the genus *Archæocidaris* (Fig. 163) are specially frequent. But the most common echinoderms are members of the great order of crinoids, which must have grown in thick groves over many square miles of the sea

FIG. 161.—Carboniferous Foraminifer (*Fusulina cylindrica*, ♀).

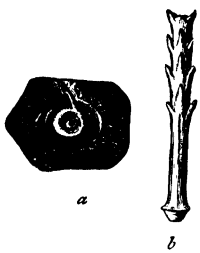


*a* *b*

FIG. 162.—Carboniferous Rugose Corals. (*a*), *Zaphrentis Enniskilleni* (½), (*b*), *Lithostrotion junceum* (natural size)

bottom. So prodigiously numerous were they that their remains form a large part of beds of limestone hundreds of feet in thickness, hence known as crinoidal or encrinite limestone (Fig 78). The general plant-like form of these animals is shown in Fig. 164. But usually the calcareous joints and plates fell asunder. Frequent genera are named *Platycrinus*, *Poteriocrinus*, *Cyathocrinus* The Carboniferous seas were tenanted by a peculiar extinct order of

echinoderms known as Blastoids or Pentremites (Fig 165), distinguished from true crinoids by the want of free arms, and by the arrangement of the plates forming the cup. These creatures are



*a* *b*

FIG 163 — Carboniferous Sea-Urchin (*Archæocidaris Urei*, natural size) (*a*), Single plate, (*b*), portion of spine.

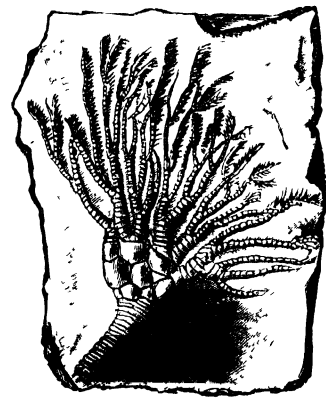
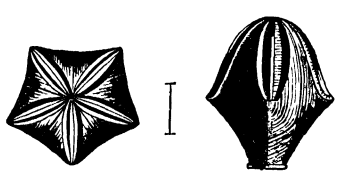


FIG 164 —Carboniferous Crinoid (*Woodocrinus expansus*, ½)

characteristically Carboniferous, though they are found also in the higher part of the Silurian system and in Devonian rocks.

The Crustacea of the Carboniferous period presented a strong



*a* *b*

FIG. 165 —Carboniferous Pentremite, magnified) above; (*b*), side view Blastoid (Cup of (*a*), View from

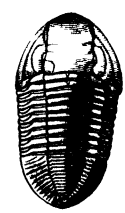


FIG 166 —Carboniferous Trilobite (*Phillipsia derbiensis*, natural size)

contrast to those of earlier geological time. In particular, the great family of the Trilobites, so characteristic of the older Palæozoic systems, now died out altogether Instead of its numerous types in the Silurian and Devonian rocks, it is represented in the Carboniferous system by only four genera, all the

species of which are small (*Phillipsia*, Fig. 166, *Griffithides*, *Brachymetopus*), and none of which rises into the next succeeding system. The most abundant crustaceans were ostracods—an order still abundantly represented at the present day. They are minute forms enclosed within a bivalve shell or carapace which entirely invests the body. Many of these live in fresh water; the *Cypris*, for example, being abundant in ponds and ditches. Others are marine, while some are brackish-water forms. In the Carboniferous lagoons, as at the present time, they lived in enormous numbers; their little seed-like valves are crowded together in some parts of the shale which represents the mud of these lagoons, sometimes they even form beds of limestone Doubtless, they served as food to the smaller fishes whose remains are usually to be found where the ostracod valves are plentiful One of the principal genera is *Leperditia*. There were likewise long-tailed shrimp-like crustaceans (*Anthrapalæmon*, *Palæocrangon*), and king-crabs (*Prestwichia*); while in the earlier part of the period Eurypterids still survived in the waters.

Some of the most delicately beautiful fossils of the Carboniferous Limestone belong to the Polyzoa. These animals, of which familiar living examples are the common sea-mats of our shores, are characterised by their compound calcareous or horny framework studded with minute cells, each of which is occupied by a separate individual, though the whole forms one united colony. One of the most abundant Carboniferous genera is *Fenestella* (Fig 167). So numerous are the polyzoa in some bands of limestone as to constitute the main part of the stone Their delicate lace-like fronds are best seen where the rock has been exposed for a time to the action of the weather; they then stand out in relief and often retain perfectly their rows of cells.

FIG. 167 —Carboniferous Polyzoon (*Fenestella Morrisii*, natural size)

The Brachiopods, so preponderant among the molluscs of the earlier divisions of Palæozoic time, now decidedly wane before the great advance of the more highly organised lamellibranchs and gasteropods. Some of the most characteristic genera (Fig. 168) are *Productus*, *Spirifera*, *Streptorhynchus*, *Rhynchonella*, *Athyris*, *Chonetes*, *Terebratula* (*Dielasma*), *Lingula*, *Discina*

Some of the species appear to range over the whole world, for

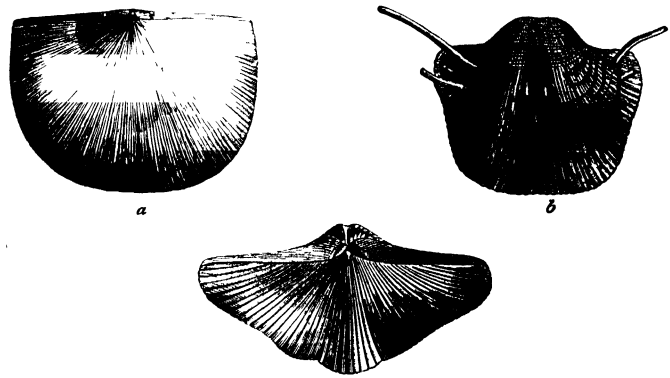



FIG. 168 Carboniferous Brachiopods (*a*), *Streptorhynchus crenistria* (½); (*b*), *Productus semireticulatus* (½), (*c*), *Spirifera striata* (½)

they have been met with across Europe, in China, Australia, and North America. Among these cosmopolitan forms are *Productus*

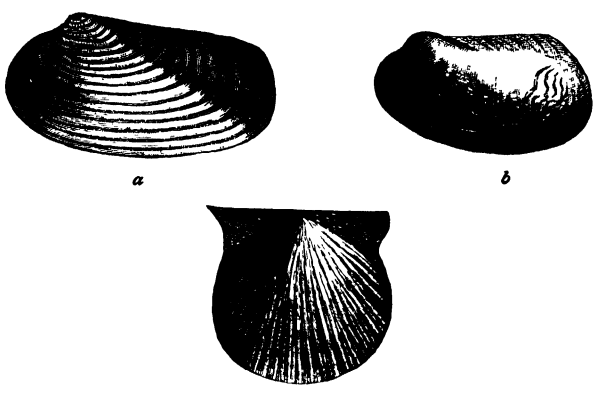



FIG 169 —Carboniferous Lamellibranchs (*a*), *Edmondia sulcata* (½); (*b*), *Anthracomya Adamsii* (½); (*c*), *Aviculopecten fallax* (⅔).

*semireticulatus*, *Productus longispinus*, *Streptorhynchus crenistria*, *Spirifera glabra*, *Terebratula hastata.*

Some of the more common Lamellibranch molluscs (Fig. 169) belong to the genera *Aviculopecten*, *Nuculana*, *Nucula*, *Edmondia*, *Modiola*, *Anthracomya*. Among the Gasteropods *Euomphalus*, *Pleurotomaria*, *Loxonema*, and *Bellerophon* (Fig. 170) are not infrequent. A Pteropod (*Conularia*, Fig. 171) may be gathered

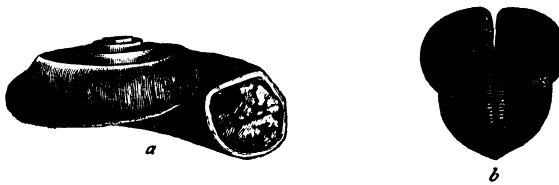



FIG. 170.—Carboniferous Gasteropods. (*a*), *Euomphalus pentangulatus* (½); (*b*), *Bellerophon tenuifascia* (⅔).

in great numbers in some parts of the Carboniferous Limestone. The Cephalopods were represented by numerous species of *Orthoceras*, *Nautilus*, and *Goniatites* (Fig. 172).

Remains of fishes are not infrequent in the Carboniferous Limestone. But they present a striking contrast to those of the

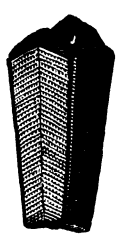


FIG. 171.—Carboniferous Pteropod (*Conularia quadrisulcata* (⅔).

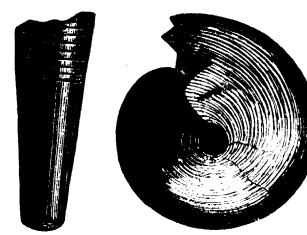



FIG. 172.—Carboniferous Cephalopods. (*a*), *Orthoceras goldfussianum* (½); (*b*), *Goniatites sphæricus* (natural size).

black shales and ironstones of the Coal-measures. They consist for the most part of teeth or of spines belonging to large predatory sharks. These teeth were placed as a kind of pavement and roof in the mouth, and were used as effective instruments for crushing the hard parts of the animals, on which these larger creatures preyed. If, as is probable, the sharks fed upon the ganoid fishes of the time, they must have required a powerful

apparatus of teeth for crushing the hard, bony armour in which these fishes were encased. Of the commoner genera of sharks, which have been named from the forms of their teeth—the only hard parts of their structure that have survived—the following may be mentioned: *Cochliodus*, *Orodus* (Fig 173, *b*), *Psammodus*, *Petalodus*. The small ganoids that so abound in the black shales, ironstones, and coal-seams which represent the deposits of the sheltered lagoons of the coal-jungles, are hardly to be found in the thick limestone, whence we may infer that they were

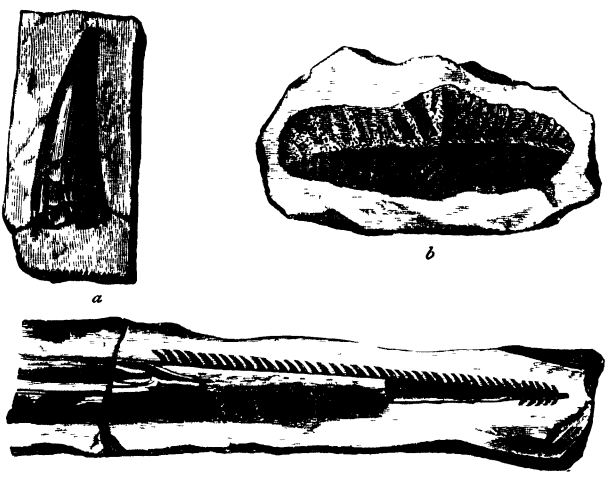



FIG 173.—Carboniferous Fishes (*a*), Tooth of *Rhizodus Hibberti* (½), (*b*), *tooth of Orodus ramosus* (½), (*c*), *Ichthyodorulite* or Fin-spine of *Pleuracanthus laevissimus* (½)

inhabitants of the quiet shore-waters, and did not venture out into the open sea, where the sharks found their congenial element. But the occasional occurrence of the teeth and spines of sharks in the Coal-measure shales and coal-seams shows that these monsters now and then made their way into the inland waters, where they would find abundant food

The Carboniferous system in Europe presents at least two well-marked subdivisions. In the lower section the strata are in large measure marine, for they include the Carboniferous Limestone; in the upper part they consist mainly of sandstones, shales, fire-clays, and coal-seams, constituting what are called the Coal-

measures, or coal-bearing division of the system The subjoined Table shows the order of succession of the rocks in Britain :—

| | |
|---|---|
| Lagoon type (Moscovian or Westphalian Series of European Continent) | Coal-Measures —At the top, red and grey sandstones, clays, and thin limestone, resting upon a great thickness of white, grey, and yellow sandstones, clays, shales, and fire-clays, with numerous workable coal-seams, and with a lower subdivision of coal-bearing beds, among which there occur marine fossils (*Orthoceras*, *Posidonomya*, etc ) Thickness in South Wales, 12,000 feet , South Lancashire, 8000 feet , Central Scotland, 3000 feet |
| Marine type, but passing northwards into that of the lagoons (Dinantian or Culm Series of the Continent). | Millstone Grit —Grits, flagstones, sandstones, and shales, with thin seams of coal and occasional bands containing marine fossils Thickness 400-1000 feet, increasing in Lancashire to 5500 feet<br>Carboniferous Limestone —Consisting typically of massive marine limestones and shales, but passing laterally into sandstones and shales, with thin coal-seams, which indicate alternations of marine and brackish water conditions Thickness in South Wales, 500 feet, increasing northwards to more than 4000 feet in Derbyshire, and to upwards of 6000 feet in Lancashire, but diminishing northwards into Scotland<br>The base of the Carboniferous Limestone series passes down conformably into the Upper Old Red Sandstone |

The Carboniferous system occupies a number of detached areas on the European continent. Its largest tract extends from the north of France, through Belgium, into Westphalia. The most important coal-fields of continental Europe in this system are those of Belgium, Westphalia, the north of France, Saarbrucken, St. Etienne in Central France, Bohemia, and the Donetz in Southern Russia. Carboniferous rocks have been detected by means of their characteristic fossils in the Alps, and even as far north as Spitzbergen. They have been found also in Northern Africa, in the peninsula of Sinai, in Palestine, and in Cape Colony, while in Asia they are largely developed, covering many thousands of square miles in China. In Australia and New Zealand also thick masses of sedimentary strata contain recognisable Carboniferous organic remains. In New South Wales they include a valuable succession of coal-seams.

The system is largely developed in the United States, where it presents a wide diversity in its stratigraphical development. Along the eastern parts of the Continent, from Newfoundland southwards, across Pennsylvania and Western Virginia into Alabama and westwards beyond the Mississippi, the European type of lagoon-deposits is well displayed in a succession of im-

portant coal-fields. In the western regions of the interior, however, the marine type prevails, being represented there by thick and widespread accumulations of limestone with no trace of coal.

In Pennsylvania the following subdivisions are recognised :—

| | |
|---|---|
| Upper Carboniferous | Upper productive coal-measures (about 500 feet), containing a number of workable seams of coal intercalated among sandstones, shales, fire-clays, clay-ironstones, etc. (Monongahela Series) |
| | Barren measures (650 feet), consisting of thick sandstones and red shales, with thinner bands of fire-clay, limestone, and clay-ironstone, and a number of thin coals (Conemaugh Series) |
| | Lower productive coal-measures (200 to 300 feet) generally similar to the upper productive series, with a group of good seams of coal (Allegheny Series) |
| | Pottsville Conglomerate or Millstone Grit—a compacted quartzose gravel, which is from 800 to 1700 feet thick in the anthracite region of Pennsylvania. |
| Lower or Sub-Carboniferous. | Mauch Chunk reddish shales and shaly sandstones, with some thin siliceous limestone |
| | Pocono sandstone and conglomerete—hard grey rocks which, sometimes 1400 feet thick, cap the plateau in the north of the State and are said to form the higher peaks of the Catskill Mountains lying immediately on the Upper Devonian strata. |

# CHAPTER XXI

## PERMIAN

THE prolonged subsidence during which the Coal-measures were accumulated was at last brought to an end in Europe by a series of terrestrial disturbances, whereby the lagoons and coal-growing swamps were in great measure effaced from the geography of the region. So abrupt in some regions is the discordance between the Coal-measures and the next series of strata, that geologists have naturally been led to regard this break as one of great chronological importance, serving as the boundary between two distinct systems of strata and two well-marked divisions of geological time. Nevertheless, so far as the evidence of fossils goes, there is no such interruption of the Geological Record as might be supposed from this stratigraphical unconformability, some of the Carboniferous types of life having survived the terrestrial disturbances. Though the discordance among the strata is, in some regions, striking, yet it is by no means universal. On the contrary, some localities (Autun in France, and the Bohemian coal-field, for example) escaped the upheaval and prolonged denudation which elsewhere have produced so marked a hiatus in the chronicle. And in these places a gradual passage can be traced from the strata and fossils of the Coal-measures into those of the next succeeding division of the series, no sharp line being there discoverable, nor any evidence to warrant the separation of the overlying strata as an independent system distinct from the Carboniferous. Hence, by many geologists, the rocks now to be described are regarded as the upper part of the Carboniferous system.

To these overlying rocks the name of PERMIAN was given, from the Russian province of Perm, where they are well developed. In Europe they consist of red sandstones, marls, conglomerates,

and breccias, with limestones and dolomites. In Germany they have been called Dyas, because they are there easily grouped in two great divisions. The coarsest strata—breccias and conglomerates—are composed of rounded and angular fragments of granite, diorite, gneiss, greywacke, sandstone, and other crystalline and older Palæozoic rocks, which must have been upheaved and exposed to denudation before Permian time. The sandstones are usually bright brick-red in colour, owing to the presence of earthy peroxide of iron which has cemented the particles of sand together. The shales or marls are coloured by the same pigment. So characteristic indeed is the red colour of the rocks that they form part of a great series of strata, originally known as the New Red Sandstone. Generally, greenish or whitish spots and streaks occur in the red beds, marking where the iron-oxide has been reduced and removed by decaying organic matter. Red strata are, as a rule, singularly barren of organic remains, probably because the water from which the iron-peroxide was precipitated must have been unfitted for the support of life. The red Permian rocks are generally unfossiliferous. Among them, however, as developed more especially in Germany, occur dark shales or "marl-slate," which have yielded numerous remains of fishes. The limestones too are fossiliferous, but they are associated with unfossiliferous dolomite, gypsum, anhydrite, and rock-salt. In some places seams of coal also occur.

This European development of the Permian formations tells distinctly the story of their origin. Such strata as red sandstone, dolomite, gypsum and rock-salt could not have been deposited in the open sea, but rather in basins more or less shut off from it, wherein the water was charged with iron and was liable to concentration, with the consequent precipitation of its solutions. The beds of anhydrite, gypsum, and rock-salt are direct memorials of different stages of these processes. The dolomite may at first have been laid down as limestone which afterwards was converted into dolomite by the action of the magnesian salts in the concentrated water. In such intensely saline and bitter solutions, animal life would not be likely to flourish, and hence, no doubt, the poverty of fossils in the Permian series of rocks But it is observable that where evidence occurs of the cessation of ferruginous, saliferous, and gypseous deposition, fossils not infrequently appear. The German brown Marl-Slate, for example, and the thick beds of limestone are sometimes abundantly fossiliferous, and indeed are almost the only bands of rock in the whole series where

organic remains occur. They were probably deposited during intervals when the barriers of the inland seas or salt-lakes were broken down, or, at least, when from some cause the waters came to be connected with the open sea, and when a portion of the ordinary marine fauna swarmed into them. Volcanic action showed itself during Permian time in many parts of Western, Central, and Southern Europe There was a group of small volcanoes in the south of Scotland. Great eruptions took place in Germany, notably in the area of the present Vosges Mountains, and the region of volcanic activity extended across the region where now the Alps stand, as far south as Cannes on the shores of the Mediterranean

The Permian system covers by far the largest part of European Russia. Over many thousands of square miles its nearly horizontal strata of sandstone, marl, shale, conglomerate, limestone, dolomite, gypsum, rock-salt and thin coal stretch across the vast plain up to the flanks of the Ural Mountains, and from the White Sea to the Khirgis Steppes. It reappears in Asia with similar characters and is extensively developed in the Salt Range of the Punjab. Farther south in India it seems to form the lower part of the great freshwater series of deposits known as the Gondwána system, and includes some remarkable conglomerates (Talchir) which contain boulders with smoothed and striated faces, suggestive of ice-action. In Southern Africa a similar group of rocks likewise contains a conglomerate (Dwika), which has been compared to a glacial boulder-clay. Still more striking are the analogous strata in New South Wales, where a group of coal-bearing strata overlies the Coal-measures and includes boulder-beds (Bacchus Marsh), which contain well-striated stones and lie upon polished and striated rock-surfaces, closely resembling the glacial phenomena of Post-tertiary time in the northern hemisphere.

In North America sedimentary deposits believed to represent the Permian system of Europe are best developed in Texas and Kansas, where they include some marine bands in their lower portions, while their upper parts display proofs of enclosed basins like those of Europe, in which chemical deposits accumulated, such as gypsum, rock-salt, and dolomite. Farther east and north the Permian formations diminish in importance. In the Pennsylvanian coal-field, where they follow conformably upon the top of the Coal-measures, and are known as the "Upper Barren Measures," they consist of sandstones, shales, limestones, and thin coals, and become very red towards the top.

From the peculiar geographical conditions in which the Permian strata seem to have been laid down over a large part of the globe, the flora and fauna of their time have been but scantily preserved and are comparatively little known. The small number of species and genera obtained from Permian rocks forms a singular contrast to the ample assemblages which have been recovered from the older systems But that the land of these times was still richly clothed with vegetation and the open sea abundantly

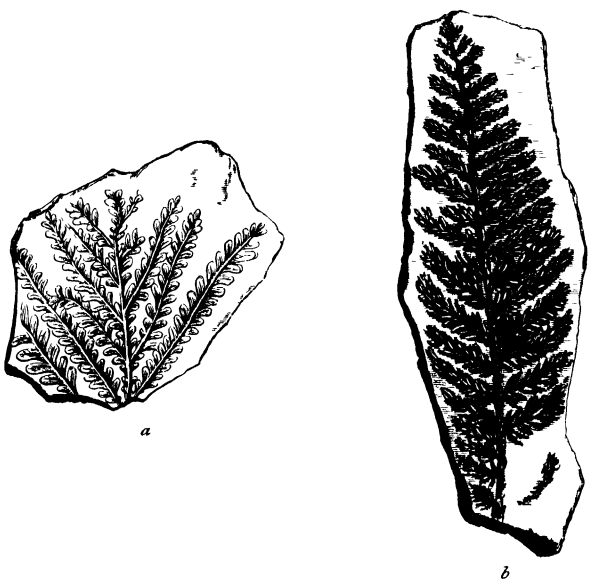



FIG 174 —Permian Plants (*a*), *Callipteris conferta* (½), (*b*), *Walchia piniformis* (½).

stocked with animal life, there can be no doubt. The flora appears to have closely resembled that of the Carboniferous period, a considerable proportion of the species of plants being survivals from the Carboniferous jungles and forests The Lepidodendra, Sigillariæ, and Calamites, which had been such conspicuous members of all the Palæozoic floras, now appear in diminishing number and variety, and finally die out With their cessation, new features arise in the vegetation. Among these may be mentioned the abundance of tree-ferns, which, though they

sparingly existed even as far back as Devonian times, now attained a conspicuous development (*Psaronius*, *Caulopteris*). The genus of ferns called *Callipteris* likewise played a prominent part in the Permian woodlands (Fig. 174, *a*). Other genera of ferns were *Pecopteris*, *Sphenopteris*, *Tæniopteris*, *Neuropteris*. But perhaps the most remarkable feature in the flora was the abundance of its conifers, and the appearance of the earliest forms of cycads (*Pterophyllum*). The yew-like conifer *Walchia* (Fig. 174, *b*), if we may judge from the abundance of its remains, flourished in great profusion on the drier grounds, mingled with others that bore

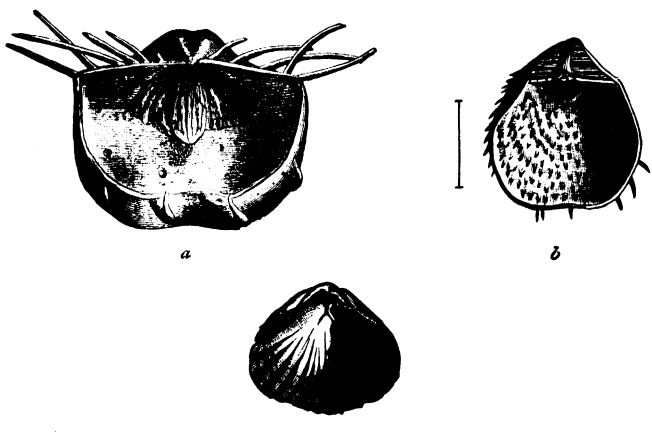



FIG. 175.—Permian Brachiopods. (*a*), *Productus horridus* (reduced); (*b*), *Strophalosia Goldfussi*; (*c*), *Camarophoria humbletonensis* (⅔).

cones (*Ullmannia*). The cycads, which now made their advent, continued during Mesozoic time to give the leading character to the vegetation of the globe.

The scanty relics of the Permian fauna, as above stated, have been almost wholly preserved in those strata which were deposited during temporary irruptions of the open sea into the inland salt-basins of the time. Among these marine forms of life reference may be made here to occasional corals (*Stenopora*), polyzoa (*Fenestella*, *Polypora*), and crinoids (*Cyathocrinus*). Some of the Carboniferous genera of brachiopods still survived—*Productus*, *Spirifera* and *Strophalosia* being conspicuous (Fig. 175).

Among the lamellibranchs *Bakevellia* and *Schizodus* are frequent forms (Fig 176). Among the higher molluscs, which have been but sparingly preserved in the European rocks, the old types of *Orthoceras*, *Cyrtoceras*, and *Nautilus* are still to be noticed. But

Fig. 176.—Permian Lamellibranchs (*a*), *Bakevellia tumida* (natural size); (*b*), *Schizodus Schlotheimi* (natural size)

in the Permian deposits that represent the opener seas of the time a remarkable advent of new types of cephalopods has been detected These were the forerunners of the great Ammonite family of later ages. They are found in the Alps, in the basin of the Mediterranean, in the Ural region, in India, and in Texas.

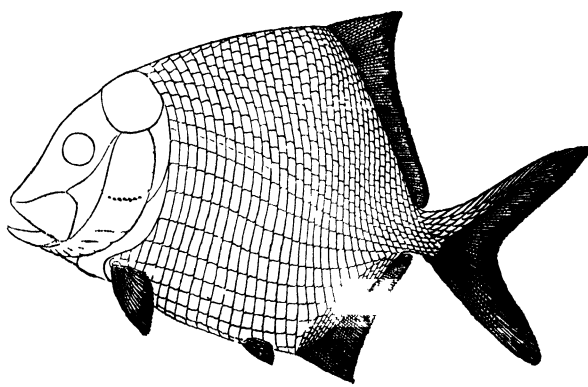


Fig. 177.—Permian Ganoid Fish (*Platysomus striatus*, ½).

Among their more frequent genera are *Medlicottia*, *Popanoceras*, *Stacheoceras*, and *Cyclolobus*. In Europe, the fishes of the time have been chiefly sealed up in the marl-slate or copper-shale (Kupferschiefer); two of the most frequent genera being *Palæoniscus* and *Platysomus* (Fig 177).

Labyrinthodonts continued to abound in the waters. Some of

the Carboniferous genera still survived, but with these were associated many new forms, outwardly resembling modern salamanders and lizards, most of which have been discovered in the strata overlying the true Coal-measures of Bohemia Some of these genera are *Branchiosaurus* (Fig. 178), *Dawsonia*, *Sparodus*, and *Limnerpeton*. But a great onward step in the advance of animal organisation was made in Permian time by the appearance of the earliest known reptiles. These ancestral forms include the genus *Proterosaurus*, which, like the living crocodile, had its teeth implanted in distinct sockets. *Palæohatteria* was a form that presented structural resemblances to the amphibia. Other genera, regarded as reptiles but possessing amphibian

FIG. 178.—Permian Labyrinthodont (*Branchiosaurus salamandroides*, natural size).

character, are *Pantylus*, *Bolosaurus*, *Diadectes*, and *Empedias* found in the Permian formations of Texas.

In Britain the Permian strata rest more or less unconformably on the Carboniferous system, which must have been disturbed and denuded before they were deposited. They consist of the following subdivisions :—

Upper red sandstones, clays, and gypsum (50 to 100 feet thick in the east of England, but swelling out west of the Pennine Chain to 600 feet).

Magnesian limestone—a mass of dolomite ranging up to 600 feet in thickness, and the chief repository of the Permian fossils ; remarkable for the curious concretionary forms assumed by many of its beds on the coast of Durham (Fig. 86). [Zechstein of Germany.]

Marl-slate—a hard brown shale with occasional limestone bands. [Kupferschiefer.]

Lower red and variegated sandstones with conglomerates and breccias. This division attains a thickness of 3000 feet in Cumberland, but is hardly represented in the east of England. [Rothliegende of Germany.]

In Germany, where the Dyas or twofold development of the Permian rocks is so well displayed, the lower sub-division, called

Rothliegende, consists of great masses of conglomerate with sandstones, shales, thin limestones, and important intercalations of contemporaneous volcanic rocks, both lavas and tuffs. The upper section is composed chiefly of limestone called Zechstein, and answering to the Magnesian limestone of England. With it are associated beds of anhydrite, gypsum, rock-salt, and bituminous limestone, and underneath it lies the celebrated Kupferschiefer or copper-shale—a black bituminous shale, about two feet thick, which has long been extensively worked on the flanks of the Hartz Mountains for the ores of copper with which it is impregnated. This shale, which is the great repository in Europe for the fossil fishes of the Permian period, was probably deposited in one of the inland basins, which at first may have maintained a free communication with the open sea. But eventually mineral springs, not improbably connected with the volcanic action of the time, brought up such an abundant supply of dissolved metallic salts as to kill the fish and render the water unsuitable for their existence. The metallic salts were reduced and precipitated as sulphides round the organisms, and impregnated the surrounding mud. In the overlying succession of strata, we see how the area was once more overspread by the clearer and opener water, which brought in the fauna of the Zechstein, and then how the basin gradually came to be shut off once more, until from its concentrated waters the various beds of anhydrite, gypsum, and rock-salt were thrown down.

In the heart of France, at Autun, the Coal-measures pass upward into Permian strata, as already stated. That area appears to have escaped the disturbance which in other parts of Western Europe placed the Permian unconformably upon the Carboniferous rocks. It presents a mass of sandstones, shales, coal-seams, and some bands of magnesian limestone, the whole having a thickness of more than 3000 feet referred to the Permian system. The plants in the lower part of this group of strata are unmistakably Carboniferous, but Permian forms appear in increasing numbers as the beds are followed upwards until the highest stage presents a predominant Permian flora Besides the characteristic Permian fishes, these strata have yielded remains of several of the salamander-like animals (*Branchiosaurus* or *Protriton*, *Melanerpeton*), and of some labyrinthodonts (*Actinodon*, *Euchirosaurus*, etc )

The upper Permian formations of Russia have furnished the remains of many anomodont reptiles (*Pareiasaurus*, etc ) together with some amphibians (*Melanerpeton*, etc ) and other forms

These fossils are associated with abundant relics of the so-called *Glossopteris* flora in which the ferns *Glossopteris*, *Gangamopteris*, *Tæniopteris*, *Sphenopteris*, *Callipteris*, and others are prominent

As in Europe, the Coal-measures of North America, especially in Nova Scotia, New Brunswick, Prince Edward Island and the Appalachian coal-field, pass up into reddish sandstone and shales in which the plants show a commingling of Carboniferous and Permian types, but in which there are comparatively few animal remains. These strata comprise the "Upper Barren Measures" (1000 feet thick) of Pennsylvania, which immediately overlie the upper productive Coal-measures. In Kansas the red and green strata that overlie the Carboniferous formations include seams of limestone and masses of gypsum and rock-salt, and contain some Permian genera of shells (*Bakevellia*). But it is in Texas that the system is best developed. It there attains a thickness of more than 6000 feet and is divided into three sections. A lower group, known as the "Witchita beds," consists of red and mottled clays, sandstones, and concretionary limestones, from which a flora has been obtained similar to that found in the "Upper Barren Measures" of the Appalachian coal-field, together with many of the ammonoid cephalopods above mentioned. The middle division, called the Clear Fork group, consists mainly of marine limestones, while in the Upper or Double Mountain group the proofs of concentrated inland water-basins are once more displayed in deposits of gypsum and saliferous clay and shale. Further relics of these inland seas are traceable westward in the Grand Cañon region and in southern Utah, where deposits of bright red sandstones with gypsum cover considerable areas.

In India, South Africa, and Australia strata which have been regarded as Permian contain a remarkable development of the *Glossopteris* flora in which the younger types of ferns are associated with the last representatives of the *Lepidodendra* and *Sigillariæ* of Palæozoic time.

# CHAPTER XXII

## THE MESOZOIC PERIODS—TRIASSIC

THE great series of red strata referred to in the foregoing chapter as overlying the Carboniferous system in England was called "New Red Sandstone," to distinguish it from the "Old Red Sandstone" which underlies that system. But the progress of geology on the European continent eventually indicated that, notwithstanding their general similarity of lithological character, two series of rocks had been comprised under the general title of New Red Sandstone. The older of these, separated from the rest under the name of Permian, was placed at the top of the great succession of Palæozoic formations. The younger division (still sometimes spoken of in England as New Red Sandstone) was called Trias, and was regarded as the first system in the great Mesozoic (*Middle Life*) or Secondary succession.

Essentially the Permian strata form merely the upper part of the Carboniferous system. Their types of life are fundamentally Palæozoic, but, as we have seen, both the flora and fauna are marked by a decrease in the number and variety of old forms, and by the advent of the precursors of a new order of things. Conifers and cycads now began to replace the early types of lepidodendron and sigillaria; ammonoid mollusca appeared in numbers as precursors of the Mesozoic ammonites; amphibians became more abundant, and saurians now took their place at the head of the animal world.

But when we ascend into the Trias, though in Europe the physical conditions of deposition remained much the same as in Permian time, we meet with a decided contrast in the organic remains. A new and more advanced phase of development presents itself in that richer and more varied assemblage of plant and animal life which characterised Mesozoic or Secondary time.

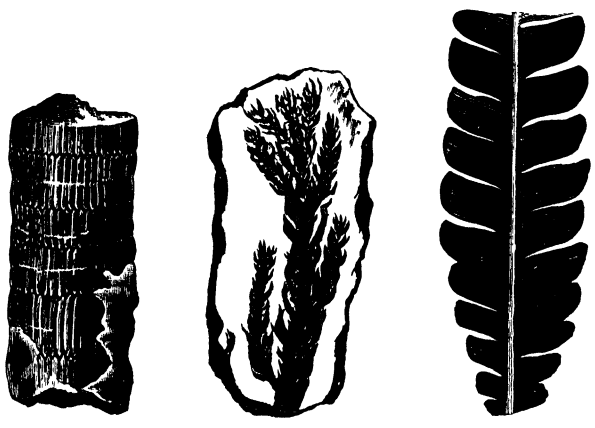
The word TRIAS has reference to the marked threefold division of the rocks of this system in Germany. In that country, and generally in Western Europe, the rocks consist of bright red sandstones and marls or clays, with beds of gypsum, anhydrite, rock-salt, dolomite, and limestone. These rocks, so closely resembling the Permian series below, had evidently a similar origin. They were in large part deposited in inland seas or salt-lakes, wherein, by evaporation and concentration of the water, the dissolved salts were precipitated upon the bottom, and where, consequently, the conditions must have been extremely unfavourable for the presence of living things. The sites of these inland basins can still be partially traced. They extended at least as far west as the north of Ireland. One or more of them lay across the site of the plains of Central England. Others were dotted over the lowlands of middle Europe. The largest of them occupied an extensive area now traversed by the Rhine. It stretched, on the one hand, from Basel to the plains of Hanover, and, on the other, from the highlands of Saxony and Bohemia across the site of the Vosges Mountains westward to the flank of the Ardennes. The continent must then have been somewhat like the steppes of Southern Russia—a region of sandy wastes and salt-lakes, with a warm and dry climate. Probably higher land rose to the north, as in earlier geological times, for traces of its vegetation have been found in Sweden. But southwards lay the more open sea, spreading over part at least of the site of the modern Alps, and thence probably across much of Asia to the Indian and Pacific Oceans.

So long as only the deposits of the salt-basins had been explored, it was but natural that comparatively little should be known of the flora and fauna of the Triassic period. The climate around these lakes was perhaps not a very salubrious one, and hence there may have been only a scanty terrestrial fauna in their immediate vicinity, while the waters of the lakes themselves were unsuited for the support of life. It is not surprising, therefore, that the strata deposited in these tracts are on the whole unfossiliferous; that, indeed, fossils only abound where there are indications that, owing to some temporary depression or breaking down of the barriers, the open sea spread into these basins, and carried with it the organisms whose remains gathered into beds of limestone. But over the tracts that lay under the open sea, a more abundant marine fauna lived and died. It is in the records of that sea-bottom, rather than in those of the salt-basins, that we must seek for the evidence of the general character of the life over the globe,

and for the fossil data with which to compare together the Triassic rocks of distant regions.

There are traces of contemporaneous volcanic action among the Triassic strata A group of volcanoes appears to have existed during Triassic time in the region of the Eastern Alps, especially around Predazzo in the Tyrol.

The flora of the Triassic period has been preserved chiefly in the dark shales and coal-seams formed in some of the inland basins So far as known to us it consisted chiefly of ferns, equisetums or horse-tails, conifers, and cycads, which in some



*a* *b* *c*

FIG 179.—Triassic Plants (*a*), Horse-tail Reed (*Equisetum columnare*, ½), (*b*), Conifer (*Voltzia heterophylla*, ½), (*c*), Cycad (*Pterophyllum Blasii*, ½)

places accumulated in such quantities as to form matted deposits that eventually became beds of coal. Among the ferns a few Carboniferous genera still survived (*Pecopteris*, *Cyclopteris*), but the characteristic forms belonged to later types (*Glossopteris*, *Tæniopteris*, *Macrotæniopteris*, *Clathropteris*, *Lepidopteris*) True horse-tails are common in the Trias (Fig 179, *a*) The most abundant conifer is the cypress-like *Voltzia* (Fig. 179, *b*), also *Araucarites*, *Abietites*. Cycads, already a feature in the vegetation of the Permian system, now increase in number and variety During the Mesozoic ages they continued to be the most characteristic members of the terrestrial

flora, insomuch that this division of geological time is sometimes spoken of as the "Age of Cycads." Some of the more common cycads in the Triassic rocks are *Pterophyllum*, *Zamites*, and *Podozamites* (Fig 179, *c*).

The red gypseous and saliferous strata, for the reason already given, are on the whole unfossiliferous. Here and there, footprints of amphibians, preserved on the sandstones, give us a glimpse of the higher forms of life that moved about on the margin of the salt-lakes The beds of limestone, which represent intervals when, for a time, the sea overspread the lakes, contain sometimes abundant fossils. But these are numerous in individuals rather than in species or genera, as if the conditions for life in those waters were still somewhat unfavourable. On the other hand, the limestones laid down in the opener sea are crowded with a varied fauna. One of the most typical fossils of the Trias is the crinoid *Encrinus liliiformis* (Fig. 180), abundantly present in the limestones (Muschelkalk) which in Germany form the central division of the system. Among the lamellibranchs, *Myophoria*, *Avicula*, *Pecten*, *Cardium*, *Pullastra*, *Halobia*, and *Monotis* are characteristic genera (Fig. 181), some species such as *Avicula contorta*, *Pecten valoniensis*, and *Cardium rhæticum* being eminently useful in tracing the upper parts of the Trias (Rhætic) all over Europe from Italy to Scandinavia. One of the most distinctive features of the Triassic fauna is its development of cephalopod life. In the limestones of the middle subdivision in Germany, a few species of cephalopods occur, the two prevalent forms being species of *Nautilus* and the ammonite *Ceratites* (Fig 182). But when we turn to the deposits of the more open sea, such as those of the Eastern Alps, Northern Kashmir, Western Thibet, and the Pacific borders of North America, we meet with a remarkable abundance and variety of cephalopods, and with a striking admixture of ancient and more modern types. For example, the venerable genus *Orthoceras*, which occurs even down in the Cambrian rocks, is found also here as a survival from Palæozoic ages The great tribe of the Ammonites, so pre-eminently typical of the molluscan life of the Mesozoic seas, reached its culmination in Triassic time. In the strata of that age it is represented by numerous genera (*Arcestes*, *Trachyceras*, *Pinaco-*

Fig 180 — Triassic Crinoid (*Encrinus liliiformis*, ½)

*ceras*, *Ptychites*, etc ) and more than 1000 species. Among the fishes of the Trias, the genera *Hybodus*, *Acrodus*, *Ceratodus*, *Diplurus*, *Gyrolepis*, *Dapedius*, *Pholidophorus*, *Semionotus* may be mentioned.

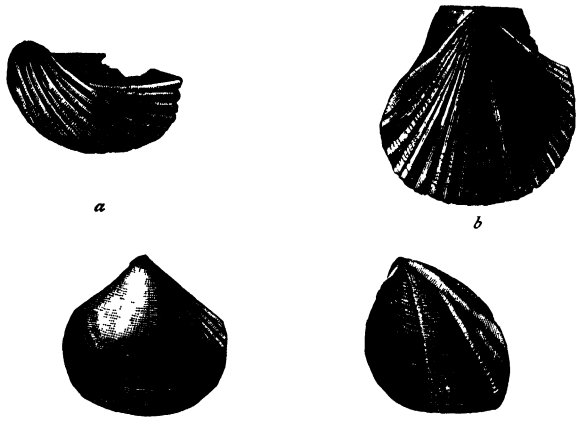



FIG 181 —Triassic Lamellibranchs (*a*), *Avicula contorta* (natural size), (*b*), *Pecten valoniensis* (½), (*c*), *Cardium rhæticum* (natural size), (*d*), *Myophoria vulgaris* (½)

Labyrinthodonts still haunted the lagoons and sandy shores, where they have left their footprints and sometimes their bones (*Mastodonsaurus*, *Trematosaurus*); but they no longer remained

FIG 182 —Triassic Cephalopods.
(*a*), *Temnocheilus* (*Nautilus*) *bidorsatus* (⅛), (*b*), *Ceratites nodosus* (reduced)

the most important members of the animal world. Various early types of reptiles now took their places in the ranks of creation; among these were new representatives of the lizard-like Rhynchocephalia, a tribe which had already appeared in Permian

time, but is almost extinct at the present day (*Hyperodapedon*, *Telerpeton* (Fig 183), *Rhynchosaurus*). Anomodont reptiles, characterised by the jaws having the form of a beak,

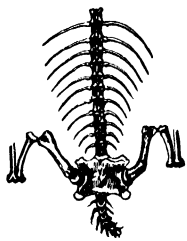


FIG 183.—Triassic Lizard (*Telerpeton elginense*, ½)

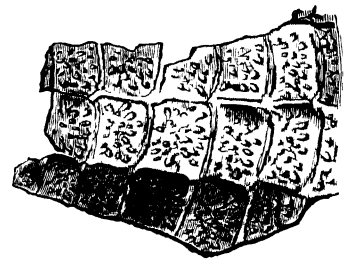


FIG. 184.—Triassic Crocodile (Scutes of *Stagonolepis elginensis*, ½)

somewhat like that of a turtle, were abundant; *Dicynodon*, one of these forms, carried two huge tusks in the upper jaw. A remarkable and long-extinct order of reptiles, that of the Deinosaurs, made its first appearance in Triassic time. These creatures were marked by peculiarities of structure that linked them both with true reptiles and with birds, while in size they sometimes resembled elephants and rhinoceroses. Some of them seemed to have walked mainly on their hind feet, like birds, their three-toed or five-toed footprints being numerous on some beds of sandstone, both in Europe and in the Eastern United States. They are characteristically Mesozoic types of life. Other not less typically Mesozoic forms, those of the Ichthyosaurs and Plesiosaurs, likewise began in Triassic time; but these became much more abundant and varied in the succeeding geological age. They will be more particularly alluded to in the next chapter. The earliest known crocodiles have been found in Triassic rocks; some of the scutes or scales of one of these animals are shown in Fig. 184. But possibly the most important advance in the fauna of the globe during the Triassic period was the first appearance of mammalian life. Detached teeth and lower jaws have been met with

FIG 185 — Triassic Monotreme? (*Microlestes Moorei*). (*a*), Lower molar tooth, outer side (4), (*b*), Ditto (nat size), (*c*), Ditto, front side (4)

in the uppermost parts of the Triassic system, which have been described as possessing structures like those of the marsupial Myrmecobius or Banded Ant-eater of Australia (*Microlestes*, Fig. 185, *Dromatherium*, *Microconodon*). It is interesting to know that the earliest representatives of the great class of the Mammalia, if these remains be truly mammalian, belonged to one of its lowest divisions. They were small creatures, some of them probably resembling the *Ornithorhynchus* and *Echidna* of Australia.

The Triassic strata of the inland basins of Europe (England, Germany, France, etc.) have been subdivided into the following groups :—

| | |
|---|---|
| Rhætic | Red, green, and grey marls, black shales, sandstones, bone-beds, and in Germany sometimes thin seams of coal Characteristic fossils are *Cardium rhæticum*, *Avicula contorta*, *Pecten valoniensis*, *Pullastra arenicola*, *Acrodus*, *Ceratodus*, *Hybodus*, Saurians, *Microlestes* |
| Keuper or Upper Trias | Red, grey, and green marls, with beds of rock-salt and gypsum.<br>Red sandstones and marls (England), grey sandstones and dark marls and clays, with thin seams of earthy coal (Germany) |
| Muschelkalk or Middle Trias. | Limestones and dolomites, with bands of anhydrite, gypsum, and rock-salt The limestones are the great repository of the fossils This subdivision is absent or only feebly represented in England |
| Bunter or Lower Trias | Mottled red or green sandstones, marls, and sometimes pebble-beds. |

The salt-beds of Cheshire have long been worked for commercial purposes. The lower bed is sometimes more than 100 feet thick; but the salt deposits of Germany are much more important. Thus at Sperenberg, 20 miles south of Berlin, a boring was put down through about 290 feet of gypsum, and then through upwards of 5000 feet of rock-salt, without reaching the bottom of the deposit.

The alternation of bands of rock-salt with thin layers of anhydrite or of gypsum no doubt marks successive periods of desiccation and inflow; in other words, each seam of sulphate of lime (which is the least soluble salt, and is therefore thrown down first) seems to indicate a renewed supply of salt water from outside, probably from the open sea, while the overlying rock-salt shows continued evaporation, during which the water became

a concentrated solution and deposited a thicker layer of sodium chloride. Sometimes the concentration continued until still more soluble salts, such as chlorides of potassium and magnesium, were also eliminated. These phenomena are well displayed at the great salt-mines of Stassfurt, on the north flank of the Harz Mountains. The lowest rock there found is a mass of pure, solid, crystalline rock-salt of still unknown thickness, but which has been pierced for about 1000 feet. This rock is separated into layers, averaging about $3\frac{1}{2}$ inches in thickness, by partings of anhydrite $\frac{1}{4}$ inch thick or less. If each of these "year rings," as the German miners call them, represents the deposit formed during the dry season of a single year, then the mass of 1000 feet has taken more than 3000 years for its formation. But there do not appear to be any good grounds for believing that each band marks one year's accumulation. Above the rock-salt lie valuable deposits of the more soluble salts, particularly chlorides of potassium and magnesium, with sulphates of lime and magnesia. Among these salts, the compound known as Carnallite (a double chloride of potassium and magnesium) is now the chief source of the potash salts of commerce.

In the Rhætic group of England, one of the most interesting bands is the so-called "bone-bed"—a thin layer of dark sandstone, charged with bones, teeth, and scales of fishes and saurians, which can be followed for many miles. A similar bone-bed runs through Hanover, Brunswick, and Franconia. A thin seam of limestone in the same group of strata in England (Cotham Stone) contains wings and wing-cases of insects.

The type of Triassic deposits which represents the tract of open sea is well developed in the Eastern Alps, where it reaches a thickness of many thousand feet, and forms great ranges of mountains. The lower division of that region, probably equivalent to the Bunter series of Central Europe, contains certain red, sandy, and micaceous shales (Werfen beds), and runs throughout the Alps with considerable uniformity of character, so that it forms a useful platform from which to investigate the complicated geological structure of these mountains. The Muschelkalk is represented by a great group of marine limestones and dolomites arranged in lenticular reef-like masses. It contains some of the typical Muschelkalk fossils, but is distinguished by the presence of abundant ammonites (*Ptychites*, *Trachyceras*, *Arcestes*, etc.). The Upper Alpine Trias consists of several thousand feet of shales, marls, limestones, and dolomites, while the Rhætic group swells out into a great succession of

limestones and dolomites, with reefs of coral. During the time when the Triassic sea stretched over the site of the Alps there were evidently considerable oscillations of level, and there likewise occurred extensive volcanic eruptions, whereby large masses of lavas and tuffs were ejected. These rocks now form conspicuous hills in the Tyrol.

Triassic rocks have been traced in Beloochistan, the Salt Range of the Punjab, Northern Kashmir, and Western Thibet. They have been recognised in Australia and New Zealand. Rocks which have been assigned to the same geological period (Karoo beds) occur in South Africa, and have there yielded a remarkable series of amphibian and reptilian remains.

The two types of Trias, that of inland seas, as in Germany and that of the more open ocean, as in the Alps and the north of India, are well developed in North America. The former type prevails over the Atlantic border and the interior, while the latter appears on the Pacific side of the continent. From Nova Scotia southwards to South Carolina, red sandstones, conglomerates, shales, and thin limestones appear in detached areas and represent the Triassic system. These strata, like the similar deposits of Europe, are generally poor in organic remains. In some places (North Carolina and Virginia) they include thick seams of workable coal, but for the most part the flora of the time has only been scantily preserved. Some sandstones (in Connecticut and elsewhere) are covered with bird-like footprints of deinosaurs which frequented the shores of the inland waters. Remains of the lavas which were poured out at the surface mark some of the volcanoes of the time. On the Pacific slope, on the other hand, a thick mass of strata containing marine fossils represents the pelagic or deep sea type of the Alps and Asia. These fossils include the same commingling as in Europe of Palæozoic forms of life with such characteristic Mesozoic forms as Ammonites.

# CHAPTER XXIII

## JURASSIC

THE system which follows the Trias, though it has been traced by means of its characteristic fossils over much of the Old World and the New, is most fully developed in Europe, and has there been most fully studied. It has received its name, JURASSIC, from the Jura Mountains, where it is specially well represented. It contains the record of a great series of geographical changes, which in Europe entirely effaced the inland basins and sandy wastes of the previous period, and during which sedimentary rocks were accumulated that now extend in a broad belt across England, from the coasts of Dorset to those of Yorkshire, cover an enormous area of France and Germany, and sweep along both sides of the Alps and the Apennines. These strata vary greatly in composition and thickness as they are traced from country to country. In one district they present a series of limestones which, as they are followed into another area, pass into shales or sandstones. The widespread uniformity of lithological character, so marked among the Palæozoic systems, gives place in the Mesozoic series to greater variety. Sandstones, shales, and limestones alternate more rapidly with each other, and are more local in their extent. They indicate greater vicissitudes in the process of deposition, more frequent alternations of sea and land, and not improbably greater differences of climate than in Palæozoic time

The flora of the Jurassic period is marked by the same general characters as that of the Trias—ferns (*Alethopteris*, *Sphenopteris*, *Phlebopteris*, *Oleandridium*, *Tæniopteris*), equisetums, conifers, and cycads being its distinguishing elements. Cycads now abound (*Pterophyllum*, *Zamites*, *Cycadites*, Fig. 186). The Ginkgo or Maiden-hair tree of China had here some of its earliest representatives (*Baiera*, etc.). Among the conifers are the remote ancestors

of our "Puzzle-monkeys," and of our pines and firs (*Araucarites*, *Pinus*, etc.). This vegetation flourished luxuriantly over the area of Britain; on the site of Yorkshire it grew so densely as to give rise to thick peaty accumulations, which now form beds of coal. It

FIG 186.—Jurassic Cycad (*Cycadeoidea microphylla*, ½)

went far northward, for its remains have been abundantly preserved in Spitzbergen, where numerous cycads have been found among them. These plants unquestionably grew and flourished within the Arctic Circle, so that, though the climates of the globe were already beginning to emerge from the greater uniformity of Palæozoic time, the Arctic regions still enjoyed a temperature like that of sub-tropical countries at the present time.

FIG 187.—Jurassic reef-building Coral (*Isastræa explanata*, ½) From the Corallian stage

The animal world during the Jurassic period, if we may judge of it from its fossil remains, must have been much more varied alike on land and in the sea than during the previous ages of the earth's history. From the circumstances in which the strata were deposited in the European area, relics of the life of the land are there frequently met with among the abundant records of the sea. A characteristic feature of the period was the profusion of corals, which at different times spread over much of the site of modern

Europe. They were no longer the rugose forms so distinctive of the Palæozoic seas, but true reef-building astræids, belonging to

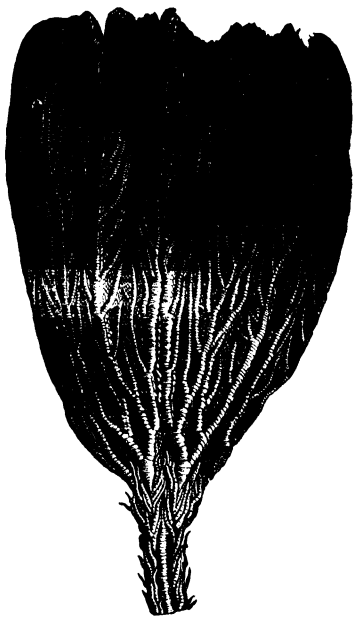


FIG. 188.—Jurassic Crinoid (*Pentacrinus fasciculosus*, ⅓).

the genera *Isastræa*, *Thamnastræa*, *Montlivaltia*, *Thecosmilia*, etc. (Fig. 187). Crinoids were still abundant, though less so than in the Carboniferous limestone sea; the old forms were now replaced by others, among which the most conspicuous was the Pentacrinite (Fig. 188)—a genus still living in the seas of to-day. Sea-urchins swarmed on some parts of the sea-floor; among their more frequent genera are *Cidaris* (Fig. 189), *Diadema*, *Hemicidaris*, *Acrosalenia*, *Glyptichus*, *Pygaster*. Of the contrasts between the Mesozoic and Palæozoic faunas, one of the most marked is to be found among the Brachiopods. Except the

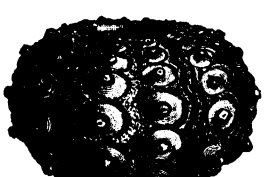
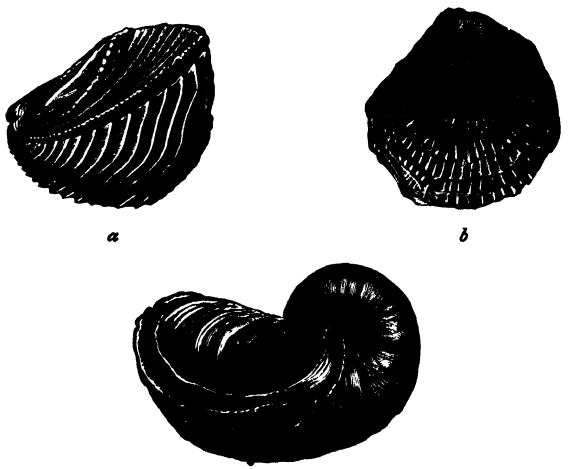


FIG. 189.—Jurassic Sea-urchin (*Cidaris florigemma*, ⅓), Corallian.

persistent inarticulate types which have lived on from Cambrian time to the present day (*Crania*, *Lingula*, *Discina*), the numerous and varied forms which played so important a part in the life of the Palæozoic seas died out almost entirely at the close of the Palæozoic period The ancient Spirifers and Leptænids lingered on until the Jurassic period, and then disappeared. On the other hand, the Rhynchonellids and Terebratulids, which occupied a subordinate place in earlier ages, now became the chief representa-



*a* *b*

FIG. 190.—Jurassic Lamellibranchs (*a*), *Trigonia monilifera* (½), Kimmeridge Clay, (*b*), *Plicatula spinosa* (½), Middle Lias, (*c*), *Cryphæa arcuata* (*incurva*) (½), Lower Lias

tives of the brachiopods. They abounded throughout Mesozoic time, but they have gradually diminished in number since then, and at the present day survive only in a small number of species. With the decay of the brachiopods, the other divisions of the Mollusca proportionately advanced. The Lamellibranchs attained a great development in Mesozoic time, some characteristic genera being *Gervillia*, *Exogyra*, *Lima*, *Ostrea*, *Pecten*, *Pinna*, *Astarte*, *Hippopodium*, *Trigonia* (Fig 190). Some of the oysters were particularly abundant, *Gryphæa*, for instance, being so plentiful in some bands of limestone as to give the name of "Gryphite limestone" to them. But undoubtedly the distinctive

feature of the molluscan fauna of Mesozoic time was the great development of the Cephalopods. The chambered division was represented by an extraordinary variety of Ammonites (Fig, 191),

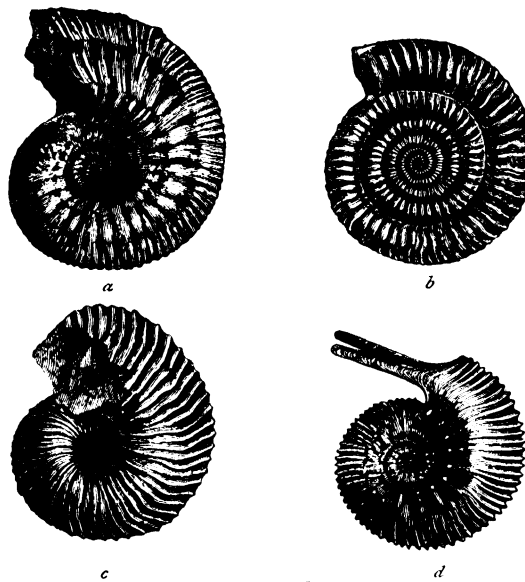



FIG. 191.—Jurassic Ammonites. (*a*), *Ammonites* (*Liparoceras*) *striatus* (¼), Middle Lias; (*b*), *A.* (*Dactylioceras*) *communis* (⅛), Upper Lias; (*c*), *A.* (*Cardioceras*) *cordatus* (⅛), Lower Calcareous Grit; (*d*), *A.* (*Cosmoceras*) *Jason* (⅛), *Oxford Clay.*

and the cuttle-fishes by many species of Belemnite (Fig. 192). The ammonites have been made use of to mark off the formations into distinct zones; for, as a rule, the vertical range of each

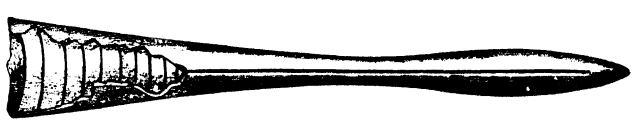


FIG 192.—Jurassic Belemnite (*B. hastatus*, natural size), Middle Oolite.

species is comparatively small. The band of strata characterised by a particular species of ammonite is called the zone of that species, *e.g.* Zone of *Amm. planorbis*, which is the lowest zone of the

Lower Lias. The ammonites are now grouped in a number of families and genera The earlier part of the Jurassic period was marked by the genera *Arietites*, *Aegoceras*, *Amaltheus*, *Lytoceras*, *Phylloceras*, *Harpoceras*, and *Stephoceras*, in later time the genera *Cosmoceras* and *Aspidoceras* were prevalent, while towards the close of the period *Perisphinctes* and *Oppelia* were conspicuous

Another striking contrast is presented by the Jurassic Crustacea when compared with those of the Palæozoic ages. The ancient order of trilobites, so abundant in the seas of the older time, had now entirely disappeared; the eurypterids, which took their place upon the scene as the trilobites were on the wane, had likewise vanished. In their stead there now came abundant ten-footed crustacea, including both long-tailed forms—the ancestors of our lobsters, prawns, shrimps, and cray-fish—and short-tailed forms that heralded the coming of our living crabs (Fig. 193). Among

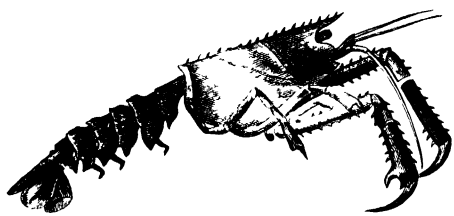


FIG. 193 —Jurassic Crustacean (*Scapheus ancylochelis*).

the Jurassic strata there occasionally occur thin bands, which have received the name of "insect-beds" from the numerous insect-remains which they contain. These layers may represent the sites of sheets of shallow water over which insects were blown from some neighbouring land, and where they were drowned and enveloped in the mud or marl on the bottom. The neuroptera are most frequent, but orthoptera and coleoptera also occur. Among these remains are forms of dragon-fly, May-fly, grasshopper, and cockroach. The wing-cases of beetles also are not uncommon

Fishes abounded in the Jurassic waters. Those of which the remains have been preserved are chiefly small ganoids (*Pholidophorus*, *Dapedius*, *Lepidotus*, *Pycnodus*, Fig. 194), with no representatives of the huge bone-cased "placoderms" of earlier time. There were likewise various tribes of sharks and rays (*Hybodus*, *Acrodus*, *Squalorata*).

But, taking the Jurassic fauna as a whole, undoubtedly its most

striking character was given by the extraordinary development of its reptiles. So remarkably varied was the reptilian life throughout the Mesozoic period that this part of the earth's history has been called the "Age of Reptiles." There were forms which haunted the sea, others that frequented the rivers, some that lived on the

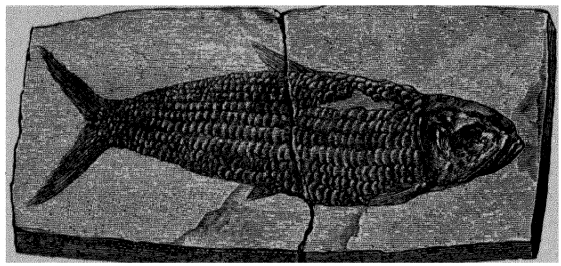


FIG. 194.– Jurassic Fish (*Pholidophorus Bechei*, ½), Lower Lias.

land, some that flew through the air. Never before or since has there been such a profusion of reptilian types. Some of these are still represented at the present time. The Jurassic *Teleosaurus* and *Steneosaurus*, for example, have their counterparts now in the living crocodile and alligator. The modern turtles, too, are descendants of those which lived in Jurassic times. But it is the long-extinct types that fill us with astonishment. One of the

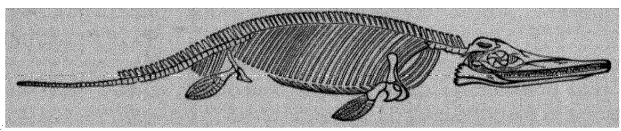


FIG. 195.—Jurassic Sea-lizard (*Ichthyosaurus communis*, $\frac{1}{10}$) Lias.

most abundant of them is that of the enaliosaurs or sea-lizards, of which the two leading forms were the *Ichthyosaurus* and *Plesiosaurus*. The former creature (Fig. 195), occasionally 30 to 40 feet long, somewhat resembled a whale in shape and bulk, its head being joined by no distinct neck to the body, which was furnished with a fish-like tail. It swam by means of two pairs of strong paddles, and steered itself by a vertical fin on the tail. Its eyes were large, and had a ring of bony plates round the eyeball, which remain distinct in the fossil state. Its jaws were armed

with numerous strong pointed teeth, not set in distinct sockets. This reptile probably lived chiefly in the sea, feeding there upon the abundant ganoid fishes which its huge protected eyes enabled it to track even into the deeper water. But it no doubt also sought the land, and was able to waddle along the shore or to lie there basking in the sunshine. The Plesiosaurus, in many respects like the Ichthyosaurus, was distinguished by its proportionately shorter tail, longer neck, smaller head, larger paddles, and the insertion of the teeth in distinct sockets. It also probably haunted the lagoons, rivers, and shallow seas of the time. Its long swan-like neck enabled it to lie at the bottom and raise its

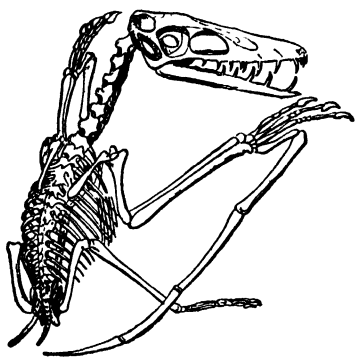


FIG. 196.—Jurassic Pterosaur, or flying reptile (*Scaphognathus crassirostris*), Upper Oolite.

head to the surface to breathe, or, when at the surface, to send down its powerful jaws and catch its prey at the bottom.

Still more extraordinary were the Pterosaurs or flying reptiles—strange bat-like creatures with disproportionately large heads and large eyes like those of Ichthyosaurus. The outermost finger of each forefoot was prolonged to a great length, and supported a membrane with which the animals could fly. The bones were hollow and filled with air like those of birds. Various forms of these winged lizards are found in the Jurassic rocks, the most typical being *Pterodactylus* and *Scaphognathus* (Fig. 196); others are *Dimorphodon*, *Rhamphorhynchus*, *Rhamphocephalus*, and *Dorygnathus*.

The Deinosaurs, which have already been noticed as having appeared in Triassic time, attained a far greater development in

the Jurassic period. These hugest land-reptiles now reached their maximum in size and variety. One of their genera, *Megalosaurus*, is believed to have been 25 feet long, and to have walked on its massive hind legs along the margins of the shallow waters in search of the smaller animals on which it preyed. Another form, *Cetiosaurus*, which may have been as much as 50 feet from

FIG. 197.—Jurassic Bird (*Archæopteryx macrura*, about ½). Solenhofen Limestone, Middle Jurassic.

the snout to the tip of the tail, and stood some 10 feet high, fed on the vegetation that shaded the rivers and lagoons where it lived. Still more gigantic were some deinosaurs, of which the remains have been found in the Jurassic rocks of North America. *Brontosaurus*, about 50 feet or more in length and weighing perhaps more than 20 tons, had a short body, long neck and tail, small head, and enormous feet, each of which made an imprint

measuring about a square yard in area. *Stegosaurus*, another sluggish dinosaur, was protected by numerous huge plates and spines of bone on its back, some of the latter more than 3 feet long. The largest of all these monsters, and perhaps the most colossal animal that ever walked on the earth, was the *Atlantosaurus*, which is believed to have been not much less than 100 feet in length, and 30 feet or more in height

In another respect, the fauna of the Jurassic period seems to have stood out from those that preceded it, it contains the earliest known birds. These interesting prototypes differed much from modern birds, more particularly in the possession of certain peculiarities of structure that linked them with reptiles. They had teeth in their jaws, and some of them carried long lizard-like tails, each vertebra of which bore a pair of quill-feathers. The best known genus, *Archæopteryx* (Fig. 197), found in the

FIG. 198.— Jurassic Marsupial (*Phascolotherium Bucklandi*). (*a*), Teeth magnified; (*b*), Jaw, natural size.

lithographic limestone of Solenhofen, was about the size of a rook.

Monotreme and marsupial types, which possibly appeared in Triassic time, continued to be the only representatives of the Mammalia during the Jurassic period, at least no other types have yet been discovered among the fossils. Lower jaws and detached teeth (Fig. 198) have been obtained from two distinct platforms in England—the Stonesfield Slate and Purbeck beds—and have been referred to a number of genera which seem to find their nearest modern representatives in the Australian bandicoots and in the American opossums (*Plagiaulax*, *Ctenacodon*, *Bolodon*, *Phascolotherium* (Fig. 198), *Dryolestes*, *Amphitherium*, *Spalacotherium*, *Priacodon*) A much more varied series of similar types has been obtained from lacustrine Jurassic clays in Wyoming, Dakota, and other States.

The Jurassic system of Western Europe was first studied in England, where it is remarkably well developed. The names originally given there to its subdivisions have in large part been adopted in other countries, as will be seen from the subjoined Table.

| | | |
|---|---|---|
| Upper or Portland Oolites | 8. Purbeckian [1] | Upper fresh-water beds (Purbeck).<br>Middle Marine beds ,,<br>Lower fresh-water beds ,, |
| | 7. Portlandian [2] | Limestones and calcareous freestones (Portland Stone), *Cerithium portlandicum*, *Ammonites* (*Perisphinctes*) *giganteus*, *Trigonia gibbosa*<br>Sandstones and marls (Portland Sand), *Exogyra bruntrutana*, with zone of *Ammonites* (*Olcostephanus*) *gigas* |
| | 6 Kimeridgian [3] | Dark shales and clays (Kimeridge Clay), *Exogyra virgula*, with an upper zone of *Ammonites* (*Perisphinctes*) *biplex* and *A.* (*Aspidoceras*) *longispinus*, and a lower zone of *Ammonites* (*Cardioceras*) *alternans*. |
| Middle or Oxford Oolites | 5 Corallian [4] | Coral rag (limestone with corals), clays, and calcareous grits, *Thamnastræa*, *Isastræa*, *Cidaris florigemma*, with zone of *Ammonites* (*Perisphinctes*) *plicatilis* above, and *A* (*Aspidoceras*) *perarmatus* below |
| | 4 Oxfordian [5] | Blue and brown clay (Oxford Clay), with zones of *Ammonites* (*Cardioceras*) *cordatus* (Fig 191, *c*), *A.* (*Cosmoceras*) *ornatus*, and *A Jason* (Fig 191, *d*)<br>Calcareous sandstone (Kellaways Rock—Callovian), zone of *Ammonites* (*Kepplerites*) *calloviensis*. |
| Lower or Bath Oolites | 3 Bathonian [6] | Shelly limestones, clays, and sands (Cornbrash, Bradford Clay, and Forest Marble), with zones of *Ammonites* (*Macrocephalites*) *macrocephalus*, *A* (*Oppelia*) *discus*<br>Shelly limestones (Great or Bath Oolite), Stonesfield Slate, *Ammonites* (*Perisphinctes*) *arbustigerus*<br>Fuller's Earth, zone of *A* (*Macrocephalites*) *subcontractus* |
| | 2 Bajocian [7] (Inferior Oolite) | Marine calcareous freestones and grits (Cheltenham), containing zones of *Ammonites* (*Parkinsonia*) *Parkinsoni*, *A* (*Stepheoceras*) *Humphriesianus*, *A.* (*Ludwigia*) *Murchisonæ*, *A* (*Lioceras*) *opalinus*, represented in Yorkshire by 800 feet or more of estuarine sandstones, shales, and limestones, with beds of coal. |

[1] So called from the Isle of Purbeck in Dorset, where the group is typically displayed.
[2] From the Isle of Portland in Dorset.
[3] From Kimeridge, a parish in Dorset.
[4] From the abundant corals in the group.
[5] From the county of Oxford
[6] From the city of Bath.
[7] From Bayeux, in the Department of Calvados, France.

| | | | |
|---|---|---|---|
| Lias. | 1 | Liassic[1] . . | Sandy beds and clays (Upper Lias, Toarcian), with zones of *Ammonites* (*Lytoceras*) *jurensis* at top, *A* (*Dactylioceras*) *communis*, *A* (*Harpoceras*) *serpentinus*, *A.* (*Dactylioceras*) *annulatus* at bottom. |
| | | | Limestones, sands, clays, and ironstones (Middle Lias, Marlstone), with zones of *Ammonites* (*Amaltheus*) *margaritatus*, and *A* (*Paltopleuroceras*) *spinatus*. |
| | | | Thin blue and brown limestones, and dark shales (Lower Lias, Sinemurian and Hettangian); *Ammonites* (*Psiloceras*) *planorbis*, *A* (*Oxynoticeras*) *oxynotus*, *A* (*Aegoceras*) *Jamesoni*. |

1. The **Lias,** so called originally by the Somerset quarrymen from its marked arrangement into "layers," extends completely across England from Lyme Regis to Whitby. It can be divided into three distinct sections: (*a*) A lower group of thin blue limestones and dark shales with limestone nodules, the limestones being largely used for making cement. In this group eleven distinct ammonite zones have been noted. The lowest has already been referred to as that of *Ammonites* (*Psiloceras*) *planorbis*. This group is one of the chief platforms for reptilian remains, entire skeletons of ichthyosaurus, plesiosaurus, etc., having been exhumed at Lyme Regis. (*b*) Marlstone or Middle Lias—hard argillaceous or ferruginous limestones which form a low ridge or escarpment rising from the plain of the Lower Lias; in Yorkshire it contains a thick series of beds of earthy carbonate of iron, which are extensively mined as a source for the manufacture of iron. (*c*) Upper Lias clays and shales surmounted by sandy beds (Upper Lias Sands). The organic remains of the Lias are abundant and well preserved. They are chiefly marine; but that the rocks containing them were deposited near land is indicated by the numerous leaves, branches, and fruits imbedded in them, and by the various insect-remains that have been obtained from them.

In Germany, where the Lias is well developed and presents a general resemblance to the English type, it is known as the Lower or Black Jura. It is still better shown in France, where its three stages attain in Lorraine a united thickness of more than 600 feet. To the south, however, in Provence, it reaches the great thickness of 2300 feet.

2. The **Bajocian** stage is so named from Bayeux in Normandy, where it is well displayed. In England, under the name of

[1] From "Lias," the Somerset provincial word first adopted for the formation by William Smith, the "Father of English Geology."

Inferior Oolite, it presents two distinct types, being a thoroughly marine formation in the south-western counties, and passing northward into a series of strata which were accumulated in an estuary and which contain the chief repositories of the British Jurassic flora. Among the estuarine beds of Yorkshire a few thin coal-seams occur, which have been worked to some extent.

On the European continent, this division is characteristically marine; it reaches its greatest development in Provence, where it is 950 feet thick. It runs through the Jura Mountains, where it is made up of more than 300 feet of strata, chiefly limestone. In Germany the strata from the top of the Lias to the base of the Callovian group—that is, the two stages of Bajocian and Bathonian—are classed together as the Middle, Dogger, or Brown Jura, its prevalent colours being dark, owing to the preponderance of brown sandstones and shales.

3. The **Bathonian** stage is named from Bath in the south-west of England, where its subdivisions are admirably exposed. At its base lies a local argillaceous band known as Fuller's Earth, because long used for fulling cloth. The chief member of the stage in the south-west of England is the Great or Bath Oolite, a succession of limestones, often oolitic, with clays and sands. The Stonesfield Slate is the name locally given to some thin-bedded limestones and sands, forming the lower part of the Great Oolite, and of high geological interest from having supplied among their fossils remains of land-plants, numerous insects, bones of enaliosaurs and deinosaurs, and of small marsupials. The Great Oolite abounds in corals, and contains numerous genera of mollusca, fishes, and reptiles. The Cornbrash (so named from its friable (*brashy*) character, and from its forming good soil for corn) is one of the most persistent bands in the English Jurassic system, retaining its characters all the way from the south-western counties to near the Humber. It is the zone of *Macrocephalites macrocephalus*.

On the mainland of Europe this stage is well represented. In Normandy it includes the famous building-stone of Caen, which from its saurian and other fossils may be paralleled with the Stonesfield Slate. In Northern Germany the abundant limestones of the western region are represented mainly by clays and shales, with bands of oolitic ironstone.

4. The **Oxfordian** stage, sometimes called the Middle or Oxford Oolite, in its English development consists of a lower zone of calcareous sandstone, known as the Kellaways rock or Callovian, from the name of a place in Wiltshire, and of a thick upper stiff

blue and brown clay, called, from the district where it is well developed, the Oxford Clay, and containing numerous ammonites, belemnites, and oysters, but no corals. In Germany, the strata from the base of the Callovian to the top of the Purbeckian group are known as the Malm or White Jura. They attain a thickness of more than 1000 feet, and consist mainly of white limestones and marls, whence the name bestowed on them, in contrast to the more sombre tints of the Brown Jura below. In France, the subdivision is found well represented on the coast of Calvados, but it diminishes towards the Jura, and is only feebly developed in the Alps. Yet the Oxfordian fossils are found to characterise a particular group of dark sandy clays in the widely extended Jurassic system of Russia. Some of the characteristic ammonite genera of the formation have even been recognised in Cutch, where both the Oxfordian and its Callovian sub-stage appear to be represented in a mass of strata estimated to exceed 6000 feet in thickness.

5. The **Corallian** stage, so named from the corals with which it abounds, is one of the most distinctive in the Jurassic system. It is traceable across the greater part of England, over the continent of Europe from Normandy to the Mediterranean, through the east of France, and along the whole length of the Jura Mountains and the flank of the Swabian Alps. While it was being formed, the greater part of Europe lay beneath a shallow sea, the floor of which was clustered over with reefs of coral. In France and the Jura the upper half of this stage is regarded as a distinct subdivision under the name of Sequanian, while the lower part is placed in the Oxfordian stage

6. The **Kimeridgian** group or stage is typically displayed at Kimeridge on the coast of Dorsetshire, whence its name. It there consists of dark shales, some of which are so highly bituminous as to burn readily, and which may be eventually of commercial value as a source for the distillation of mineral oil. This group of strata has yielded a larger number of reptilian genera and species than any other in the Mesozoic system of Britain—plesiosaurs, ichthyosaurs, pterosaurs, deinosaurs, turtles, and crocodiles. It is well developed in the north of France, where the clays of England are represented by a succession of limestones and marls between 500 and 600 feet thick, divided into two sub-stages, the upper called Virgulian from the abundance in it of the oyster *Exogyra virgula*, the lower known as Pterocerian from the prevalence of the gasteropod *Pterocera*. These strata extend southwards into the Jura, where they include as their central member

a mass of coral-reef more than 300 feet thick. They are prolonged also into Germany, where their most celebrated member is the famous lithographic stone of Solenhofen near Munich, from which so remarkable a series of terrestrial organic remains has been obtained.

7. **The Portlandian** stage, so called from the Isle of Portland, where it is well seen, consists of a lower set of sandy beds (Portland Sand, Bononian), and a higher and thicker series of limestones and calcareous freestones, some of the beds containing abundant nodules and layers of flint. These rocks are prolonged into France near Boulogne-sur-Mer, and by their characteristic fossils are recognisable also in Germany. In the basin of the Mediterranean, however, the rapid alternations of limestones, sandstones, shales, and clays so characteristic of the Jurassic system are replaced, as regards the formations above the Oxfordian, by a series of singularly uniform limestones known as Tithonian, which in the Basses Cevennes attain a thickness of between 1200 and 1400 feet. Such a contrast of lithological character indicates great difference in the conditions of sedimentation. The later Jurassic rocks of England and the northern part of the continent were deposited during a time of considerable terrestrial oscillation and disturbance, whereas in the south of Europe they seem to have accumulated, with little or no interruption, in deeper water and at a greater distance from land.

8. The **Purbeckian** group or stage is best seen in the Isle of Purbeck, hence its name It lies on an upraised surface of Portlandian beds, showing that after the deposition of these strata there was some disturbance of the sea-floor, portions of which were uplifted partly into land and partly into shallow brackish and fresh waters. The Purbeck Beds are subdivided into three substages: the lowest consisting of fresh-water limestones, with layers of ancient soil ("dirt-beds"), in which the stumps of cycadaceous trees (Fig. 186) still stand in the positions in which they grew; the middle sub-stage contains oysters and other marine shells which prove that the area subsequently sank under the sea; while in the higher subdivision fresh-water fossils reappear. Among the more interesting organisms yielded by the Purbeck Beds are the remains of numerous insects and of the marsupials already referred to, which chiefly occur as lower jaws in a stratum about five inches thick. When the bodies of dead animals float out to sea, the first bones likely to drop out of the decomposing carcases are the lower jaws; hence the greater frequency of these

bones in the fossil state. Strata belonging to the Purbeckian stage, including red and green marls, with dolomite and gypsum (Serpulit and Munder Mergel), are found in North-Western Germany, showing in that region also the elevation of the floor of the Jurassic sea into detached basins.

In India the thick mass of strata above referred to as existing in Cutch is believed to represent the European Jurassic system from the Bajocian up to the top of the Portlandian stage. In Queensland, Western Australia, and New Zealand recognisable Jurassic fossils have also been found, showing the extension of the Jurassic system even to the Antipodes.

In North America, Jurassic rocks have not been found to be largely developed. They appear to be entirely absent from the Atlantic side of the United States. They are found, however, in the interior and still more distinctly along the Pacific border. In California and Oregon a series of strata is developed which from their fossils may be paralleled with the Lias of Europe. Upper Jurassic rocks, recognisable by their fossils, attain a thickness of about 1800 feet in the Wasatch Mountains, but in California and British Columbia they are much thicker, and consist largely of slates and metamorphic schists, with accompanying volcanic tuffs and veins of auriferous quartz. In Colorado certain strata, which by some observers have been classed in the Jurassic system, by others in the Cretaceous, have yielded an abundant series of organic remains, including fishes, tortoises, pterosaurs, deinosaurs, crocodiles, and marsupials. Representatives of various members of the Jurassic system extend northwards along the west coast of the Continent up among the islands within the Arctic Circle, from which bones of *Ichthyosaurus* have been obtained The system likewise stretches southward along the Pacific border of South America, fossils of Lower and Middle Jurassic age having been found in Bolivia and also in Argentina.

# CHAPTER XXIV

## CRETACEOUS

THE CRETACEOUS system received its name in Western Europe, because in England and in Northern France its most conspicuous member is a thick mass of white chalk (Latin, *Creta*). Appearing in many detached but often extensive areas, it covers a large part of the surface of this continent, especially towards the west and east. Its western extremity reaches to the north of Ireland and the Western Islands of Scotland. It spreads over a large part of the east and south of England, stretching thence into France, where it forms a broad band, encircling the Tertiary basin of Paris. It sweeps across Belgium into Westphalia, underlies the vast plain of Northern Germany and Denmark, whence it is prolonged into Southern Russia, where it overspreads many thousands of square miles. It flanks most of the principal mountain-chains of Europe—the Pyrenees, Alps, Apennines, and Carpathians. It spreads far and wide over the basin of the Mediterranean Sea, extending across vast tracts of Northern Africa, and from the Adriatic athwart Greece and Turkey into Asia Minor, whence it is prolonged through the Asiatic continent.

As most of the rocks of the system are of marine origin, we at once perceive how entirely different the Cretaceous geography must have been from that of the present day, and to what a great extent the existing land of the Old World lay then below the sea. But in tracing out the distribution of the rocks, geologists have found that the Cretaceous sea did not sweep continuously across Europe. On the contrary, as they have ascertained, the old northern land still rose over the site of Northern Britain and Scandinavia, while to the south of it a wide depression extended across the area of Southern Britain, Northern France, Belgium, and the North German plain, eastwards to Bohemia and Silesia.

This vast northern basin was the theatre of a remarkable succession of geological revolutions. While its eastern portions, during the earlier part of the Cretaceous period, were submerged under the sea, its western tracts were the site of the delta of a great river, probably descending from the land that still lay massed towards the north. During the later ages of the period, the whole of this area formed a broad and long gulf or inlet, the southern margin of which seems to have been defined by the ridge of old rocks that runs from the headlands of Brittany through Central France, the Black Forest, and the high grounds of Bohemia. South of that ridge lay the open ocean which extended all over Southern Europe and the north of Africa, and spread eastwards into Asia.

Bearing in mind this peculiar disposition of sea and land, we can understand why the European development of the Cretaceous system, alike in regard to its deposits and its fossils, should be so different in the area of the northern basin from that of the southern regions. In the one case, we meet with the local and changing accumulations of a comparatively shallow and somewhat isolated portion of the sea-bed, wherein were mingled abundant traces of the proximity of land. In the other, we are presented with evidence of a wide open sea, where the same kinds of deposits and the same forms of marine life extended with little change over vast distances, and continued in existence for a long interval of time. It will be remembered that this contrast in the geography of the north and south of the continent had already been established before the end of the Jurassic period. Obviously, it is not the local type of the northern basin, but the more general and widespread type of Southern Europe that should be taken for the distinctive characteristics of the Cretaceous system. But the northern basin was the first to be systematically explored, and is still the best known, and hence its features have not unnaturally usurped the place of importance which ought properly to be assigned to the other wider area.

In North America also, the marine and terrestrial types of Cretaceous geography are well displayed. The marine formations of the Southern United States are even more extensively developed than those of Southern Europe, while in the centre and west of the continent a marvellous series of lacustrine and terrestrial deposits has been accumulated, replete with the remains of the fauna and flora of the land of the period. These rocks are more particularly referred to on p. 363.

Regarding the period as a whole, let us first consider the

general character of its distinguishing flora and fauna, and then pass on to trace the history of the period as revealed by the succession of strata. The plants of the Cretaceous system show that the vegetable kingdom had now made a most important advance in organisation. In the lower half of the system the fossil

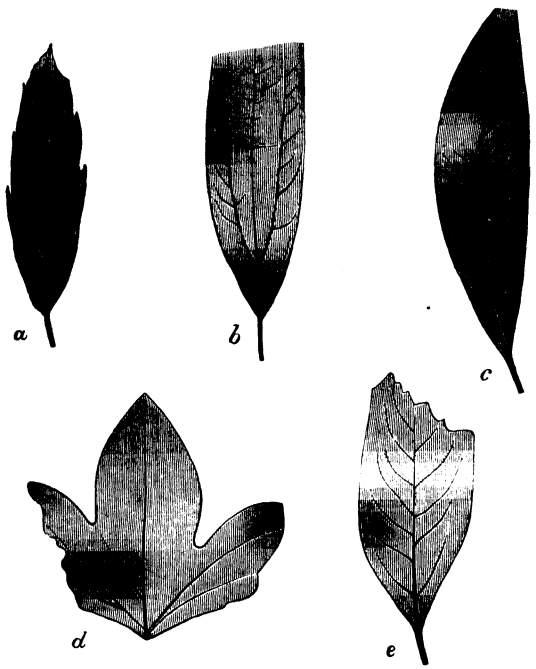



FIG. 199.—Cretaceous Plants. (*a*), *Quercus rinkiana* (⅔); (*b*), *Cinnamomum sezannense* (⅔); (*c*), *Ficus atavina* (⅔); (*d*), *Sassafras recurvata* (⅔); (*e*), *Juglans arctica* (½).

plants hitherto found are on the whole like those of the Jurassic rocks—that is, they include some of the same genera of ferns, cycads, and conifers which these rocks contain. But already the ancestors of our common trees and flowering plants must have made their appearance, for in the upper half of the system their remains occur in abundance. This earliest dicotyledonous flora numbered among its members species of maple, alder, aralia, poplar, myrica, oak, fig, walnut, beech, plane, sassafras, laurel,

cinnamon, ivy, dogwood, magnolia, gum-tree, ilex, buckthorn, cassia, credneria, and others. The modern aspect of this assemblage of plants is in striking contrast to the more antique look of

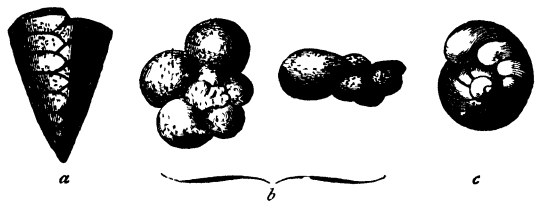



FIG. 200.—Cretaceous Foraminifera (*a*), *Textularia baudouiniana* ($\frac{20}{1}$); (*b*), *Globigerina cretacea* ($\frac{70}{1}$), (*c*), *Rotalia voltziana* ($\frac{40}{1}$)

all the older floras. There were likewise species of pine (*Pinus*), Californian pine (*Sequoia*), juniper, and other conifers, various cycads, forms of screw-pine (*Pandanus*), palms (*Sabal*), and numerous ferns (*Gleichenia*, *Asplenium*, etc.) This flora spread over the land surrounding the northern Cretaceous basin, and extended northwards even as far as North Greenland, from which some 200 species of Cretaceous plants have been obtained. The inference may be deduced that the climate of the globe must then have been much warmer than at present. The luxuriant vegetation disinterred from the Cretaceous rocks of North Greenland includes more than forty kinds of ferns, besides laurels, figs, magnolias, and other plants, which show that, though the winters were no doubt dark, they must have been extremely mild. There could have been no perpetual frost and snow in these Arctic latitudes in Cretaceous times.

FIG. 201.—Cretaceous Sponge (*Ventriculites decurrens*, $\frac{1}{2}$).

Foraminifera abound in some of the Cretaceous limestones, indeed, in some places they form almost the only constituent of these rocks. They are plentiful in the white chalk of England, France, and Belgium, one of the more frequent genera being *Globigerina* (Fig. 200) which still lives in enormous numbers in the Atlantic, and forms at the bottom of that ocean a grey ooze not unlike chalk (Fig. 42). Sponges lived in

great numbers in the Cretaceous sea. Their minute siliceous spicules are abundant in the chalk, and even entire sponges enveloped in flint are not uncommon (*Ventriculites*, Fig. 201). Sea-urchins are among the most familiar fossils of the chalk, and must

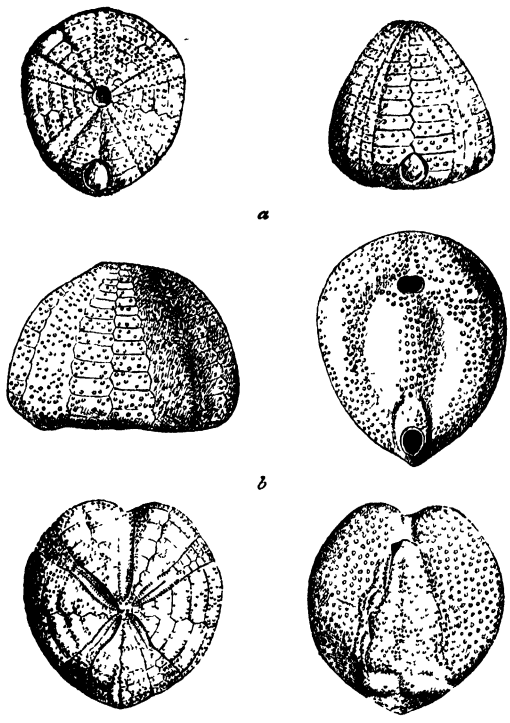
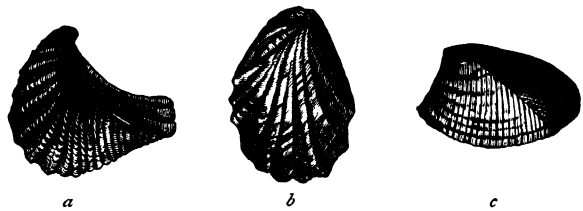



FIG. 202.—Cretaceous Sea-urchins (*a*), *Galerites* (*Echinoconus*) *conicus* ($\frac{2}{3}$), under surface and side view, (*b*), *Ananchytes ovatus* ($\frac{1}{2}$), side view and under surface, (*c*), *Micraster cor-anguinum* ($\frac{1}{2}$), upper and under surface

have lived in great numbers on the Cretaceous sea-bottom. Some of their genera are still living, and have been dredged up in recent years from great depths in the ocean. Among the more characteristic Cretaceous types are *Ananchytes*, *Holaster*, *Micraster*, and *Echinoconus* (Fig. 202). The brachiopods were still represented

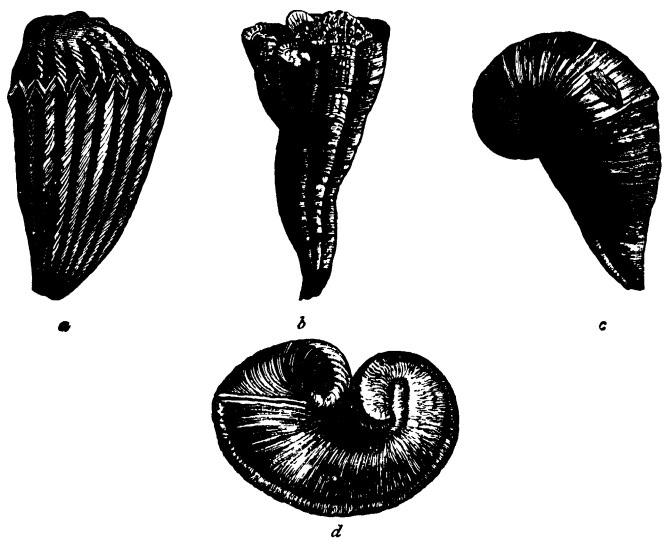
chiefly by the ancient genera *Terebratula* and *Rhynchonella*. Lamellibranchs abounded, especially the genera *Ostrea*, *Exogyra*,



*a* *b* *c*

FIG 203 Cretaceous Lamellibranchs. (*a*), *Trigonia alaeformis* (½), (*b*), *Inoceramus sulcatus* (½), (*c*), *Nucula bivirgata* (natural size)

*Inoceramus* (Fig. 203), *Lima*, *Pecten* The various forms of Diceratids (*Requienia*, Fig 204), Monopleurids, Caprinids (*Caprina*, *Plagioptychus*, Fig. 204), Radiolitids (*Radiolites*, Fig 204), and Hippuritids (*Hippurites*, Fig 204), are specially



*a* *b* *c* *d*

FIG 204 —Cretaceous Lamellibranchs (*a*), *Radiolites acuticostata* (½), a Diceratid, (*b*), *Hippurites toucasiana* (¼), a Hippuritid, (*c*), *Plagioptychus Aguilloni* (⅛), a Caprinid, (*d*), *Requienia toucasianus* (⅛), a Diceratid

characteristic of the Cretaceous system; hence their occurrence

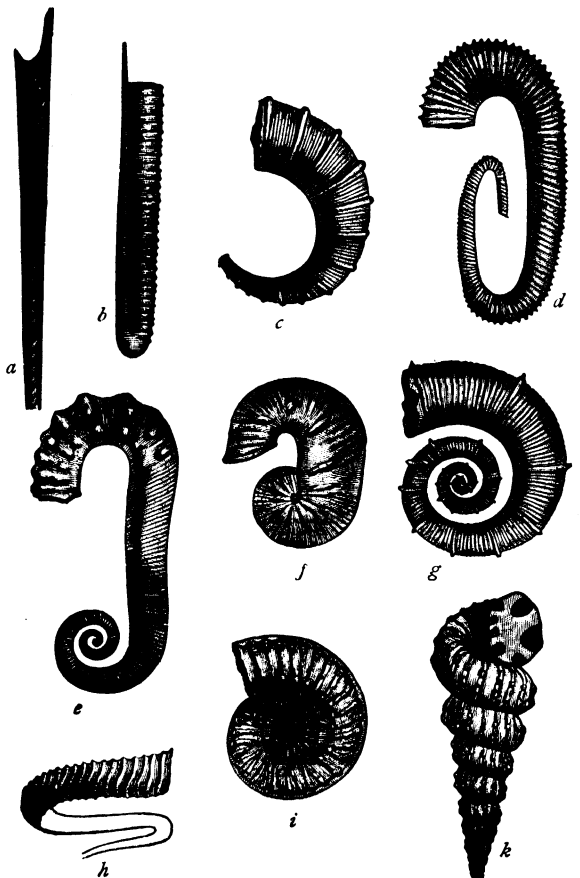



FIG. 205.—Cretaceous Cephalopods. (*a*), *Baculites anceps* ($\frac{1}{6}$); (*b*), *Ptychoceras emericianum* ($\frac{1}{2}$); (*c*), *Hamites* (*Toxoceras*) *bituberculatus* ($\frac{2}{3}$); (*d*), *Hamites rotundus* ($\frac{1}{3}$); (*e*), *Ancyloceras renauxianum* ($\frac{1}{10}$); (*f*), *Scaphites æqualis* ($\frac{2}{3}$); (*g*), *Crioceras villiersianum* ($\frac{1}{3}$); (*h*), *Helicoceras annulatum*; (*i*), *Ammonites* (*Schloenbachia*) *rostratus* ($\frac{1}{2}$); (*k*), *Turrilites catenatus* ($\frac{1}{2}$).

generally serves to indicate the Cretaceous age of the rock containing them. They have been imbedded in such numbers in

the limestones of the south of Europe as to give the name of "hippurite-limestone" to these rocks They are comparatively infrequent in the strata of the northern Cretaceous basin.

On the other hand, the ammonites, which are comparatively rare in the Cretaceous series of the south of Europe, display in the corresponding strata of central Europe an extraordinary variety of forms and ornamentation. Some of these variations are illustrated in Fig. 205. The old type of coiled shell now became uncoiled in many different degrees and with much diversity of pattern. Sometimes the departure from the normal type went so far as to lead to a straight tapering shell that recalls the ancient orthoceratites of Palæozoic time (*Baculites*) In other cases it produced whorled spires like those of gasteropods (*Turri-*

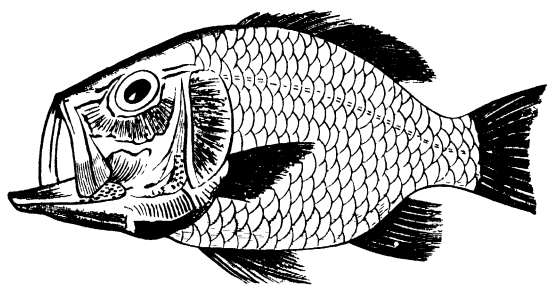


FIG 206 —Cretaceous Fish (*Hoplopteryx lewesiensis*, ½)

*lites*), while many of the genera developed a profusion of external tubercules These deviations have been looked upon as evidence that the race had outlived its vigour and was decaying from old age. They have also been regarded as signs of retrogression rather than advance in evolution, and as not improbably indicative of some widespread unfavourable change in the biological conditions of the sea in which the animals found themselves during the Cretaceous period. Whether from senility or as an ultimate consequence of uncongenial environment, the ammonites did not survive the close of that period. One of the most striking features in the whole series of formations that constitute the Geological Record is the absence of these fossils from the Tertiary deposits Of the thousands of species which flourished during Mesozoic time and gave such a distinctive character to the marine

fauna, few or none have been met with in any deposits younger than the Chalk, and none have been discovered among the forms living in our present seas.

The fishes of the Cretaceous period are chiefly known by teeth and spines belonging to various genera of sharks and rays (*Hybodus*, *Acrodus*, etc.), and by scales and exoskeletons of ganoids (*Pholidurus*, *Lepidotus*, etc.). But they also include representatives of the modern osseous or teleostean fishes, such as the herring, sea-bream, and eel (*Diplomystus*, *Urenchelys*, *Hoplopteryx*, etc., Fig. 206).

Already reptilian life seems to have been on the decline, at

FIG. 207.—Cretaceous Deinosaur (*Iguanodon*, about $\frac{1}{100}$).

least there is much less variety and abundance of it in the Cretaceous system than in that which immediately preceded it. Turtles and tortoises continued to haunt the low shores of the time. Ichthyosaurs, plesiosaurs, pterosaurs, and deinosaurs still lived, but in diminishing numbers, and they are not known to have survived the Cretaceous period. One of the most remarkable of the deinosaurs, and interesting from being one of the last of its race, is that known as *Iguanodon* (Fig. 207). Only scattered teeth and bones of this animal were known, until the fortunate discovery of a number of entire skeletons in Belgium enabled its structure to be almost completely made known, and threw much fresh light on the osteology of the deinosaurs. It was a herbivorous and probably amphibious creature, able, no doubt, to walk

along the shores, with an unwieldy gait, on its long hind legs, and balancing itself by its strong massive tail, which was doubtless a powerful instrument of propulsion through the water. Its extraordinary fore legs, with the strong spurs on the digits, must have been formidable weapons of defence against its carnivorous contemporaries. Another gigantic reptile, the *Mosasaurus*, believed to have been 75 feet long, was furnished with fin-like paddles for swimming Several kinds of crocodiles (*Goniopholis*, *Heterosuchus*) have also been disinterred from Cretaceous rocks in Europe.

Still more remarkable is the assemblage of remains of animal life exhumed from corresponding rocks in the Western Territories of North America. Among these the *Cimoliasaurus* was a snake-like animal some 40 feet long, with a swan-like neck supporting a slim head which it could raise 20 feet out of the water, or dart to the bottom and catch its prey. The pythonomorphs or sea-serpents were especially numerous.

The remains of true birds have been obtained from the Cretaceous rocks both of Europe and North America Some are related to the living ostrich, but were furnished with teeth set in a continuous groove (*Hesperornis*), others had large teeth in distinct sockets (*Ichthyornis*).

From different members of the Cretaceous series of North America a varied assemblage of small mammals has been obtained. These organisms show close affinities to those of Jurassic and Triassic times, being representatives of the modern Monotremes and Marsupials, but with no rodents, ungulates, or carnivores. Among those allied to Monotremes are the genera *Meniscoessus*, *Cimolomys*, and *Camptomus*. Among the Marsupials are *Didelphops*, *Cimolestes*, and *Dryolestes*.

The following are the principal subdivisions of the Cretaceous system in Europe in descending order. The stages are based upon more or less well-marked fossil evidence, but they are also for the most part to be distinguished by lithological characters :—

| | | |
|---|---|---|
| Upper | Danian | Pisolitic limestone of Paris basin ; Chalk of Hainault, Ciply, Maestricht, Faxoe in Denmark, and the south of Sweden, absent in England (*Belemnitella mucronata*, *Baculites Faujasii*, *Nautilus danicus*, etc ) |
| | Senonian | Chalk-with-flints of Norwich, Brighton, Flamborough Head, and Dover, north of France (with the following zones in descending order 1, *Belemnitella mucronata*, 2, *Actinocamax quadratus*, 3, *Marsupites testudinarius*, 4, *Micraster cor-anguinum* and *M cor-testudinarium*), sandstones of Westphalia and Saxony. |

| | | |
|---|---|---|
| Upper | Turonian | Chalk-without-flints of Dover and north of France (with zones of, 1, *Holaster planus*, 2, *Terebratulina lata* (*gracilis*), 3, *Rhynchonella Cuvieri*), sandstones, limestones, and marls of Saxony and Bohemia, Hippurite limestone of Southern France and Mediterranean basin |
| | Cenomanian | Grey Chalk of Folkestone (with zones of, 1, *Actinocamax plenus*, *Holaster subglobosus*, and 2, *Ammonites* (*Schloenbachia*) *varians*), Chalk-Marl, red chalk of Hunstanton, Glauconitic Marl and Cambridge Greensand, Chalk of Rouen, earthy limestones and marls in Hanover replaced southwards by plant-bearing sandstones, clays, and thin coal-seams, Hippurite limestones of Southern Europe. |
| | Albian . . | Warminster Beds, Gault and Upper Greensand (with zones of, 1, *Pecten asper* and *Cardiaster fossarius*, 2, *Ammonites* (*Schloenbachia*) *rostratus*, 3, *Ammonites* (*Hoplites*) *lautus* and *A* (*H*.) *interruptus*, 4, *Ammonites* (*Douvilleiceras*) *mammillatus* |
| Lower. | Neocomian | In Southern England a fluviatile (partly marine) succession of sands and clays (Wealden), surmounted by sands, clays, and limestones (Lower Greensand), in Northern England a series of clays and limestones, with marine fossils (upper part of Speeton Clay), limestones and marls of Neuchâtel, compact crystalline limestones in Provence |

It will be remembered that towards the close of the Jurassic period the floor of the sea in the western part of the European area was gently raised, some of the younger Jurassic marine limestones being ridged up into islets or low land, with lakes or estuaries in which the Purbeck beds were deposited. This terrestrial condition of the geography was maintained and extended in the same region during the early part of the Cretaceous period. The geological history of Europe as revealed by the various subdivisions in the foregoing Table may be briefly given.

**Neocomian** (from Neocomum, the old Latin name of Neuchâtel in Switzerland). This stage in the south of England, and thence eastwards across Hanover, consists of a mass of sand and clay sometimes 1800 feet thick, representing the delta of a river which flowed into a broad estuary or lake that covered the sites of most part of the counties of Surrey, Sussex, and Kent. This stream carried down the drifted vegetation of the land, together with occasional carcases of the iguanodons and other terrestrial or amphibious creatures of the time. From their great development in the Weald of Sussex, these delta-deposits have been called

Wealden. They there consist of the following subdivisions in descending order :—

| | 1000 feet |
|---|---|
| Weald Clay . . | |
| Hastings Sand group, comprising– | |
| 3 Tunbridge Wells Sand | 140 to 380 ,, |
| 2 Wadhurst Clay | 120 to 180 ,, |
| 1 Ashdown Sand | 400 to 500 ,, |

Beyond the area overspread by the sand and mud of the delta, the ordinary marine sediments accumulated, with their characteristic organic remains. We find these sediments in Yorkshire (upper part of Speeton Clay), which must then have lain beyond the estuary of the river. Careful examination of the sections exposed on the Yorkshire coast, compared with those which have been studied in Russia, has established the existence of a succession of zones in the Neocomian division, each characterised by a distinct assemblage of fossils and recognisable more particularly by different species of belemnites. At the base lies the zone of *Belemnites lateralis*. Higher come in succession the zone of *B. jaculum*, that of *B. brunsvicencis* (*semicanaliculatus*) and that of *B. minimus*. The Lower Greensand which, with the Atherfield clay at its base, overlies the Wealden group in the south of England contains marine fossils, and points to the submergence of the delta.

The Neocomian stage is well displayed in the eastern part of the Paris basin, where it rests unconformably upon the uppermost Jurassic rocks; but it attains a much greater development in the south of France, where it consists of limestones, replaced in large measure by marls towards the south and reaching a thickness of 1600 feet. At Neuchâtel, the typical district for this subdivision of the Cretaceous system, the Neocomian strata are separable into two sub-stages, of which the lower (Valenginian) is composed of 130 to 260 feet of limestones and marls (*Toxaster Campichei*, *Belemnites dilatatus*, *Ammonites* (*Oxynoticeras*) *gevrilianus*); while the upper (Hauterivian) consists of about 250 feet of blue marls (*Toxaster complanatus*, *Exogyra Couloni*, *Ammonites* (*Hoplites*) *radiatus*). Above the Neocomian rocks the French geologists have found a group of strata which they have called Urgonian (from Orgon, near Arles) and which differ widely from the northern type, inasmuch as they consist of massive hippurite limestones. A higher group of marls and limestone well seen at Apt in Vaucluse is known as Aptian.

**Albian** (from the department of the Aube in France). In England this stage includes the band of dark, stiff, blue clay known as Gault, and the group of green and yellow sands called Upper Greensand. It comprises four palæontological zones as shown in the Table, p. 358. Extending over the Wealden sands and clays, the Gault (100 to 200 feet or more in thickness), with its abundant marine fossils, shows how thoroughly the Wealden delta was now submerged beneath the sea.

The Albian stage is continued through the north of France in the form of greensands and clays and a peculiar calcareous and argillaceous sandstone called *Gaize*. It is prolonged into north-western Germany in various clays containing characteristic Albian fossils and surmounted by a dark clay with flame-like streaks (Flammenmergel).

**Cenomanian** (from Coenomanum, the old Latin name of the town of Mans in the department of Sarthe, France). This stage comprises a group of impure chalky, glauconitic, and sandy deposits lying at the base of the Chalk in England and the north of France. It is often spoken of in England as the Lower Chalk, where it is more than 300 feet thick, and is separable into the following subdivisions in descending order :—

Grey chalk, forming the base of the Chalk.
Chalk Marl (Red Chalk of Hunstanton).
Glauconitic Marl
Upper Greensand

Certain sandy portions of this group have been called the Upper Greensand. The Glauconitic (or Chloritic) Marl is an impure, dull white, or yellowish chalk, sometimes 15 feet thick, with grains of glauconite and phosphatic nodules. The Chalk-Marl is an impure band of chalk, occasionally more than 100 feet thick, overlain by a zone of Grey Chalk which attains a maximum thickness of about 200 feet, and forms the base of the true Chalk-without-flints. In these deposits two zones of stratigraphical importance have been distinguished, as given in the Table, p. 358.

Traced eastwards into Germany, the Cenomanian stage undergoes great changes in lithological characters, passing at last in Saxony and Bohemia into sandstones and clays (Quader) full of remains of terrestrial vegetation, and even including some thin seams of coal. It is in these beds that the oldest dicotyledonous plants in Europe have been found. It is evident that land existed in the heart of Germany during this stage of the Cretaceous

period. In Southern France, on the other hand, the corresponding strata are massive hippurite-limestones, which sweep through the great Mediterranean basin, and show how large an area of Southern Europe then lay under the sea.

**Turonian** (from Touraine). This stage, sometimes called the Middle Chalk, includes the lower part of the Chalk, above the Grey Chalk. The thick mass of white crumbly limestone known as the Chalk, which has been referred to as the most conspicuous member of the Cretaceous system in the west of Europe, has long been grouped in England into two parts, a lower band of "Chalk-without-flints," and an upper band of "Chalk-with-flints." The former corresponds, on the whole, with the Turonian stage, which in England is sometimes more than 200 feet thick. The Chalk, as a whole, is a remarkably pure limestone, composed chiefly of crumbled foraminifera, urchins, molluscs, and other marine organisms. It comprises the three zones shown in the Table on p. 358. It must have been laid down in a sea singularly free from ordinary sandy or muddy sediment; but there is no evidence that this sea was one of great depth. On the contrary, though the Chalk itself resembles the Globigerina ooze of the deeper parts of the Atlantic Ocean, the characters of its foraminifera and other organic remains indicate comparatively shallow-water conditions. The basin in which it was laid down shallowed eastwards, where, from the evidence of sandstones, coal-seams, and plants, there was land at the time; while towards the west there was open sea. During the deposition of the Chalk it is not improbable that most of the British Isles lay submerged under the Cretaceous ocean

The English type of the Turonian stage is prolonged into northern France, but traced into Germany it undergoes a change similar to that of the underlying parts of the Chalk, passing into massive sandstones, limestones, and marls. In the south and south-east of France the type of hippurite-limestones sets in, and stretches across the centre of Europe and along both sides of the Mediterranean basin into Asia. As above stated, this development of the Cretaceous rocks has a much wider range than the Chalk from which the system derives its name.

**Senonian** (from Sens, in the department of Yonne). This stage corresponds generally with the original English Upper Chalk, or Chalk-with-flints, which is the thickest subdivision, since it reaches a thickness of 700 feet. Its most conspicuous feature is the presence of the layers of nodules or irregular

lumps of black flint which mark the stratification of the Chalk. The origin of these concretions has been the subject of much discussion among geologists, and it cannot be said to have been even yet satisfactorily solved. Some marine plants (diatoms) and animals (radiolarians, sponges, etc.) secrete silica from sea-water, and build it up into their framework. But the flints are not mere siliceous organisms, though organic remains may often be observed enclosed within them. They are amorphous lumps of dark silica, containing a little organic matter. By some process, not yet well understood, these aggregations of silica have gathered usually round organic nuclei, such as sponges, urchins, shells, etc. The decomposition of organic matter on the sea-floor may have been the principal cause in determining the abstraction and deposition of silica. Not infrequently an organism, such as a brachiopod or echinus, originally composed of carbonate of lime, has been completely transformed into flint.

Four divisions of the Senonian stage are recognisable by their fossils. The lowest is marked by the abundance of sea-urchins belonging to the genus *Micraster* (*M. cor-testudinarium* in the under part, and *M cor-anguinum* in the higher part). Next comes the Margate Chalk or zone of Marsupites, followed by the zone of *Actinocamax* (*Belemnitella*) *quadratus*, while the highest part of the English Chalk, that of Norwich, is distinguished by the zone of *Belemnitella mucronata*.

The total thickness of the English Chalk, including the Cenomanian, Turonian, and Senonian stages, exceeds 1200 feet. It is well exposed along the sea-cliffs of the east and south of England. It forms the promontories of Flamborough Head, Dover, Beachy Head, and the Needles in the Isle of Wight.

The white cliffs of Kent are repeated on the opposite coast of France, where the same general type of Senonian calcareous sediments is developed. Towards the Mediterranean basin, the hippurite-limestones with sandstones and marls take the place of the northern Chalk. But they include some fresh-water deposits and beds of lignite, which point to the shallowing of the sea there towards the end of Cretaceous time and the uprise of land. In Germany, the Senonian stage displays a still greater development of thick sandstones, which form the picturesque district known as Saxon Switzerland.

**Danian** (from Denmark). This stage has not been recognised in England. Its component chalky strata occur in scattered patches over Northern France, Belgium, and Denmark, to the

south of Sweden. They rest unconformably on the Chalk, and though they contain some Cretaceous species of fossils, the general aspect of their organic remains resembles that of the Tertiary series. Evidently the break between the Senonian and Danian stages represents a prolonged interval of time.

The Cretaceous hippurite-limestones of Southern Europe and the basin of the Mediterranean are prolonged through Asia Minor into Persia, where they cover a vast area. They have been found likewise on the flanks of the Himalaya Mountains, so that the open Cretaceous sea at one time stretched right across the heart of the Old World. In the Indian Deccan, a great extent of country, estimated at 200,000 square miles, lies buried under horizontal or nearly horizontal sheets of lava, which have a united thickness of from 4000 to 6000 feet or more. They were erupted during the later ages of the Cretaceous period. These eruptions, from the presence of interstratified layers containing remains of fresh-water shells, land-plants, and insects, are believed to have taken place on land and not under the sea.

Cretaceous rocks cover an enormous area in North America, and in some regions attain a thickness of many thousand feet. They include marine and fresh-water strata, and thus reveal a wide variety of geographical conditions during their deposition, so that the succession of formations in the system varies widely in different parts of the continent. In the Eastern States, from Rhode Island southward into Georgia, a strip of Cretaceous formations has long been known. In New Jersey, the clays and sands have furnished an abundant marine fauna, while in Virginia there is a characteristic terrestrial flora. Stretching westward beyond the Mississippi into Texas, Oklahoma, and New Mexico, the Cretaceous system attains a great development, until it is said to be from 10,000 to 20,000 feet thick. In that region the marine type of sediments is well displayed, and the limestones contain abundant hippurites, like those of Europe. Where they have remained undisturbed the strata retain much of their original soft chalky or marly character, but where they have been ridged up into mountain ranges they have acquired the hardness of solid rocks.

In the vast interior region including Colorado, Utah, Wyoming, and a wide expanse of British territory from Manitoba across the Rocky Mountain region westward to the Pacific coast, the Cretaceous system covers many thousands of square miles and sweeps northward into the Arctic regions. In Utah,

Wyoming, and the surrounding regions, it consists of enormous piles of sediment which appear to have been laid down for the most part in large fresh-water lakes, though on several horizons proofs of the intervention of the sea at intervals are furnished by clays, shales, and limestones, containing such characteristic marine Cretaceous shells as *Inoceramus*, *Baculites*, *Scaphites*, and *Belemnitella*. The highest formation in the series, known as the Laramie group, has furnished a large assemblage of land-plants, half of which are allied to still living American trees, and in some places these plants are aggregated into valuable seams of coal. The numerous reptilian and bird remains found in these strata have been already noticed. Towards the close of the Cretaceous period volcanic activity prevailed extensively in the western portions of the continent, and some of the uppermost of the Cretaceous formations in that region consist mainly of volcanic tuffs. There was likewise great disturbance of the terrestrial crust, which was powerfully ridged up into mountains and plateaux, such as those of the Rocky Mountains, the Pacific coast-ranges, and the high tablelands of Arizona and Utah.

Rocks assigned to the Cretaceous system cover a wide region of Queensland, and also attain a considerable thickness in New Zealand.

# CHAPTER XXV

## THE TERTIARY OR CAINOZOIC PERIODS—EOCENE—OLIGOCENE

THE Cretaceous system closes the long succession of Secondary or Mesozoic formations. The rocks which come next in order are classed as Tertiary or Cainozoic (Recent Life). When these names were originally chosen, geologists in general believed not only that the divisions into which they grouped the stratified rocks of the earth's crust correspond on the whole with well-defined periods of time, but that the abrupt transitions, so often traceable between systems of rocks, serve to mark geological convulsions, in which old forms of life, as well as old geographical conditions, disappeared and gave place to new. One of the most notable of such breaks in the record was supposed to separate the Cretaceous system from all the younger rocks This opinion arose from the study of the geology of Western Europe, and more especially of South-Eastern England and North-Western France. The top of the Chalk, partly worn down by denudation, was found to be abruptly succeeded by the pebble-beds, sands, and clays of the lower Tertiary groups. No species of fossils found in the Chalk were known to occur also in the younger strata. It was quite natural, therefore, that the hiatus at the top of the Cretaceous system should have been regarded as marking the occurrence of some great geological catastrophe and new creation, and, consequently, as one of the great divisional lines of the Geological Record.

More detailed investigation, however, has gradually overthrown this belief. In Northern France, Belgium, and Denmark, various scattered deposits (Danian, p 362) serve to bridge over the gap that was supposed to separate Mesozoic and Cainozoic formations. In the Alps, no satisfactory line has been found to separate undoubtedly Cretaceous strata from others as obviously Tertiary.

And in various parts of the world, especially in Western North America, other testimony has gradually accumulated to show that no general convulsion marked the end of the Secondary and beginning of the Tertiary periods, but that the changes on the earth's surface proceeded in the same orderly connection and sequence as during previous and subsequent geological ages. The break in the continuity of the deposits in Western Europe only means that in that part of the world, owing to some important geographical changes, specially to elevation of the sea-floor, the record of the intervening ages has not been preserved. Either strata containing the record were never deposited in the region in question, or, having been deposited, they have subsequently been removed by denudation.

Bearing in mind, then, that such geological terms are only used for convenience of classification and description, and that what is termed Mesozoic time glided insensibly into what is called Cainozoic, we have now to enter upon the consideration of that section of the earth's history comprised within the Tertiary or Cainozoic periods. The importance of this part of the geological chronicle may be inferred from the following facts. During Tertiary time the sea-bed was ridged up into land to such an extent as to give the continents nearly their existing area and contour. The crust of the earth was upturned into great mountain ranges, and notably into that long band of lofty ground stretching from the Pyrenees right through the heart of Europe and Asia to Japan. Some portions of the Tertiary sea-bed now form mountain peaks 16,000 feet or more above the sea. The generally warm climate of the globe, indicated by the world-wide diffusion of the same species of shells in Palæozoic, and less conspicuously in Mesozoic time, now slowly passed into the modern phase of graduated temperatures, from great heat at the equator to extreme cold around the poles. At the beginning of the Tertiary or Cainozoic periods, the climate was mild even far within the Arctic Circle, but at their close, it became so cold that snow and ice spread far southward over Europe and North America.

The plants and animals of Tertiary time are strikingly modern in their general aspect. The vegetation consists, for the most part, of genera that are still familiar in the meadows, woodlands, and forests of the present day. The assemblage of animals, too, becomes increasingly like that of our own time, as we follow the upward succession of strata in which the remains are preserved.

In one strongly marked feature, however, does the Tertiary fauna stand contrasted alike with everything that preceded and followed it. If the Palæozoic or Primary periods formed the "Age of Invertebrates and Fishes," and if the Mesozoic or Secondary periods could appropriately be grouped together under the name of the "Age of Reptiles," Cainozoic or Tertiary time may not less fitly be called the "Age of Mammals." As the manifold reptilian types died out, the mammals, in ever-increasing complexity of organisation, took their place in the animal world. By the end of the Tertiary periods they had reached a variety of type and a magnitude of size altogether astonishing, and far surpassing what they now present. The great variety of pachyderms is an especially marked feature among them.

The rocks embraced under the terms Cainozoic or Tertiary have been classified according to a principle different from any followed with regard to the older formations. When they began to be sedulously studied in Western Europe, it was found that the percentage of recent species of shells became more numerous as the strata were followed from older to newer platforms. The French naturalist Deshayes determined the proportions of these species in the different Tertiary groups of strata, and the English geologist Lyell proposed a scheme of classification based on these ratios. His names, with modifications as to their application, have been generally adopted. They are compounds of the Greek καινος, recent, with affixes denoting the proportion of living species.

To the oldest Tertiary deposits, containing only about 3 per cent of living species of shells, the name Eocene (dawn of the recent) was given. The next series, containing a larger number of living species, has received the name of Oligocene (few recent). The third division in order is named Miocene, to indicate that the living species though in still larger proportions, are yet a minority of the whole shells. The overlying series forming the uppermost of the Tertiary divisions is termed Pliocene (more recent), because the majority are now living species. The same system of nomenclature has been retained for the next overlying group, which forms the lowest member of the Post-tertiary or Quaternary series. This group is called Pleistocene (most recent), and all the species of shells in it are still living at the present time. It must not be supposed that the mere percentage of living or of extinct species of shells in a deposit always affords satisfactory evidence of geological age. Obviously, there may have been circumstances favourable or unfavourable to the

existence of some shells on the sea-bottom which that deposit represents, or to the subsequent preservation of their remains. The system of classification by means of shell-percentages must be used with some latitude, and with due regard to other evidence of geological age.

## EOCENE

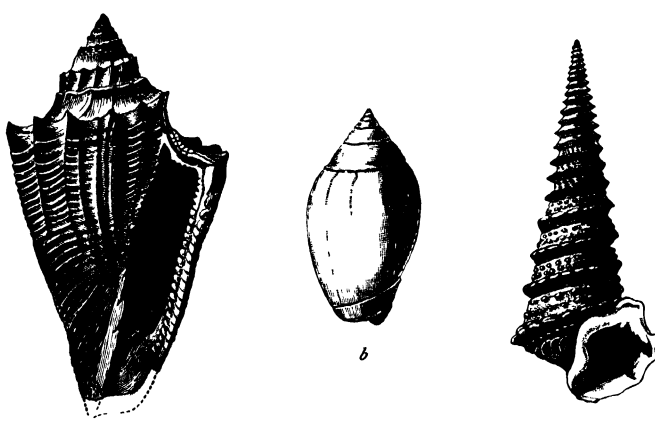
In Europe great geographical changes took place at the close of the Cretaceous period. The wide depression in which the Chalk had been deposited was gradually and irregularly elevated, and over its site a series of somewhat local deposits of clay, sand, marl, and limestone was laid down, partly in small basins of the sea-floor, and partly in estuaries, rivers, or lakes. In Southern Europe, however, the more open sea maintained its place, and over its floor were accumulated widespread and thick sheets of limestone which, from the crowded nummulites which they contain, are known as Nummulitic Limestone. These characteristic rocks extend all over the basin of the Mediterranean, stretching far into Africa and sweeping eastwards through the Alps, Carpathians, and Caucasus, across Asia to China and Japan. In North America the rocks classed as Eocene present two contrasted types. Down the eastern and western borders of the continent, from the coast of New Jersey into the Gulf of Mexico on the one side, and along the coast ranges of California and Oregon on the other, they are marine deposits, though occasionally presenting layers of lignite with terrestrial plants. Over the vast plateaux which support the Rocky Mountains, however, they are of lacustrine origin, and show that in what is now the heart of the continent the bed of the Cretaceous sea was upraised into a succession of vast lakes, round which grew a luxuriant vegetation. In these lakes a total mass of Eocene strata, estimated at not less than 12,000 feet, was deposited, entombing and preserving an extraordinarily abundant and varied record of the plant and animal life of the time.

The Eocene flora points to a somewhat tropical climate. Among its plants are many which have living representatives now in the hotter parts of India, Australia, Africa, and America. Above the ferns (*Lygodium*, *Asplenium*, etc) which clustered below, rose clumps of palms, cactuses, and aroids; numerous conifers and other evergreens gave the foliage an umbrageous aspect, while many deciduous trees—ancestors of

some of the familiar forms of our woodlands—raised their branches to the sun. Among the conifers were many cypress-like trees (*Callitris*), pines (*Pinus*, *Sequoia*), and yews (*Salisburia* or Ginkgo). Species of aloe (*Agave*), sarsaparilla (*Smilax*), and amomum were mingled with fan-palms (*Sabal*, *Chamærops*) and screw-pines (*Pandanus*, *Nipa*), together with early forms of fig (*Ficus*), elm (*Ulmus*), poplar (*Populus*), willow (*Salix*), hazel (*Corylus*), hornbeam (*Carpinus*), chestnut (*Castanea*), beech (*Fagus*), plane (*Platanus*), walnut (*Juglans*), liquidambar, magnolia, alder-like plants, water-bean (*Nelumbium*), water-lily (*Victoria*), maple (*Acer*), gum-tree (*Eucalyptus*), cotoneaster, plum (*Prunus*), almond (*Amygdalus*), laurel (*Laurus*), cinnamon tree (*Cinnamomum*), and many more (Fig. 208)

Fig. 208.—Eocene Plant (*Petrophiloides Richardsonii*), natural size

The fauna likewise points to the extension of a warm climate



*a* *b* *c*

Fig. 209.—Eocene Molluscs (*a*), *Voluta luctatrix* (⅓), (*b*), *Oliva Branderi* (natural size), (*c*), *Cerithium tricarinatum* (⅓)

over regions that are now entirely temperate. This is particularly noticeable with regard to the mollusca. The species are, with perhaps a few exceptions, all extinct, but many of the genera are

still living in the warmer seas of the globe. Some of the most characteristic forms are species of *Nautilus*, *Oliva*, *Voluta*, *Conus*, *Mitra*, *Cyrena*, *Cytherea*, *Chama*. The genus of Foraminifera, called *Nummulites* from the fancied resemblance of the organism to a piece of money, is enormously abundant in the limestones above referred to as nummulitic limestones. It must have flourished in vast profusion over the floor of the sea, which in older Tertiary time spread across the heart of the Old World from the Atlantic to the Pacific Oceans. Some of the most common fish-remains found in the Eocene strata, chiefly in the form of scattered teeth and ear-bones, belong to the genera *Lamna*, *Myliobatis*, *Pristis*. Reptilian life, which enjoyed such a preponderance during the Mesozoic ages, is conspicuously

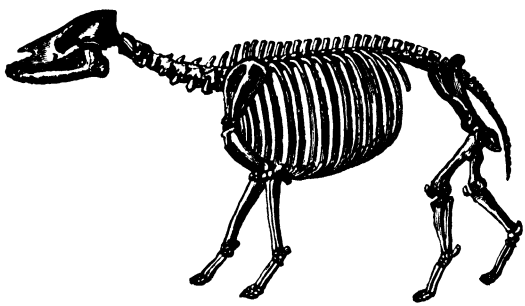


FIG 210.—Eocene Mammal (*Palæotherium magnum*, $\frac{1}{87}$).

diminished in the Eocene deposits alike in number of individuals and variety of structure. The genera are chiefly turtles, tortoises, crocodiles, and sea-snakes, presenting in their general assemblage a decidedly modern aspect, compared with the reptilian fauna of the Secondary rocks. Remains of birds are comparatively rare as fossils. We have seen that the earliest known type has been obtained in the Jurassic system, and that others have been found in the Cretaceous rocks. Still more modern forms occur in Eocene strata; they include one (*Argillornis*) which may have been a forerunner of the living albatross; another, of large size (*Dasornis*), possibly akin to the gigantic extinct ostrich-like moa (*Dinornis*) of New Zealand, a third (*Agnopterus*) shows an affinity with the flamingo; while the buzzard, woodcock, quail, pelican, ibis, and African hornbill are represented by ancestral forms

But, as stated above, it was chiefly in higher forms of life that

the fauna of early Tertiary time stood out in strong contrast with that of previous ages of geological history. The mammalia now took the leading place in the animal world, which they have retained ever since Among the Eocene mammals reference may here be made to the numerous tapir-like creatures which then flourished (*Coryphodon*, *Palæotherium*, Fig. 210, *Anchilophus*, etc ) Some of the forms were intermediate in character between tapirs and horses, and included the supposed ancestors of the modern

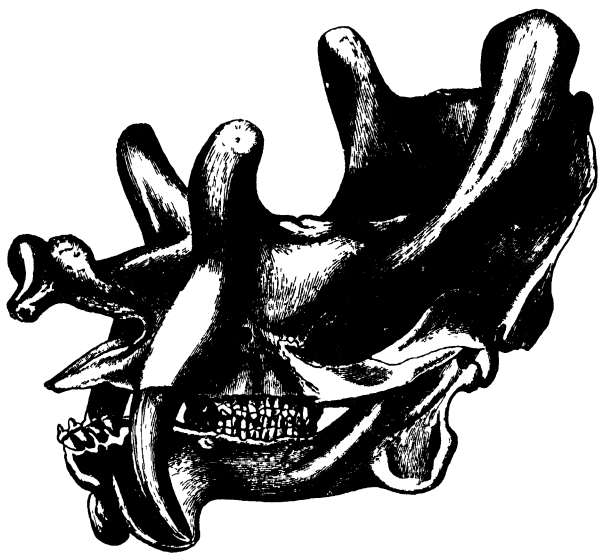


FIG 211 —Skull of *Uintatherium* (*Tinoceras*) *ingens* (about $\frac{1}{7}$).

horse (*Eohippus*, etc.)—small pony-like animals, with three, four, and even traces of five toes on each foot. Many of the mammals of Eocene time presented more or less close resemblances to wolves, foxes, wolverines, and other modern forms There were likewise true opossums Numerous herds of hog-like animals (*Hyopotamus*) and of hornless deer and antelopes wandered over the land, while in the woodlands lived early ancestors of our present squirrels, hedgehogs, bats, and lemurs. Among these various tribes which recall existing genera, othe of strange and long-extinct types roamed along the borders of

great lakes in western North America. The Tillodonts were a remarkable order, in which the characters of the ungulates, rodents, and carnivores were curiously combined. These animals, perhaps rather less in size than the living tapir, had skeletons resembling those of carnivores, but with large prominent incisor teeth like those of rodents, and with molar teeth possessing grinding crowns like those of ungulates. Still more extraordinary were the forms to which the name of Dinocerata has been given (*Uintatherium*, Fig. 211). These were somewhat like elephants in size, and like rhinoceroses in general build, but the skull bore a pair of horn-like projections on the snout, another pair on the forehead, and one on each cheek.

The west-European type of the Eocene deposits is well displayed in England, France, and Belgium. In England it is confined to the south-eastern part of the country, from the coast of Hampshire into Norfolk. The strata vary in character from district to district, sands and gravels being replaced by clays according to the conditions in which the sediment was accumulated. A similar succession of deposits is prolonged from Hampshire into the Paris basin and from the London area into the Belgian basin. Arranged in tabular form this succession may be grouped as follows :—

| | England. | France and Belgium. |
|---|---|---|
| Upper. | Barton Clay of Hampshire Basin, Upper Bagshot Sands of London Basin. | Marine gypsum and marls of Paris (Ludian), sands and calcareous sandstones of Belgium (Wemmelian)<br>Sands (Sables Moyens) marine, with estuarine and fresh-water limestones, etc (Bartonian) |
| Middle. | Bracklesham Beds of Hampshire (leaf-beds of Alum Bay and Bournemouth), Middle and part of Lower Bagshot Sands of London Basin | Calcaire Grossier divided into (3) Caillasses, upper limestones, with marine and fresh-water fossils, (2) middle limestones, with marine shells and terrestrial vegetation, (1) lower glauconitic marine limestones and sands (Lutetian)<br>Sandstones and sands (Laekenian and Bruxellian) of Belgium. |
| Lower. | Part of Lower Bagshot Sands<br>London Clay (Bognor Beds).<br>Oldhaven Beds<br>Woolwich and Reading Beds.<br>Thanet Sand. | Panselian sands of Belgium<br>Ypresian clays and overlying sands of Belgium. Absent in Paris basin<br>Sands of Bracheux (Paris basin), Landenian gravels and sands, and Heersian beds of Belgium, marls of Meudon, fresh-water limestones of Rilly and Sézanne (Thanetian) |

In striking contrast with these comparatively thin and locally developed deposits are those of the Alps, Southern Europe, and the basin of the Mediterranean. Masses of nummulitic limestone and sandstone (Flysch), several thousand feet thick, have been upraised, folded, and fractured, and now form important parts of the great mountain chains which run through Europe and the north of Africa. Similar rocks have been uplifted along the flanks of the great chain of heights that sweeps through the heart of Asia, reaching in the Himalaya range a height of 16,500 feet above the sea-level. We thus learn not only that a large part of the existing continents lay under the sea during Eocene time, but that the principal mountain-chains of the Old World have been upheaved to their present altitudes since the beginning of the Tertiary periods. In North America the two contrasted types of the Atlantic border and the interior are grouped in the following subdivisions.—

| | Atlantic Border (chiefly Marine) | Interior (Lacustrine). |
|---|---|---|
| Upper | Vicksburg group of limestones, blue marls, and lignitic clays and lignites, numerous marine fossils (*Cardium*, *Panopæa*, *Cypræa*, *Mitra*, *Conus*, Madrepores, *Orbitoides*) | Uinta group of lacustrine strata, "Diplacodon Beds" (800 feet), with an abundant terrestrial fauna (*Paramys*, *Ephippus*, *Diplacodon*, *Telmatotherium*, etc.). |
| Middle | Jackson group of white and blue marls with marine fossils, underlain by lignitic clay and lignite<br>Claiborne group of white and blue marls and sands, with marine shells, corresponding to the Calcaire Grossier of the Paris Basin<br>Buhrstone or Lower (siliceous) Claiborne group of sandstones and impure siliceous limestones, with marine fossils like those of the group above | Bridger group (2000 feet) consisting of lacustrine deposits, which include the "Deinoceras Beds" of Professor Marsh, with a singularly varied fauna, comprising numerous lemuroids, rodents, creodonts, tillodonts, edentates, deinoceres, insectivores, bats, and tapirs<br>Huerfano lacustrine group of Southern Colorado. |
| Lower | Lignitic sands and clays, with remains of a terrestrial flora and marine fossils in some of the strata. | Wind River group (800 feet), (*Hyopsodus*, *Viverravus*, *Uintacyon*, *Coryphodon*, *Hyracotherium*, *Proterohippus*, etc)<br>Wahsatch group (2000 feet); Coryphodon beds, consisting of sediments that mark the site of one or more large lakes (*Hyopsodus*, *Pelycodus*, *Sinopa*, *Coryphodon*, nine or more species, etc) |
| Basal | Torrejon group (300 feet) Many of the fossils in the higher members of the series are here absent, among those present are species of *Pantolambda*, *Neoplagiaulax*, *Deltatherium*, *Clænodon*, *Mioclænus*, *Psittacotherium*, etc<br>Puerco group (500 feet), containing a fauna supposed to be older than any mammalian fauna in Europe, and including *Polymastodon*, *Protochriacus*, *Oxyacodon*, *Protogonodon*, etc | |

In the western regions of the United States, a marked feature of the scenery of the Tertiary strata is that of the so-called "Bad Lands"—tracts of nearly horizontal clays, marls, limestones, and sandstones which, under the influence of atmospheric denudation, in a somewhat arid climate, have been carved into an intricate

network of gullies, chasms, ridges, and buttes, nearly or wholly devoid of vegetation and with the aspect of almost crumbling into

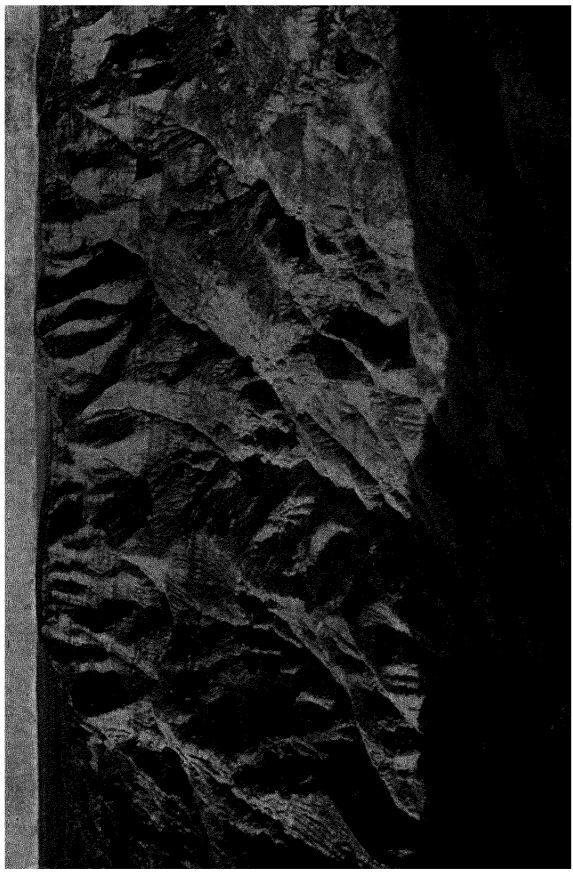


FIG. 212.—Typical "Bad Lands," carved by denudation out of Tertiary strata at the base of Scott's Bluff, Western Nebraska. Photograph by Mr. N. H. Darton, U.S. Geol. Survey.

dust under one's eyes. It is a repulsive landscape, verdureless, treeless, and waterless. Some of its characteristic aspects are represented in Fig. 212.

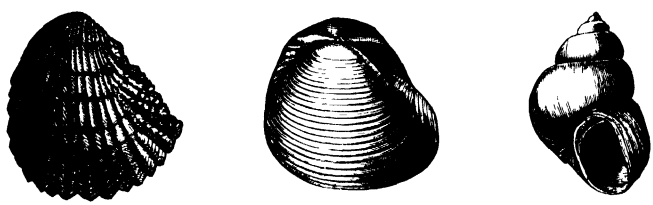
## OLIGOCENE.

Under this name geologists have placed a group of strata usually of comparatively insignificant thickness, chiefly of fresh-water and estuarine, but partly also of marine origin, which, in Western and Central Europe, show how the bays and shallow seas of that region in the Eocene period were gradually obliterated, and replaced by land and by sheets of fresh water. They attain in Switzerland a thickness of several thousand feet, composed of sandstones, conglomerates, and marls, almost entirely of lacustrine origin, and forming a group of massive mountains (Rigi, Rossberg) A large lake occupied their site and continued to be an important feature in the geography of Central Europe during this and the following geological period. Other sheets of fresh water were scattered over the west of Europe. One of the largest of these lay in Central France, over the old district known as the Limagne d'Auvergne. In Germany, lacustrine and terrestrial deposits, including numerous seams of lignite or brown coal, are separated by a group of strata full of marine shells, foraminifera, etc, showing that for a time the lakes and woodlands were submerged beneath the sea. In the Paris basin, and in the Isle of Wight, the strata were chiefly deposited in fresh-water, but contain occasional marine intercalations. Evidently the Oligocene period, throughout the European area, was one of considerable oscillation in the earth's crust. During this time, too, the volcanic eruptions took place whereby the great sheets of basalt that form the terraced hills of the north of Ireland, the Western Islands of Scotland, and the Faroe Isles, were thrown out.

An epoch of frequent change in the relative positions of sea and land is one in which there may be exceptional facilities for the preservation of a record of the plants and animals of the time. Oligocene strata in Europe have accordingly a peculiar interest from the abundant remains they contain of the contemporaneous terrestrial plants and animals. The land flora of that period is probably better known than that of any other section of the Geological Record, chiefly from the extraordinary abundance of its remains which have been preserved in the sediments of the ancient Swiss lake. Judging of it from these remains, we learn that it was in great measure made up of evergreens, and in various ways resembled the existing vegetation of tropical India and Australia and that of sub-tropical America. Its fan-palms, feather-palms, conifers, evergreen oaks, laurels, and other evergreen trees,

gave a peculiarly verdant umbrageous character to the landscape in all seasons of the year, while numerous proteaceous shrubs glowed with their bright blooms on the lower grounds

Of the terrestrial fauna numerous remains have been found in the lacustrine deposits of the time. We know that the borders of the lakes in Central France were frequented by many different kinds of birds—paroquets, trogons, flamingoes, ibises, pelicans, maraboots, cranes, secretary birds, eagles, grouse, and other forms This association of birds recalls that around the lakes of Southern Africa at the present time The mammals appeared in still more numerous and abundant types. Among them came the *Anoplotherium*—a slender, long-tailed animal, about the size of an ass, with three toes on each foot; certain transitional types of ungulates, with affinities to the pigs, peccaries, and chevrotains (*Anthracotherium*, *Chœropotamus*, *Hyopotamus*, etc.); various forms of the tapir family, and of lemuroids, dogs, civets, martens, marmots, bats, moles, and shrews The carnivora still presented marsupial characters, and in not a few of the animal types features



*a* *b* *c*

FIG 213 —Oligocene Molluscs (*a*), *Ostrea ventilabrum* (½), (*b*), *Corbula subplsum* (½), (*c*), *Viviparа lenta* (natural size)

of structure were combined which are now only found in distinct genera. The Eocene palæotheres and the Oligocene anoplotheres appear to have died out before the end of the Oligocene period. The fresh water teemed with molluscs, belonging chiefly to genera that still live in our rivers and lakes, such as *Unio*, *Cyrena*, *Paludina*, *Planorbis*, *Limnæa*, *Helix*, and others (Fig. 213), while the seas were tenanted by species of Oyster, *Pecten*, *Nucula*, *Cardium*, *Murex*, *Typhis*, *Conus*, *Voluta*, and other genera

In the Isle of Wight the highest Eocene strata were followed by a group of fresh-water, estuarine, and marine deposits, formerly classed as Upper Eocene, but now placed in the Oligocene division. They are arranged in the following manner in descending order .—

Hamstead group—clays, marls, and shelly layers, with marine shells in a band at the top, while the main part of the group contains fresh-water and estuarine shells and land-plants About 260 feet

Bembridge group—marls and limestone, with fresh-water estuarine and marine shells above, and fresh-water and land shells forming a band of limestone below About 110 feet

Osborne group—clays, marls, sands, and limestones, with abundant fresh-water shells About 100 feet

Headon group—consisting of an upper and lower division, containing fresh and brackish water fossils, and a middle group in which marine shells and corals occur. 100 to 350 feet

These Isle of Wight strata, having a total depth of more than 600 feet, were for many years the only known examples in Britain referable to this portion of the Geological Record, and they form still the only series in this country which, in its abundant molluscs, allows a comparison to be made between it and corresponding rocks on the Continent. But at Bovey Tracey in Devonshire a small lake-basin has been discovered, the deposits of which have yielded a large number of terrestrial plants comparable with those found in the Oligocene strata of Switzerland and Germany Between the great sheets of basalt, also, that form the plateaux of Antrim and the Inner Hebrides, numerous remains of a similar vegetation have been discovered. There can be no doubt that these volcanic rocks were poured out over the surface of the land, and that the plants, whose remains have been disinterred from the intercalated layers of lignite, tuff, and hardened clay, grew upon that land. The basalts and other lavas, even after the great denudation which they have undergone, are still in some places more than 3000 feet thick. They were poured out in wide-spreading sheets that completely buried the previous topography, and extended as vast lava-plains, like those of younger date which form so impressive a feature in the scenery of Montana, Idaho, and Oregon, in western North America.

In the Paris basin, the Oligocene strata pass down conformably into the Eocene group described on p. 373, and present the following subdivisions in descending order :—

| | |
|---|---|
| Aquitanian stage | A lacustrine limestone (Calcaire de la Beauce), green marl and sands, passing to the Helix limestone of the Orléanais, with abundant land and fresh-water shells and some terrestrial mammals (*Anthracotherium*, *Aceratherium*, *Rhinoceros*, etc ) |
| Stampian stage. | Sands and sandstone of Fontainebleau with a marine fauna, overlying oyster-marls which, by arresting the underground water that descends through the thick overlying porous sandy series, form an important water-bearing horizon |

Tongrian stage — A lacustrine limestone (Calcaire de la Brie) underlain by green *Cyrena*-marls which are followed by supra-gypseous blue marls; white marls (Marnes de Pantin with *Planorbis*, *Bithinia*)

In Switzerland the Oligocene series of formations attains a thickness of more than 6000 feet. Rising into prominent groups of mountains, it has preserved a singularly full and interesting record of the terrestrial life of the time, together with proofs of the early presence of the sea. By far the largest part of these deposits consists of compacted sands, gravels, and clays, which were laid down in a lake. These strata are arranged in the three following groups .—

3 Aquitanian stage, or Red Molasse (1300 feet)—a great development of red sandstones, marls, and conglomerates, some of which contain marine shells, while others enclose an abundant terrestrial vegetation, sometimes aggregated into seams of lignite

2 Tongrian stage (Upper Flysch, Lower marine Molasse, 2600 feet in Reussthal), consisting of sandstones which enclose marine and brackish-water shells, also shales containing early forms of herring, cod, mackerel, and other fishes

1 Ligurian stage (Rigi beds, Lower Flysch), grey shales, limestones, sandstones and conglomerates with marine fossils

In Northern Germany the subjoined succession of strata in descending order has been noted :—

Upper — Marine marls, clays, and sands; Brown coal of the Lower Rhine, with abundant terrestrial vegetation and some marine bands

Middle — Sands and Septaria-clay, with abundant marine fauna, occasionally a brown-coal group occurs

Lower — Marine beds of Egeln, with marine shells and corals; Amber beds of Konigsberg, containing 4 or 5 feet of glauconitic sand, with abundant land plants and pieces of amber, which is the fossil resin of different species of coniferous trees A large number of species of insects has been enclosed and preserved in the amber. The sands contain marine shells, sea-urchins, etc; Lower Brown coal—sands, sandstones, clays, and conglomerates, with interstratified seams of brown coal and an abundant terrestrial flora, in which coniferæ are prominent, with forms of oak, laurel, cinnamon, magnolia, fig, maple, palms, etc.

In North America, the probable representatives of the European Oligocene formations include no marine bands, but consist of lacustrine and fluviatile sands and clays (White River group), which mark the former presence of a series of large lakes in the interior of the continent. The most extensive of these inland waters stretched across South Dakota and the west of Nebraska, southwards into Colorado and westwards into Wyoming. Other lakes lay farther north, at least as far as the Cypress Hills of

Western Canada In Colorado, the shales at Florissant have yielded an abundant assemblage of terrestrial plants and insects. In upper Missouri and across the Rocky Mountains into Utah, the White River group of lacustrine deposits has furnished a striking series of vertebrate remains, including three-toed horses (*Anchitherium*, *Miohippus*, *Mesohippus*), tapir-like animals (*Lophiodon*), hogs as large as rhinoceroses (*Elotherium*), true rhinoceroses, huge elephant-like creatures allied to *Deinoceras* and tapir (*Brontotherium*, *Titanotherium*), beavers (*Steneofiber*), *Protoceras*, a small animal about the size of a sheep, remotely related to the American deer; together with carnivorous genera, some of which are like European Tertiary wolves, lions, and bears. The group has been subdivided into the following stages, named after their more distinctive mammalian remains

3 Protoceras beds, in which *Protoceras* is especially prominent, together with *Steneofiber*, *Protapirus*, *Hyopotamus*, etc

2 Oreodon beds, containing marsupials (*Didelphys*), rodents (*Ischyromys*), a creodont (*Hyænodon*), carnivores (*Daphænos*, *Cynodictis*, etc ), a primitive form of horse (*Mesohippus*), several forms of Rhinoceros, *Oreodon* (several species), and various types of camel (*Poebrotherium*, *Protomeryx*), etc

1 Titanotherium beds, with various titanotheres, also *Leptaceratherium*, *Elotherium*, etc

# CHAPTER XXVI

## MIOCENE—PLIOCENE

THE geological period at which we are now arrived, one of the most important in the history of the configuration of the existing continents, embraced that portion of geological time during which the great mountain-chains of the globe were uplifted into their present commanding positions. There is good reason to believe that these lines of elevation are of great geological antiquity, and that they have again and again been pushed upward during great terrestrial disturbances. But the intervals between these successive upthrusts were probably often of immense duration, so that the mountains, being exposed to continuous and prolonged denudation, were worn down, sometimes perhaps almost to the very roots. In all probability the nucleus of the line of the Alps, for example, dates back to a remote geological period. But only in Tertiary time did it attain its present dimensions. We have seen that, during the Eocene period, the sea of the nummulitic limestone extended over at least a considerable part of the Alpine region, and that, as the limestone now forms crumpled and dislocated mountainous masses, the great upheaval of the chain must have taken place after Eocene time. Not improbably the process was a prolonged one, advancing in successive uplifts, with intervals of rest. The final upheaval that gave the Alps their colossal bulk did not take place until the Miocene period or later, for the Miocene strata have been involved in the earth-movements, and have been thrust up, bent, and broken. Nor were the terrestrial convulsions confined to Central Europe, all over the globe there seem to have been extensive disturbances. The Eocene sea-bed with its thick accumulations of nummulite-limestone was ridged up into land, and portions of it, as already remarked, were carried upward on the flanks of the mountains, in the Himalayas to a height of 16,500 feet above the sea.

While these revolutions were taking place in its topography, Europe continued to enjoy a climate which, to judge from the remains of plants and animals preserved in the Miocene rocks, must still have been of a somewhat tropical character. The flora that clothed the slopes of the Alps was not unlike that of the forests of India and Australia at the present time. Palms of various kinds still flourished all over Central and Western Europe, mingled with conifers, laurels, evergreen oaks, magnolias, myrtles, mimosas, acacias, sumachs, figs, oaks, and various still living

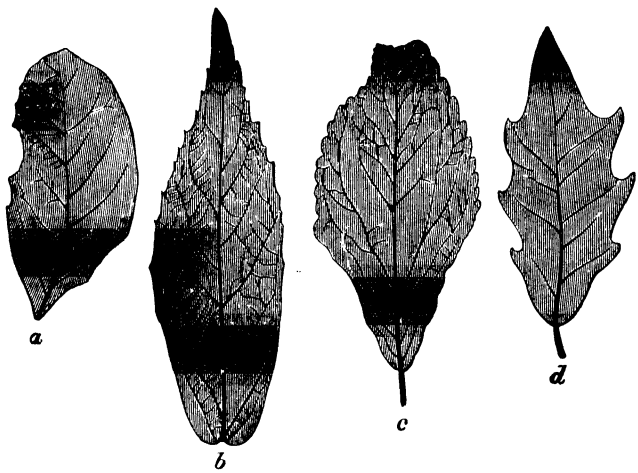



FIG. 214.—Miocene Plants. (*a*), *Magnolia Inglefieldi* (½); (*b*), *Rhus Meriani* (natural size); (*c*), *Ficus decandolleana* (½); (*d*), *Quercus ilicoides* (⅔).

genera of proteaceous shrubs (Fig. 214). But there is evidence of the incoming of a more temperate climate, for, in the higher parts of the Miocene series of strata, the vegetation was characterised by the abundance of its beeches, poplars, hornbeams, elms, laurels, pondweeds, etc.

Remains of the terrestrial fauna have been well preserved in the deposits that gathered over the floors of the lakes. We know, for instance, that in the woodlands surrounding the large Miocene lake of Switzerland insect life was remarkably abundant. From the proportions of the different kinds that have been exhumed, it has been inferred that the total insect population was then more

varied in some respects than it is now in any part of Europe. wood-beetles being especially numerous and large. In the thick underwood, frogs, toads, lizards, and snakes found their food. Through the forests there roamed antelopes, deer, and three-toed horses, while opossums, apes, and monkeys (*Pliopithecus*, *Dryopithecus*, *Oreopithecus*) gambolled among the branches. Wild cats, bears (*Hyænarctos*), and sabre-toothed lions (*Machairodus*) were among the prominent carnivores of the time. But the most striking denizens of these scenes were undoubtedly the huge proboscidian creatures, among which the Mastodon and Deinotherium took the lead. The now long extinct mastodon (Fig.

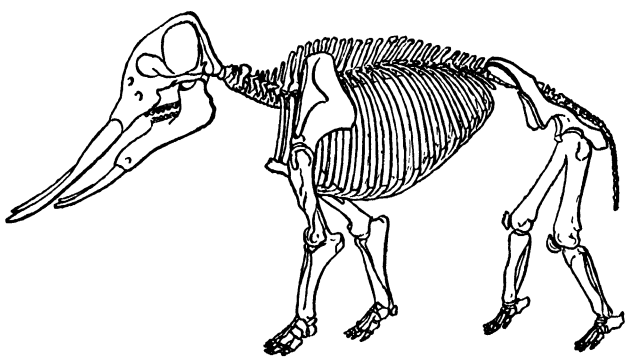


FIG. 215.—*Mastodon angustidens* ($\frac{1}{12}$).

215) was a large form of elephant, which, besides tusks in the upper jaw, had often also a pair in the lower jaw. The deinotherium (Fig. 216) possessed two large tusks in the lower jaw which were curved downwards. This huge animal probably frequented the rivers of the time, using its powerful curved tusks to dig up roots, and perhaps to moor itself to the banks. Contemporaneous with these colossal pachyderms were species of rhinoceros, hippopotamus, and tapir. The rivers were haunted by crocodiles, turtles, beavers, and otters; while the seas were tenanted by ancestors of our living morse, sea-calf, dolphin, and lamantin. It is strange to reflect that such an assemblage of animals should once have found a home all over Europe.

The deposits referable to the Miocene period in Europe indi-

cate a great change in the geography of the region since Eocene and Oligocene times. While most of the Continent remained land, with large lakes scattered over its surface, certain tracts had subsided beneath shallow seas which penetrated here and there by long arms into the very heart of the region. Britain continued to be a land surface, and as such was continuously exposed to denudation, so that, instead of the formation of new deposits, there was an uninterrupted waste of those already existing So vast indeed has been the destruction of the Tertiary strata of Britain that it has evidently been in progress for an enormous period of time Much of it, no doubt, took place during the long interval required

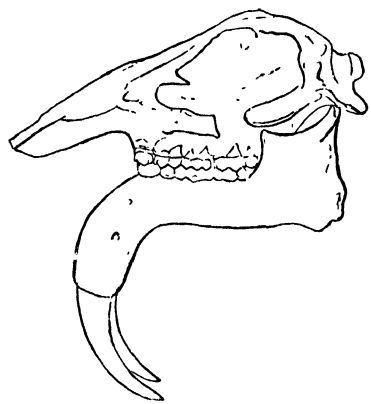


FIG. 216.—Skull of *Deinotherium giganteum* (reduced).

elsewhere for the accumulation of the Miocene series of rocks. Not only were the soft sands and clays of the older Tertiary groups of south-eastern England worn away from hundreds of square miles which they originally covered, but even the hard basalt-sheets of Antrim and the inner Hebrides have been so cut down by the various agents of denudation that wide and deep valleys have been carved out of them, and hundreds of feet of solid rock have been gradually removed from their surface

While Britain remained land, and thus contains no representatives of the marine Miocene deposits of the Continent, arms of the sea spread over what is now Belgium, likewise over the basins of the Loire, Indre, and Cher, stretching across Southern France to the Mediterranean, passing along the northern base of the Alps,

running into the valley of the Rhine as far north as Mainz, sweeping eastwards round the eastern end of the Alps, and expanding into the broad gulf of Vienna among the submerged heights of Austria and Hungary.

The strata that tell this story of submergence contain an abundant assemblage of marine shells, many of which belong to genera that now live in warmer seas than those which at present bathe the coasts of Europe. Among them are *Cancellaria*, *Cypræa*, *Mitra*, *Murex*, *Strombus*, *Arca*, *Cardita*, *Cytherea*, *Pectunculus*, *Spondylus*, together with genera, such as *Ostrea*, *Pecten*, *Cardium*, *Tapes*, *Tellina*, which are familiar in the northern seas.

In France and Italy the various scattered Miocene deposits have been classified in three divisions At the base lies (1) the Langhian or Burdigalian stage, which attains in the north of Italy a thickness of nearly 2000 feet, consisting of blue marine marls. Next comes (2) the Helvetian stage, so called from its development in Switzerland. In the north of Italy it consists of marine marls, molasse, and conglomerates, having a united thickness of more than 3000 feet. This subdivision is represented in the Paris basin by the "Faluns" of Touraine. The uppermost member of the series or (3) Tortonian stage is made up of blue marls in the north of Italy, having a thickness of 650 feet and containing an abundant and varied marine fauna. Further north the deposits of this stage indicate a general retirement of the sea and the spread of a series of lakes between the basin of the Rhone and that of the Danube.

It is not difficult to picture the geographical conditions which prevailed over Central and Southern Europe during the Miocene period. The Faluns of Touraine represent the floor of a shallow Miocene strait which extended across France, and the general character of the shells which they contain marks a warmer climate than now exists in Southern Europe. The tableland of Spain, with its northern mountainous border, rose along the southern margin of this strait which connected the Atlantic and the Mediterranean. Through this broad passage the large cetaceans of the time passed freely from sea to sea, for their bones are found in the upraised sea-bottom. The carcases of the mammals that then lived among the Pyrenees—mastodons, rhinoceroses, lions, giraffes, deer, apes, and monkeys—were likewise swept down into the sea. The deposits of the shallow Miocene straits and bays thus supply us with evidence of the position of the land and the character of its inhabitants. Eastwards the sea appears

to have deepened over the region now occupied by the Gulf of Genoa and the encircling mountain ranges, for the Miocene deposits of that part of the basin of the Mediterranean, consisting almost wholly of blue marls, reach the great thickness of more than 5000 feet. Beyond that depression, the sea once more shallowed across the site of South-Eastern Europe.

On the northern side of the Swiss Alps, the lake which was formed by the uplifting of the Eocene sea-floor, and in which so thick a succession of Oligocene strata was laid down, eventually disappeared among the terrestrial movements that submerged so much of Europe beneath the Miocene sea. Marine bands containing undoubted Miocene shells extend across Switzerland; but among them there are such abundant remains of terrestrial vegetation as to show that the land was not far off. No doubt the Alps, not yet uplifted to their ultimate height, rose along the southern borders of the strait that ran across Central Europe, and bore on their slopes luxuriant forest-growths. In Switzerland, however, we learn that before the close of the Miocene period the sea was once more excluded from the district, and another lake made its appearance. The marls, limestones, and sandstones accumulated in this lake (Œningen Beds) are among the most interesting geological deposits in Europe, from the great number and perfect preservation of the plants, insects, fishes, and mammals which have been obtained from them. A large part of our knowledge regarding the terrestrial vegetation and animal life of the Miocene period has been derived from these strata.

Passing beyond the European area, we find that some of the characteristic vegetation of Miocene time spread northwards far within the Arctic Circle. In Spitzbergen and in North Greenland an abundant series of plant-remains has been discovered, including a good many which occur also as fossils in the Miocene deposits of Central Europe. More than half of them are trees, among which are thirty species of conifers, also beeches, oaks, planes, poplars, maples, walnuts, limes, and magnolias. This flora has been traced as far as 81° 45′ north latitude, where the last naval expedition sent out from England found a seam of coal 25 to 30 feet thick, covered with black shales full of plant-remains.

The same twofold development—marine and lacustrine—which characterised the earlier ages of Tertiary time in North America, continued to prevail during the rest of the period. The Miocene strata of the Atlantic border are unequivocally marine deposits, as are likewise those on the western margin of the Continent, while

the vast interior region presents a succession of lacustrine sediments. The marine Miocene type is displayed along the coast of New England and southwards from New Jersey into Texas, where the strata reach a thickness of 1500 feet. Three groups have been recognised in this series. At the base lies the Chattahoochee stage, which contains an assemblage of fossils like those of the Miocene rocks of the West Indies; next comes the Chipola stage, characterised by a shell-bearing sand from which several hundred species of molluscs have been obtained, having affinities with a warm or sub-tropical fauna; the uppermost stage (Yorktown) contains an assemblage of shells that marks a more temperate climate than that of the strata below.

In the lacustrine Miocene development of the interior two stages have been discriminated. The lower of these (John Day stage) is typically seen in Eastern Oregon between the Cascade and Blue Mountains, where it reaches a thickness of between 3000 and 4000 feet, and consists in great part of stratified volcanic tuffs. The higher stage (Loup Fork and Deep River) is well displayed in Nebraska, whence it stretches southward, but not continuously, into Mexico. The flora of the Miocene deposits of the interior approximates more closely to that of these regions at the present time, though still indicating a warmer climate. It included species of beech, elm, hickory, maple, oak, and poplar. The fauna comprised forms of mastodon, numerous three-toed horses more like modern types than those of previous periods, tapiroid animals, hogs as large as rhinoceroses, true rhinoceroses, huge elephant-like creatures allied to deinoceras and tapir, stags, camels, beavers, wolves, bears, and lions. As in Europe, the close of the Miocene period in North America witnessed a series of important movements of the earth's crust. The Mesozoic and older Tertiary formations along the oceanic border in California and Oregon were plicated and upheaved into mountainous land. This period was likewise characterised by the great vigour of its volcanic activity all over the western half of the interior down into Mexico and Central America.

## PLIOCENE

The last division of the Tertiary series of formations lays before us the history of the geological changes that brought about the present general distribution of land and sea, and completed the existing framework of the continents. Contrasted with the previous

Tertiary groups, it is, on the whole, insignificant in thickness and extent, and it probably records the passing of a much less period of time, during which the amount of terrestrial revolution was comparatively trifling Only in the basin of the Mediterranean are there any European Pliocene strata worthy of note on account of their thickness. The floor of that sea slowly subsided until sands, clays, and accumulated shell-beds had been piled up to a depth of several thousand feet. An important volcanic episode then took place. Etna, Vesuvius, and the other volcanoes of Central Italy began their eruptions. Thick masses of Pliocene sediments were ridged up on both sides of the Apennines, and in Sicily were upheaved to a height of nearly 4000 feet above the present sea-level. This elevation of the Pliocene sea-bed in the Mediterranean area was not improbably connected with other movements within the European region. The shallow firths and bays which still indented the Continent were finally raised into dry land, and the Alps may then have received their final uplift. While the European Pliocene deposits have their maximum thickness in the Mediterranean basin, they elsewhere represent the sediments of shallow seas and of lakes and rivers.

The flora of the Pliocene period affords evidence of the continued advance of a more temperate climate. The tropical types of vegetation one by one disappeared from the land of the European region, leaving behind them a vegetation that partook of the characters of those of the present Canary Islands, of North America, and of Eastern Asia and Japan, but which, as time wore on, approached more and more to the present European flora (Fig. 217). It included species of bamboo, sarsaparilla (*Smilax*), glyptostrobus, taxodium, sequoia, magnolia, tulip-tree (*Liriodendron*), maple (*Acer*), buckthorn (*Rhamnus*), sumach (*Rhus*), plum (*Prunus*), laurel (*Laurus*), cinnamon-tree (*Cinnamomum*), sassafras, fig (*Ficus*), elm (*Ulmus*), willow (*Salix*), poplar (*Populus*), alder (*Alnus*), birch (*Betula*), liquidambar, oak (*Quercus*), evergreen oak (*Quercus ilex*), plane (*Platanus*), walnut (*Juglans*), hickory (*Carya*), and other now familiar trees, together with some now common wild flowers and water plants, including the buttercup, marsh-marigold, chickweed, milfoil, dock, sorrel, mare's-tail, pondweed, sedge, reed, etc.

The fauna presented likewise evidence that the climate, during at least the earlier part of the Pliocene period, still continued warm enough to permit tribes of animals to roam over Europe, the descendants of which are now confined to regions south of the

Mediterranean basin. Some of the huge mammalian types that had survived from an earlier time now died out; such appears to have been the case with the deinotherium and (at least in

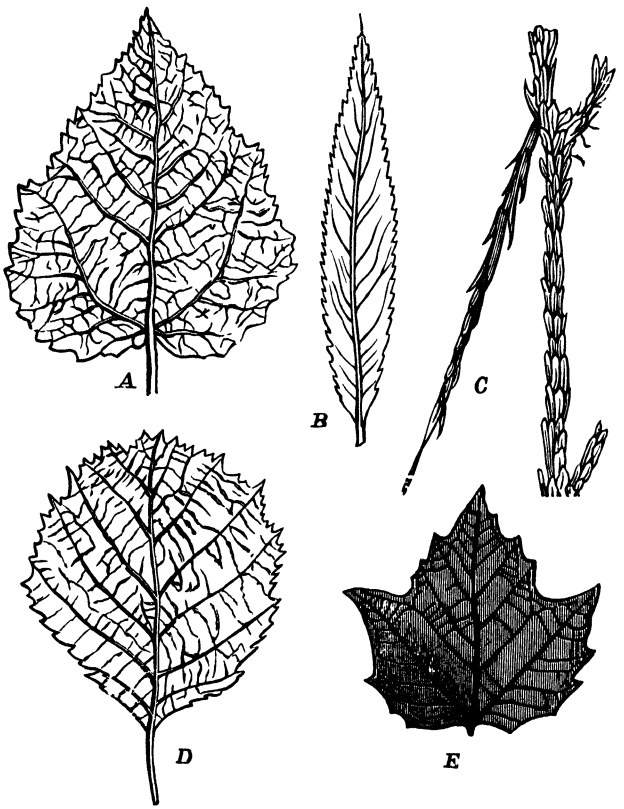



FIG 217 —Pliocene Plants (*A*), *Populus canescens*, (*B*), *Salix alba*, (*C*) *Glyptostrobus europæus*, (*D*), *Alnus glutinosa*, (*E*), *Platanus aceroides* (all natural size except *E*, which is ½).

Europe) the mastodon. Herds of pachydermatous animals formed a distinguishing feature of the fauna — rhinoceroses, hippopotamuses, and elephants, with troops of herbivorous

quadrupeds—gazelles, antelopes, deer, giraffes, horses, oxen, and strange types that linked together genera which are at present quite distinct. There were, likewise, carnivores (wild-cats, bears, hyænas, etc.), and many monkeys. The remains of monkeys have been found fossil in Europe 14° farther north than their descendants now live.

The shells of the Pliocene deposits afford important evidence regarding the gradual change of climate. The great majority of them belong to still living species (Fig. 218). They consequently

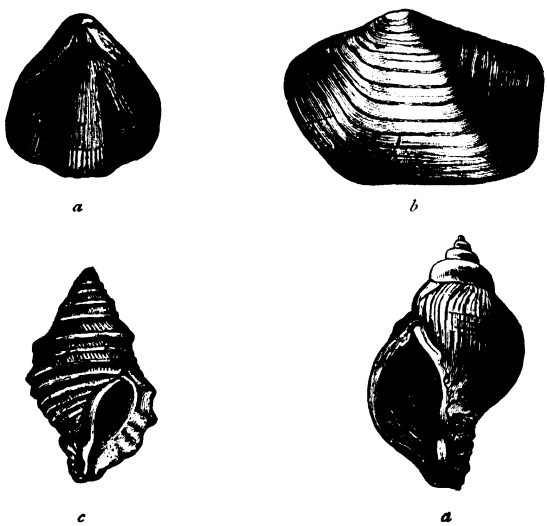



FIG. 218.—Pliocene Marine Shells. (*a*), *Rhynchonella psittacea* (natural size); (*b*), *Panopæa norvegica* (½); (*c*), *Purpura lapillus* (½); (*d*), *Neptunea* (*Chrysodomus*, *Trophon*) *antiqua* (¼).

supply an excellent basis for comparison with the existing distribution of the same species. When the deposits containing them are examined with reference to the present habitats of the species, it is found that the percentage of what are now northern shells increases from the lower to the higher parts of the series. Each species, no doubt, flourished only in that part of the Pliocene sea where it found its congenial temperature and food. We infer that its requirements are still the same at the present day, in other words, that the temperature of the regions within

which the species is now confined affords, on the whole, an indication of the temperature of the areas within which it lived in the Pliocene seas. On this basis of comparison, the inference has been drawn that the climate in the northern hemisphere, after becoming temperate, passed on to a more rigorous stage. In the end thoroughly Arctic conditions spread over most of Europe and a large part of North America during the period that succeeded the Pliocene (p. 395).

In Britain, Pliocene deposits are almost entirely confined to the counties of Norfolk and Suffolk. They consist of various shelly sands, gravels, and marls, which have long been known as "Crag." Arranged in descending order, the following are the recognised subdivisions :—

Arctic Fresh-water Bed—a thin local deposit of loam, clay, and sand found on the Norfolk coast overlying the division below. Its plants include the dwarf Arctic birch and willow (*Betula nana* and *Salix polaris*) with various mosses, like the meagre vegetation of high latitudes at the present day. This subdivision belongs properly to the Pleistocene series (see p 400)

Newer (indicating a cold temperate climate)

- **Yoldia (Leda) myalis Bed** — Loam, sand, and clay (20 feet or more), with boreal and Arctic marine shells This zone also may belong more properly to the Pleistocene series It lies unconformably on the deposits below
- **Forest-Bed Group** — Upper fresh-water, estuarine, and Lower fresh-water sands and silts, with layers of peat, branches and stumps of trees, having a total depth of 10 to 60 feet. Among the terrestrial plants are cones of Scotch fir (*Pinus sylvestris*) and spruce (*Abies*), leaves of water-lily (*Nymphæa alba*), yellow pond-lily (*Nuphar luteum*), hornwort (*Ceratophyllum*), blackthorn (*Prunus spinosa*), bog-bean (*Menyanthes trifoliata*), oak, and hazel, with land and fresh-water shells, and many mammals, including species of wolf, fox, machairodus, hyæna, glutton, bear, seal, whale, walrus, horse, rhinoceros, hippopotamus, pig, ox, musk-sheep, deer, beaver, trogontherium (a huge extinct kind of beaver), mole, elephant (*E. antiquus*, *E meridionalis*, *E. primigenius*), etc This group of strata is found at the base of the sea-cliff of boulder-clay in Norfolk, and extends under the present sea.
- **Weybourn Crag and Chillesford Clay** — Sands and clays occurring as a thin local deposit in Suffolk, 6 to 16 feet thick, with marine shells, of which nine or more species live in northern waters (*Trophon scalariformis*, *Astarte borealis*, *Cardium groenlandicum*).

| | | |
|---|---|---|
| NEWER—*continued* | Norwich (fluvio-marine or mammaliferous) Crag | Shelly sand and gravel, 5 to 10 feet thick, containing 112 species of marine shells, of which 9 are Arctic, 7 live in the Mediterranean, and 18 are believed to be extinct With these fossils there are found also bones and teeth of mastodon, elephant (*E meridionalis, E antiquus*) hippopotamus, rhinoceros, etc The northern shells include *Cancellaria viridula, Pleurotoma pyramidalis, Trophon scalariformis, Velutina undata, Astarte borealis, A. elliptica, Cardium groenlandicum, Nuculana pernula.* More than twenty species of land or freshwater shells also occur |
| | Red Crag | A local and inconstant accumulation, sometimes 25 feet thick, of red and dark brown ferruginous shelly sand, with some 350 species of marine shells, of which 23 are northern forms, 20 are Mediterranean, and upwards of 36 appear to be extinct |
| OLDER (indicating a warm temperate climate) | St. Erth Beds | A local deposit of clays and gravels found at St. Erth in Cornwall, with abundant and well-preserved shells, probably of older Pliocene age, about 43 per cent being of extinct species |
| | White (Suffolk or Coralline) Crag | Shelly sands and clays, which have yielded numerous species of marine molluscs, of which 38 per cent are extinct 26 per cent are southern and 1 per cent northern forms One of the characteristics of the deposit is the large number (122 species) of coral-like polyzoa (corallines or bryozoa), whence one of the names given to this subdivision About 60 per cent of these organisms are believed to be extinct Among their more characteristic forms are large bunches of *Alveolaria* and *Theonoa* (*Fascicularia*) |
| | Lenham Beds (Diestian) | Sands and ironstones filling pipes and hollows of the Chalk on the North Downs, more than 600 feet above the sea, and containing upwards of 60 species of fossils, which have a general southern character (*Arca diluvii, Cardium papillosum, Cupularia canariensis*) These relics of a sea-floor correspond with the Diestian group, which has a wide extent in Belgium |

On the European continent the youngest Tertiary deposits cover comparatively small areas and mark some of the last tracts occupied by the sea. The marine deposits of the south-east of England reappear in the north of France, in Belgium, and in Holland, so that these portions of the mainland were also then submerged. In Holland the subsidence must have been considerable, for at Utrecht Pliocene strata have been bored to a depth of 1198 feet without revealing their base. But no proof has been obtained that the sea stretched at that time eastwards into Ger-

many. In the Vienna basin there is evidence that the sea, shut off from the main ocean, and partly converted into an inland sea, like the Caspian, was gradually filled up with sediment and raised into land Along the northern borders of the Mediterranean Sea thick masses of marine Pliocene strata show the prolonged depression of that region during Pliocene time, and its subsequent elevation. In the south of France these strata, lying unconformably on everything older than themselves, reach a height of 1150 feet above the sea. Along both sides of the Apennine chain, Pliocene blue marls, clays, and sands, known as the sub-Apennine beds, have been uplifted into a range of low hills. These deposits swell out southwards, reaching their greatest thickness (2000 feet or more) and their highest elevation above the sea (nearly 4000 feet) in Sicily, which was probably the region of maximum subsidence during Pliocene time Here and there, in the Italian strata of this period, remains of terrestrial vegetation and land-animals are abundantly preserved. One of the most noted localities for these fossils is the upper part of the valley of the Arno

The following classification has been made of the Pliocene deposits of Italy and the south of France —

| | |
|---|---|
| NEWER (COLD TEMPERATE) | Arnusian (Sicilian, Villafranchian), seen in the Val d' Arno, where they consist of an upper group (Villafranchian) of fluvio-lacustrine strata and a lower group (Fossanian) which indicates littoral and estuarine conditions (*Elephas meridionalis, Mastodon arvernensis*) |
| | Astian, marine sands and gravels, represented in France by fresh-water deposits containing *Mastodon arvernensis, Rhinoceros leptorhinus*, etc |
| OLDER (WARM TEMPERATE) | Plaisancian marls and clays, with abundant marine shells, of which from about a third to a half belong to living species This stage in some regions (Tuscany) is represented by lignites and other terrestrial deposits from which a varied assemblage of mammalian remains has been obtained, including *Hipparion, Sus erymanthius, Antilope Massoni, Tapirus priscus, Semnopithecus*, etc |
| | Messinian or Zanclean sandy marls, with seams of gypsum and limestone This group marks alternations of brackish water and marine conditions Some of the marls are full of leaves of land-plants |

Perhaps the most curious and interesting assemblage of the land-fauna of Europe during Pliocene time has been found in some hard red clays, alternating with gravels, at Pikermi in Attica. Thirty-one genera of mammals have there been obtained, of which twenty-two are extinct. The ruminants, specially well represented

among these remains, include species of giraffe (*Helladotherium*, Fig. 219), antelopes, gazelles, and other forms allied to, but distinct from, any living genera. There are likewise the bones of gigantic wild boars, several species of rhinoceros, mastodon, deinotherium, porcupine, hyæna, various extinct carnivores, edentates (*Ancylotherium*), a monkey (*Mesopithecus*), and several kinds of birds.

In India a somewhat similar fauna has been obtained from a massive series of fresh-water sandstones, known as the Siwalik group. A large proportion of the organic remains belong to existing

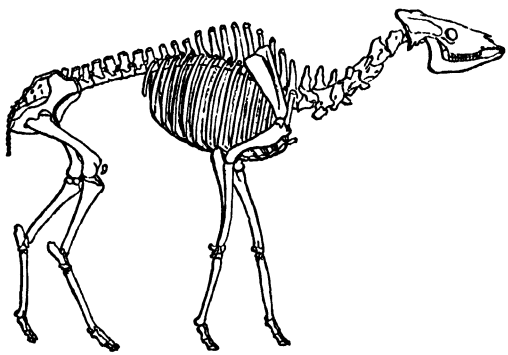


FIG. 219.—*Helladotherium Duvernoyi* ($\frac{1}{60}$)—a gigantic animal belonging to the same family as the living giraffe, Pikermi, Attica.

genera of animals, such as macaque, bear, elephant, horse, hippopotamus, giraffe, ox, porcupine, goat, sheep, and camel. Various extinct types were contemporary with these animals, two of the most extraordinary of them being the *Sivatherium* and *Bramatherium*—colossal, four-horned creatures, allied to our living antelopes and prong-bucks.

The Pliocene deposits of the North American Atlantic border are best seen in Florida and some of the neighbouring States, where they contain numerous marine shells (*Arca*, *Chama*, *Strombus*, etc.). They reach, however, a great thickness on the Pacific border, where the Merced group of San Francisco is stated to consist of nearly 6000 feet of sandstone. In the interior of the continent a series of lacustrine deposits, believed to be referable to Pliocene time, occurs in Texas, Kansas, and Oregon. Volcanic action continued to manifest itself during this period on a great scale in that region.

# CHAPTER XXVII

## POST-TERTIARY OR QUATERNARY PERIODS—PLEISTOCENE OR POST-PLIOCENE—RECENT

WE have now arrived at the last main division of the Geological Record, that which is named POST-TERTIARY or QUATERNARY, and which includes all the formations accumulated from the close of the Tertiary periods down to the present day. But no sharp line can be drawn at the top of the Tertiary groups of strata. On the contrary, it is often difficult, or indeed impossible, satisfactorily to decide whether a particular deposit should be classed among the younger Tertiary or among the Post-tertiary groups. All the molluscs of Post-tertiary deposits are believed to belong to still living species, but the mammals, although also mostly of existing species, include some which have become extinct. These extinct forms are numerous in proportion to the antiquity of the deposits in which they have been preserved. Accordingly, a classification of the Quaternary strata has been adopted, in which the older portions, containing a good many extinct mammals, have been formed into what is termed the Pleistocene, Post-pliocene, or Glacial group, while the younger deposits, containing few or no extinct mammals, are termed Recent.

The gradual refrigeration of climate which is revealed to us by the shells of the Crag was prolonged and intensified in Post-tertiary time. Ultimately the northern part of the northern hemisphere was covered with snow and ice, which extended into the heart of Europe, and descended beyond the fortieth parallel of latitude in North America. The previous denizens of land and sea, in the southern portions of the terrestrial region affected, were in large measure driven out, or even in many cases wholly extirpated by the cold, while northern forms advanced southward to take their places. The reindeer, for instance, wandered in great numbers across Southern France, while in North America its bones have

been found as far south as New Haven. An Arctic vegetation spread all over Northern and Central Europe, even to the Pyrenees. After the cold had reached its climax the ice-fields began to retreat, and the northern flora and fauna to retire before the advance of the plants and animals which had been banished by the increasingly severe temperature. And at last the present conditions of climate were reached. The story of this Ice Age is told by the Pleistocene or Post-pliocene formations, while that of the changes which immediately led to the establishment of the present order of things is made known in the Recent deposits.

## PLEISTOCENE, POST-PLIOCENE, OR GLACIAL

The evidence from which geologists have unravelled the history of the Ice Age or cold episode, which came after the Tertiary periods in the northern hemisphere, may here be briefly given. All over Northern Europe and the northern part of North America the solid rocks, where of hardness sufficient to retain it, are found to present a characteristic smoothed, polished, and striated surface. Even on crags and rocky bosses that have remained for long periods exposed to the action of the weather this peculiar worn surface may be traced; but where they have been protected by a covering of clay, even the finest striæ are often as fresh as when they were first made. The groovings and scratches do not occur at random, but in every district run in one or more determinate directions. The faces of rock that look one way are rounded off, smoothed, and polished; those that face to the opposite quarter are more or less rough and angular. The quarter to which the worn faces are directed corresponds with that to which the trend of the striæ and grooves on the rock-surfaces points. There can be no doubt that all this smoothing, polishing, grooving, and striation has been done by land-ice; that the striæ mark the direction in which the ice moved, those faces of rock which looked towards the ice being ground away, while those that looked away from it more or less escaped. By following out the directions of the rock-striæ we can still trace the march of the ice across the land (see Chapter VI.)

As the ice travelled it carried with it more or less detritus, as a glacier does at the present day. Some of this material may have lain on the surface, but probably most of it was pushed along at the bottom or within the lower part of the body of the ice. Accordingly, above the ice-worn surfaces of rock there lies a

great deposit of clay and boulders, evidently the debris that accumulated under the ice-sheet and was left on the surface of the ground when the ice retired. This deposit, called Boulder-Clay or Till, bears distinct corroborative testimony to the movement of the ice. It is always more or less local in origin, but contains a variable proportion of stones which have travelled for a greater or less distance, sometimes for several hundred miles. When these stones are traced to their places of origin, which are often not hard to find, they are found to have come from the same quarter as that indicated by the striation of the rocks. If, for example, the ice-worn bosses of rock show the ice to have crept from north to south, the boulders will be found to have had a northern source. The height to which striated rock-surfaces and scattered erratic blocks can be traced affords some measure of the depth of the ice-sheet.

From this kind of evidence it has been ascertained that the whole of Northern Europe, amounting in all to probably not less than 770,000 square miles, was buried under one vast expanse of snow and ice. The ice-sheet was thickest in the north and west, whence it thinned away southward and eastward. Upon Scandinavia it was not improbably between 6000 and 7000 feet thick It has left its mark at heights of more than 3000 feet in the Scottish Highlands, and over North-Western Scotland it was perhaps not less than 5000 feet thick Where it abutted upon the range of the Harz Mountains it appears to have been still not far short of 1500 feet in thickness.

This vast mantle of ice was in continual motion, creeping outward and downward from the high grounds to the sea. The direction taken by its principal currents can still be followed. In Scandinavia, as shown by the rock-striæ and the transport of boulders, it swept westward into the Atlantic, eastward into the Gulf of Bothnia, which it completely filled up, and southward across Denmark and the low grounds of Northern Germany. The basin of the Baltic was completely choked with ice; so also was that of the North Sea as far south as the neighbourhood of London. From the same evidence we know that the ice which streamed off the British Islands moved eastward from the slopes of Scotland into the hollow of the North Sea, part of it turning to the left to join the south-western margin of the Scandinavian sheet, and move with it northwards and westwards across the Orkney and Shetland Islands into the Atlantic, and another branch bending southwards and moving with the southerly expansion of the

Scandinavian ice along the floor of the North Sea and the low grounds of the east of England; and that on the west side of Scotland the ice filled up and crept down all the fjords, burying the Western Islands under its mantle and marching out into the Atlantic. The western margin of the ice-fields, from the south-west of Ireland to the North Cape of Norway, must have presented a vast wall of ice some 1200 or 1500 miles long, and probably several hundred feet high, breaking off into icebergs which floated away with the prevailing currents and winds. The Irish Sea was likewise filled with ice, moving in a general southerly direction.

Northern Europe must thus have presented the aspect of North Greenland at the present time. The evidence of rock-striæ and ice-borne blocks enables us to determine approximately the southern limit to which the great ice-cap reached. As even the southern coast of Ireland is intensely ice-worn, the edge of the ice must have extended some distance beyond Cape Clear, rising out of the sea with a precipitous front that faced to the south. Thence the ice-cliff swung eastwards, passing probably along the line of the Bristol Channel and keeping to the north of the valley of the Thames

The ice-sheet doubtless diminished in thickness towards its southern limits, and some of the higher grounds in that direction may have risen above its surface, so as to escape glaciation. Such appears to have been the case with the high wolds of East Yorkshire during at least the later part of the glacial period. The ice was arrested along their northern front, and ponding back the drainage of the valleys there, formed a series of lakes. Perhaps at the same time the higher mountains of North Wales also stood above the level of the ice that crept round them from the north.

That the northern ice moved down the bed of the North Sea is shown by the boulder-clays and transported stones of the eastern counties of England, among which fragments of well-known Norwegian rocks are recognisable. Its southern margin ran across what is now Holland, and skirted the high grounds of Westphalia, Hanover, and the Harz, which probably arrested its southward extension. There is evidence that the ice swept round into the lowlands of Saxony up to the chain of the Erz, Riesen, and Sudeten Mountains, whence its southern limit turned eastward across Silesia, Poland, and Galicia, and then swung round to the north, passing across Russia by way of Kieff and Nijni Novgorod to the Arctic ocean.

In North America three great centres of accumulation and dispersion of the sheet of land-ice have been recognised. One of these covered the region of Labrador, and streamed thence southward over the Eastern States and into the basin of the Mississippi. The second lay over the country on the west side of Hudson Bay, whence it marched across the plains westward to the Rocky Mountains and southward across Canada as far as Iowa, while on the north side it moved towards the Arctic Ocean. The third ice-sheet had its centre of origin on the great mountain ranges of British Columbia. To the south of these vast sheets of northern ice separate systems of glaciers were nourished in the higher groups of mountains, such as the Sierra Nevada and the Rocky Mountains. Interesting proofs have been obtained of the thickness of some parts of the great covering of land-ice. Thus the Catskill Mountains have been ground smooth and striated up to near their summits, so that the ice which filled the broad valley of the Hudson must have been more than 3000 feet thick. Similar evidence has been found on the White Mountains at a height of 5500 feet, and in British Columbia at 7000 feet above the sea.

In Europe no distinct and generally distributed topographical feature appears to mark the southern limit reached by the ice-sheet; this limit can usually be approximately fixed only by the most southerly localities where striated rocks and transported blocks have been observed. In Scandinavia, however, the successive stages in the retreat of the margin of the ice-sheet are impressively marked by winding ridges of coarse detritus, each of which represents what was for a time the terminal moraine. In North America this feature is displayed on a far more gigantic scale. The southern edge of the great ice-cap is there prominently defined by two lines of detritus, which sometimes coalesce, each from one to six miles in breadth, and rising several hundred feet above the surrounding country. This vast terminal moraine, beginning on the coast of Massachusetts, runs across the Continent with a wonderful persistence for several thousand miles.

The detritus left by the ice-sheet consists of earthy, sandy, or clayey material (Boulder-Clay, Till) more or less charged with stones of all sizes up to blocks weighing many tons. For the most part it is unstratified, and bears witness to the irregular way in which it was tumbled down by the ice. In some districts, where it has been more or less arranged in water, it assumes a stratified character. The stones in the detritus, more especially

where they are hard and are imbedded in a clayey matrix, present smooth striated surfaces, the striæ usually running along the length of the stone, but not unfrequently crossing each other, the older being partially effaced by a newer set (Fig. 32). This characteristic striation points unmistakably to the slow creeping motion of land-ice

But the boulder-clays, earths, and gravels left by the great ice-sheet are not simply one continuous deposit. On the contrary, they contain intercalations of stratified sand, clay, and even peat. In these included strata, organic remains occur, for the most part those of terrestrial plants and animals, showing that the ice again and again retreated, leaving the country to be covered with vegetation, and to be tenanted by land-animals; but that after longer or shorter periods of diminution it once more advanced southward over its former area. These intervals of retreat are known as "interglacial periods" Possibly some of them were of prolonged duration, the climate becoming comparatively mild and equable while they lasted The occurrence of boulder-clays above the interglacial deposits shows a subsequent lowering of the temperature, with a consequent renewal of glacial conditions

The Pleistocene deposits thus reveal to us a prolonged period of cold broken up by shorter intervals of milder climate. The fossils which they contain throw curious and interesting light on these oscillations of temperature. Among the plants, leaves of Arctic species of birch and willow (*Betula nana*, *Salix polaris*, *S. reticulata*) are found in the lower parts of the oldest peat-mosses and elsewhere, far to the south of their present limits; on the other hand, remains of plants now confined to temperate latitudes are found fossil in Siberia, and others, now living in more genial climates than those of Central Europe, are associated in interglacial deposits with the remains of the still indigenous vegetation.

To the same effect, but still more striking, is the testimony of the Pleistocene fauna, with its strange mingling of northern and southern forms. The marine shells imbedded in the glacial clays, though chiefly belonging to species that still live in the adjoining seas, include a few that are now restricted to more northern latitudes (*Pecten islandicus*, *Nuculana* (*Leda*) *pernula*, *Saxicava arctica*, *Portlandia* (*Yoldia*) *arctica*, *Tellina* (*Macoma*) *calcarea*, etc., Fig. 220). Turning to the terrestrial mammals, we find among the Pleistocene deposits the remains of the last of the huge pachyderms which, through Tertiary time, had been so striking a feature of the animal population of Europe. The hairy mammoth (*Elephas*

*primigenius*, Fig. 221) and the woolly rhinoceros (*R. tichorhinus*) now roamed all over the Continent and across Britain, which had not yet become an island. During the retreat of the snow and ice they found their way into the forests and pastures of Northern Siberia. Driven southwards when the cold increased, they were accompanied or followed by numerous Arctic animals which have

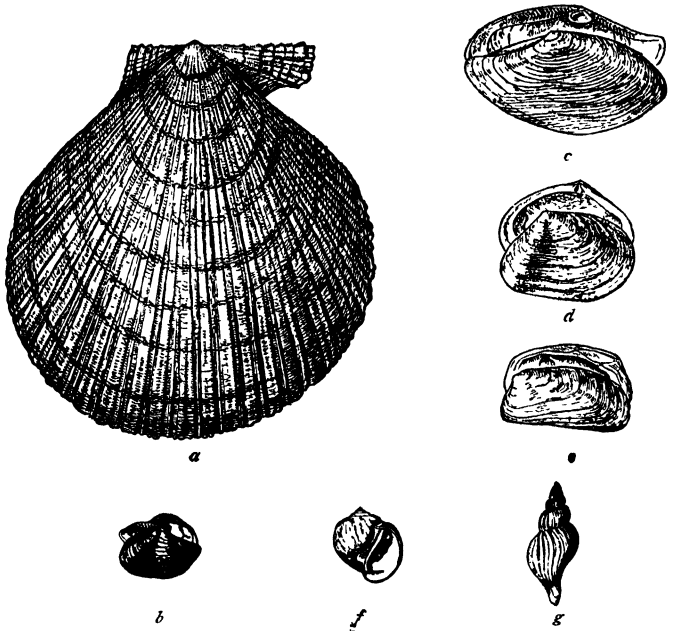



FIG. 220.—Pleistocene or Glacial Shells (*a*), *Pecten islandicus* (½), (*b*), *Portlandia glacialis* (*Nuculana truncata*) (½), (*c*), *Yoldia* (*Nuculana*) *lanceolata* (½), (*d*), *Tellina* (*Macoma*) *calcarea* (*lata*) (½), (*e*), *Saxicava rugosa* (½), (*f*), *Natica affinis* (*clausa*) (½); (*g*), *Trophon scalariformis* (½)

not yet become extinct. Herds of reindeer (*Cervus tarandus*) sought the pastures of Central France and Switzerland; the glutton (*Gulo luscus*) came to the south of England and to Auvergne; the musk-sheep (*Ovibos moschatus*, Fig 222) and Arctic fox (*Canis lagopus*) wandered southward to the Pyrenees. But as each oscillation of climate slowly brought in a milder temperature, and pushed the snow and ice northward, animals of southern types made their way into Southern and Central Europe.

Among these immigrants were the porcupine (*Hystrix*), leopard (*Felis pardus*), African lynx (*Felis pardina*), lion (*Felis leo*), hyæna, elephant, and hippopotamus, the bones of which have been found in the Pleistocene deposits.

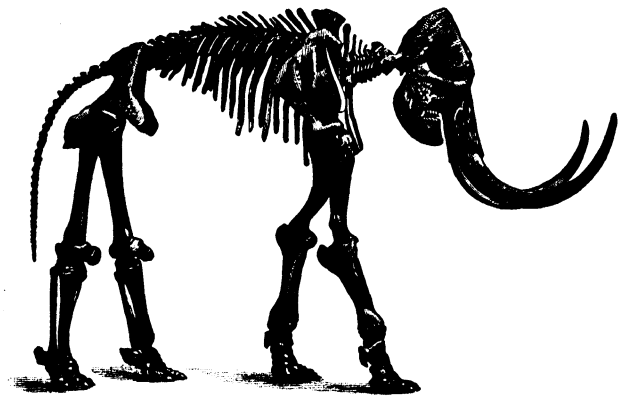


FIG. 221.—Mammoth (*Elephas primigenius*) from the skeleton in the Musée Royal, Brussels.

After the height of the cold period or Ice Age had been reached and the general temperature of the northern hemisphere began to rise again, the ice retreated from the low grounds, but still continued among the mountains. The existing snow-fields and glaciers of the Alps, the Pyrenees, and Scandinavia are the lineal descendants of those vaster ice-sheets which formerly overspread so much of Europe. The glaciers of the Alps, large though they are, can be shown to be merely the relics of their former size. The glacier of the Rhone, for example, as is proved by rock-striæ and transported blocks, once extended 170 miles in direct distance from its modern termination, and rose hundreds of feet above its present surface, burying the valleys and overflowing considerable ridges of hills.

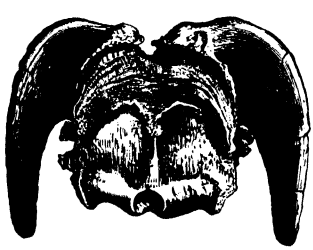


FIG. 222.—Back view of skull of musk-sheep (*Ovibos moschatus*, ½), *Brick-earth*, Crayford, Kent.

The glacier of the Aar stretched once as far as Berne—a distance of about 70 miles from its present termination; and, judging from the marks it has left on the mountains, it must have been not less than 4000 feet thick at the Lake of Brienz

Though elsewhere in Europe the latest or valley-glaciers have long ago vanished from most of the high grounds, they have left unmistakable traces of their former presence. Thus in hundreds of valleys among the Highlands of Scotland, in the Lake District, and North Wales, admirably ice-worn bosses of rock and beautifully perfect moraines may be seen. We can even trace, in the succession of moraines that become smaller as they approach the head of a valley, the stages of retreat of the original glacier as it shrank before the increasing warmth, till at last it disappeared together with the snow-basin from which it was fed.

The spread of great sheets of land-ice and the growth of valley-glaciers led to considerable interruption of the water-drainage in the areas that were not overspread with ice. The water was ponded back and formed lakes, which continued in existence as long as their ice-barriers remained, and which, as these barriers shrank, left memorials of their successive levels in lines of horizontal terrace formed of their shore-deposits. The most stupendous examples of such glacial lakes are to be found in North America. The largest of them, called Lake Agassiz after the pioneer of glacial geology, is shown by its shore-lines to have been 700 miles long from north to south, and to have covered an area of 110,000 square miles, which is more than the total united extent of Lakes Superior, Michigan, Huron, Erie, and Ontario. Its site is now partly occupied by Lakes Winnipeg and Manitoba and a host of smaller sheets of water The present Great Salt Lake is the mere shrunk remnant of a vast lake which once covered a great part of Utah, and to which the name of Lake Bonneville has been given in memory of the explorer. Further west lay another large expanse of water (Lake Lahontan). So greatly has the climate changed in this region since glacial times that the shrunken lakes of the great inland basin, having now no outlet to the sea, have become saline and bitter. In Europe one of the most famous glacial lakes is that of which the successive levels are marked by the terraces known as "Parallel Roads" in the west of Scotland (Fig. 20). Many other striking examples are to be seen along the chain of high grounds between Norway and Sweden.

Other relics of the retirement of the ice-sheet are supplied by the long mounds and heaps of gravel and sand, so abundantly

strewn over many low lands in Northern Europe. These sometimes form ridges, rising 20 or 30 feet above the ground on either side of them, and running for a number of miles Elsewhere they are heaped together irregularly, often enclosing pools of water. They are known as *Osar* in Sweden, *Kames* in Scotland, and *Eskers* in Ireland

During the later stages of the Ice Age the level of the land in Western Europe was lower than it is now. When elevation began, the upward movement continued, with long intervals of rest, until the land reached its present position. These pauses during the prolonged upheaval are marked by lines of raised beach (p. 123), well seen along both sides of Scotland, and also along the sea-margin of Northern Norway. North America likewise affords evidence that the land stood at a lower level than now during some part of the Glacial period. The depression in the valley of the St. Lawrence appears to have been as much as from 500 to 600 feet. In consequence of this subsidence the sea deposited over the submerged low grounds sheets of sand and gravel (Champlain series), with marine shells and bones of cetacea.

So slowly and gradually did the great cold disappear that the Ice Age insensibly passed into the Recent or existing period. There can be no doubt that man appeared in Europe before the climate had become as mild as it now is, for his flint-flakes and bone implements are found associated with the bones of Arctic animals, and traces of his presence in rudely chipped stone instruments occur in deposits which point to frozen rivers. Indeed, in a certain sense, it may be said that both in Europe and in North America the Ice Age still survives among the remaining snow-fields and glaciers.

Arranged in chronological order, the evidence from which the history of the Pleistocene period is determined may be given as follows :—

Last traces of local glaciers; terminal and lateral moraines shore-lines ("parallel roads") of ice-dammed lakes

Marine terraces or raised beaches, sometimes with moraines resting upon them, rock-shelves cut probably by waves and floating ice, and marking former levels of the sea These beaches and shelves indicate pauses during the last upheaval of the land Marine deposits with Arctic shells and bones of whales, walruses, and northern seals

Erratic blocks chiefly transported by the great ice-sheet, but partly also by floating ice during the rise of the land, and by valley-glaciers

Sands and gravels (kames, eskers) arranged in heaps, mounds, and ridges, and due in some way, not yet satisfactorily explained, to the accumulation of detritus under the ice-sheet, often associated with lacustrine deposits

formed in their hollows, and containing lake-shells and terrestrial plants and animals

Boulder-clay, till, or bottom-moraine of the great ice-sheet, the upper part sometimes rudely stratified, and in some regions separated from the lower part by a series of "middle sands and gravels", the lower part unstratified and full of transported stones and boulders Finely laminated clays, sands, layers of peat, and traces of terrestrial surfaces occur at different levels in the boulder-clay, and mark intervals, or what have been called "interglacial periods," of milder climate

Polished and striated surfaces of rock, ground down by the movement of the ice-sheet

## RECENT

The insensible gradation of what is termed the Pleistocene into the Recent series of deposits affords a good illustration of the true relations of the successive geological formations to each other. We can trace this gradual passage because it is so recent that there has not yet been time for it to be obscured by geological revolutions, like those which in the past have so often removed or concealed evidence that would otherwise have been available to show that each period merged insensibly into that which followed it.

The recent formations are those which have been accumulated since the present general arrangement of land and sea, the present distribution of climate, and the present floras and faunas of the globe were established They are particularly distinguished by traces of the existence of man. Hence the geological age to which they belong is spoken of as the Human period. But, as has already been pointed out, there is good evidence that man had already appeared in Europe during Pleistocene time, so that the discovery of human relics does not afford certain evidence that the deposit containing them belongs to the Recent series Nevertheless, it is in this series that vestiges of man become abundant, and that the proofs of his advancing civilisation are contained.

Man differs in one notable respect from the other mammals whose remains occur in a fossil state. Comparatively seldom are any of his bones discovered as fossils; but he has left behind him other more enduring monuments of his presence in the form of implements of stone, metal, bone, or wood. These relics are in a sense more valuable than his bones would have been, for while they afford us certain testimony to his existence, they give at the same time some indication of his degree of civilisation and

his employments. His handiwork thus comes to possess much geological value; his stone hatchets, flint-flakes, bone needles, and other pieces of workmanship are to be regarded as true fossils, from which much regarding his early history may be determined.

In the river valleys of the north-west of France and south-east of England human implements have been found imbedded in the higher alluvial terraces. After careful exploration, it has been ascertained that these objects have not been buried there subsequently, but must have been covered up at the time the gravel was being formed. The higher terraces are, of course, the older deposits of the rivers, which have since deepened their valleys, until they now flow at a much lower level (p. 43). The excavation of valleys is a slow process. Within a human lifetime no appreciable lowering of the ground from this cause can be detected. Even during the many centuries of which we have authentic human records we hardly anywhere obtain satisfactory proofs of such a change. How vast then must have been the interval between the time when the rivers flowed at the level of the upper terraces and the present day! Other evidence of the great age of these higher alluvia is to be found in the number of extinct animals whose remains are buried in them. The human implements likewise bear their testimony in support of the antiquity of the terraces, for they are extremely rude in design and construction, indicative of a race not yet advanced beyond the early stages of barbarism. In the lower, and therefore younger terraces, and in other deposits which may also be regarded as belonging to a later date, the articles of human fabrication exhibit evidence of much higher skill and more tasteful design, whence they have been inferred to be the workmanship of a subsequent period when men had made considerable progress in the arts of life. Accordingly, a classification has been adopted based upon the amount of finish in the stone weapons and implements, the ruder workmanship being assumed to mark the higher antiquity. The older deposits, with coarsely chipped and roughly finished human stone implements, are termed Palaeolithic, and the younger deposits with more artistically finished works in stone, bone, or metal, are known as Neolithic. It will be understood that this arrangement is one rather for convenience of description than for a determination of true chronological sequence. It is quite probable, for example, that some of the palæolithic gravels date back to the Pleistocene Ice Age, while other deposits containing similar weapons, together

with an assemblage of extinct mammals, may belong to a much later time, when the ice had long retreated to the north. It is obvious, too, that we know nothing of the relative progress made in the arts of life by the early races of man. One race may have continued fashioning the palæolithic type of implement long after another race had already learnt to make use of the neolithic type. Even at the present day we see some barbarous races employing rude weapons of stone, not unlike those of the palæolithic gravels, while others fabricate stone arrow-heads and implements of bone exactly resembling those of the neolithic deposits. It would hardly be incorrect to say that, in some respects, certain tribes of mankind are still in the palæolithic or neolithic condition of human progress.

## 1. Palæolithic

The formations included under this term are distinguished by containing the rudest shapes of human stone implements, associated with the remains of mammals, some of which are entirely extinct, while others have disappeared from the districts where their remains have been found. These deposits may be conveniently classed under the heads of alluvium, brick-earth, cavern-beds, calcareous tufas, and loess.

Alluvium.—Reference has just been made to the upper river-terraces, which, rising sometimes 100 feet or more above the present level of the rivers, belong to a very ancient period in the history of the excavation of the valleys, and yet contain rude human implements. The mammalian bones found in the sands, loams, and gravels of these terraces, include extinct species of elephant, rhinoceros, hippopotamus, and other animals. The human tools are roughly-chipped pieces of flint or other hard stone, and their abundance in some river-gravels has suggested the belief that they were employed when the rivers were frozen over, for breaking the ice and other operations connected with fishing. The high river-gravels of the Somme and of the valleys in the south-east of England have been specially prolific in these traces of early man.

Brick-earth.—On gentle slopes and on plains, the slow drifting action of wind and rain transports the finer particles of soil, and accumulates them as a superficial layer of loam or brick-earth. In the south-east of England considerable tracts of country have been covered with a deposit of this nature. It is

still in course of accumulation, but, as already stated (p. 20), its lower parts must date back to a high antiquity, for they contain the bones of extinct mammals, together with human implements of Palæolithic type.

Cave-earth and stalagmite.—The origin of caverns in limestone districts was described in Chapter V., and reference was made to the formation of stalagmite on their floors, and to the remarkably perfect preservation of animal remains in and beneath

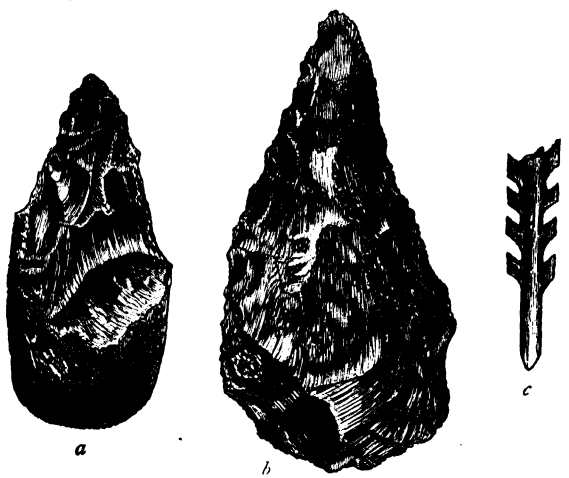



FIG. 223.—Palæolithic Implements. (*a*), Flint implement, reculver (½), chipped out of a rounded pebble; (*b*), flint implement (½) from old river-gravel at Biddenham, Bedford, where remains of cave-bear, reindeer, mammoth, bison, hippopotamus, rhinoceros, and other mammalia have been found; (*c*), bone harpoon-head (½) from the red cave-earth underlying the stalagmite floor of Kent's Cavern (*a* and *b* reduced from Sir John Evans's "Ancient Stone Implements").

that deposit. Many of these caves were dens tenanted by hyænas or other beasts of prey (p. 65). Some of them were inhabited by man. In certain cases they have communicated with the ground above by openings in their roofs, through which the bodies of animals have fallen or been washed by floods. The stalagmite, by covering over the bones left on the floor of the caverns, or in the earth deposited there by water, has preserved them as a singularly interesting record of the life of the time.

Calcareous Tufa.—Here and there the incrustation of tufa formed round the outflow of calcareous springs has preserved the

remains of the vegetation and of the land-animals of Palæolithic time (compare Fig. 27).

Loess.—This is the name given to a remarkable accumulation of pale yellowish calcareous sandy earth which occurs in some of the larger river valleys of Central Europe, especially in those of the Rhine and the Danube; it likewise covers vast regions of China, and is found well developed in the basin of the Mississippi. It is unstratified and tolerably compact, so that it presents steep slopes or vertical walls along some parts of the valleys, and can be excavated into chambers and passages. In China subterranean villages have been dug out of it along the sides of the valleys which it has filled up. It contains remains of terrestrial plants and snail-shells, also occasional bones of land-animals. It bears little or no relation to the levels of the ground, for it crosses over from one valley to another, and even mounts up to heights several thousand feet above the sea and far above the surrounding valleys. Its origin has been the subject of much discussion among geologists and travellers. But the result of much careful investigation bestowed upon it goes to show that the loess is probably, for the most part, a sub-aerial deposit formed by the long-continued drifting of fine dust by the wind. It was probably accumulated during a comparatively dry period. At that time the climate of Central Europe, after the disappearance of the ice-sheet, probably resembled that of the steppes of the south-east of Russia at the present day. The assemblage of animals whose bones have been found in the loess closely resembles that of those steppes; for it includes species of jerboa, porcupine, wild horse, antelope, etc. Among its fossils, however, there occur also the bones of the mammoth, woolly rhinoceros, musk-sheep, hare, wolf, stoat, etc., together with Palæolithic stone implements.

Thus the association of animals in the Palæolithic formations shows a commingling of the denizens of warmer and colder climates, like that already noticed as characteristic of the Ice Age, and hence the inference above alluded to has been drawn, that the Palæolithic gravels may themselves be interglacial. Among the animals distinctively of more southern type mention may be made of the lion, hyæna, hippopotamus, lynx, leopard, Caffer cat; while among the northern forms are the glutton, Arctic fox, reindeer (Fig. 224), Alpine hare (*Lepus variabilis*), Norwegian lemming (*Myodes torquatus*), and musk-sheep. The animals which then roamed over Europe, but are now wholly extinct, included the mammoth, woolly rhinoceros, and other

species of the same genus, Irish deer (*Megaceros hibernicus*), and cave-bear (*Ursus spelæus*) The traces of man consist almost entirely of pieces of his handiwork; only rarely are any of his bones to be seen. Besides the rudely-chipped flints, he has left behind him, on tusks of the mammoth and horns and bones of the reindeer and other animals, preserved in the stalagmite of cavern-floors, vigorous incised outline sketches and carvings representing the species of now extinct animals with which he was

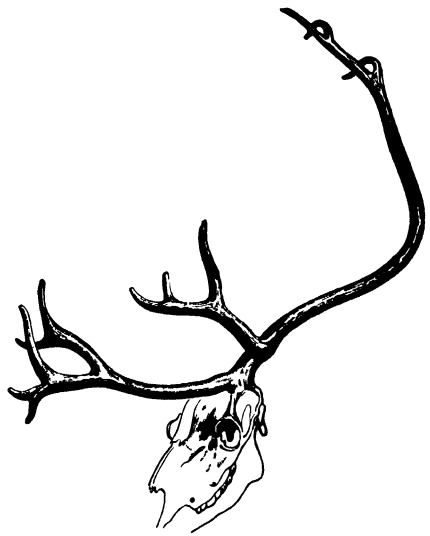


FIG. 224.—Antler of Reindeer ($\frac{1}{4}$) found at Bilney Moor, East Dereham, Norfolk.

familiar, also many paintings of these animals on the walls of caverns in Southern France He was evidently a hunter and fisher, living in caves and rock-shelters, and pursuing with flint-tipped arrow and javelin the bison, reindeer, horse, mammoth, rhinoceros, cave-bear, and other wild beasts of his time.

## 2. Neolithic

In this division the human implements indicate a considerable advance in the arts of life, and the remains of the mammoth,

rhinoceros, and other prevalent extinct forms of the Palæolithic series are absent The deposits here included consist of river-gravels, cave-floors, peat-bogs, lake bottoms, raised beaches, sand-hills, pile-dwellings, shell-mounds, and other superficial accumulations in which the traces of human occupation have been preserved.

After the extinction of the huge pachyderms, the European fauna assumed the general character which it now presents, but

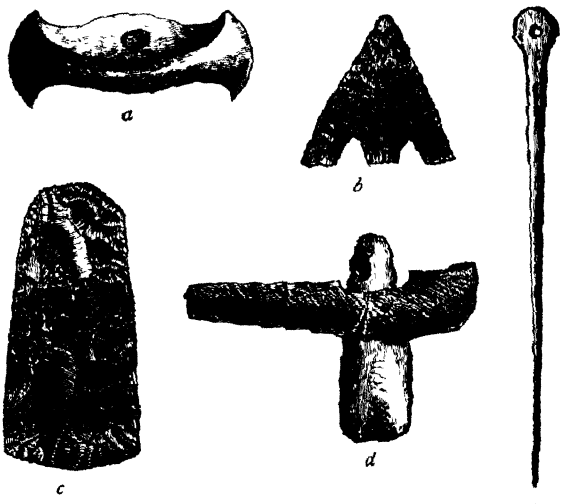



FIG. 225.—Neolithic Implements (*a*), Stone axe-head (½), (*b*), barbed flint arrow-head (natural size), (*c*), roughly-chipped flint celt (½), (*d*), polished celt (½), with part of its original wooden hand still attached, found in a peat bog, Cumberland, (*e*), bone-needle (natural size), Swiss lake dwellings, *a*, *b*, *c*, *d*, reduced from Sir John Evans's "Ancient Stone Implements."

with the presence of at least one animal, the Irish deer, that has since become extinct, and of others, such as the reindeer, elk, wild ox or urus, grizzly bear, brown bear, wolf, wild boar, and beaver, which, though still living, have long been extirpated from many districts wherein they were once plentiful. This local extinction has no doubt, in many if not in most cases, been the result, directly or indirectly, of human interference But man not only drove out or annihilated the old native animals As tribe after tribe of human population migrated into Europe from some region in Asia,

they carried with them the animals they had domesticated—the hog, horse, sheep, goat, shorthorn, and dog. The remains of these creatures never occur among the Palæolithic deposits; they make their appearance for the first time in the Neolithic accumulations, whence the inference has been drawn that they never formed part of the aboriginal fauna of Europe, but were introduced by the human races of the Neolithic period.

The stone articles of human workmanship found in Neolithic deposits consist of polished celts and other weapons, together with hammers, knives, and many other implements of domestic use. Knives, needles, pins, and other objects were made out of bone or horn. There is evidence also that the arts of spinning, weaving, and pottery-making were not unknown. The discovery of several kinds of grain shows that the Neolithic folk were also farmers. Vast numbers of these various relics have been found at the pile-dwellings of Switzerland and other countries. For purposes of security these people were in the habit of constructing their wooden dwellings in lakes, on foundations of beams, wattled-work, stones, and earth. Sometimes these erections were apt to be destroyed by fire, as well as to decay by age. And their places were taken by new constructions of a similar kind built on their site. Hence, as generation after generation lived there, all kinds of articles dropped into the lakes were covered up in the silt that slowly gathered on the bottom. And now, when the lakes are drained, or when their level is lowered by prolonged drought, these accumulated droppings are laid open for the researches of antiquaries and geologists.

Many important relics of Neolithic man have likewise been obtained from the floors of caverns and rock-shelters—places which from their convenience would continue to be used as in Palæolithic time. Interesting evidence, also, of the successive stages of civilisation reached by early man in Europe is supplied by the older Danish peat-bogs, in the lower parts of which remains of the Scotch fir (*Pinus sylvestris*), a tree that had become extinct in that country before the historic period, are associated with Neolithic implements In a higher layer of the peat trunks of common oak are found, together with bronze implements, while in the uppermost portion the beech-tree and iron weapons take their place.

Between the Neolithic and the present period no line can be drawn. They shade insensibly into each other, and the materials from which the history is compiled of their geographical and

climatal vicissitudes, their changes of fauna and flora, and their human migrations and development, form a common ground for the labours of the archæologist, the historian, and the geologist.

During the Recent period the same agencies have been and are at work as those which were in progress during the vast succession of previous periods. In the foregoing pages we have followed in brief outline each of these great periods, and after this survey we are led back again to the world of to-day with which the first chapters of this book began. In this circle of observation no trace has been detected of any general break in the continuity of the evolution through which our globe has passed. Everywhere in the rocks beneath our feet, as on the surface of the earth, we see proofs of the operations of the same laws and the working of the same processes.

Such, however, have been the disturbances of the terrestrial crust that, although undoubtedly there has been no universal interruption of the Geological Record, local interruptions have almost everywhere taken place. The sea-floor of one period has been raised into the dry land of another, and again, the dry land, with its chronicles of river and lake, has been submerged beneath the sea. Each hill and ridge thus comes to possess its own special history, which it will usually reveal if questioned in the right way

We are surrounded with monuments of the geological past. But these monuments are being slowly destroyed by the very same processes to which they owed their origin. Air, rain, frost, springs, rivers, glaciers, the sea, and all the other connected agents of demolition, are ceaselessly at work wherever land rises above the ocean. It is in the course of this demolition that the characteristic features of the scenery of the land are carved out. The higher and harder parts are left as mountains and hills, the softer parts are hollowed out into valleys, and the materials worn away from them are strewn over plains. And as it is now, so doubtless has it been through the long ages of geological history. Decay and renovation in never-ending cycles have followed each other since the beginning of time.

But amid these cycles there has been a marvellous upward progress of organic being. It is undoubtedly the greatest triumph of geological science to have demonstrated that the present plants and animals of the globe were not the first inhabitants of the earth, but that they have appeared only as the descendants of a vast

ancestry,—as the latest comers in a majestic procession which has been marching through an unknown series of ages. At the head of this procession we ourselves stand, heirs of all the progress of the past and moving forward into the future, wherein progress towards something higher and nobler must still be for us, as it has been for all creation, the guiding law.

# APPENDIX

## THE VEGETABLE KINGDOM

### I. Cryptogams or Flowerless Plants [1]

These bear spores that differ from true seeds in consisting only of one or more cells without an embryo. They include the following divisions —

**Algæ—Fungi.**—These embrace the smallest and simplest forms of vegetation—fresh-water confervæ, desmidiæ, mushrooms, lichens, sea-weeds, etc Some of them secrete carbonate of lime and form a stony crust, as in the case of the marine nullipores (p 94), others secrete silica, as in the frustules of diatoms (p. 40, Fig 94). These hard parts are most likely to occur as fossils, but impressions of some of the larger kinds of sea-weeds may be left in soft mud or sand (pp 269, 277). Fungi are not well adapted for preservation, but traces of them have been noticed even in rocks of the Carboniferous period.

**Characeæ** are fresh-water plants, some of which abstract carbonate of lime from the water and deposit it as an incrustation on their surface Hence their calcified nucules or spiral seed-like bodies [gyrogonites] and stems may accumulate at the bottom of lakes

**Muscineæ**, mosses, and liverworts afford little facility for fossilisation. But some of the mosses (sphagnum, etc ) form beds of peat (p 92).

**Filices**, ferns, bearing fronds on which are placed the sporangia or spore-cases. Many of them possess a tough tissue which can for some time resist decomposition. Traces of ferns are consequently abundant among the fossiliferous rocks (Figs. 145, 155, 174)

**Ophioglossaceæ**, adder's tongues and moonworts.

**Rhizocarpeæ**, pepperworts.

**Equisetaceæ**, horse-tails, with hollow striated siliceous jointed stems or shoots (Figs. 157, 179). These stems possess considerable durability, and where buried in mud or marl may retain their forms for an indefinite period. Allied plants [*Calamites*, Fig. 157] have been abundantly preserved among some of the older geological formations (Old Red Sandstone, Carboniferous, Permian).

**Lycopodiaceæ**, club-mosses, plants with leafy branches like mosses, growing in favourable conditions into tree-like shrubs that might be

[1] Names placed within square brackets [ ] are fossil forms, now mostly extinct.

mistaken for conifers Their dichotomous stems and their fertile branches, which resemble cones and bear spore-cases, offer themselves for ready preservation as fossils The spores are highly inflammable, and it is worthy of notice that similar spores have been detected in enormous abundance in the Carboniferous system *Lycopodium* and *Selaginella* are familiar living genera. (For an extinct form see Fig. 156, p. 301 )

## II. Phanerogams or Flowering Plants

1. Gymnosperms or plants with naked seeds, that is, seeds not enclosed in an ovary

**Cycadeæ**, small plants resembling both palms and tree-ferns The pinnate leaves are hard and leathery, and have been frequently preserved as fossils. *Cycas* and *Zamia* are two typical genera (Figs. 179 *e*, 186)

**Coniferæ**, the Pine family.—The stiff hard leaves and the hard seed-cones may be looked for in the fossil state (Figs 174 *b*, 179 *b*) The resinous wood also sometimes long resists decomposition, and may be gradually petrified Trunks of pine are often met with in peat-mosses The Coniferæ include the following subdivisions —

1. Cupressineæ, cypresses, including *Juniperus* (Juniper), *Libocedrus*, *Thuja*, *Thujopsis*, *Cupressus*, *Taxodium*, *Glyptostrobus*.
2. Abietineæ, pines and firs, including *Pinus*, *Abies*, *Cedrus*, *Araucaria* (p 333), *Dammara*, *Cunninghamia*, *Sequoia*
3. Podocarpeæ, trees growing in New Zealand, Java, China, Japan, etc , bearing a succulent fruit or a thick fleshy stalk.
4. Taxineæ, yews, plants with fleshy fruit, including the genera *Taxus*, *Salisburia*, *Phyllocladus*.

**Gnetaceæ**, joint-firs, small trees or shrubs with jointed stems (*Gnetum*, *Ephedra*, *Welwitschia*)

II Angiosperms, or plants bearing their seed within an ovary They are subdivided into two great classes—the Monocotyledons, and the Dicotyledons or Exogens

**Monocotyledons**, so called from their having only one cotyledon or seed-lobe With very few exceptions, their stems after reaching a certain thickness do not continue to increase in diameter, as in the Dicotyledons. Their seeds are usually enclosed in strong sheaths or shells, of which the coco-nut is a striking example The following are some of the families —

Lemnaceæ (duck-weeds); Potamogetoneæ (pond-weeds); Pandanaceæ (screw-pines), Palmaceæ (palms); Typhaceæ (typhads, marshy plants); Cyperaceæ (sedges); Gramineæ (grasses), Juncaceæ (rushes); Liliaceæ (lilies), Irideæ (irises); Dioscoreaceæ (yams); Taccaceæ (tacca); Musaceæ (plantains and bananas); Zingiberaceæ (gingerworts); Orchideæ (orchids).

**Dicotyledons**, or plants that have two cotyledons or seed-lobes; also called "Exogens," because their stems increase by successive layers added to the exterior. This division includes the most highly organised members of the vegetable kingdom. Our common flowers and hard-wood trees belong to it. The sections, orders, and families into which it has been partitioned are so numerous that only some of the

more interesting or important to the geologist can be inserted here. It is chiefly the leaves and seeds that occur in the fossil condition and furnish means of recognising the plants (Figs. 199, 214, 217).

Urticaceæ (nettles), Platanaceæ (planes), Cannabineæ (hemps), Ulmaceæ (elms), Betulaceæ (birches); Nelumbiaceæ (lotus plants), Nymphæaceæ (water-lilies), Ranunculaceæ (crowfoots), Anonaceæ (custard-apples); Berberideæ (barberries), Laurineæ (laurels), Myristicaceæ (nutmegs), Papaveraceæ (poppies), Fumariaceæ (fumitories), Cruciferæ (plants with cross-shaped flowers, such as wallflower, *Brassica*, which is the original genus from which our cultivated cabbage, cauliflower, broccoli, and turnip are derived, *Sinapis* or mustard, cress, radish, etc.); Convolvulaceæ (bindweeds), Solanaceæ (nightshades, potato); Bignoniaceæ (trumpet flowers), Plantagineæ (ribworts or plantains); Labiatæ (plants with labiate flowers, such as mint, sage, lavender), Oleaceæ (olives), Jasminiaceæ (jasmines); Gentianaceæ (gentians), Valerianaceæ (valerians), Cucurbitaceæ (cucumbers and gourds), Campanulaceæ (bell-flowers), Compositæ (plants with compound flowers), Primulaceæ (primroses); Ericaceæ (heaths); Rhamnaceæ (buckthorns), Sapindaceæ (soap-trees), Balsamineæ (balsam tribe), Geraniaceæ (cranesbills, geraniums); Euphorbiaceæ (spurge tribe), Araliaceæ (ivy tribe); Cornaceæ (dogwood tribe), Saxifragaceæ (saxifrage tribe), Proteaceæ (found principally in Australia and Cape of Good Hope), Papilionaceæ (plants bearing flowers like those of the pea, bean, clover, etc.); Pomeæ (apple tribe), Rosaceæ (rose tribe), Amygdaleæ (almond tribe), Myrtaceæ (myrtle tribe); Cactaceæ (Indian figs, cactus tribe), Myricaceæ (galewort tribe), Juglandeæ (walnut tribe)

## THE ANIMAL KINGDOM

### I INVERTEBRATES

I. PROTOZOA.—Animals simple in structure and usually minute in size, with bodies composed of a jelly-like substance (protoplasm) which, in some cases, secretes siliceous or calcareous needles or shells which serve to protect them. It is only these hard parts which have any chance of being preserved as fossils.

1. RHIZOPODS, having generally a calcareous shell or siliceous skeleton; divided into the following three orders —

**Foraminifera**—having usually a calcareous shell pierced with fine pores through which slender thread-like processes protrude from the jelly-like body. These minute creatures live in enormous abundance in various parts of the ocean, and their shells gather as a deposit of ooze at the bottom (*Globigerina*, *Lagena*, *Nummulina*). Their remains are also found in the geological formations, sometimes constituting masses of limestone (Figs. 42, 161, 200).

**Heliozoa**—fresh-water forms sometimes with a radial siliceous skeleton (*Acanthocystis*, *Clathrulina*).

**Radiolaria**—marine creatures mostly with radial siliceous skeleton, which usually consists of small siliceous needles or spicules united together. They occur in vast numbers on some parts of the sea-

floor, where their remains form a siliceous ooze (*Thalassicolla*, *Polycistina*, p. 94)

ii. FLAGELLATA, iii CILIATA, iv. SPOROZOA—protozoa living chiefly in fresh water, and having a definite form enclosed within an external membrane, and usually with a mouth and anus From their perishable nature these animals are not met with in a fossil state

II. SPONGIDA (sponges), chiefly marine forms possessing an internal skeleton of horny fibres or of calcareous or siliceous spicules. The horny sponges are illustrated by the common sponge of domestic use which is the skeleton of a Mediterranean genus, composed of a close network of horny fibres. Such forms are too perishable to be looked for as fossils. The siliceous sponges secrete minute siliceous spicules which are dispersed in a network of sponge-fibres, sometimes in a glassy framework of six-rayed spicules (*Hexactinellidæ*). The calcareous sponges, as their name implies, secrete carbonate of lime as the substance of which their spicules consist (see Fig 201).

III. CŒLENTERATA (zoophytes), mostly radially symmetrical animals with a body composed of cells arranged in an outer and inner layer (and a middle layer, with or without cells) enclosing a body-cavity.

**Hydrozoa**, including the fresh-water *Hydra*, and the marine jelly-fishes, millepores, *Campanularia*, *Sertularia*, etc. Most of these animals offer little facility for preservation as fossils, but some of them possess horny or calcareous structures which have been preserved in sedimentary deposits. Among these an extinct type of Hydrozoa, known as Graptolites, occurs abundantly in some of the older parts of the Geological Record (Figs 131, 135)

**Ctenophora**—spherical or cylindrical animals, including the Venus Girdle of the Mediterranean, and the Beroe of Northern waters

**Actinozoa** (anemones and corals), Polypes having a cavity in the body divided by vertical partitions into a number of compartments The common *Actinia* or sea-anemone is an example The soft parts sometimes secrete, and are supported by, a horny or calcareous skeleton. It is this calcareous skeleton which forms the familiar part of corals.

Rugosa (Tetracoralla), the older forms of coral in which the calcareous partitions are arranged in multiples of four with transverse partitions [*Zaphrentis*, *Cyathophyllum*, *Amplexus*, etc., Figs. 136*a*, 151, 162]

Alcyonaria (Octocoralla), including *Alcyonia*, *Pennatula*, and *Gorgonia*, animals with eight-plumed tentacles and a calcareous or horny skeleton (Fig 136*b*), or with loosely arranged calcareous spicules (sclerodermites).

Zoantharia (Hexacoralla), including the more modern forms of corals, wherein the tentacles are either six or some multiple of six Among the families comprised in this Order are the soft-bodied *Actinidæ*; also *Turbinolidæ*, *Oculinidæ*, *Astræidæ* or star-corals, *Fungidæ* or mushroom corals, *Madreporidæ* (Fig. 187)

IV. ECHINODERMATA—animals possessing usually a symmetrical fivefold grouping of parts, and enclosed in a skin which is strengthened by hard calcareous granules, spicules, or close-fitting plates.

**Crinoidea**—having a globular or cup-shaped calyx, with jointed arms, and usually fixed by a jointed calcareous stalk. Most of the Crinoids

are now extinct. Among the living forms are *Pentacrinus*, *Rhizocrinus*, *Bathycrinus*, and *Antedon* (see Figs. 164, 180, 188) Allied to the Crinoids are the extinct Cystideans (Fig. 137) and the Blastoids (Fig 165), found in Palæozoic formations.

**Asteroidea** (star-fishes) —The parts of these animals most readily preserved as fossils are the calcareous plates which run along the five rays of the star. These have been found in the marine deposits of many geological periods (Fig. 137). In the Brittle Stars (Ophiuroidea) the arms are flexible, cylindrical, and quite sharply marked off from the central disc

**Echinoidea** (sea-urchins), spherical, heart-shaped, or disc-shaped, with a usually immovable skeleton of calcareous plates which encloses the body like a shell and bears calcareous movable spines. They comprise the regular echinoids (*Cidaris*, *Echinus*, etc., Figs 163, 189), and the irregular echinoids either compressed into the form of a shield (*Clypeaster*) or of a heart-shape (*Spatangus*, Fig 202).

**Holothuroidea**—elongated animals, with a leathery body in which the calcareous secretion is confined to isolated particles, scales, or spicules. These calcareous bodies have been found abundantly in the Carboniferous system, and are the only evidence of the existence of this division of the echinoderms at so ancient a period

V. VERMES, comprising the various forms of worms Comparatively few of these animals occur in the fossil state Many of them are worms or flukes living in the intestines or other parts of the body The only important class to the student of geological history are the annelides or segmented worms.

1. *Polychæta*—**Errantia**, free-swimming predaceous sea-worms. The only hard parts of these creatures capable of surviving as fossils are the horny jaws which have been met with in some numbers even in ancient geological formations. But as many of the species live in and crawl over mud, they leave behind them, in their burrows and trails, evidence of their presence. Such markings remain abundantly in many ancient rocks (Fig. 138)

**Tubicola**—sedentary worms, living within tubes within which they can withdraw for protection. This tube may remain as the only permanent relic of their existence Sometimes it is a leathery substance; in other cases it consists of grains of sand or other particles cemented by a glutinous secretion, or of solid carbonate of lime The most familiar example of this order is the *Serpula* which may so frequently be seen encrusting dead shells thrown up upon the beach

ii. *Oligochæta*—earthworms and aquatic worms—are not found as fossils But the common earthworm is an important agent in mixing the soil and bringing up its fine particles within reach of rain and wind (p 19).

VI. MOLLUSCOIDA—under this division may be grouped the Tunicates, Polyzoa, and Brachiopoda. The true affinities of these three classes are not clear.

i. **Tunicata**, sea-squirts—simple or compound, fixed or free organisms which have been named from the leathery integument within which they are enclosed. Though some of them abstract carbonate of lime from sea-water, they present no hard parts for fossilisation, and the class is not known in the fossil state

ii. **Polyzoa** (Bryozoa), sea-mats and sea-mosses—composite animals,

each enclosed in a horny or calcareous case, and united into colonies which are generally attached to some foreign body and often resemble plants in outer form The calcareous colonies form durable objects which have been abundantly preserved as fossils Polyzoa are met with among the oldest fossiliferous formations and still abound in the present sea. The common lace-like *Flustra*, so frequently to be seen encrusting the fronds of sea-weeds or dead shells, is a familiar example of them Among the fossil forms (many of which have long been extinct) some of the most important genera are *Fenestella* ("lace-coral," Fig 167), *Polypora*, *Retepora*, *Glauconome*, *Hippothoa*, *Heteropora*, *Fasciculariа*.

III. **Brachiopoda**, lamp-shells—animals having bivalve, calcareous, or horny shells, one valve placed on the back, the other on the front of each individual, and taking their name from two long ciliated arms which proceed from the sides of the mouth and create the currents that bring their food They may be grouped in two Orders (1) The Inarticulata, in which the two valves are not united along the hinge line (*Lingula*, Fig. 133, *Discina*, *Crania*), and (2) the Articulata, in which the two valves are hinged together with teeth (*Terebratula*, *Rhynchonella*, Figs 141, 152, 168, 175, 218) The brachiopods attained their chief development during the earlier periods of geological time, and are now represented by comparatively few living forms The shells are almost always equal sided, but the ventral is usually larger than the dorsal valve, and is often prolonged into a prominent beak, through which the pedicle passes whereby it is attached to the sea-floor The following are characteristic genera :—

*Terebratula* (still living), *Stringocephalus* (Devonian), *Thecidium* (Trias to present time), *Spirifera* (chiefly Palæozoic), *Atrypa* (Palæozoic), *Rhynchonella* (Lower Silurian to present time), *Pentamerus* (Silurian and Devonian), *Orthis*, *Strophomena*, *Productus* (Palæozoic), *Leptæna* (Palæozoic to Lias), *Crania*, *Discina*, *Lingula* (from early Palæozoic to present time)

VII MOLLUSCA — animals with soft bodies, having the integument of the dorsal side produced to form a free fold called the mantle , this usually secretes a strong calcareous shell These hard shells are durable objects, and when covered up in sediment remain for an indefinite period as evidence of the existence of the animals to which they belonged The great abundance of the mollusca also in the sea and in terrestrial waters gives a peculiar value to their remains They (with the Brachiopoda) furnish by far the most valuable data to the geologist for the identification and comparison of marine sedimentary deposits of all ages They are divided into the following classes —

1. **Lamellibranchiata**—ordinary bivalves like the cockle, mussel, and oyster, in which the valves are placed on the right and left sides of the body The following are some of the more important families :—

Aviculidæ, wing-shells—*Avicula* (Fig 181), [*Posidonomya*, *Monotis*, *Aviculopecten*, Fig 169]
Pectinidæ—*Pecten*, *Hinnites*.
Limidæ—*Lima*
Pernidæ—*Perna*, [*Bakevellia*, Fig 176, *Gervillia*, *Inoceramus*, Fig. 188].
Pinnidæ—*Pinna*
Spondylidæ—*Spondylus*, *Plicatula* (Fig. 190).

Anomiidæ—*Anomia.*
Ostreidæ, Oysters—*Ostrea* (Fig. 213), *Gryphæa* (Fig. 190), [*Exogyra*].
Mytilidæ, mussels—*Mytilus* (mussel), *Modiola* (horse-mussel), *Lithodomus, Dreissensia.*
Nuculidæ—*Nucula* (Fig 203), *Nuculana* (Fig 220).
Arcidæ, including among other genera *Arca, Cucullæa* (Fig. 153), *Pectunculus*
Chamidæ—*Chama*, [*Diceras, Requienia*, Fig. 204]
[Caprinidæ—*Caprina* ]
[Rudistæ—*Hippurites, Radiolites*, confined to the Cretaceous system Fig 204]
[Anthracosidæ—*Anthracosia*].
[Cardinidæ—*Cardinia*]
Unionidæ—*Unio* (river mussel), *Anodon.*
Trigonidæ—*Trigonia* (Figs. 190, 203), [*Myophoria*, Fig 181 *d*, *Schizodus*, Fig 176]
Astartidæ—*Astarte, Cardita*
Lucinidæ—*Lucina, Corbis*, [*Axinus*]
Cardiidæ—*Cardium* (cockle, Fig 181)
Tridacnidæ—*Tridacna*
Cyrenidæ—*Cyrena, Sphærium*, fluviatile and estuarine shells.
Cyprinidæ—*Cyprina, Isocardia, Cypricardia*
Veneridæ—*Venus, Cytherea, Dosinia, Tapes.*
Tellinidæ—*Tellina* (Fig 220), *Psammobia, Sanguinolaria, Donax.*
Solenidæ—*Solen* (razor-shell).
Mactridæ—*Mactra, Lutraria*
Edmondiidæ—*Edmondia* (Fig 169)
[Pleuromyidæ—*Pleuromya, Ceromya*]
Panopæidæ—*Panopæa* (Fig 218), *Saxicava* (Fig 220)
Pholadomyidæ—*Pholadomya.*
Anatinidæ—*Anatina, Thracia*
Myidæ—*Mya* (gaper), *Corbula* (Fig 213).
Pholadidæ—*Pholas, Teredo*

ii. **Gasteropoda** or snails are named from the way in which they creep on the broad foot-like expansion of the lower part of the body They are almost all protected by a univalve shell which is usually spiral. They may be subdivided as follows —

*a* Amphineura Bilaterally symmetrical. The genus *Chiton* has a shell consisting of eight articulating plates

*b* Prosobranchiata, with gills situated in front of the heart Some of the more important genera are *Patella* (rock limpet), *Fissurella, Haliotis*, [*Bellerophon*, Figs. 143, 170, *Pleurotomaria, Murchisonia, Euomphalus*, Fig 170], *Turbo, Trochus, Nerita, Neritina, Littorina*, (periwinkle), *Cyclostoma, Capulus, Calyptræa, Natica* (Fig 220), *Paludina, Vivipara* (Fig. 213), *Rissoa, Scalaria, Turritella, Chemnitzia*, [*Loxonema*], *Melania, Neritnea, Cerithium* (Fig 209), *Aporrhais, Strombus, Rostellaria, Cypræa* (cowry), *Cassidaria, Buccinum* (whelk), *Nassa* (Dog-whelk), *Purpura* (Fig. 218), *Murex, Fusus, Pyrula, Mitra, Voluta* (Fig 209), *Oliva* (Fig. 209), *Pleurotoma, Conus.*

*c.* Opisthobranchiata. With gills situated behind the heart.

In the sea-slugs a shell is sometimes absent, or may be so small and thin as to be wholly or partially concealed by the animal, and therefore unlikely to be preserved in a fossil state Some, however, have stronger shells and occur as fossils, such as the genera *Actæon*, [*Actæonella*], *Bulla*, and *Cylichna*.

*d.* Pulmonata The air-breathing gasteropods include the land-snails. They have a broad foot and usually a spiral shell The following are among the more important genera . *Helix*, *Vitrina*, *Succinea*, *Bulimus*, *Pupa*, *Clausilia*, *Limax* (slug), *Limnæa* (pond-snail), *Ancylus* (river-limpet), *Planorbis*, *Cyclostoma*.

*e.* Heteropoda. The heteropod gasteropods are animals inhabiting the open sea, in which they are fitted to swim by a peculiar expansion of the foot into a fin-like tail or a fan-shaped ventral fin The living genera *Carinaria* and *Atlanta* are also found in late Tertiary strata.

iii. **Pteropoda**—a small group of molluscs swarming in the open sea, in which they swim by means of two wing-like fins proceeding from the sides of the mouth. They are all small, but extinct forms of much larger size are found fossil in rocks of all ages, even in some of the most ancient. The shell when present in the living forms is glassy and translucent, but in some of the fossil genera it is thicker. The living genera *Hyalea* and *Cleodora* occur also fossil among the Tertiary rocks. The important fossil genera *Pterotheca*, *Hyolithes*, *Tentaculites*, and *Conularia* (Fig 171), all of which occur in the Palæozoic formations, may perhaps belong to this order

iv. **Cephalopoda**—the cuttle-fishes, squids, and pearly nautilus—are the highest division of the mollusca, being distinguished by the long muscular arms placed round their mouth, and the plume-like gills by which they breathe. The living forms are nearly all destitute of an outer shell, which, however, is possessed by the pearly nautilus and argonaut or paper nautilus. Some of them have a horny or calcareous internal bone (cuttle-bone) They also possess powerful horny or partly calcareous jaws like a parrot's beak. It is only these hard parts that can be expected to occur as fossils.

In former periods the cephalopods were enormously more abundant than they are now, and as most of them possessed an outer shell their remains have been abundantly preserved among the rocks. During the earlier ages of geological history, they appear to have been the magnates of the sea.

According to the number of their breathing gills, cephalopods are grouped into Dibranchiate or two-gilled, and Tetrabranchiate or four-gilled.

The Dibranchiate forms now living include the *Argonauta* or paper-sailor, the *Octopus*, the calamaries or squids (*Loligo*, *Sepiola*, *Sepioteuthis*, etc.), *Sepia*, and *Spirula* Some of these occur also in the fossil state, but the genus *Belemnites* and its allies (Fig. 192), so abundant in Jurassic and Cretaceous time, died out at the close of Secondary time.

The Tetrabranchiate genera are protected by an external chambered shell with siphuncle They attained their chief development in Palæozoic and Mesozoic time, and are now almost extinct. The shell in the fossil forms is sometimes quite straight [*Orthoceras*],

and from this simplest form successive stages of curvature may be observed till it becomes a flat coil (Ammonites). The more important fossil genera are *Nautilus* (Fig. 182), the only living genus, found also fossil as far back as early Palæozoic deposits, *Lituites* (Fig 144) *Clymenia* (Fig 153), *Orthoceras* (Figs. 144, 172), *Phragmoceras*, *Cyrtoceras*, *Goniatites* (Fig 172) *Ceratites* Fig. 182), many genera formerly known collectively under the name *Ammonites* (Figs 191, 205), *Crioceras*, *Toxoceras*, *Ancyloceras*, *Scaphites*, *Turrilites*, *Hamites*, *Baculites*. (For some of the leading varieties of type, see Fig 205).

VIII. ARTHROPODA These differ from the worms in having jointed appendages attached to the body, which serve as organs of locomotion. They possess a tough chitinous skin which usually becomes hardened by the deposit of calcareous matter. The articulate animals are divided into four great classes as follows :—

i. **Crustacea**—chiefly aquatic forms with two pairs of antennæ and numerous paired legs. They include the Phyllopods, remarkable for their compressed bivalve shell, which is frequently found in the fossil state, the Ostracods, small forms enclosed in a bivalve shell, and with seven pairs of appendages, the minute shells being abundant in the fossil state (*Cypris*); the Cirripedes or barnacles, so commonly seen encrusting shore rocks; the Amphipods; the Isopods, the Decapods, which are either macrurous (with long abdomen), as in prawns and lobsters (Fig 193), or brachyurous (with short abdomen), as in sea-crabs and land-crabs. A remarkable group of extinct Crustaceans is comprised in the Order Eurypterida (Fig 149) The Xiphosura are still found living in the form of Limulus or King-crab; but they date back to the Silurian period. The earliest forms of Crustaceans belong to another extinct Order, the Trilobites (Figs 132, 139, 150, 166).

ii. **Arachnoidea**—air-breathing arthropods, with two pairs of jaws and four pairs of ambulatory legs, including mites, spiders, and scorpions. Some of these animals (scorpions) have chitinous integuments which resist decomposition and have been abundantly preserved in the rocks (pp. 240, 284, 304, and Fig 160)

iii. **Myriapoda**, including the chilopods or centipedes, feeding entirely on animals which they bite and kill with their poisonous secretion; and the chilognaths or millipedes and galley-worms which live in damp places and feed on vegetable and dead animal matters.

iv. **Insecta**.—Among the orders of insects of most interest in geological history are—

*Orthoptera*, with two usually unequal pairs of wings (earwigs, cockroaches, praying-insect, grasshoppers, locusts, crickets, etc.).

*Neuroptera*, insects with wings in which the nervures form a network (*Corydalis*, camel-neck flies, ant-lions, termites or white ants, ephemeridæ or may-flies, dragon-flies, phryganidæ or spring-flies).

*Hemiptera*, including lice, cochineal insect, plant-lice, cicadas, bugs, water-bugs, water-scorpions.

*Diptera*, with large glassy front wings, including the various kinds of flies, such as the house-fly, dung-fly, gad-fly, gnat, gall-fly, and flea.

*Lepidoptera*, butterflies and moths.

*Coleoptera*, beetles, the most durable parts of which are the horny wing-covers (elytra), so often to be found in woods and peat-mosses They include lady-birds, stag-beetles, tiger-beetles, etc

*Hymenoptera*, with four membranous wings, having few nervures, comprising ants, wasps, bees.

VERTEBRATA

i. **Leptocardii**—animals possessing neither brain nor heart, ribs nor jaws, and so lowly an organism that their claim to be ranked among the vertebrata is disputed (*Amphioxus*).

ii. **Cyclostomi**—animals with a cartilaginous skeleton, the skull not separate from the body, and no real jaws or ribs Some of them have horny denticles on the mouth, and these are the only hard parts that offer any facilities for fossilisation The living Lamprey and the Hag-fish are examples Certain tooth-like bodies called "Conodonts," which occur in Palæozoic rocks, have been supposed to be teeth of Cyclostomes The genus *Palæospondylus*, from the lower Old Red Sandstone of Scotland, is the representative of an order which, unlike those living at the present day, shows a calcification of the skeletal parts

iii. **Ostracodermi**—A curious group of animals well represented in Silurian and Devonian rocks The head and body were protected by strong dermal plates Examples are *Pteraspis* and *Cephalaspis* (Fig. 148) The exact affinities of the Ostracoderms are doubtful, but they have been regarded by some authors as true fishes, and placed in the sub-class Placodermi

PISCES, fishes—The parts most likely to be preserved in a fossil state are the bones of the skeleton, especially the teeth , also bony scales and external plates and spines Those types of fishes which possess these hard parts have accordingly been abundantly preserved among the stratified rocks of the earth's crust.

i. **Elasmobranchii,** with a cartilaginous skeleton, and a skin which may be naked and is never covered with scales as in the osseous fishes, but may bear small prominences which harden by the secretion of carbonate of lime and become tooth-like, or where small and close-set, form shagreen These calcareous portions sometimes form dermal plates or tubercules, and also spines which commonly rise in front of the dorsal fins It is these dermal defences which are so common in the fossil state under the name of Ichthyodorulites (Fig 173) The Elasmobranchs include the Sharks and Rays. The Acanthodians form a Palæozoic group [*Acanthodes* (Fig 147), *Cheiracanthus*]

ii **Holocephali**—comprising the chimæroid fishes , they are represented in the living *Chimæra* and by the fossil *Rhynchodus* (Devonian), *Ischiodus* (Mesozoic), *Edaphodon* (Cretaceous, Eocene, and Miocene), besides other extinct forms.

iii **Dipnoi**—represented by the living *Lepidosiren* of the Amazon, *Protopterus* of tropical Africa, and *Ceratodus* of Queensland rivers ; and by *Dipterus* and *Phaneropleuron* of the Old Red Sandstone, in addition to other fossil forms. The order Arthrodira, comprising the Devonian *Coccosteus* and allied fishes, may perhaps belong to the

Dipnoi Its true position is doubtful, and some authors have united it with the Ostracoderms, regarding all as "placoderm" fishes

iv. **Teleostomi**—embrace the "Ganoids," the great majority of which are extinct forms, and the "Teleosteans," which include most fishes living at the present day No hard-and-fast line can be drawn between the Ganoidei and Teleostei The former have a cartilaginous or ossified skeleton, the body and tail are usually covered with hard "ganoid" scales, and occasionally there are bony plates The Ganoids comprise the following orders —

(1) Crossopterygii, including the modern *Polypterus* of the Nile and many extinct genera, as the Palæozoic *Diplopterus*, *Megalichthys*, *Osteolepis* (Fig 147), *Cœlacanthus*, *Holoptychius* (Fig 146), *Strepsodus*, etc , (2) Chondrostei, of which the living sturgeon is a type, and which includes *Cheirolepis* (Devonian), *Palæoniscus* (Permian), *Platysomus* (Carboniferous and Permian, Fig 177), *Chondrosteus* (Lias), and other fossil forms, (3) Pycnodonti, entirely extinct, represented among the Mesozoic formations by *Gyrodus*, *Pycnodus*, and other genera, (4) Lepidostei, of which the living *Lepidosteus* or "gar-pike" of North America is the type Large numbers of extinct genera have been met with in Mesozoic rocks Among these are *Pholidophorus* (Fig 194) and *Lepidotus*, (5) Amioidei, represented by the living *Amia*, a mud-fish of the fresh waters of the United States, and by several Mesozoic and Tertiary extinct genera, as *Caturus*, *Megalurus*

The Teleosteans possess a bony skeleton, and hence are often spoken of as the osseous fishes The vertebræ are usually biconcave, each face showing a deep conical hollow Most of them possess teeth which are usually isolated and pointed They are for the most part covered with overlapping horny scales, but sometimes they have dermal plates of true bone, or are encased in a calcareous cuirass (Fig 206) As examples may be cited—the perch, mullet, bream, swordfish, John Dory, sunfish, mackerel, tunny, lump-sucker, goby, blenny, stickleback, wrass, cod, whiting, haddock, hake, ling, flat-fishes, carp, pike, salmon, trout, herring, pilchard, eel.

AMPHIBIA—newts, frogs, salamanders, etc —are divisible into four orders as follows —

i **Stegocephalia**—animals now entirely extinct which possessed bodies somewhat like those of the salamanders, with relatively weak limbs and long tail. The head was defended by hard plates of bone, the breast by three sculptured bony plates, and the lower side of the body by an armour of oval plates or scales The feet appear to have been five-toed The footprints of these creatures were first found, but more or less perfect skeletons of them have since been obtained These include the Labyrinthodonts, so called from the labyrinthine structure of their large teeth. The earliest known labyrinthodonts are from the Carboniferous system, they formed the magnates of the world until they were supplanted in early Mesozoic time by the great development of Reptilians (Fig. 178)

ii. **Gymnophiona**, or snake-like amphibians—animals with serpentiform bodies without limbs They are not known as fossils.

iii **Urodela** or tailed amphibians—animals with elongated bodies and relatively short limbs, devoid of scales or pectoral plates. They com-

prise the living newts (*Triton*), salamanders, and mud-eels (*Siren*). It is only in the Wealden and in Tertiary strata that undoubted remains of Urodela have been found.

iv. **Anura**, or tailless amphibians—animals with relatively short and broad bodies and two pairs of limbs, of which the hinder are longer and stronger. Though there are no scales nor pectoral plates, portions of the skin of the back are in some cases ossified. They are typified by the frogs and toads. They are only found fossil in Tertiary deposits.

REPTILIA or true reptiles, with horny scales or bony scutes, are represented now by turtles, tortoises, snakes, lizards, and crocodiles, but flourished formerly in many remarkable forms which have long been extinct. Embracing all the known living and extinct types in one view, we may group them into the following orders:—

i. **Rhynchocephalia**—represented at the present day only by the genus *Sphenodon* in New Zealand. *Palæohatteria* and *Proterosaurus* occur in Permian strata; in the Triassic period lived the *Rhynchosaurus*, *Hyperodapedon*, and *Telerpeton* (Fig. 183).

ii. **Squamata**—Lizards, snakes, and the extinct Pythonomorpha and Dolichosauria. The gigantic Pythonomorph *Mosasaurus* and the long-necked *Dolichosaurus* are Cretaceous genera. Fossil lizards are principally known from Tertiary and more recent strata. The snakes, remarkable for the number of their vertebræ (which, in some pythons, amount to more than 400), are known as fossils principally by fragmentary remains in Tertiary strata.

iii. **Ichthyosauria**—animals somewhat resembling whales in shape, the head being joined to the body with no distinct neck, and the body tapering away behind. They appear to have been covered merely with skin, and moved through the water by means of two pairs of paddles. In the huge head a conspicuous feature was the large eye-orbits containing a circle of bony plates that remain often well preserved. The typical genus, *Ichthyosaurus*, is abundant in the Lias (Fig. 193).

iv. **Sauropterygia**—Nothosaurs and Plesiosaurs—distinguished for the most part by the disproportionate length of the neck and the smallness of the head. Like the ichthyosaurs, they appear to have had no bony covering upon their skin; they had two pairs of paddles, those behind being largest, and a comparatively short tail. The earliest representatives are found in Triassic rocks (*Nothosaurus*, *Simosaurus*, *Pistosaurus*), but they are most characteristic of the Jurassic formations (*Plesiosaurus*, *Pliosaurus*).

v. **Theromorpha**—land reptiles with biconcave vertebræ and teeth placed in sockets. They are confined, so far as we know, to the Permian and Triassic periods, and have been found in supposed Triassic strata in Scotland, South Africa, and India (*Pariasaurus*, *Dicynodon*, *Oudenodon*). The sub-order Theriodontia constitutes a group of reptiles remarkable for possessing teeth which have been classed by Professor Owen as incisors, canines, and molars. Their remains have been found in the Karoo Formation (supposed Triassic) in South Africa.

vi. **Chelonia**—the tortoises and turtles, distinguished for the most part by the bony case or box in which the body is enveloped. As many of these animals are of aquatic habits, their hard parts must often be

covered up and preserved in sedimentary deposits They are not uncommon in the fossil state, and are known as far back as the Triassic series

vii. **Crocodilia**—the crocodiles, alligators, and gavials form the highest type of living reptiles. The earliest trace of them in a fossil state is perhaps in the *Stagonolepis* of the Trias (Fig 184) They abounded in the Jurassic seas, the genera *Teleosaurus* and *Steneosaurus* being conspicuous, while in Cretaceous time the *Goniopholis* abounded None of the modern crocodiles, however, are truly marine

viii **Deinosauria**—a remarkable group of animals, mostly of enormous size, which presented structures linking them with birds Some of them had a covering only of naked skin, others possessed an armour of bony plates like those of the crocodile. The hind-limbs are usually enormously developed in comparison with the fore-limbs, showing that the animals probably walked on their hind-feet. The deinosaurs abounded during the Mesozoic ages and in many diverse types Some of the more important genera are *Iguanodon* (Fig. 207), *Hylæosaurus*, *Cetiosaurus*, *Megalosaurus*, and *Compsognathus* The largest animal yet known, the *Atlantosaurus*, has been found in the Jurassic rocks of North America (p 341)

ix. **Pterosauria**, flying reptiles or Pterodactyls—distinguished by the length of their heads and necks, and the proportionately great size of their fore-limbs, on which the outer finger was enormously elongated to support a wing-like membrane. These animals no doubt flew from tree to tree, and hopped or shuffled along the ground. They appear to have been confined to the Mesozoic periods The important genera are *Pterodactylus*, *Rhamphorhynchus*, *Dimorphodon*, and *Pteranodon* (Fig 196).

AVES, birds—This important section of the animal kingdom has been but sparingly found in the fossil state. The facility with which birds can escape by flight from the destruction that befalls other land-animals will no doubt suffice to explain why their fossil remains should be so infrequent The oldest known birds had curious reptilian affinities, being furnished with jaws and teeth. Taking all the known forms of birds, recent and fossil, they may be grouped in the following order —

i. **Saururæ**—in this singular extinct group the vertebral column was prolonged into a long lizard-like tail, each vertebra of which, however, bore a couple of quill-feathers The only known example is the *Archæopteryx* of the Jurassic system—the oldest bird yet discovered (Fig. 197)

ii. **Ratitæ**—the cursores or running birds, such as the ostrich, cassowary, rhea, emeu, and apteryx The true running birds have not with certainty been found fossil in strata older than the Tertiary series The gigantic extinct *Dinornis* of New Zealand belongs to this order.

The Upper Cretaceous sub-order Odontolcæ comprises diving birds with rudimentary wings, ratite sternum, powerful legs, a strong tail for steering, and jaws with numerous conical teeth sunk in a deep continuous groove (*Hesperornis*).

iii. **Carinatæ**—generally possessing powers of flight. These include most of the birds of the present day. The earliest carinate birds are the Odontormæ, which were provided with strong wings and had their teeth sunk in separate sockets, as in the crocodiles They have been

found in the Upper Cretaceous rocks of North America The arrangement of the modern carinate birds into definite sub-orders has not been yet satisfactorily accomplished The student, however, may find some advantage in making himself acquainted with the following names which, though in process of being superseded, are still in common use Natatores—swimmers or palmipeds, with short legs placed behind and provided with webbed feet These include gulls, penguins, geese, ducks, swans, cormorants, etc Remains of this sub-order are found in Cretaceous and Tertiary strata Grallatores—waders, chiefly found by the shores of rivers, lakes, or the sea, distinguished by the length of their legs, which are not completely webbed They include, plovers, cranes, flamingoes, storks, herons, snipes, etc. They have been found fossil in Cretaceous and Tertiary rocks. Rasores—scratchers or gallinaceous birds, including the various tribes of fowls and pigeons They are found fossil in Tertiary strata Scansores—climbers, including the parrots, cuckoos, toucans, and trogons They are only found fossil in Tertiary and Post-tertiary rocks Insessores—perchers, passerine birds include by far the largest number of living birds, and all the ordinary song-birds They have not been met with in a fossil state in rocks older than the Tertiary series Raptores or birds of prey, comprising birds with strong, curved, sharp-edged, and pointed bills, and strong talons, as the eagles, hawks, falcons, vultures, and owls This sub-order also has not been obtained fossil except in Tertiary and Post-tertiary rocks

MAMMALIA —The highest class of the vertebrata is represented chiefly on the land, the marine representatives being few in number, though often of large size (whales, dolphins, porpoises, manatee, seals, morse) In marine deposits, therefore, we need not expect to find mammalian remains abundant at the present time Doubtless from the time of their first appearance mammals have always been, on the whole, terrestrial animals, their fossil remains consequently occur but sparingly among ancient geological formations. The earliest known examples, which are of a doubtful nature and belong probably to Monotreme or Marsupial types, have been found in the Triassic and Jurassic rocks of Europe and North America

I PROTOTHERIA or ORNITHODELPHIA—including the two living types of *Ornithorhynchus* and *Echidna*. *Microlestes* from the Rhætic beds (Fig 185) may possibly belong to this sub-class

II. METATHERIA or DIDELPHIA—Marsupial animals Comprising the Opossums (Didelphidæ), Dasyures, Myrmecobius, Perameles, Kangaroos, and Wombats. As just mentioned, it is representatives of this section of the vertebrates that occur fossil among the Mesozoic rocks [*Amphitherium*, *Phascolotherium*, Fig 198]

III. EUTHERIA or MONODELPHIA—including the vast majority of living and extinct mammalia. They may be grouped as follows —

**Edentata**—sloths, ant-eaters, armadilloes, pangolins, and African ant-eaters. Some enormous extinct types of Edentates have been found in America [*Megatherium*, *Mylodon*, *Glyptodon*]

**Sirenia**—aquatic fish-like animals including the manatee, dugong, sea-cow. The last-named is now extinct, the last having been killed so recently as 1768. Numerous fossil remains of Sirenians occur in Miocene and Pliocene deposits of Europe [*Halitherium*]

**Cetacea**—whales, including the Balænidæ or whalebone whales, Delphi-

noidea or toothed whales (Sperm whale, Ziphius, Narwhal, Porpoise, Ca'ing whale, Grampus, Dolphin) Cetacean ear-bones and other bones are not infrequent in Tertiary and Post-tertiary strata.

**Insectivora**—small terrestrial mammals like shrews, moles, and myogale No fossil insectivores older than Eocene times are known.

**Cheiroptera**—animals with the fore-limbs adapted for flight, including the tribe of bats Fossil representatives are found as far back as Eocene rocks

**Rodentia**—small terrestrial plant-eating mammals, distinguished by their large chisel-shaped incisor teeth, specially adapted for gnawing, and by the absence of canines Among them are squirrels, marmots, beavers, dormice, rats, mice, voles, lemmings, jumping mice, jerboas, porcupines, chinchillas, cavies, rabbits, and hares. Fossil rodents belonging to most of the existing families have been met with in Tertiary and Recent strata, together with some extinct types

**Ungulata** or hoofed animals include the Hyrax, the Proboscideans (elephants, Fig 221, and the extinct types of *Mastodon*, Fig 215, *Deinotherium*, Fig 216, etc ) and the extinct type of the *Deinocerata* (Fig 211) , the perissodactyl or odd-toed group (tapirs, rhinoceroses, horses [*Palæotherium*], Fig 210), and the artiodactyl or even-toed group (hippopotamus, peccary, swine, llama, camel, chevrotains, the true ruminants, such as deer, antelopes, giraffes [*Helladotherium*, Fig 219], and all bovine animals). The earliest known forms are of Eocene age.

**Carnivora**—so named from the majority of them subsisting on animal food and being eminently beasts of prey They are divided into (1) Creodonta, primitive carnivores which approach closely to certain early ungulates , (2) Fissipedes or true carnivores, generally adapted for life on land, comprising (*a*) the Æluroids or cat-like forms (lions, tigers, cats, puma, jaguar, cheetah, civet-cat, ichneumon, hyæna, and various fossil forms found in Tertiary and Post-tertiary deposits) , (*b*) the Cynoids or dog-like forms (dogs, wolves, foxes) ; and (*c*) the Arctoids or bears and their allies (otters, badgers, weasels, raccoons, panda) , (3) Pinnipedes or aquatic carnivores, divisible into three well-marked families . (*a*) Otariids or sea-bears , (*b*) Trichechids or walruses ; (*c*) Phocids or true seals

**Primates**, the highest division of vertebrate life, comprising (1) the Lemuroid animals , (2) the Hapalids or marmosets , (3) the Cebids or American monkeys , (4) the Cercopithecids, the monkeys of the Old World, exclusive of the apes , (5) the Simiids or man-like apes (*Troglodytes*, *Gorilla*, *Simia*, and *Hylobates*) ; (6) Man.

# INDEX

An asterisk (*) denotes that a figure of the subject will be found on the page indicated


Aar Glacier, former extension of, 403
*Abies*, 391
*Abietites*, 325
Abysmal deposits of the ocean, 88, 94*, 96*, 102
Acacia, fossil, 382
Acadian series, place of, in Geological Record, 257, 275
*Acanthodes*, 290*
Acanthodian fishes, 289
*Acer*, 369, 388
*Aceratherium*, 378
*Acervularia*, 293
Acid rocks, 178
Acids and bases, 129
Acids, organic or humous, influence of, in geological changes, 17, 27, 54, 60, 91, 175
*Acrodus*, 327, 337, 356
*Acrosalenia*, 334
*Acrotreta*, 273
*Acrydiidæ*, fossil, 304
*Actinocamax*, 358
*Actinodon*, 321
Actinolite, 148, 189
Actinoliteschist, 190
Adelsberg, caverns at, 61
*Ægoceras*, 337
Africa, Carboniferous system in, 312, Permian rocks of, 316; Trias in, 331; Cretaceous system in, 349; Eocene rocks in, 368
*Agave*, 369
Agglomerate, 170
*Agnopterus*, 370
*Agnostus*, 272*
Air, geological work of the, 11
Air-breathers, fossil, 304
Alabaster, 151
Alaska, glaciers of, 74*
Albian stage, 358, 360
Albite, 146, 178
Alcyonarian corals, 279*
Alder, fossil, 350, 388, 389*
*Alethopteris*, 300*, 332
Algæ, *see* Seaweeds
Algonkian, place of, in Geological Record, 257, rocks described, 262
Alkali metals, 136
Alkaline carbonates, 133, 143
Alkaline earths, 136
Allegheny series, 313
Allotriomorphic crystals, 177
Alluvial cones or fans, 40*
Alluvium, formation of, 38, 42*; palæolithic remains in, 407
Almond, fossil, 369
*Alnus*, 388, 389*
Aloe, fossil, 369
Alpine hare, 409
Alps, glaciers of, 72, 74, 79, 402, plication and thrust-planes in, 221, pre-Cambrian nucleus of, 262, Silurian rocks in, 285, Carboniferous rocks in, 312; Permian volcanic action in, 316; Permian system in, 319, Trias of, 324, 326, 330, Jurassic rocks in, 344, 345; Cretaceous rocks of, 348; Tertiary formations in, 365, Eocene of,

368, 373; Miocene of, 382, 383, 386; successive uplifts of, 366, 381, 386, 388
Alum, 153, 188
Alum-slate, 188, 276
Alumina, 131, silicates of, 131, 145
Aluminium in earth's crust, 129, 131
*Alveolaria*, 391
*Alveolites*, 306
*Amaltheus*, 337
Amber, insects in, 239, 240
Amber Beds of Konigsberg, 379
*Ambonychia*, 283
America, North, glaciation of, 77, 395, 399, 403; peat-bogs of, 93, fissure-eruptions of, 119, Geological Record in, 256, pre-Cambrian rocks of, 262, Cambrian rocks of, 275, Silurian system in, 286, Devonian system in, 287, 295, Carboniferous system in, 312, Permian rocks of, 316, 321, Trias of, 331, Jurassic rocks in, 346, Cretaceous rocks of, 349, 357, 363, Tertiary formations in, 366, Eocene of, 368, 372, 374, Oligocene of, 379, Miocene of, 386, Pliocene of, 394, Pleistocene of, 395, 399
Amethyst, 142
Ammonia, 137
Ammonites, 246, 319, 322, 323, 326, 327*, 330, 336*, 354*, 355
*Amomum*, 369
Amorphous condition of minerals, 141
Amphibia, fossil, 304, 305, 319, 320*, 323, 326
Amphibole, 147
Amphibolites, 190
*Amphitherium*, 341
*Ampyx*, 281
Amygdaloidal structure, 107*, 108, 109*, 147*, 183
*Amygdalus*, 369
*Anaenchytes*, 352*
*Anchilophus*, 371
*Anchitherium*, 380
Anchor-ice, 69
*Ancyloceras*, 354*
*Ancylotherium*, 394
Andalusite-slate, 188
Andes, volcanic rocks of, 183
Andesine, 146
Andesite, 182
*Angelina*, 174
Anhydrite, 151, 172, 315, 321, 324, 330
Animals and plants as materials for geological history, 6, preservation of remains of, 6, 91, geological action of, 91, deposits formed of remains of, 95, preservation of remains of, in sediments, 99, disappearance of terrestrial, 100, 239, conditions for preservation of records of, 100, 101, 238, durable parts of, 240
Animikean series, 257
Annelids, earliest known, 271, Silurian, 281
Anomodont reptiles, 328
*Anoplotherium*, 246, 377
*Anopolenus*, 275
Anorthite, 146
Ant, white, removal of soil by, 19
Antelopes, fossil, 371, 383, 390, 392, 394, 409
Anthracite, 175
*Anthracomya*, 304, 309*
*Anthracosaurus*, 305
*Anthracosia*, 304
*Anthracotherium*, 377, 378
*Anthrapalæmon*, 308
Anticline, 213*, 215*, 217*
Apatite, 152
Apennines, uplift of, 388, 393
Apes, fossil, 246, 383
Aplite, 179
Aptian, 359
Aqueous, definition of, 158
Aqueous solution, crystallisation from, 158
Aquitanian stage, 378, 379
Arachnids, fossil, 240
Aragonite, 150
Aralia, 350
Araucarian pines, fossil, 303, 332
*Araucarioxylon*, 303
*Araucarites*, 325, 333
*Arca*, 385, 392, 394
*Arcestes*, 326
Archæan, place of, in Geological Record, 257, formations described, 258

*Archæocidaris*, 306, 307
*Archæocyathus*, 271
*Archæopteryx* 240*, 341
*Archegosaurus*, 305
Architecture and Geology compared, 7
Arctic birch, 391, 400
Arctic Fresh-water Bed, 391
Arctic fox, 401, 409
Arctic regions, Jurassic flora of, 333, Miocene flora of, 386
Arctic vegetation once spread over much of Europe, 92, 395
Arctic willow, 391, 400
*Arenicolites*, 275, 281
Arenig group, place of, in Geological Record, 257, 286, possibly included in "Dalradian," 261
Argillaceous cement in sandstone, 167, 168
*Argillornis*, 370
Aridity and weathering, 24
*Arietites*, 337
Arnusian, stage, 393
Aroids, fossil, 368
*Asaphus*, 174, 281, 282*
Asbestus, 148
*Ascoceras*, 283
Ashdown Sand, 359
Ashes, volcanic, *see* Tuffs
*Aspidoceras*, 337, 342
*Asplenium*, 351, 368
Assise in stratigraphy, 248
*Astarte*, 335, 391, 392
*Asterophyllites*, 302*, 303
Astian stage, 393
Astronomy and Geology, 252
*Athyris*, 293, 308
*Atlantosaurus*, 341
Atmosphere, composition of, 129, probable origin of the, 253, 254
Atolls, 98, 123
*Atrypa*, 282, 283*, 293
*Auchenaspis*, 284
Augite, 140*, 148, 184
Augite-andesite, 182
Augite-diorite, 182
Augite-picrite, 184
Australia, Great Barrier Reef of, 99; pre-Cambrian rocks of, 263; Cambrian rocks of, 275, Silurian rocks of, 285, Permian rocks of, 316, Trias in, 331, Jurassic rocks in, 346, Cretaceous rocks in, 364
Auvergne, extinct volcanoes of, 106
Avalanches, 70
*Avicula*, 326, 327*
*Aviculopecten*, 305, 309*
Axes of crystals, 138
Axmouth, landslip of, 58
Aymestry Limestone, 286

Babylon, buried under wind-borne soil, 21
"Backs" in quarrying, 208
*Bactrites*, 295
*Baculites*, 354*, 355, 364
Bad lands of the United States, 374, 375*
Bagshot Sands, 373
*Baiera*, 332
Bajocian, 342, 343
*Bakevellia*, 319*
Bala group, place of, in Geological Record, 257, 286
Baltic Sea, once filled with ice, 74, 397
Bamboo, fossil, 388
Banding of gneiss, 258, 260
Bannisdale Flags, 286
*Baphetes*, 305
Barium in earth's crust, 129, 136, 151, 234
Barnacles as evidence of elevation of land, 123
Bars at river-mouths and on coasts, 86
Barton Clay, 373
Bartonian, 373
Barytes, 136, 151, 234
Basalt, 184, 185*; altered into amphibolite, 190
Basalt-glass, 183, 232
Basalt-rocks, 183
Basalt-tuff, 169
Basaltic (columnar) structure, 184
Base-level of erosion, 38, 85
Base or ground-mass of igneous rocks, 159, 177
Bases and acids, 129
Bath Oolite, 342, 344
Bathonian, 342, 343
Bats, fossil, 371, 374, 377
Beaches, raised, 123, 124*, 404, 411

Bears, fossil, 379, 383, 387, 391, 394, 410, 411
Beavers, fossil, 383, 387, 391, 411
Bed (in stratigraphy), 158, 194, 247
Bedding, false, 195, deceptive in schists, 258
Beech, fossil, 350, 369, 382, 387, in Danish peat-bogs, 412
Beetles, fossil, 337, 383
*Belemnitella*, 357, 362, 364
Belemnites, 336*, 355, 359
*Bellerophon*, 273, 283, 284*, 310*
Bembridge group, 378
Bermuda, limestone formed out of calcareous sand at, 95, 167
Bertrand, M., on Alpine structure, 221
Beryl, 179
*Betula*, 388, 391, 400
Biotite, 147
Birch, fossil, 388, 391, 400
Birds, fossil, 246, 340*, 341, 357, 370, 377
Bird's-eye Limestone, 286
Bison, 410
Black Jura (of Germany), 343
Black River group, 286
Blackthorn, fossil, 391
Blastoid Echinoderms, 246, 307*
*Blattidæ*, fossil, 304
Bleaching of rocks by organic matter, 17
Blende, 235
Blocks, erratic, 72*, 73*, 76*, 397, volcanic, 112, 169, 229
Blow-holes, 80, 81*
Boar, fossil, 394, 411
Bog-bean, fossil, 391
Bog-iron-ore, 144
Bog-manganese, 145
Bognor Beds, 373
Bogs; *see* Peat
*Bolodon*, 341
*Bolosaurus*, 320
Bombs, volcanic, 169
Bone-beds, 176, 330, 408
Bone-breccia, 176
Bone-caves, 65, 101, 176, 408, 411, 412
Bononian, 346
Bosses, 225, 226*, 227*
Boulder-clay, 397, 399, 405
Bracheux, sands of, 373
"Brachiopods, Age of," 273
Brachiopods, fossil, 273*, 282, 283, 294*, 308, 309*, 318*, 334, 352, 390*
*Brachymetopus*, 308
Bracklesham Beds, 373
Bradford Clay, 342
Brahmaputra, delta of, 86
*Bramatherium*, 394
*Branchiosaurus*, 320*
Breakers; *see* Waves
Breaks in stratigraphical succession, 247
Breccia, Brecciated, 164, 165*, 169
Brick-clay, 168
Brick-earth, 20*, relics of man in, 407
Bridger group, 374
Brienz, Lake of, once filled by a glacier, 403
Britain, progress of sand-dunes in, 21, amount of dissolved mineral matter removed annually from parts of, 29, lake-marl of, 53, salt and gypseous deposits in, 55, landslips in, 58, 59*, 60, caverns of, 61, glaciation of, 73*, 74, 79, 397, 403, force of breakers on coasts of, 80, 83*, waste of coast-line of, 82, gain of land in, 87, former volcanic action in, 106, 112, 232, 268, 276, 288, 301, 316, 376, 377, volcanic dust from Iceland transported by winds to, 113, fissure-eruptions in, 120, pitchstone of, 181, trachyte of, 182, curved strata in, 213*, 214*, cleaved strata in, 217; lines of great fault in, 219, 220*, dykes crossing faults in, 233*, fossil scorpions of, 240, 304*, pre-Cambrian rocks of, 260, Cambrian rocks of, 274; Silurian rocks of, 276, 285, 286, Devonian system in, 287, 295, Old Red Sandstone of, 288, Carboniferous system in, 296, 301, 312, Permian rocks of, 314, 316, 320, Trias of, 323, 329, Jurassic system in, 341, Tertiary formations of, 367, Eocene of, 373; Oligocene of, 376, 377; denudation of, in Tertiary time, 384; Pliocene of, 391, Pleistocene

of, 397, 398, 403; Recent formations of, 406, 407
Brittle-stars, 281
*Bronteus*, 292*, 293
*Brontosaurus*, 340
*Brontotherium*, 380
Bronze, implements in peat-bogs, 412
Bronzite, 184, 186
Brooks, transport of soil by, 22, chemical action of, 27, 28*, mechanical action of, 29
Brown coal, 175, 376, 379
Brown, colour, cause of, in rocks, 132, 144, 167
Brown iron-ore, 143, 173
Bruxellian, 373
Buckthorn, fossil, 351, 388
Buhrstone, 374
Bunter group, 329
Burdigalian stage, 385
Burrows of worms, 92, 237, 281
Butter-cup fossil, 388
Buttes or rock-masses left by subaerial waste, 23*

Cactus, fossil, 368
Caen-stone, 344
Caffer cat, fossil, 409
Caileasses, 373
Cainozoic formations, place of, in Geological Record, 257, account of, 365
Cairngorm stones, 142
*Calamites*, 289, 302*, 317
Calc-sericite-schist, 190
Calc-silicate-hornfels, 188
Calc-sinter, formation of, 65, preservation of remains of plants and animals in, 66, 101, 408
Calcaire de la Beauce, 378
Calcaire de la Brie, 379
Calcaire-grossier, 373
Calcareous Tufa; *see* Tufa
*Calceola*, 293*
Calciferous group, place of, in Geological Record, 257, 286
Calcification of organisms, 242
Calcite, 138*, 149, 150*, 156; in mineral veins, 234
Calcium, in earth's crust, 129, 132
Calcium-carbonate; *see* Lime, Carbonate of
Calcium-sulphate; *see* Gypsum
*Callipteris*, 317*, 318, 322
*Callutis*, 369
Callovian, 342, 344
*Calymene*, 281
*Calymmatotheca*, 301
*Camarophoria*, 318*
Cambrian system, place of, in Geological Record, 257, formations described, 267, origin of name, 267
Camels, fossil, 380, 387, 394
*Camptomus*, 357
Camptonite, 181
Canada, frozen rivers of, 69; coast-ice of, 69, ancient ice-sheets of, 74, 79, 399, Archæan rocks of, 262; Cambrian rocks of, 275, Silurian rocks of, 285; Devonian and Old Red Sandstone of, 288, 289, 295; Carboniferous system in, 299, Permian system of, 321, Trias in, 331, Jurassic rocks in, 346, Cretaceous rocks of, 363, older Tertiary formations in, 379, Pleistocene deposits in, 403
*Cancellaria*, 385, 392
*Canis*, 401
Cañons, erosion of, 36, 37*
*Capsina*, 353
Caradoc group, place of, in Geological Record, 257, 286
Carbon in earth's crust, 129, 134, 137
Carbon-dioxide, 134, proportion of, in the atmosphere, 134, solubility of, in water, 134
Carbonates, formed by rain-water, 14, oxidation and precipitation of, 17, in saline lakes, 55, 56, solution of, by percolating water, 61, alkaline, 133, 134, in the earth's crust, 137, 149
Carbonic acid, influence of, in weathering, 14, action of, in solution of carbonates, 61, 95, 96, composition of, 134
Carboniferous Limestone, 257, 296, 305, 312
Carboniferous system, place of, in Geological Record, 257, account of, 296
Carbonisation of plants, 241
*Cardiaster*, 358

*Cardioceras*, 336*, 342
*Cardita*, 385
*Cardium*, 326, 327*, 377, 385, 391, 392
Carnallite, 330
Carnivores, fossil, 372, 377, 380, 383, 390, 394
*Carpinus*, 369
*Carpolithes*, 303*
*Carya*, 388
*Caryocaris*, 282
Cassia, fossil, 351
*Castanea*, 369
Casts and moulds of organisms in rocks, 241*
Cat, fossil, 383, 390, 409
Catskill group, place of, in Geological Record, 257, 295
Cauda-galli grit, 295
*Caulopteris*, 318
Cave-bear, 410
Cave-earth, human relics in, 408
Caverns, formation of, in limestone, 61, 62*; sometimes hollowed out by the sea, 80, 84*, preservation of animal remains in, 408, 410, 411
Cellular structure, 107*, 108, 109*, 160
Cellulose of plants, 239
Celts, Palaeolithic, 408*; Neolithic, 411*
Cement-stone, 342, 343
Cementation of sediment, 207
Cenomanian stage, 358, 360
*Cephalaspis*, 246, 284, 290, 291*
Cephalopods, early fossil, 274, 283, 285*, 294*, 295, 310*, 319, 326, 336*, 354*, 355
*Ceratiocaris*, 282, 283*
*Ceratites*, 326, 327*
*Ceratodus*, 290, 327
*Ceratophyllum*, 391
*Cerithium*, 342, 369*
*Cervus*, 246, 401
*Ceteosaurus*, 340
*Chæropotamus*, 377
*Chætetes*, 306
Chalcedony, 142*
Chalk, 174, 361
Chalk formation, 348, 357, 360, 361, 368
Chalk-marl, 360
Chalybeate springs, 67, 153
Chalybite, 150
*Chama*, 370, 394
Chamærops, 369
Champlain series, 404
Chattahoochee stage, 386
Chazy group, place of, in Geological Record, 257, 286
*Cheirodus*, 305
Chemung group, place of, in Geological Record, 257, 295
Chert, 142, 176
Chestnut, fossil, 369
Chiastolite-slate, 188, 227
Chickweed, fossil, 388
Chilled edge of intrusive rocks, 183, 228, 232
Chillesford Clay, 391
China-clay, 147
Chipola stage, 387
Chitin, preservation of, 240
Chlorides, 118, 129, 137, 152 329
Chlorine in earth's crust, 129, 136
Chlorite, 149
Chlorite-schist, 190
Chloritic Marl, 360
*Chondrites*, 277*
*Chonetes*, 293, 308
Chromic-iron, 186
*Chrysodomus*, 390*
Chrysotile, 186
*Cidaris*, 334
*Cimolestes*, 357
*Cimolisasaurus*, 357
*Cimolomys*, 357
Cincinnati group, place of, in Geological Record, 257, 286
*Cinnamomum*, 350*, 369, 379, 388
Cipollino, 189
Civet, fossil, 377
*Clænodon*, 374
Clastic, definition of, 155; rocks, 164
*Clathropteris*, 325
Clay, composition of, 131, 145, 147, kinds of, 168; red, as an oceanic deposit, 88, associated with limestone, 200
Clay-ironstone, 151*, 156*, 173, 176, 194, 199; as a petrifying medium, 243
Clay-slate, 187

Clayborne group, 374
Clear Fork group, 322
Cleavage in minerals, 138*, in rocks, 168, 187, 215, 217*
*Cleidophorus*, 283
Cliff-debris, 164
Climate indicated by fossils, 237, 244, 266, 369, 385, 390, 395, 400, uniformity of, in Palæozoic ages, 266, in Mesozoic time, 332, 351, in Tertiary time, 366, 368, 369, 385, 390, 394, in Post-tertiary time, 395, 396, 400, 403, 409
Clinometer, 210*
Clinton group, place of, in Geological Record, 257, 286
*Clisiophyllum*, 306
Club-mosses, fossil, 277, 289, 301*
*Clymenia*, 294*, 295
Coal, composed mainly of carbon, 134, varieties of, 175, mode of formation of, 194, 298
Coal-gas, 135
Coal-measures, place of, in Geological Record, 257, account of, 312
Coblentzian, place of, in Geological Record, 257, 295
*Coccosteus*, 290
*Cochliodus*, 311
Cockroaches, fossil, 284, 304, 337
Cod, fossil, 379
Coleoptera, 337, 383
Colorado River, grand cañon of, 37*, 38
Columnar structure, 184, 185*
Compression, effect of, on rocks, 209, 214*
Conchoidal fracture, 180
Concretionary, definition of, 156, structure in minerals, 141, 150, 151*, 155*, in rocks, 199
Conemaugh series, 313
Conformability, 204
Conglomerate, 165, 166*, 194, schistose, 189, not associated with shale, 200, local character of, 201
Coniferæ, fossil forms of, 289, 303, 318, 323, 325*, 332, 351, 368, 369, 376, 382
Coniston grits, 286
*Conocoryphe*, 274
Contact metamorphism, 187, 188, 226, 227*, 228, 232, 234
Contemporaneous sheets, 229
Continents, evolution of the, 265, 284, 296, 366
Contortion of strata, 214*, 215*
*Conularia*, 310*
*Conus*, 370, 377
Copper-ores, 321
Coprolites, 156*, 176, 240, 305
Coral-reefs, 97*, 123, 173, 174, 295, 296, 331, 333*, 345
Corallian stage, 342, 345
Coralline Crag, 392
Corals, fossil, 279*, 293*, 306*, 318, 333*, 345
*Corbula*, 377*
*Cordaites*, 303*
Cornbrash, 342, 344
Cornifelous group, place of, in Geological Record, 257, 295
*Corylus*, 369
*Coryphodon*, 371, 374
Coryphodon Beds, 374
Cosmic dust, 131
*Cosmoceras*, 336*, 337
Cotham stone, 330
Cotoneaster, fossil, 369
Crabs, fossil, 337
Crag, 391
Cranes, fossil, 377
*Crania*, 335
Crater, volcanic, 105, 114
Cray-fish, fossil, 337
Credneria, fossil, 351
Creodonts, 374, 380
Cretaceous system, place of, in Geological Record, 257, account of, 348
Crevasses, 71
Crickets, fossil, 304
Crinoids, fossil, 271, 280, 293, 296, 306, 307*, 318, 326*, 334*
Crinoidal limestone, 174, 175*, 306
*Crioceras*, 354*
Crocodiles, fossil, 328*, 357, 370, 383
Crushing of rocks, 221, 260
Crust of the earth, defined, 103, 254; elements composing, 128, sedimentary rocks of, 192, general arrangement of, 255

Crustacea, fossil, 271, 272*, 281, 282*, 283*, 292*, 293, 307*, 337*, chitin of, 240
*Cryphæus*, 293
Crystalline structure, definition of, 158, superinduced in calcareous materials by infiltrating water containing dissolved carbonic acid, 64, 95, 98, 170, of lavas, 107, 108, conditions for development of, 141, 158, 233, types of, 159, in regional metamorphism, 221
Crystallites, 158, 159*, 169, 180, 217
Crystals, geometrical forms of, 138, gas and other inclusions in, 158*, 160, zones of growth in, 160
*Ctenacodon*, 341
*Ctenodonta*, 273, 282
Cubical system in crystallography, 139*
*Cucullea*, 294*, 295
Culm series, 312
*Cupressocrinus*, 293
*Cupularia*, 392
Current-bedding, 42*, 195
Curvature of strata, 212*, 214*, 215*
"Cutters" in quarrying, 208
Cuttle-fishes, 274
*Cyathaxonia*, 279
*Cyathocrinus*, 293, 306, 318
*Cyathophyllum*, 279, 293*
Cycads, fossil, 246, 303, 318, 323, 325*, 332, 333*, 350
"Cycads, Age of," 326
*Cycadeoidea*, 333*
*Cycadites*, 332
*Cyclolobus*, 319
*Cyclopteris*, 325
*Cynodictis*, 380
*Cypræa*, 385
Cypridina-shales, 295
*Cypris*, 308
*Cyrena*, 370, 377
*Cyrtia*, 293
*Cyrtoceras*, 274, 283, 295, 319
Cystideans, 246, 271, 280*
*Cystiphyllum*, 293
*Cytherea*, 370, 385

Dacite, 182
*Dactylioceras*, 336*
*Dadoxylon*, 303
*Dalmania*, 292*, 293
Dalradian, place of, in Geological Record, 257, described, 261
Danian stage, 357, 362, 365
*Dapedius*, 327, 337
*Daphænos*, 380
Darton, Mr. N. H., photographs by, 23*, 375*
Darwin on action of earth-worms, 19, on coral reefs, 123
*Dasornis*, 370
*Dawsonia*, 320
Dead Sea, 55, 173
Decalcification of organisms, 242
Deep River stage, 387
Deer, fossil, 271, 383, 390, 391
Deer, Irish, 410, 411
Deformation of rocks, 190, 191, 216, 260
Deinoceras Beds, 374
Deinocerata, 246, 372, 374, 380
Deinosaurs, 328, 339, 356*
*Deinotherium*, 383, 384*, 389, 394
Deltas in lakes, 51, in the sea, 86, preservation of animal remains in, 100, relics of ancient, 358
*Deltatherium*, 374
Denbighshire Grits, 286
*Dendrerpeton*, 305
Dendrites, 145*
*Dendrocrinus*, 280
Denudation, effects of, 204*, 225, 231*, 233*, 384, 406, rate of, 28 (*see* Weathering, Rain, Springs, Rivers, Glaciers, Sea)
Deserts or sand-wastes, 22, 166
Desiccation, influence of, in weathering, 13
Devitrification, 108, 159*, 169, 177, 180, 183
Devonian system, place of, in Geological Record, 257; description of, 287; disturbance of rocks of, 300
Diabase, 184, altered into amphibolite, 190
*Diadectes*, 320
*Diadema*, 334
Diallage, 148
Diamond, 134
Diatom earth, 94*

Diatoms, secretion of silica by, 94, 240, 361
Diceratids, 353
Dicotyledons, fossil, 350, 360
*Dictyograptus*, 270*
*Dictyonema*, 270*
*Dicynodon*, 328
*Didelphops*, 357
*Didelphys*, 380
*Didymograptus*, 278*
*Dielasma*, 308
Diestian, 392
*Dikelocephalus*, 274
Dimetric system in crystallography, 139*
*Dimorphodon*, 339
Dinantian series, 312
*Dinichthys*, 290
*Dinornis*, 370
Diopside, 148
Diorite, 181, altered into amphibolite, 190, into hornblende schist, 222
Dip of strata, 209, 210*, 211*
Dip-joints, 208
Diplacodon Beds, 374
*Diplograptus*, 278*
*Diplomystus*, 356
*Diplopterus*, 289
*Diplurus*, 327
*Dipterus*, 290
Dirt Beds, 346
*Discina*, 305, 308, 335
*Discinocaris*, 282
*Discinopsis*, 273
Dislocation of strata, 217, 220*
Distortion of rocks, measurement of, 215, 216*
Dock, fossil, 388
Dog, fossil, 377, domesticated, 412
Dogger, or Brown Jura, 343
Dogwood, fossil, 351
Dolerite, 184, altered to amphibolite, 190
Dolomite, 133, 150, 171, 172*, 315, 324; metamorphism of, 189
Dolphin, fossil forms of, 383
*Dorygnathus*, 339
Double Mountain group, 322
*Douvilleiceras*, 358
Dragon-flies, fossil, 304, 337
Drainage, affected by earthquakes, 122
*Dromatherium*, 329
Drusy cavity, 147*
*Dryolestes*, 341, 357
*Dryopithecus*, 383
Dunes, 21, 22*, 166, protected by vegetation, 92
Dunite, 186
Dust, transport of, by wind, 18, 21 cosmic, 89, 132
Dyas, 315, 320
Dykes, 118, 119*, 232, 233*, 234

Eagles, fossil, 377
Earth, history of the, 4, 7, 8, 10, 251, crust of, 103, 254, condition of interior of, 103, 104, 254, internal heat of, 104, 254, continued loss of heat by, 105, tremors of, 121, earliest condition of, 252; density of, 254, form of, 254; former greater velocity of rotation of, 254
Earth-tremors, 121
Earthquakes, effects of, 2, 121, 122; causes of, 121
Earthworms, influence of, upon soil, 16, 19, 92
*Echinoconus*, 352*
Echinoderms, fossil, 271, 280*, 307*, 326*, 334*, 352*
Eclogite, 191
Edentates, fossil, 374, 394
*Edmondia*, 309
Egeln Beds, 379
Eifelian, 295
Elæolite-syenite, 181
Elasmobranch fishes, 289
Elements, simple, in earth's crust, 128
Elephant, fossil forms of, 246, 379, 382, 389, 391, 392, 393, 394, 400, 402*, 407
Elevation of land, influence of, on rivers, 44; proofs of, 123, 402
Elk, 411
*Ellipsocephalus*, 272*
Elm, fossil, 369, 382, 388
*Elotherium*, 380
*Empedias*, 320
Enaliosaurs, or sea-lizards, 338*

Encrinite-limestone, 174, 175*, 306
*Encrinurus*, 281
*Encrinus*, 326*
Enstatite, 148, 184, 186
Enstatite-picrite, 186
Eocene definition of term, 367, formations, place of, in Geological Record, 257; account of, 368
*Eohippus*, 371
*Eophyton*, 269*
*Eoscorpius*, 304*
*Eozoon*, nature of, 260
Ephemera, fossil, 289
Epidiorite, 190
*Epihippus*, 374
Equisetaceæ, fossil, 301, 302*, 325*, 332
*Equisetum*, 325*
*Eremopteris*, 300*
Erosion, base-level of, 38, 85; by weathering, 22, 23*, by running water, 32, by glaciers, 76, by the sea, 84*, extremely slow in river-action, 406
Erratic-blocks, 72*, 73*, 76*, 397, 404
Eruptive, definition of, 158; rocks, 176, 224
Eskers, 404
Etna, 119, beginning of activity of, 388
*Eucalyptus*, 369
*Euchirosaurus*, 321
*Euomphalus*, 310*
Eurite, 179
Europe, composition of water of rivers of, 28; sediment carried by rivers of, 30, 31, mean height of, 32; former glaciers of, 74, 395, 397, 398, 402, 403; peat-bogs of, 93, 411, 412, disappearance of forests of, 100, bone-caves of, 101, 408; extinct volcanoes of, 106, fissure-eruptions of, 120, lacustrine formations of, 243, mean thickness of fossiliferous rocks of, 256, pre-Cambrian rocks of, 260, oldest topography of, 201, Cambrian of, 275; Silurian rocks of, 276, 285, Devonian system in, 287, 295; Carboniferous system, 296, 312; Permian system in, 314, 316, 320; Trias of, 323, 329; Jurassic system in, 332, 341-346, Cretaceous system in, 348, 357, 358, Tertiary formations of, 367, Eocene of, 372, Oligocene of, 375, Miocene of, 384, Pliocene of, 391; Pleistocene of, 395, recent deposits of, 406
Eurypterid crustacea, 291, 292*, 293, 308, 337
Evergreen oak, 376, 382, 388
*Exogyra*, 335, 353

*Fagus*, 369
Fairy stones, 155*, 199
False-bedding, 195, 196*
Faluns of Touraine, 385
Famennian, place of, in Geological Record, 257, 295
Fan-palms, fossil, 369, 376
*Fascicularia*, 392
Fault-rock, 217
Faults, 217, 218*, 219*
*Favosites*, 279, 306
Feather-palms, 376
*Felis*, 402
Felsite, 179, 180
Felsitic, 159
Felspars, 145, 177
Felted structure (in Andesite), 182
*Fenestella*, 308*, 318
Ferns, fossil, 277, 289, 300*, 425, 332, 351, 368
Ferric oxide, 132
Ferro-magnesian minerals, 179
Ferrous carbonate, 150
Ferrous oxide, 132, 150
Ferruginous minerals, decomposition of, by organic matter, 17
Fibrous structure in minerals, 141
*Ficus*, 350*, 369, 382*, 388
Fig, fossil, 350*, 369, 382*, 388
Fir, fossil, 391, in Danish peat-bogs, 412
Fireclay, 168, 194, represents former soil, 298
Fishes, fossil, 284, 289, 290*, 291*, 305, 310, 311*, 319*, 321, 327, 337, 355*, 370; sudden destruction of, 291
Fissure-eruptions, 119
Fissures, volcanic, 113, 118, 232;

caused by earthquakes, 122; filled by mineral veins, 234, reopening of, 236
Fjords, 51
Flamingoes, fossil, 377
Flammenmergel, 360
Fleckschiefer, 188
Flint, 142, 176, 199, 361
Flint-implements, 408*, 411*, found under London, 3
Flood-plain of a river, 44
Flow structure, 161*, 162, 180
Fluid-cavities in crystals, 158*
Fluor-spar, 136, 139, 153*, 234
Fluorides, 137, 152
Fluorine in earth's crust, 129, 136
Fluvio-marine Crag, 302
Fluxion-structure, 161*, 162, 180
Flysch, 373, 379
Foliated structure, 162, 186
Fontainebleau Sandstone, 378
Footprints in sedimentary rocks, 196, 327, 328
Foraminifera, in diatom-ooze, 94*, ooze formed of, 96*; fossil forms of, 278, 305, 306*, 351*, 370
Forest-Bed group, 391
Forest Marble, 342
Forests, cause of decay of, 18, protective influence of, 92, disappearance of, 100
Formation in stratigraphy, 248
Fossanian group, 393
Fossilisation, 99, 240
Fossils, definition of, 237, nature and use of, 237, as guides to former geographical conditions, 243, 296; as an indication of former climates, 237, 244, 266, 369, 385, 390, 395, 400, in relation to geological chronology, 245
Fox, fossil, 391, 401, 409
Fragmental, definition of, 155; rocks, 164
Frasnian, place of, in Geological Record, 257, 295
Freestone, 167
Frogs, fossil, 383
Frost, destructive effects of, 2; influence of, in weathering, 13, on rivers and lakes, 69
Fruchtschiefer, 188
Fucoids, fossil, 269, 277
Fuller's Earth, 342, 344
Fundamental Gneiss, place of, in Geological Record, 257
*Fusulina*, 305, 306

Gabbro, 183, altered into amphibolite, 190
Gaize, 360
Gale, effects of a, 1
Galena, 235
*Galerites*, 352*
*Gangamopteris*, 322
Ganoids, fossil, 289, 290,* 305, 311*, 319*, 327, 337
Garbenschiefer, 188
Garnet, 188, 191
Gas enclosed in crystals, 158
Gasteropods, fossil, 273, 283, 310
Gault, 358, 359
Gazelles, fossil, 390, 394
Gedinnian, place of, in Geological Record, 257, 295
Genesee group, place of, in Geological Record, 257, 295
Geneva, Lake of, 34, 49
Geographical conditions indicated by fossils, 237, 243
Geological history, materials for, 3, 4, 5, 10, 124, breaks in, how marked, 205, use of fossils in, 238
Geological Record, 247, 251, 255, 256; continuity of, 413
Geology, scope of, 4, 6, 8, 251, based on observation, 8, 9
Georgian series, place of, in Geological Record, 257, 275
*Gervillia*, 335
Geysers, 67, 173
Giants' kettles, 78*
Gilbert, Mr. G K., on laccolites, 226, photographs by, 52*, 74*, 200*
Ginkgo, fossil, 332, 369
Giraffes, fossil, 385, 390, 394*
Givetian, 295
Glacial deposits, their place in the Geological Record, 256, described, 396
Glaciation, 72*, 75*, 76*, 78; of the northern hemisphere, 395

Glaciers, 70; transport by, 71*, striation of rock by, 75*, 76*, erosion by, 76, 77; former greater size of, 396, 402; diminution of, since the Ice Age, 402
Glass, volcanic, 107, 140, 158, 159, 169, 177, 180, 181, 232
Glauconite, 149, as a green colouring material, 167
Glauconitic Marl, 358, 360
*Gleichenia*, 351
*Globigerina*, 96*, 351*
*Glossopteris*, 322, 325
Glutton, fossil, 391, 401, 409
*Glypticus*, 334
*Glyptocrinus*, 280
*Glyptolæmus*, 289
*Glyptostrobus*, 388, 389*
Gneiss 191, 258, intrusive, 260
Goat, fossil, 394, domesticated, 412
Gold, 137
Gondwána series, 316
*Goniatites*, 295, 305, 310*
*Goniopholis*, 357
Gorges eroded by rivers, 35*
Granite, decay of, into soil, 15*; an eruptive rock, 158; holocrystolline structure of, 159, 178, description of, 178*; varieties in character of peripheral parts of, 179, 182, metamorphism by, 188, metamorphosed into gneiss, 222; bosses of, 226, 227*
Granitic type of rocks, 177
Granitite, 179
Granitoid (like granite), 181, 182, 183
Granophyre, 179
Granulite, 191
Graphic structure, 179
Graphite, 134
Graphite-schist, 260
Graptolites, 246, 270*, 278*, 279, 292
Grasshopper, fossil, 337
Gravel, geological history of, 4, 165, limited extent of, 201
Green colour, origin of, in some rocks, 132
Greensand, Upper, 360, Lower, 258, 359
Greenstone, 182
Greywacke, 167, 187; as the name of a series of rocks, 267
*Griffithides*, 308
Grit, 167, schistose, 189
Grizzly bear, 411
Grottoes, subterranean, cause of, 64
Ground-ice, 69
Ground-mass (in rocks), 159, 177, 182, 184
Group (in stratigraphy), 248
Grouse, fossil, 377
*Gryllidæ*, fossil, 304
*Gryphæa*, 335*
Gryphite Limestone, 335
Guano, 176
*Gulo*, 401
Gum-tree, fossil, 351, 369
Gypsum, in sea-water, 28 *note*; in river-water, 29, in salt lakes, 55; composition of, 129, crystalline form of, 140, 151, 152*, composition and occurrence of, 151; solubility of, 151; as a rock-former, 170, 171, 315, 321, 322, 324, 329
*Gyracanthus*, 305
*Gyrolepis*, 327

Hade of a fault, 218*
Hæmatite, 143*, 173, formation of 17
Halite, 152
*Halobia*, 326
*Halysites*, 279
Hamilton group, place of, in Geological Record, 257, 295
*Hamites*, 354*
Hamstead group, 378
Hardness in water, cause of, 132
Hare, fossil, 409
Harlech group, 275
*Harpes*, 292*
*Harpoceras*, 337
Hastings Sand, 359
Hauterivian, 359
Hazel, fossil, 369, 391
Headon group, 378
Heavy spar, 136, 151
Hedenbergite, 148
Hedgehogs, fossil, 371
Heersian Beds, 373
Helderberg group, place of, in Geological Record, 257, 286, 295

*Helicoceras*, 354*
*Heliolites*, 279
*Heliopora*, 279
*Helix*, 377
Helix-limestone, 378
*Helladotherium*, 394*
Helvetian stage, 385
*Hemicidaris*, 334
Hemicrystalline structure, 159
Herring, fossil, 379
*Hesperornis*, 357
*Heterosuchus*, 357
Hettangian, 342
Hexagonal system in crystallography, 139*
Hickory, fossil, 387, 388
Hill, Mr R T., photograph by, 116*
*Hipparion*, 393
*Hippopodium*, 335
Hippopotamus, fossil, 383, 389, 391, 392, 394, 402, 407, 409
Hippurite limestone, 355, 357, 358, 360, 361, 362
*Hippurites*, 246, 353*
Hog, fossil, 380, 387, domesticated, 412
*Holaster*, 352, 358
Holland, great Pliocene subsidence in, 392
Holocrystalline structure, 159, 177
*Holopea*, 283
*Holoptychius*, 289, 290*
*Homalonotus*, 281, 282*, 292*, 293
Honestone, 188
*Hoplites*, 358
*Hoplopterix*, 355*, 356
Horizon in stratigraphy, 247
Hornbeam, fossil, 369, 382
Hornblende, 140, 148*
Hornblende-andesite, 182
Hornblende-diorite, 182
Hornblende-picrite, 184
Hornblende-rock, 190
Hornblende-schist, 190; produced by the crushing of diorite, etc, 222
Hornfels, 188, 227
Hornwort, fossil, 391
Horse (*Equus*) characteristic of younger Tertiary and Recent rocks, 246; ancestral forms of, 371, 383, 387; fossil, 390, 391, 394, 410, domesticated, 412
Horse-tail reeds, fossil, 301, 302*, 325*
Hudson River group, 286
Huerfano group, 374
Human Period, 405
Humous Acids *see* Organic Acids
Humus, origin of, 15
Huronian, place of, in Geological Record, 257, rocks described, 262
*Hyænarctos*, 383
Hyænas, fossil, 246, 390, 391, 394, 402, 408, 409
*Hyænodon*, 380
Hyalomelan, 183
*Hybodus*, 327, 337, 356
Hydraulic limestone, 171
Hydrocarbons, 135
Hydrochloric acid, 135
Hydrogen in earth's crust, 129, 135
Hydrosphere, 253
Hydrozoa, fossil, 246, 270*, 278*, 279, 292
*Hymenicaris*, 272, 274
*Hyolithes*, 274
*Hyopotamus*, 371, 377, 380
*Hyopsodus*, 374
*Hyperodapedon*, 328
Hyperite, 183
Hypersthene, 148
Hypersthene-andesite, 182
Hypogene, definition of, 158, 177
*Hyracotherium*, 374
*Hystrix*, 402

Ibis, fossil, 377
Ice, transport of boulders by, 69, 72, 396, 399, striation of rock by, 75*, 76*, 396, erosion by, 76
Ice Age, history of the, 396
Ice-sheets, 70, 396-404
Iceland-spar, 138*, 149
Ichthyodorulite or fish-spine, 311*
*Ichthyornis*, 357
Ichthyosaurs, 246, 328, 338*, 347, 356
Idiomorphic crystals, 177
Igneous, definition of, 158, rocks, 176
*Iguanodon*, 356
Ilex, fossil, 351, 388
*Illænus*, 281, 282*

Ilmenite, 144
Imagination, use of, in geology, 194
Implements, human, in Palæolithic deposits, 405, 406, 408*; in Neolithic deposits, 410, 411*
Inclination of strata, 209
India, coast-lagoons and bars of, 86, extinct volcanoes of, 106, Cambrian rocks of, 275, Silurian rocks of, 285; Permian rocks of, 316, Trias of, 331; Jurassic rocks in, 344, 346; Cretaceous rocks of, 362, Eocene of, 373, Miocene of, 381, Pliocene of, 394
Infusorial earth, 93
*Inoceramus*, 353*, 364
Insect-beds, 337
Insectivores, fossil, 374
Insect in amber, 239, 240, preservation of chitin of, 240, fossil forms of, 289, 304, 330, 337, 346, 382
Interglacial periods, 400
Intermediate rocks, 181
Intrusive sheets, 228*
Irish deer, 410, 411
Iron, in earth's crust, 129, 131, as a colouring matter in nature, 132, 167; titanic, 133, 144, spathic, 150, disulphide, 153; chromic, 186; meteoric, in abysmal deposits, 89, specular, 118, implements in peat-bogs, 412
Iron-carbonate, 150, 151*, 156*, 173
Iron-oxide, deposited in lakes and bogs, 54, 91, in chalybeate springs, 67, in earth's crust, 131, 132; formation of, 130, varieties of, 143
Ironstone, 173, 175, associated with clays and shales, 200
*Isastræa*, 333*, 334
*Ischyromys*, 380
Isometric system in crystallography, 139*
Ivy, fossil, 351

Jackson group, 374
Jasper, 142
Jaws, lower, frequent as fossils, 100, 341, 346
Jelly-fish, fossil moulds of, 239
Jerboa in loess, 409
John Day stage, 387
Joints of rocks, 207
*Juglans*, 350*, 369, 388
Juniper, fossil, 351
Jura, Black, 343; Brown, 343, White, 344
Jurassic system, place of, in Geological Record, 257, account of, 332

Kames, 404
Kaolin, 147, 168
Kellaways Rock, 342, 344
*Kepplerites*, 342
Kersantite, 181
Keuper group, 329
Keweenawan, place of, in Geological Record, 257, rocks described, 263
Kimmeridgian, 342, 345
King-crabs, fossil, 308
Kirkby Moor Flags, 286
Knotted slate, 188
Kupferschiefer, 319, 320, 321
*Kutorgina*, 273, 274, 275
Kyanite, 191

Labradorite, 146
Labyrinthodonts, 305, 319, 327
Laccolite, 226
Lacustrine deposits, 4, 50*, 51*, 52*, 53*, 54, 92, 93*, 100, 110, 112, 243, 287, 375, 378, 379, 384, 386, 403, 412
Laekenian, 373
Lago di Garda, wave-action at, 52
Lagoon-channels at coral-reefs, 98
Lagoons on coasts, 86, at coral-reefs, 98
Lakes, disappearance of, 2; filter river-water, 33, 48; of fresh water, 48, silting up of, 48, 49, 51, 93; terraces of, 49*; deposits in, 4, 50*, 51*, 52*, 53, 54, 92, 93*, 100, 112, 243, 287, 368; formed by ice-dams, 50, 403, shell-marl of, 53*, 93*, iron-ore formed in, 54, 144; of salt-water, 55, 173; bitter, 55, frozen, 69, preservation of remains of animals in, 100, 243, 411, evidence for former, 110, formed by earthquakes, 122; earliest traces of, 287, Cretaceous, 368, Tertiary, 375, 378, 379, 384, 386; glacial, 403

Lamantin, fossil, 383
Lamellibranchs, fossil, 273, 284*, 294*, 309*, 319*, 326, 327*, 335*, 353*, 377*, 390*, 401*
Laminæ, 194
Laminated structure, 195
Lamination of shale, possibly sometimes a kind of cleavage-structure, 168, 216
*Lamna*, 370
Lamprophyre, 181
Land, weathering of surface of, 11, 12*, 15, 22, 23*, 27, 28*, 31; rate of lowering of surface of, 31, average general height of, 31, elevation and subsidence of, 123, earliest known, 265, ancient northern, 285
Landscape, changes of, 1, 22
Land-shells, earliest known, 266
Landslips, 58, 59*, 60, 122
Land-snails, fossil, 289, 304
Land-surfaces, traces of former, 196; evidence for, 298
Landenian gravels, 373
Langhian stage, 385
Lapilli, 169
Laramie group, 363
Laurel, fossil, 350, 369, 376, 379, 382, 388
Laurentian, place of, in Geological Record, 257
*Laurus*, 369, 388
Lava, 105; characters of, 107, temperature of, 108; structure of sheets of, 108, original molten condition of, 146; an eruptive rock, 158, proofs of interstratified character of, 229*
Lead sulphide, 235
*Leda*, 400, 401*
Leda-myalis Bed, 391
Lemming, 409
Lemuroids, 374, 377
Lemurs, fossil, 371
Lenham Beds, 392
Leopard, 402, 409
*Leperditia*, 308
*Lepidodendron*, 246, 288, 301*, 317, 322
Lepidolite, 147
Lepidomelane, 147
*Lepidopteris*, 325
*Lepidostrobus*, 301
*Lepidotus*, 337
*Leptacerathenum*, 380
*Leptæna*, 282
Leptænids, disappearance of, 335
Leptynite, 191
*Lepus*, 409
Leucite, 146, 182, 184
Levant, dried water-courses of the, 38
Lewisian gneiss, place of, in Geological Record, 257, account of, 260
Liassic formations, 342
*Libellulæ*, fossil, 304
Life, uniformity of, in Palæozoic time, 266
Lignite, 175, 374, 376
Lignitic sands (Eocene), 374
Ligurian stage, 379
*Lima*, 335, 353
Limburgite, 184
Lime, carbonate of, in river-water, 28, 132, solution of, by springs, 60, 63, 132, precipitation of, 65, 66, composition of, 132, test for, 132, 150, 154, 171, composition of, 134, crystalline forms of, 138*, 149*, 150*; abundance of, in nature, 170, 240, eliminated by some aquatic plants, 239, as a petrifying medium, 242
Lime, sulphate of, 132, in river-water, 28, in springs, 132, 149, in sea-water, 132, 239 (*see also under* Gypsum)
Lime, phosphate of, 135, 152, 176, 240
Lime-tree, fossil, 386
Lime-silicate-rocks, 188, 189
Limestone, solution of, by water, 27, 61, 63; formed by rain out of calcareous sand, 95, 166; formed of recent marine shells, 95*, 96, 97, abundant in nature, 135, chiefly of animal origin, 135, 149, 170, 174, 296; formed by chemical precipitation, 170; alteration of, 188, formation of, from animal remains, 194; associated with clays, 200, slow growth of, 201,

proofs of subsidence of sea-floor furnished by, 296; made of calcareous organisms, 305, formed of ostracods, 308, formed of polyzoa, 308, gryphite, 335
*Limnæa*, 377
*Limnerpeton*, 320
Limonite, 17, 144, 173, 176
*Lingula*, 273, 305, 308, 335
Lingula-flags, 272, 273
*Lingulella*, 273*
Linton Slates, 295
Lion, fossil forms of, 379, 383, 387, 402, 409
Liparite, 180
*Liparoceras*, 336*
Liquidambar, fossil, 369, 388
*Liriodendron*, 388
Lithosphere, 254
*Lithostrotion*, 306*
*Lituites*, 283, 285*
Lizards, fossil, 383
Llandeilo group, place of, in Geological Record, 257, 286
Llandovery group, place of, in Geological Record, 257, 286
Loam, 168; origin of, 17
Lobsters, fossil, 337
Locusts, fossil, 304
Loess, 169, 409
London, geological records of the history of, 3
London Clay, 373
Longmyndian, place of, in Geological Record, 257, rocks of, 262
*Lonsaldeia*, 306
*Lophiodon*, 380
Loup Fork stage, 387
*Loxomma*, 305
*Loxonema*, 310
Ludian, 373
Ludlow rocks, place of, in Geological Record, 257, 286
*Ludwigia*, 342
*Lumbricaria*, 281*
Lutetian, 373
Lycopods, fossil, 277, 301*
Lydian-stone, 187
Lyell, Tertiary classification of, 367
*Lygodium*, 368
Lynx, 402, 409
*Lytoceras*, 337, 342
Macaque, fossil, 394
*Machairodus*, 383, 391
Mackerel, fossil, 379
Macles, 151, 152*
*Maclurea*, 273, 286
*Macoma*, 400, 401*
*Macrocephalites*, 342, 344
*Macrotæniopteris*, 325
Magma, 158, 169, 184
Magnesia, carbonate of, 170; sulphate of, 330
Magnesian limestone, 133, 150, 199, 320
Magnesian silicates, 133, 145
Magnesium in earth's crust, 129, 132
Magnesium-chloride in bitter lakes, 55; in sea-water, 153, precipitation of, 330
Magnetite, 139, 144,* 173
Magnolia, fossil, 351, 369, 379, 382*, 386, 388
Malm or White Jura, 344
Mammalia, fossil remains of, 328, 341, 357, 370*, 371*, 377, 383*, 384*, 394*, 402*, 410*
Mammaliferous crag, 392
"Mammals, Age of," 367
Mammoth, 400, 402*, 409, 410; carcases of, preserved in frozen mud, 240
Man, brief geological experience of, 124, earliest appearance of, 404, 405, proofs of presence of, 405, 406, 408*, 410, 411*; early carvings and incised drawings by, 410
Manganese in earth's crust, 129, 135; peroxide in abysmal deposits, 88, 102; association of oxides of, 144
Mangrove-swamps, 93, 194, 300
Maple, fossil, 350, 369, 379, 388
Maraboot, fossil, 377
Marble, 188; alteration of limestone into, 227; decay of, in large towns, 15
Marcasite, 153, 156
Marcellus group, place of, in Geological Record, 257, 295
Mare's-tail, fossil, 388
Marine organisms, special value of, in geological history, 238

Marl, history of lacustrine, 4, 53*, 92, 93*, 95, 174, 243
Marl Slate, 315
Marlstone (Lias), 343
Marmots, fossil, 377
Marnes de Pantin, 379
Marsh-marigold, fossil, 388
Marsupials, fossil, 328, 341*, 357
*Marsupites*, 357, 362
Martens, fossil, 377
Masonry, effects of weathering on, 11
Massive, definition of, 158
*Mastodon*, 246, 383*, 389, 392, 393, 394
*Mastodonsaurus*, 327
Mauch Chunk shales, 313
May-flies, fossil, 289, 304, 337
May Hill Sandstone, 286
Medina group, place of, in Geological Record, 257, 286
*Medlicottia*, 319
Medusæ, fossil, 239, 271
*Megaceros*, 410, 411
*Megalichthys*, 305
*Megalosaurus*, 340
*Megaptilus*, 304
*Melanerpeton*, 321
*Meniscoëssus*, 357
*Menyanthes*, 391
Merced group, 394
*Mesohippus*, 380
*Mesopithecus*, 394
Mesozoic, place of, in Geological Record, 257, 323
Messinian stage, 393
Metalloids, 129
Metals, 131
Metamorphic rocks, 186
Metamorphism, 163, 186, 216, 221, 226
Meteoric iron in abysmal deposits, 89, in meteorites, 132
Meudon, marls of, 373
Miarolitic structure, 178
Mica, 147, development of, in regional metamorphism, 221
Mica-andesite, 182
Mica-diorite, 182
Mica-schist, 189, 221, 222, 227
Mica-slate, 188, 189
Mica-traps, 181
Micaceous, 167
Mice, influence of, in the removal of soil, 19
*Micraster*, 352*, 362
Microcline, 146
*Microconodon*, 329
*Microdiscus*, 275
Microfelsitic, 159
Micrographitic structure, 179
Micrographic structure, 179
*Microlestes*, 328*
Microscope, use of, in the study of rocks, 155, 158, 180, 216, 233
Milfoil, fossil, 388
Millipedes, fossil, 289, 304
Millstone grit, place of, in Geological Record, 257, 312
Mimosas, fossil, 382
Minerals of earth's crust, 137, modes of origin of, 140, order of appearance of, in crystalline rocks, 146
Mineral-oil, 135
Mineral veins, 234, 235*
Minette, 181
Miocene, definition of term, 367
Miocene formations, place of, in Geological Record, 257; account of, 381
*Miodæmus*, 374
*Miohippus*, 380
Mississippian, 257
*Mitra*, 385
*Modiola*, 310
*Modioloides*, 273, 283
Molasse, 379
Moles, influence of, in the removal of soil, 19, 92; fossil, 377, 391
Mollusca, importance of, in geology, 272, as a basis of classification for the Tertiary formations, 367, as evidence of climate, 369, 385, 390
Monkeys, fossil, 383, 390, 394
Monoclinic system in crystallography, 140*
*Monograptus*, 278*
Monometric system in crystallography, 139*
Mononghela series, 313
Monopleurids, 353
*Monotis*, 326
Monotremes, fossil, 328*, 341, 357

Mons, limestone of, 373
*Montlivaltia*, 334
Moon formerly nearer to the earth, 254
Moraines, 71, 164, 399, 403, 405
Morasses; *see* Peat
Morse, fossil forms of, 383
*Mosasaurus*, 357
Moscovian series, 312
Mosses, precipitation of carbonate of lime by, 66, 94
Moulin pot-holes, 78*
Mountain-chains, of different ages, 123; relative age of, 205, successive uplifting of, 364, 366, 373, 381, 388
Mountain-limestone, 296
Mud, 168; wide area of deposit of, 201; unfavourable to many forms of marine life, 193, 230, 244
Mudstone, 168
Murchison on Silurian system, 267, 276; with Sedgwick named the Devonian system, 287
*Murchisonia*, 283
*Murex*, 377, 385
Muschelkalk, 326, 329
Muscovite, 147
Musk-sheep, fossil, 391, 401, 402*, 409
*Mylıobatis*, 370
Mylonitic, 162, 221
*Myodes*, 409
*Myophoria*, 326, 327*
Myriapods, fossil, 289, 304
Myrica, fossil, 350
Myrtles, fossil, 382

*Natica*, 401*
Nautilus, living pearly, 274; fossil, 283, 310, 319, 357, 370
Nebular hypothesis, 252
Necks, volcanic, 116*, 117*, 118*, 253*
*Nelumbium*, 369
Neocomian stage, 358
Neolithic deposits, 406, 410
Neolithic implements, 411*
*Neoplagiaulax*, 374
Nepheline, 146, 184
Nepheline-syenite, 181
*Neptunea*, 390*
Neuroptera, fossil forms of, 289, 337
*Neuropteris*, 300*, 301, 318
New Red Sandstone, 315, 323
New Zealand, hot springs of, 68, extinct volcanoes of, 107; pre-Cambrian rocks of, 263, Silurian rocks of, 285, Carboniferous system in, 312, Trias in, 331, Jurassic rocks in, 346; Cretaceous rocks in, 364
Niagara group, place of, in Geological Record, 257, 286
Niagara River, filtered by Lake Erie, 38; gorge of, 35, 36; falls of, 36*
Nineveh, buried under wind-borne soil, 21
*Nipa*, 369
Nitrogen, in the atmosphere, 136, in the earth's crust, 137
Non-metals, 129
Norite, 183
North Sea, once filled with ice, 74, 397, 398
Norway, ice-transported stones from, 74, 398, glaciation of, 77, 79, 396, 397, 402, 403, metamorphism of limestone in, 188, fossiliferous schists of, 190
Norwich Crag, 392
Nosean, 182
*Nucula*, 310, 353*, 376
*Nuculana*, 310, 392, 400, 401*
Nullipores, 94
Nummulites, 246, 368, 370
Nummulitic Limestone, 368, 370, 373
*Nuphar*, 391
*Nymphæa*, 391

Oak, fossil, 350*, 376, 379, 382*, 388, 391; in Danish peat-bogs, 412
*Obolella*, 274
*Obolus*, 273
Observation, faculty of, in geology, 8, 9
Obsidian, 159, 161*, 162, 180
Oceans, position and probable history of the, 253
Oceanic deposits, 88, 94

Ochre, precipitation of, by chalybeate water, 67, composition of, 144
Œningen Beds, 386
*Ogygia*, 174, 281, 282*
*Olcostephanus*, 342, 358
Old Red Sandstone, place of, in Geological Record, 257, account of, 287
*Oldhamia*, 269, 270*
Oldhaven Beds, 373
*Oleandrideum*, 332
*Olenellus*, 274
*Olenellus* series, place of, in Geological Record, 257, 274
Olenidian series, place of, in Geological Record, 257, 274
*Olenus*, 272*, 274
Oligocene formations, place of, in Geological Record, 257, definition of term, 367, account of, 376
Oligoclase, 146, 178
*Oliva*, 369
Olivine, 148*, 183, 184
Olivine-gabbro, 183
Omphacite, 191
*Omphyma*, 279*
Onondaga group, place of, in Geological Record, 257, 286
Ontario, Lake, shingle formed by, 52*
Oolite, formed on coral-reefs, 99; origin of, 157
Oolite-limestone, 171
Oolites in Jurassic system, 342
Oolitic, definition of, 157*
Ooze, diatom, 94*, globigerina, 96*, 174
Opal, 142
Ophicalcite, 189
*Ophileta*, 273, 283
Opossums, fossil, 371, 383
*Oppelia*, 337
*Orbitoides*, 374
Order of succession in the appearance of organisms on the earth, 245; of superposition, 247
Ordovician, 257, 277, 286
*Oreodon*, 380
Oreodon beds, 380
*Oreopithecus*, 383
Ores, metallic, 234
Organic acids, geological action of, 17, 27, 91, 132, 175
Organic matter in soil, 17; bleaching effect of, 315
Organic remains, conditions for preservation of, 238
Oriskany group, place of, in Geological Record, 257, 295
*Orodus*, 311*
*Orthis*, 273, 282, 283*, 293
*Orthoceras*, 246, 274, 283, 285*, 295, 310*, 319, 326
Orthoclase, 146, 178
Orthoclase-porphyry, 181
*Orthonota*, 283, 284*
Orthophyre, 181
Orthoptera, fossil, 289, 337
Orthorhombic system in crystallography, 139*
Ösar, 404
Osborne group, 378
*Osteolepis*, 289, 290*
Ostracoderms, 284, 291*
Ostracods, fossil, 308
*Ostrea*, 335, 353, 377*, 385
Otters, fossil, 383
Outcrop, 211*
Overlap, 203, 204*
*Ovibos*, 401, 402*
Oxen, fossil, 390, 391, 394
Oxfordian stage, 342, 344
Oxides, 129, 137, 141
Oxidation due to rain, 14
*Oxyacodon*, 374
Oxygen, influence of, in weathering, 14, in earth's crust, 129; at volcanic vents, 129, constant removal of, from atmosphere, 130
*Oxynoticeras*, 343

Pachyderms, variety of, at the close of Tertiary time, 367
*Palæaster*, 281
*Palæasterina*, 280*, 281
*Palæoblattina*, 284
*Palæochoma*, 281
*Palæochorda*, 281
*Palæocrangon*, 308
*Palæohatteria*, 320
Palæolithic deposits, 406, implements, 408*; sculpture and painting, 410
*Palæoniscus*, 319

*Palæophycus*, 281
*Palæopteris*, 288*
*Palæotherium*, 246, 370*, 371, 377
Palæozoic, place of, in Geological Record, 257, systems described, 364, uniformity of life, 266
Palms, fossil, 351, 368, 369, 379, 382
*Paltopleuroceras*, 342
*Paludina*, 377
*Pandanus*, 351, 369
Paniselian, 373
*Panopæa*, 374, 390*
*Pantolambda*, 374
*Pantylus*, 320
Paradoxidean series, place of, in Geological Record, 257, 274
*Paradoxides*, 271, 272*, 274
Paragonite, 147
Parallel Roads or Lake-terraces, 49*, 403
*Paramys*, 374
*Pareiasaurus*, 321
Paroquets, fossil, 377
Past, interpreted by the Present, 5, 11
Pearlstone, 180
Pea-stone, 157*, 171
Peat and Peat-bogs, history of, 2, 4, 92, 400, solvent action of water from, 27, 28*, rate of growth of, 93, animal remains in, 93, 100, antiseptic quality of, 93, sometimes formed of sea-weeds, 94, varieties of, 174, alternation of, with lacustrine deposits, 243; neolithic remains in, 411, 412, succession of trees in, 412
*Pecopteris*, 300*, 301, 318, 325
*Pecten*, 326, 327*, 335, 353, 358, 377, 385, 400, 401*
*Pectunculus*, 385
Pegmatite, 179
Pelican, fossil, 377
*Pelycodus*, 374
Pennsylvanian, 257
*Pentacrinus*, 334*
*Pentamerus*, 282, 283*
Pentremites, 307*
Perched Blocks, 72*, 164, 397, 402, 404
Peridot, 148
Peridotites, 184
*Perisphinctes*, 337
*Perlidæ*, fossil, 304
Perlitic, 160, 180
Permian system, place of, in Geological Record, 257; account of, 314
Permo-Carboniferous, place of, in Geological Record, 257
*Petalodus*, 311
Petrifaction, 100, 242
Petrography, 154
*Petrophiloides*, 369*
*Phacops*, 281, 293
*Phascolotherium*, 341*
*Phasmidæ*, fossil, 304
Phenocrysts, 159
*Phillipsia*, 307*, 308
*Phlebopteris*, 332
*Pholidophorus*, 327, 337, 338*
Phonolite, 182
Phosphates, 152
Phosphorus in earth's crust, 129, 135, 152
Phyllite, 188, 227
Phyllocarid fossils, 272, 281, 283*
*Phylloceras*, 337
*Phyllograptus*, 278*
Pickwell Down group, 295
Picrite, 184
Pig, fossil, 391
Pikermi, deposits of, 393
Pile-dwellings, 411, 412
Pilton group, 295
*Pinacoceras*, 326
*Pinna*, 335
*Pinus*, 333, 351, 369, 391, 412
Pisolite, 170
Pisolitic, defined, 157*
Pitchstone, 180
*Placenticeras*, 358
Placoderms, 284, 289, 291*, 337
*Plagiaulax*, 341
Plagioclase, 146
*Plagioptychus*, 353*
Plaisancian stage, 393
Plane, fossil, 350, 369, 388
Planets, origin of the, 253
*Planorbis*, 377
*Planorbis*-zone, 336
Plants as materials for geological history, 6; conditions for preservation of remains of, 6, 100, 101, 238; geological action of, 91; durable parts of, 239

Plaster of Paris, 151
*Platanus*, 388, 389*
*Platycrinus*, 306
*Platyschisma*, 283
*Platysomus*, 319*
Pleistocene, definition of term, 367; formations, place of, in stratigraphy, 256; account of, 395, 396
Plesiosaurs, 246, 328, 338, 356
*Pleuracanthus*, 305, 311*
*Pleurotoma*, 392
*Pleurotomaria*, 273, 310
Plication of rocks, 214
*Plicatula*, 335*
Pliocene, definition of term, 367, formations, place of, in the Geological Record, 257, account of, 387
*Pliopithecus*, 383
Plum, fossil, 369, 388
Plutonic, definition of, 158, rocks, 177
*Plutonides*, 275
Pocono sandstone, 313
*Podozamites*, 326
*Poebrotherium*, 380
*Polymastodon*, 374
*Polypora*, 318
Polyzoa, fossil, 308*, 318
Pond-lily, fossil, 391
Pondweeds, fossil, 382, 388
*Popanoceras*, 319
Poplar, fossil, 350, 369, 382, 388
*Populus*, 369, 388, 389*
Porcellanite, 187
Porcupine, fossil, 394, 402, 409
Porphyrite, 183
Porphyritic, 159, 160*
Porphyry, 160
Portage group, place of, in Geological Record, 257, 295
*Portlandia*, 400, 401*
Portlandian, 342, 346
Post-pliocene group of strata, 395, 396
Post-tertiary formations, relative place of, in the Geological Record, 256, account of, 395
Potash, carbonate of, in soil, 133
Potash, silicates of, 133
Potassium in earth's crust, 129, 133, in the sea, 133
Potassium-chloride, 133, 330
Potassium-sulphate, 133
*Poteriocrinus*, 306
Pot-holes, excavation of, 32, 33*, 78*
Potsdam series, place of, in Geological Record, 257, 275
Pottsville Conglomerate, 313
Prawns, fossil, 337
Pre-Cambrian, place of, in Geological Record, 257; formations, 258, chiefly found in northern regions, 263
Precipitation of mineral matter, 54, 62, 67; rocks formed by, 170
Prehistoric formation, 256
Present a key to the Past, 5, 11
Pressure, in consolidation of sediment, 207
*Prestwichia*, 308
*Priacodon*, 341
Primary, place of, in Geological Record, 257
Primordial, place of, in Geological Record, 257
*Pristis*, 370
*Productus*, 293, 308, 309*, 318*
*Protapirus*, 380
*Protaster*, 281
Proteaceous plants, fossil, 376, 382
*Proterohippus*, 374
*Proterosaurus*, 320
*Protoceras*, 380
Protoceras beds, 380
*Protochriacus*, 374
*Protocystites*, 280
*Protogonodon*, 374
*Protomeryx*, 380
*Protospongia*, 275
*Protriton*, 321
*Prunus*, 369, 388, 391
Psammites de Condroz, 295
*Psammodus*, 311
*Psaronius*, 318
*Pseudocrinites*, 280*
*Psiloceras*, 342
*Psilophyton*, 288*, 289
*Psittacotherium*, 374
*Pteraspis*, 284, 290
*Pterichthys*, 290, 291*
*Pterinea*, 294
*Pterocera*, 345

Pterocerian sub-stage, 345
*Pterodactylus*, 339
*Pterophyllum*, 318, 325*, 326, 332
Pteropods, fossil, 310
Pterosaurs, 339*, 356
*Pterygotus*, 291, 292*
*Ptychites*, 327, 330
*Ptychoceras*, 354*
Puerco group, 374
*Pullastra*, 326
Pumice, 180
Pumiceous, 161
*Pupa*, fossil, 304
Purbeckian, 342, 346, 358
*Purpura*, 390*
*Pycnodus*, 337
*Pygaster*, 334
Pyrite, 153, 155*, 156
Pyroxenes, 148, 188 , altered to hornblende, 190
Pythonomorphs, 357

Quader (Saxony), 360
Quartz, 130, 131*, 138, 140 ; characters of, 141, 142* ; in veins, 173, 234 ; in igneous rocks, 178
Quartz-diorite, 182
Quartz-gabbro, 183
Quartz-mica-diorite, 182
Quartz-norite, 183
Quartz-porphyry, 179
Quartz-schist, 189 ; formed from sandstone, 222
Quartz-veins in granite, 16
Quartzite, 187, 189
Quatenary Formations, 395
*Quercus*, 350*, 381*, 388

Rabbits, influence of, in the removal of soil, 19, 22, 92
Radio-active constituents of earth's crust, 104
Radiolaria, secretion of silica by, 94* ; fossil, 278
*Radiolites*, 353*
Rain, destructive effects of, 1 ; influence of, in weathering, 14 ; removal of soil by, 18, 26, 29 ; chemical action of, 27, 60 ; cements calcareous detritus into limestone, 95, 96
Rainfall, influence of variations in, on the transporting power of streams 30
Rain-prints in sedimentary rocks, 196, 198*
Rain-wash, 20*
Raised Beaches, 123, 124*, 404, 411
*Rastrites*, 278*
Ravines, eroded by rivers, 35*, 36*, 37*
Recent deposits, 256, 395, 405
Red colour, cause of, in rocks, 132, 143, 315 ; strata, cause of unfossiliferous character of, 315, 326
Red Crag, 392
Reed, fossil, 388
Regional metamorphism, 221
Regular system in crystallography, 139*
Reindeer, 391, 401, 409, 410*, 411
*Rensseleria*, 294
"Reptiles, Age of," 338, 367, 370
Reptiles, fossil, 320, 327, 338, 356
*Requienia*, 353*
Resinous lustre, 181
Retinite, 180
Reuss, River, 49
Reversed Faults, 218
Rhætic group, 329, 330
*Rhamnus*, 388
*Rhamphocephalus*, 339
*Rhamphorhynchus*, 339
Rhinoceroses, fossil, 378, 379, 380, 383, 387, 389, 391, 392, 393, 394, 401, 407, 409, 411
*Rhizodus*, 305, 311*
Rhone, filtered by Lake of Geneva, 33 ; gorge of, 35 , delta of, in Lake of Geneva, 49 ; ancient glacier of, 74, 402
*Rhus*, 382*, 388
Rhynchocephalia, fossil, 327
*Rhynchonella*, 282, 283*, 293, 308, 335, 353, 358, 390*
*Rhynchosaurus*, 328
Rhyolite, 179
Rigi beds, 379
Ripple-marks, 196, 197*
Rivers, effects of flooded, 1 ; geological operation of, 26 ; chemical action of, 27, 95 ; mineral matter held in solution by, 28, 29 , transporting power of, 29, 30, 38 ;

proportion of sediment in water of, 30, 31; erosive action of, 32, 406; sinuous courses of, 34*, 35*; ravines of, 35*, 36*, 37*; filtered by lakes, 33, limit to erosive action of, 36, deposit of sediment by, 38, 40*, 41*, terraces formed by, 43*, 44*, 406; flood-plains of, 43, affected by elevation of land, 44, plants and animals swept away and entombed by, 45, 48, deltas of, in lakes, 51, action of frozen, 69, marine deltas of, 85, flow of, affected by earthquakes, 122; traces of ancient, 358; human relics preserved in high terraces of, 406, 407, 411
"Roches moutonnées," 72*, 78, 396
Rock-crystal, 130, 138
Rock-salt, 152, 171, 172, 315, 321, 322, 324, 329
Rock-shelters, 412
Rocks, definition of, 154; bad conductors of heat, 105; methods of investigating, 154; classification of, 163, sedimentary, 163, 192; fragmental or clastic, 164; formed from chemical precipitation, 170, formed of remains of plants and animals, 173, eruptive or igneous, 176, 224, acid, 177, 178, intermediate, 177, 181, basic, 177, 183, metamorphic, 186, 221, depth of fossiliferous, 256
Rodents, fossil, 374, 380
Roofing-slate, 187, 216
*Rotalia*, 351*
Rothliegende, 320, 321
Rothpletz, Dr, on structure of the Alps, 221
Rugose corals, 279*, 293*, 306*
Rust, cause of, 14, 130
Rutile, 133

*Sabal*, 351, 369
Sables Moyens, 373
*Sacammina*, 306
Sahlite, 148
St. Erth Beds, 392
St Lawrence River, ice of, 69, 70
Sal-ammoniac in volcanic sublimates, 118
Salina group, 286
*Salisburia*, 369
*Salix*, 369, 388, 389*, 391, 400
Salt-lakes, 55, 173, 315, 324, 403
Salts, 129
Sand, geological history of, 4, calcareous, formed by nullipores, 94, 166, 174; varieties of, 166, extent of deposition of, 201
Sand-dunes, 21, 166; neolithic remains in, 411
Sandstone, decay of, into soil, 15*; kinds of, 167; indurated, 187, 234, changed to quartzite, 189, 234; comparatively rapid formation of, 202, changed into mica-schist, 222, 227
Sanidine, 146, 178
Sarsaparilla, fossil, 369, 388
*Sassafras*, 350*, 388
Satellites, origin of, 253
Satin-spar, 151
Saturation, influence of, in weathering, 13
Saurians, fossil, 320, 323
*Saxicava*, 400, 401*
Scandinavia, ice-borne stones from, 74, glaciation of, 77, 79, 396, 397, 402, 403, uprise of, 123, pre-Cambrian rocks of, 262
*Scapheus*, 337
*Scaphites*, 354*, 364
*Scaphognathus*, 339*
*Scenella*, 273
Scenery, slow changes in, 1
Schist, 163, 186, 222, 258
Schistose structure, 162*, 186, 190, 216
*Schizodus*, 319
*Schloenbachia*, 354*, 358
Schoharie grit, 295
*Scolithus*, 281
Scoriaceous, 161
Scorpions, fossil, 240, 284, 304*
Screes, origin of, 20, 164
Screw-pines, fossil, 351, 369
Sea, destructive and reproductive effects of, 2; demolition of land by, 80; chemical action of water of, 80, force of breakers of, 80; serious erosion only by upper part of, 82; rate of erosive action of, 84, 85*; accumulations formed by, 85;

transport of sediment by, 88, slow deposition in abysses of, 88, proportion of calcareous organisms in tropical waters of, 96, preservation of animal-remains on floor of, 101, 238, evidence of the presence of, 4, 110, 244, volcanic detritus on floor of, 112, proportion of carbonate and sulphate of lime in water of, 132
Sea-calf, fossil forms of, 383
Sea-mats, fossil, 308
Sea-serpents, fossil, 357, 370
Sea-shells, geological inference from, 4, 110
Sea-urchins, fossil, 306, 334, 352*
Sea-weeds, accumulations of, 94, fossil, 269, 277, 297, 301
Sea-worms, 277, 281*
Seals, fossil, 391, 404
Secondary rocks in Geological Record, 257
Secretary-birds, fossil, 377
Section in stratigraphy, 248
Sedge, fossil, 388
Sedgwick on Cambrian system, 267, with Murchison named the Devonian system, 287
Sediment, slow changes of, 201
Sedimentary, definition of, 156, 163, rocks, account of, 163, 192, most ancient forms of, 260
Selenite, 151
*Semionotus*, 327
*Semnopithecus*, 393
Senonian stage, 357, 361
Septaria, 156*, 199
Septaria Clay, 379
Sequanian sub-stage, 345
*Sequoia*, 351, 369, 388
Sericite (Muscovite mica), 190
Sericite-schist, 190
Series in stratigraphy, 248
Serpentine, 148*, 149, 186, schistose, 191
Serpentine-schist, 191
*Serpula*, 281
Shale, 168; baked, 187
Sharks, fossil, 310: teeth of, in abysmal deposits, 88, 102
Shearing of rocks, 162, 186, 214 215, 221
Sheep, fossil, 394; domesticated, 412
Sheets, intrusive, 228*, interstratified, 229*
Shell-banks, 95*
Shell-marl, 4, 53*, 92, 93*, 95, 174
Shell-mounds, neolithic remains in, 411
Shells, evidence from, in geological history, 4
Shingle, 165
Shores, proofs of former, 195
Shorthorn, domesticated, 412
Shrews, fossil, 377
Shrimps, fossil, 337
Sicilian stage, 393
Siderite, 151, 156*, 173
*Sigillaria*, 246, 302*, 303, 322
Sigillarioid plants, 303, 317
Silica, or silicon-dioxide in earth's crust, 130, 141, soluble form of, 143, in springs, 67, secreted by plants, 94*, 239, 361, secreted by animals, 94, 246, 361, as a petrifying medium, 242
Silicates, solution of, 61, in earth's crust, 130, 131, 133, 137, 145, 177
Siliceous pebbles, durability of, 165
Siliceous sinter, 67, 173
Silicification, 242
Silicon in earth's crust, 129, 130, 141
Sills, 228*
Silurian system, place of, in Geological Record, 257, origin of name, 267, description of, 276
*Sinopa*, 374
Sinter, calcareous, 65; siliceous, 67, 173
*Sivatherium*, 394
Siwalik group, 394
Slaggy structure, 161
Slate, 187, 216
*Smilax*, 369, 388
Snails, fossil, 289, 304
Snakes, fossil, 383
Snow, geological action of, 70
Sodium in earth's crust, 129, 133; in sea-water, 133
Sodium-carbonate in bitter lakes, 55
Sodium-chloride in salt lakes, 55,

133, in the sea, 133, 136; as a rock-former, 170
Soil, effects of frost on, 13; formation of, 15*, 16*, 18, 20*, 164; causes of variation in, 17; removal of, by rain, wind, and worms, 18, final transport of, to the sea, 22
Solar system, evolution of, 252
Sorrel, fossil, 388
*Spalacotherium*, 341
Spar, formation of, 64
*Sparodus*, 320
Spectre-insects, fossil, 304
Specular iron, 143
Speeton Clay, 358, 359
Sphærosiderite, 151*, 156*, 173
*Sphenopteris*, 300*, 301, 318, 322, 332
Spherulites, 160, 161*, 180
Spilosite, 188
Spirifers, 293, 294*, 308, 309* 318, 335
Spirifer-sandstone, 295
*Spondylus*, 385
Sponges, fossil, 278, 351*
Spotted slate, 188
Springs, mechanical action of, 57, chemical action of, 60; deposits from, 62, calcareous, 63; chalybeate, 67; siliceous, 67, thermal, 103, 173; containing metallic solutions, 321
Spruce, fossil, 391
*Squalorata*, 337
Squids, 274
Squirrels, fossil, 371
*Stacheoceras*, 319
Stage (in stratigraphy), 248
*Stagonolepis*, 328
Stags, fossil, 387
Stalactite, 63, 64*
Stalactitic condition of minerals, 141
Stalagmite, 63; preservation of animal-remains in, 65, 100, 408, human relics in, 408, 411
Stampian stage, 378
Star-fishes, fossil, 271, 280*, 281
Staurolite-slate, 188
Steam in volcanic eruptions, 161
*Stegosaurus*, 341
*Steneofiber*, 380
*Steneosaurus*, 338
*Stenopora*, 318
*Stephoceras*, 337, 342
*Stigmaria*, 302*
Stoat, fossil, 409
Stone-flies, fossil, 304
Stone implements, geological evidence furnished by, 405, 407, 408*, 411*
Stonesfield Slate, 344
Storm-beaches, 87*
Strand-lines, 123, 124*
Strata, nomenclature of, 194; association and alternation of, 199; relative areas of, 200, chronological value of, 201; consolidation of, 207; original approximate horizontality of, 209
Stratified, definition of, 158; structure, 45, 163, 193
Stratigraphy, definition of, 9, 195; divisions of, 247
Stratum, defined, 194
*Strepsodus*, 305
*Streptorhynchus*, 308, 309*
Strike of strata, 210*, 211*
Strike-joints, 208
*Stringocephalus*, 294*
*Strombus*, 385, 394
*Strophalosia*, 318*
*Strophomena*, 282, 293
Sub-Carboniferous, place of, in Geological Record, 257, 313
Sub-group in stratigraphy, 248
Sublimates, volcanic, 118, minerals deposited as, 140, 143; crystalline structure in, 158
Submarine plane of erosion, 84*
Submerged forests, 123
Subsidence, produced by earthquakes, 122: secular, 123; proofs of, 203, 265, 297, 298, 290*, 349, 369, 385, 388, 392, 404
Subsoil, origin of, 16, 18, 164
Sub-stage in stratigraphy, 248
Suffolk Crag, 392
Sulphates, 136, 137, 151, 153
Sulphides, 129, 136, 137, 153, as petrifying agents, 242, 321
Sulphur in volcanic sublimates, 118; in earth's crust, 129, 135, 137, 152
Sulphuric acid, 129, 153

Sumach, fossil, 382, 388
Sun, history of the, 253
Sun-cracks in sedimentary rocks, 196
Superposition, order of, 3, 247
*Sus*, 393
Switzerland, landslips in, 60, glaciers of, 72, 74, 402, 403; Tertiary lakes of, 376, 379, 382, 386; pile-dwellings of, 412
Syenite, 181
Syncline, 213
System in stratigraphy, 248

Tabulate corals, 279
Tachylyte, 183
*Tæniopteris*, 318, 322, 325, 332
Talc, 149
Talc-schist, 190
Talchir series, 316
Talus, origin of, 20*
*Tapes*, 385
Tapir, fossil forms of, 371, 374, 377, 379, 383, 393
Taunusian rocks, 295
*Taxodium*, 388
*Teleosaurus*, 338
*Telerpeton*, 328*
*Tellina*, 385, 400, 401*
*Telmatotherium*, 374
Temperature, influence of, in weathering, 13, 166
*Terebratula*, 294, 308, 335, 353
*Terebratulina*, 358
*Termidæ*, fossil, 304
Terminal moraine of the ice-sheet in Europe and the United States, 399
Termite, influence of, upon soil, 19
Terrestrial surfaces, evidence of, 110
Tertiary formations, place of, in Geological Record, 257, account of, 365
Tesseral system in crystallography, 139*
Tetragonal system in crystallography, 139*
*Textularia*, 351*
*Thamnastræa*, 334
Thanet Sand, 373
Thanetian, 373
*Thecosmilia*, 334
*Theonoa*, 392
Throw of a fault, 218, 219*
Thrust plane, 220
Till or Boulder-Clay, 397, 399, 405
Tillodonts, 372, 374
Time, popular notions regarding the influence of, 11, 12; in geology, 201, geological names for divisions of, in geological history, 249, 268
*Tinoceras*, 371
Titanic iron, 133, 144
*Titanichthys*, 290
Titanium in earth's crust, 129, 133
*Titanotherium*, 380
Titanotherium beds, 380
Tithonian, 346
Toads, fossil, 383
Toarcian, 342
Tonalite, 182
Tongrian stage, 379
Topaz, 179
Topographical features due to weathering, 22, 374, 375*
Torrejon Group, 374
Torridonian, place of, in Geological Record, 257, formation described, 261,
Tortoises, fossil, 356, 370
Tortonian stage, 385
*Texoceras* 354*
*Trachyceras*, 326
Trachyte, 182
Trachyte-tuff, 169
Trails of worms, 281
Transition rocks, 267
Travertine, formation of, 65, 66*, 101; characters of, 171
Trees, evidence from, as to geological time, 201, succession of, in peat-bogs, 412
Tree ferns, fossil, 317
Tremadoc group, 274
*Trematosaurus*, 327
Tremolite, 148, 189
Trenton group, place of, in Geological Record, 257, 286
Triassic system, place of, in Geological Record, 257, account of, 323
Triclinic system in crystallography, 140
*Trigonia*, 335*, 353*
Trilobites, 246, 271, 272*, 274, 281, 282*, 292*, 293, 307*, 337
*Trinucleus*, 281*, 282*

Tripoli-powder, 94, 240
*Trochoceras*, 285*
Trogons, fossil, 377
*Trogontherium*, 391
*Trophon*, 390*, 391, 392, 401*
Tufa, calcareous, 65, 66, 101, 135, 171, 408
Tuffs, volcanic, 111, 169, 190, 229*, 263, 265, 268, 276, 288, 301, 316, 321, 331, 347, 364, 378, 387
Tulip-tree, fossil, 388
Tunbridge Wells Sand, 359
Turner, Mr H W, photograph by, 78*
Turonian stage, 358, 361
*Turrilites*, 354*, 355
Turtles, fossil, 338, 356, 370, 383
Twinning of crystals, 146, 152*
*Typhis*, 377

Uinta group, 374
*Uintacyon*, 374
*Uintatherium*, 371*, 372
*Ulmannia*, 318
*Ulmus*, 369, 388
Ultra-basic rocks, 184
*Uncites*, 293, 294*
Unconformability, 204*; examples of, 261, 262
*Unio*, 377
United States, sand-wastes of, 22; Bad Lands of, 24, 374, 375*; cañons of, 36, 37*, salt lakes of, 55, caverns of, 62, hot springs of, 67, ancient ice-sheets of, 74, 79, erosion off coasts of, 82; coast-lagoons and bars of, 85, 93; mangrove swamps of, 93; diatom-earth of, 94, extinct volcanoes of, 106, 114; volcanic necks in, 116*; volcanic scenery of, 116*, 231*; fissure-eruptions of, 120; laccolites of, 226; lacustrine formations of, 243; geological record in, 256; pre-Cambrian rocks of, 262; records of volcanic action in, 263, 347, 364, 387, 394, Cambrian rocks of, 275, Silurian rocks of, 276, 285, 286; Devonian system in, 287; Carboniferous system in, 312; Permian system in, 321; Trias in, 331, Jurassic rocks in, 346; Cretaceous system in, 349, 357, 363, Eocene of, 368, 374; Miocene of, 386; Pliocene of, 394; glaciation of, 395, 399, 403, 404
Unstratified, definition of, 158
Upheaval from earthquakes, 122, secular, 123
Uralite, 148
*Urenchelys*, 356
Urgonian, 359
Uriconian, place of, in Geological Record, 257, volcanic rocks, 262
*Ursus*, 410
Urus or wild ox, 411
Utah, Great Salt Lake of, 55, 403
Utica group, place of, in Geological Record, 257, 286

Valenginian, 359
Valleys, excavation of, 24, 406, usually independent of faults, 219
Vasculose of plants, 239
Vegetation, influence of, in formation of soil, 16, 18
Vein-quartz, 173
Veins, igneous, 118, 232; mineral, 234
Veinstones, 234
*Velutina*, 392
*Ventriculites*, 351*, 352
Vents, volcanic, 105, 113
Vermilion Creek group, 374
Vertebrates, earliest known, 266
Vesicular, 160
Vesuvius, 119, beginning of activity of, 388
Vicksburg group, 374
*Victoria*, fossil, 369
Villafranchian stage, 393
Virgulian sub-stage, 345
Vitreous condition of rocks, 140, 159
Vitrophyric condition of igneous rocks, 181
*Viverravus*, 374
*Vivipara*, 377*
Vogesite, 181
Volcanic, definition of, 158, 177; fragmental rocks, 169, ash, 169
Volcanoes, effects of, on landscape, 2; as evidence of the earth's

internal heat, 104; structure of, 105; denudation of, 106, permanent memorials of, 106, products of, 107-113; submarine, 112; illustration of the records of ancient, 229*, 263, 265, 268, 276, 287, 288, 301, 316, 321, 325, 331, 347, 363, 364, 376, 378, 388, 394
*Voluta*, 369*, 377
*Voltzia*, 325

Wad, 145
Wadhurst clay, 359
Wahsatch group, 374
*Walchia*, 317*, 318
Walcott, Mr. C. D, photograph by, 231
Walnut, fossil, 350, 369, 388
Walruses, fossil, 391, 404
Water, in geological changes, 1, 14, 18, 26, 27, 29, 57; under ground, 57, 60; composition of, 129, 135, crystalline form of, 139
Water-bean, fossil, 369
Waterfalls, recession of 35, sometimes caused by earthquakes, 122
Water-line, place of, in Geological Record, 257, 286
Water-lily, fossil, 369, 391
Water-worn rocks, 32
Waves, effects of, 80, caused by earthquakes, 123
Wealden formation, 358, 360
Weather, ancient indications of, 198
Weathering, 11, 12*, 15, 132, feeblest condition of, 18, results of, 22; topographical features carved by, 22, 23*, 116*, 231*, 374, 375*
Wemmelian, 373
Wenlock, group, place of, in Geological Record, 257, 286
Werfen Beds, 330
West Indies, coral-reefs of, 99
Westphalian series, 312
Weyborne Crag, 391
Whale, fossil, 391, 404; ear-bones of, in abysmal deposits, 88, 102
Whet-slate, 188
White-ants, fossil, 304
White Crag, 392
White River group, 379
Wild boar, 394, 411
Wild cat, 383, 390
Willow, fossil, 369, 388, 400
Wind, dried soil removed by, 18, 21; slow action of, in the production of soil and brick-earth, 18, 407; transport of volcanic dust by, 113
Wind River group, 374
Witchita Beds, 322
Wollastonite, 188, 189
Wolves, fossil, 379, 387, 391, 409, 411
*Woodocrinus*, 307*
Woolwich and Reading Beds, 373
Worms, in relation to soil, 16, 19, 92; tracks and burrows of, 277, 281*

Xenocrysts, 160

Yellow colour, usual cause of, in rocks, 132, 144
Yellowstone Park, hot springs of, 67
Yew-trees, fossil, 369
*Yoldia*, 391, 400, 401*
Yoldia myalis Bed, 391
Yorktown stage, 387
Ypresian, 373

*Zamites*, 326, 332
Zanclean stage, 393
*Zaphrentis*, 279, 306*
Zechstein, 320, 321
Zeolites, 146
Zinc, sulphide, 235
Zoisite, 189, 191
Zone in stratigraphy, 247

THE END

*Printed in Great Britain by* R. & R. Clark, Limited, *Edinburgh.*