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THE PHYSIOGRAPHIC PROVINCES OF NORTH AMERICA

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FOREWORD

During the last fifty years a widespread interest in the study of regional physiography has been developing. That study has involved the application of the principles of geomorphology, evolved during the preceding century, to the study of well-defined units of the land surface in each of which the relief features do not differ greatly.

Regional physiography has become an important branch of learning for all those who are interested in geology or geography. Those who try to work out the physical history of any portion of the land surface must rely on a knowledge of physiography in the interpretation of many events recorded in the history of the earth, and especially in working out the last chapter of that history. A physiographic province is usually a logical and convenient unit area for geologic investigation, and certainly no geologic study should be reported without placing the area under study in its appropriate physiographic setting.

An intelligent appreciation of the evolution of land forms in the great physiographic provinces of the earth is of fundamental significance to the geographer. No one can rank as an intelligent geographer who cannot explain the surface features in a landscape, and no geographer should endeavor to interpret the human drama taking place on any portion of the earth's surface without a knowledge of the physical setting where that drama is in progress. The erection of a superstructure of human geography without a firm foundation in physiography and climatology, without a knowledge of the soils and of the native vegetation, will result in disaster; such a superstructure will crumble, and the builders will find themselves humiliated. A study of regional physiography should therefore be included in the training of all geographers.

In the conduct of instructional courses in regional physiography I have offered field excursions whenever they were practicable, and I have always incorporated a large amount of laboratory work which has been based primarily upon a study of topographic maps. Because I consider the laboratory work of very great importance in the training of students, a carefully selected list of the maps that should be studied has been included at the close of each chapter dealing with a physiographic province. I am particularly indebted to my son, Wallace W. Atwood, Jr., for the conduct of the laboratory work associated with my courses in regional

physiography during the last six years, as well as for the final selection of maps.

The number of people to whom I am indebted for help in the preparation of this volume is too great to list here. I must express special appreciation, however, for a critical reading of the manuscript to Dr. Kirtley F. Mather of Harvard University. His criticisms and suggestions have been most helpful. I am indebted to the late William T. Oliver for a number of the relief drawings, and to Eugene Kingman for the frontispiece and a series of block drawings which he worked up from my personal sketches. In addition, I wish to express deep appreciation to Dr. Erwin Raisz for his artistic work reflected in the large relief map of the United States which accompanies this volume, and for numerous sketches which he has prepared for me. Credit lines have been added beneath the photographs kindly provided by professional friends and colleagues. I am especially indebted to Dr. Barnum Brown and Bradford Washburn for the privilege of reproducing several of their remarkable airplane photographs. To Mrs. Gertrude N. McGinnis, of the editorial department of Ginn and Company, I acknowledge indebtedness, for she has taken great care in preparing the maps and other illustrations for reproduction, and in helping me to carry all this material through the various technical processes involved in the publication of the volume.

To any of my former students at the University of Chicago, at Harvard University, or at Clark University, into whose hands a copy of this book may fall, much of its contents will have a familiar ring. To them and to the students who have been in the field with me I send most cordial greetings. To those who have assisted me in field studies I send sincere appreciation for their help and encouragement.

WALLACE W. ATWOOD

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THE PHYSIOGRAPHIC PROVINCES OF NORTH AMERICA

I

THE REGIONAL IDEA IN GEOGRAPHY

An Introduction

Foreword. Any large land area must be subdivided if detailed geographic studies of that area are to be undertaken. Many plans for making such subdivisions have been devised. In each case the intention has been to limit the region, or province, to an area throughout which the geographic conditions upon which the plan of subdivision is based do not differ greatly. A mountain province should naturally be limited by the extent of the mountains in a given part of a continent or island. If the area to be studied is a lowland plain, its boundaries are fixed by the limits of that plain, whether at the seashore or at the margin of some upland or highland region. In a regional subdivision based upon climatic factors such as rainfall or temperature, it is necessary to fix upon definite amounts of rainfall or certain degrees of temperature as determining factors. If combinations of climatic factors are used, as they sometimes are, the problem becomes very complex.

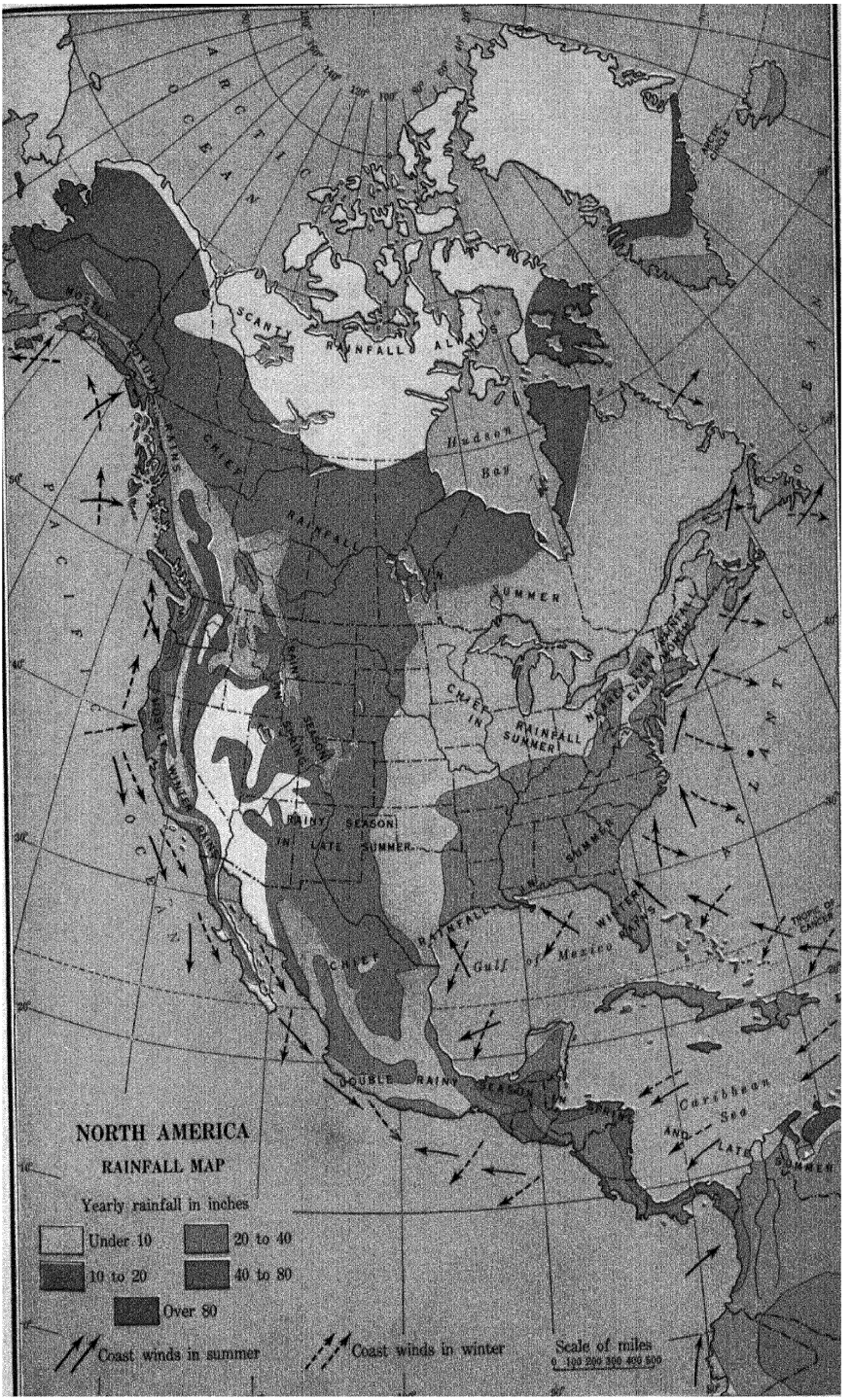
When human use of the land is accepted as the basis for subdividing land areas into geographic provinces, the possibilities become extremely varied. Numerous plans for laying out agricultural and industrial regions can be devised. Certain recreational regions have been somewhat definitely defined, and wild-life sanctuaries have been established. Areas of land have been set aside because of their educational or inspirational values, or because of historical significance. Each plan for the regional subdivision of a land area has certain advantages and certain definite weaknesses, or objectionable features.

Climatic regions. When we examine a map of North America showing the average annual rainfall in the different parts of the continent, such as the one opposite page 6, we recognize at once that there are some areas where the rainfall is very heavy and others where it is very light. If we wished to study climatic regions, we might first take up for consideration those portions of the continent where the average yearly rainfall is over 80 inches, and then turn our attention to those regions where the annual average precipitation is less than 10 inches.

Later we could consider the areas receiving from 10 to 20 inches of rain each year, and then the lands that receive from 20 to 80 inches of precipitation. The explanations of these differences in rainfall involve many interesting scientific problems, and the differences themselves are of great significance in the distribution of crops and the occupations of people in different parts of the continent. The 20-inch rainfall line is a somewhat critical line, and when interpreting its significance in problems related to the distribution of natural vegetation or agricultural crops great care must be used. Twenty inches of rainfall in some parts of the continent means much more water available for plant life than the same amount in other parts means. The rate of evaporation is more rapid in our Southern States and in the tropics than it is in the lands farther north, and therefore more rain is needed to produce crops in the southern part of the continent than in the northern part.

We find several areas in the northwestern part of the continent where the annual rainfall is over 80 inches. In these areas, however, the heavy precipitation is limited to the high mountain areas or to the very steep coastal margins of the continent. Forests and glaciers are abundant in that section of North America, but we must not think of those areas, although they are well watered, as good farming lands. There is adequate rainfall for agriculture in a portion of southern Greenland, but the topography and temperatures of that land are not suitable for crop production. If finer subdivisions based on the distribution of rainfall are made, the problem becomes even more complex.

In considering the value of rainfall regions as the basis for a plan of subdivision, we must also recognize that the boundary lines shown on our map are based upon the average rainfall during a certain period of years. Had the lines been based on another period of years, they would have been somewhat different. We know that there are, in certain parts of our country, periods of exceedingly light rainfall which are followed by years of much heavier downpours. Rainfall regions vary not only from season to season but in certain climatic cycles, with which we are as yet but little acquainted. We must recognize also that the average annual rainfall in a region is not so significant as the distribution of rainfall throughout the year. It is of prime importance that an adequate amount of rainfall come during the growing season.


NORTH AMERICA
RAINFALL MAP
Yearly rainfall in inches
Under 10
10 to 20
20 to 40
40 to 80
Over 80
Coast winds in summer
Coast winds in winter
Scale of miles
0 100 200 300 400 500
SCANTY RAINFALL
Hudson Bay
CHIEF RAINFALL IN SUMMER
RAINY SEASON IN LATE SUMMER
CHIEF RAINFALL IN SUMMER
SUMMER RAINS
WINTER RAINS
Gulf of Mexico
DOUBLE RAIN SEASON
Caribbean Sea
PACIFIC OCEAN
ATLANTIC OCEAN

Still thinking of climatic regions, we might take the length of the growing season as the basis for subdividing a land area. See Figure 1. On all lowland areas between the tropics of Cancer and Capricorn and for several hundred feet above sea level the growing season continues throughout the year, but on the upland regions in those same latitudes it varies with altitude, becoming shorter and shorter as the snow-covered summits of the high mountain peaks are approached. Along the Gulf Coast the growing season is from nine to twelve months, but for most of the lands in our Southern States, in parts of Mexico, and in the Pacific border states the frost-free period varies from six to nine months.

Northward in the United States the growing season decreases until, in the region of the Great Lakes, it is about 150 days in length. In the broad, parklike valleys of Western mountain regions it averages about 90 days in length, but high on the mountain slopes close by it is much shorter. Passing northward into Canada and finally into the arctic regions, we find that the length of the growing season steadily decreases. A combination of high altitude and high latitude virtually excludes the growth of most plants. The regional subdivision of a continent on the basis of the length of frost-free periods is exceedingly interesting and might prove to be valuable in a study of crop distribution, but we recognize at once that the boundary lines of these subdivisions may shift from year to year and that they are certain to vary with climatic cycles.

In addition to the amount of rainfall and the length of the growing season, which are very important climatic factors, the seasonal distribution of precipitation, the nature and frequency of storms, the types of winds, and the variability of the weather have great significance to the people living in the different regions. Proximity to the ocean or to large inland bodies of water also influences local climates. Continental interiors have climatic conditions that are peculiar to their locations.

It thus becomes evident that the subdivision of a continent into climatic provinces presents many complex and difficult problems. Nevertheless, excellent plans for climatic regions have been worked out by several specialists. One of those plans for North America is presented on the map facing page 8.

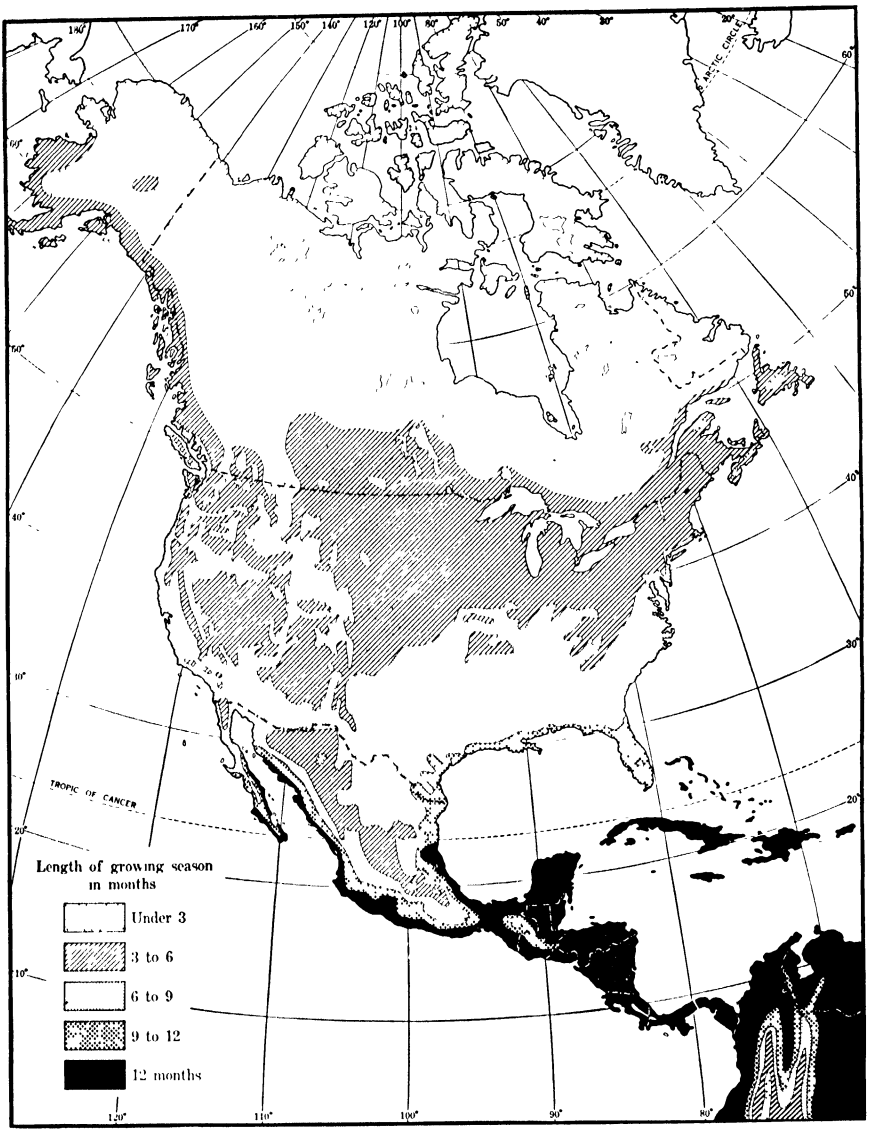


Figure 1 · Length of the frost-free period, or growing season, in the various parts of North America

Agricultural regions. In the well-settled portions of any land area certain agricultural areas, or regions, may be recognized. Their boundary lines are fixed arbitrarily. The corn belt and the wheat belts are

defined as areas within which more land is used for the cultivation of corn or wheat than for any other one crop. This does not mean, however, that corn or wheat, as the case may be, is the only crop produced in the given area. Within the cotton belt more land is used for raising cotton than for any other one crop, but corn, wheat, tobacco, peanuts, and many other money crops are produced in certain sections of that belt.

Furthermore, the boundaries of the crop belts are sure to fluctuate. The limits of the cotton belt have varied with each decade in the history of our country. Up to 1792, when the cotton gin was invented, most of the cotton produced in North America came from a small coastal area in South Carolina and Georgia. The invention of the cotton gin, the use of slave labor, and a large demand for cotton from abroad so encouraged the Southern planters that by 1862 the cotton belt extended south from Virginia through the Atlantic and Gulf states into the eastern part of Texas. Since then the belt has expanded northward and westward. Other good cotton-producing areas have been found in Mexico, New Mexico, Arizona, and California.

The northern limit of the cotton belt today is at the northern margin of the lands where the growing season is at least 200 days long. If cotton seeds that will ripen and furnish good crops in less than 200 days are ever produced, the cotton belt will undoubtedly expand northward. To the westward the cotton-growers have gone beyond the zone of rainfall necessary for the growth of cotton and have moved into areas where they must practice irrigation. Irrigation, increasing the cost of production somewhat, introduces an economic factor that may ultimately determine the limit for the profitable raising of cotton.

The Gulf margin has ceased to be a good cotton-producing land because of the abundance of boll weevils, which are numerous in the warm, moist lands of that coastal region. The boll weevil came in from Mexico in 1892 and since then has spread northward and eastward into the cotton-growing states. The cost of fighting these pests may determine, in some areas, whether cotton can be produced at a profit. Other important factors certain to affect the extent of our cotton belt are the expansion of cotton-growing in other parts of the world and the demand for cotton in the world market.

Thus, for a variety of reasons, the boundaries of the cotton belt and of other agricultural regions are constantly shifting. Nevertheless, the division of any well-used land into agricultural regions serves a useful purpose and should be recognized as an aid in geographic investigation and in the presentation of geographic data. One plan for dividing North America into agricultural regions is shown in the map opposite this page.

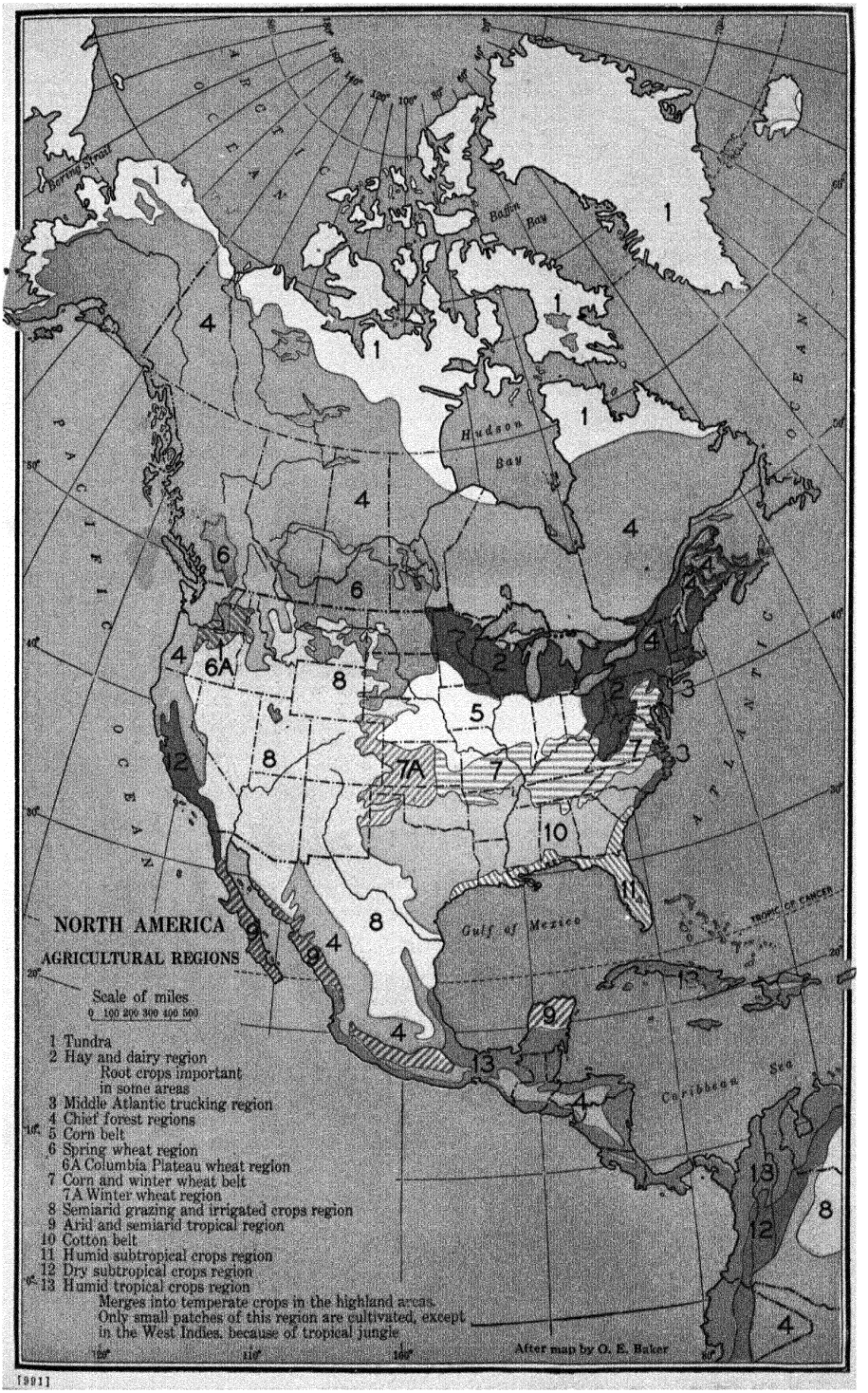
Political divisions. Political divisions are strictly man-made provinces, or regions. Their boundary lines sometimes follow physical features in the landscape, but at many places they represent compromises or the results of conquests. They are not in all cases reasonable. Nevertheless, political units are of great significance in many phases of geographic investigations.

Vegetation regions. There are geographic regions based upon the distribution of natural vegetation. These are exceedingly significant, for they reflect climatic and soil conditions and present graphically the distribution of some of the most important of the natural resources of the world. However, it is difficult to keep up with the changes which are constantly occurring in the distribution of plant life as more and more of the pasture lands are used for farming and more of the lands are deforested and left as cutover areas or put under cultivation.

Industrial regions. A variety of industrial regions have been blocked out by different investigators. Some define their regions on the basis of the number of employees within a given area who are engaged in the manufacturing industries; others, on the amount of power used in manufacturing raw material into useful articles. The money value added through manufacturing processes has also been used as a basis for defining industrial regions. A combination of these three ideas is reflected on a map of the United States prepared by Clarence F. Jones and published in *Economic Geography*.[1]

Soil regions. The soils throughout a considerable part of the United States have been classified, and their distribution has been shown on

[1] *Economic Geography*, Vol. 14 (1938), p. 219.


NORTH AMERICA
AGRICULTURAL REGIONS
Scale of miles
0 100 200 300 400 500
1 Tundra
2 Hay and dairy region
Root crops important in some areas
3 Middle Atlantic trucking region
4 Chief forest regions
5 Corn belt
6 Spring wheat region
6A Columbia Plateau wheat region
7 Corn and winter wheat belt
7A Winter wheat region
8 Semiarid grazing and irrigated crops region
9 Arid and semiarid tropical region
10 Cotton belt
11 Humid subtropical crops region
12 Dry subtropical crops region
13 Humid tropical crops region
Merges into temperate crops in the highland areas. Only small patches of this region are cultivated, except in the West Indies, because of tropical jungle
After map by O. E. Baker
Bering Strait
Baffin Bay
Hudson Bay
Gulf of Mexico
Caribbean Sea
TROPIC OF CANCER
ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN

maps; but it is impossible as yet to present a map showing the soil regions of all parts of the United States, and a long time will pass before such a map for North America can be prepared. It is not until geographic studies have proceeded to a stage that makes it possible to present the results on a map that notable progress has been made. The map is the geographer's special and peculiarly valuable means of expression. It approaches in accuracy the formulas and equations worked out in the more exact sciences.

The physiographic regions. The simplest and most generally useful subdivision of a land area into geographic regions is based upon contrasts in topography, or relief. The existence of mountains, plains, plateaus, and uplands cannot be questioned. Their influence upon the climatic conditions, and therefore upon soils and the distribution of vegetation, is significant. Their influence upon living conditions on this earth and upon the occupations of most of the people has been persistent, sometimes profound, and at all times essentially unavoidable.

The great contrasts in topography are not made by human occupation or affected by it; they are distinctly natural. Millions of years pass without the occurrence of any notable changes in the outlines of such natural subdivisions. When our knowledge is adequate, the boundary lines of provinces based upon differences in topography can be drawn with a high degree of accuracy. Revision of boundary lines should be made whenever new information is available which makes greater accuracy possible. Man does not determine physiographic regions; he discovers and defines them on a map for purposes of study or description.

The major physiographic provinces within the United States were recognized long ago. J. W. Powell published a paper in 1896 in which he incorporated a map of those regions.[1] The fundamental principles which he used are sound and have been adopted by all subsequent workers in this field of study. In 1928 Nevin M. Fenneman,[2] as chairman of a committee appointed by the Association of American Geographers, assumed the chief responsibility of revising and redefining the

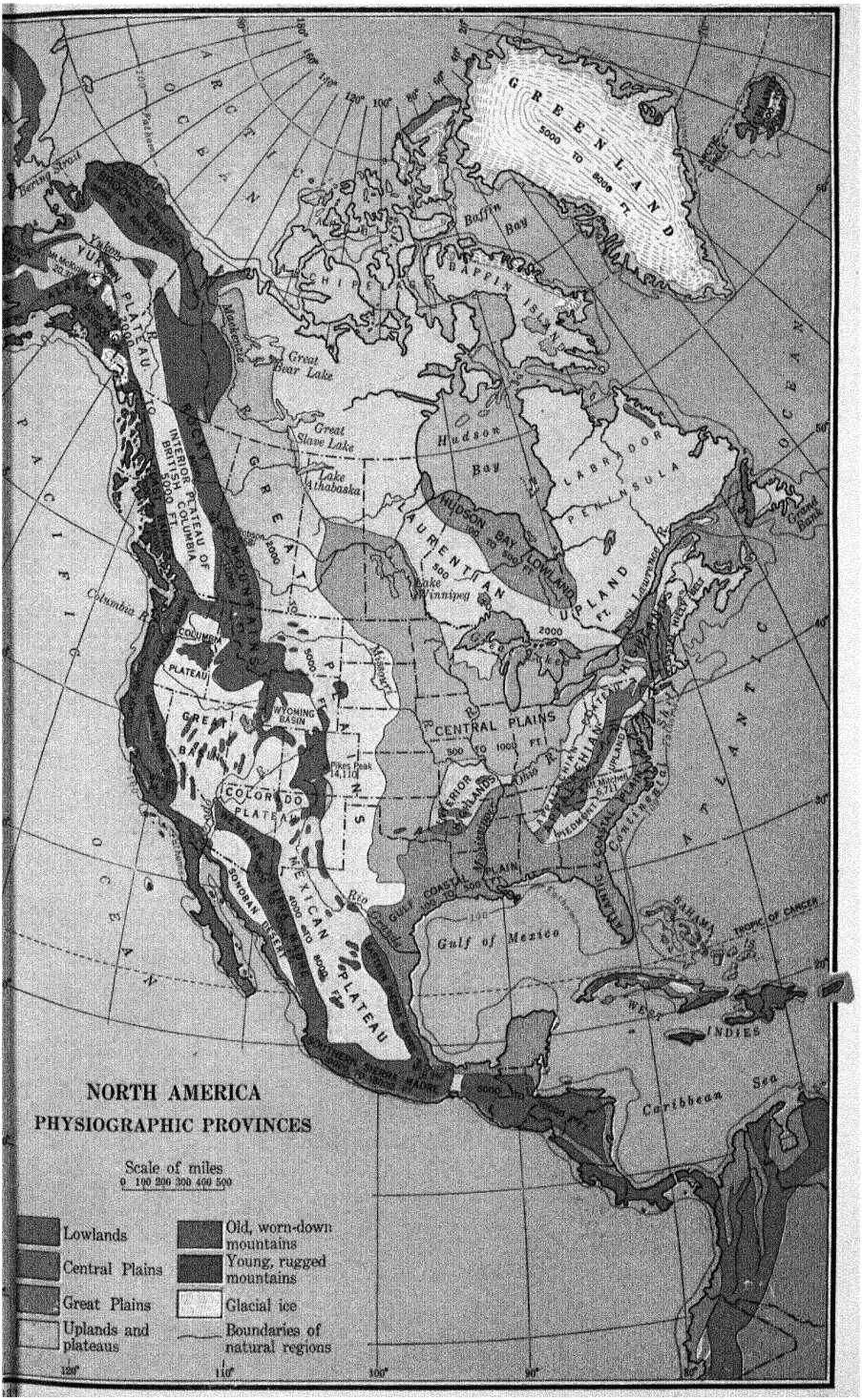
[1] J. W. Powell, "Physiographic Regions of the United States," *National Geographic Society Monographs*, Vol. 1, No 3 (1895), pp. 65–100.

[2] N M Fenneman, "Physiographic Divisions of the United States," *Annals of the Association of American Geographers*, Vol. 18 (1928), pp. 261–353.

subdivisions of our own national domain into physiographic regions and subregions. Fenneman's report was a notable contribution to our knowledge of the physiographic features of the United States. It stands as one of the classic publications in the development of the science of physiography and the scientific foundation for modern geography. Fenneman has now presented, in two large volumes, very careful and detailed descriptions of the physical features in each of the physiographic provinces within the United States.

The principles used in this country in defining physiographic provinces have been applied by various investigators in the subdivision of the other land areas of the earth's surface, and the regions thus defined have come into general use in the presentation of geographic descriptions and in the guidance of research work in the field of geography. The physiographic provinces of North America have served as the basis in organizing the material presented in this volume. These provinces are shown on the map opposite this page.

The interrelation of regional studies. If one chooses to study soil regions, he will soon discover that the differences in soils are due in large measure to differences in climate, vegetation, and topography. If he selects the climatic regions as the basis for his study, he will find himself helpless in explaining the differences in climate unless he takes into consideration the altitude of his regions, the relief features present, and the relationship of the area of study to the great wind belts of the world. A location on the windward or leeward side of a high mountain range may determine whether the region is well watered or in a rain-shadow area and therefore semiarid. The altitude of the land will determine in part the temperatures in that area. He simply cannot understand his climate unless he recognizes the significance of the physical features of the landscape. Some are particularly interested in the plant regions; but they cannot explain the distribution of plants without calling upon climatology, pedology (soil science), and physiography. Regardless of the plan that may be adopted for regional subdivision, a student of geography will soon discover that his plan bears a relationship to one or more other bases for regional subdivision. Frequent reference should be made to the various maps presented in this chapter.


NORTH AMERICA
PHYSIOGRAPHIC PROVINCES
Scale of miles
0 100 200 300 400 500
Lowlands
Central Plains
Great Plains
Uplands and plateaus
Old, worn-down mountains
Young, rugged mountains
Glacial ice
Boundaries of natural regions
GREENLAND
5000 TO 8000 FT.
Baffin Bay
BAFFIN ISLAND
Hudson Bay
LABRADOR PENINSULA
HUDSON BAY LOWLAND
LAURENTIAN UPLAND
Great Bear Lake
Great Slave Lake
Lake Athabaska
Lake Winnipeg
Great Lakes
CENTRAL PLAINS
500 TO 1000 FT.
INTERIOR PLATEAU OF BRITISH COLUMBIA
5000 FT.
YUKON PLATEAU
BROOKS RANGE
COLUMBIA PLATEAU
WYOMING BASIN
GREAT BASIN
COLORADO PLATEAU
MEXICAN PLATEAU
SONORAN DESERT
Pikes Peak 14,110
Columbia R.
Missouri R.
Ohio R.
Mississippi R.
Rio Grande
Gulf of Mexico
GULF COASTAL PLAIN
ATLANTIC COASTAL PLAIN
PIEDMONT
Mt. Mitchell 6,711
BAHAMA IS.
TROPIC OF CANCER
WEST INDIES
Caribbean Sea
Grand Bank
Bering Strait
Yukon
Mackenzie R.
Fathom
ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
120°
110°
100°
90°
80°

A brief treatment of a sample case will prove helpful in illustrating some of these many relationships. The example chosen includes the Black Hills of South Dakota and eastern Wyoming.

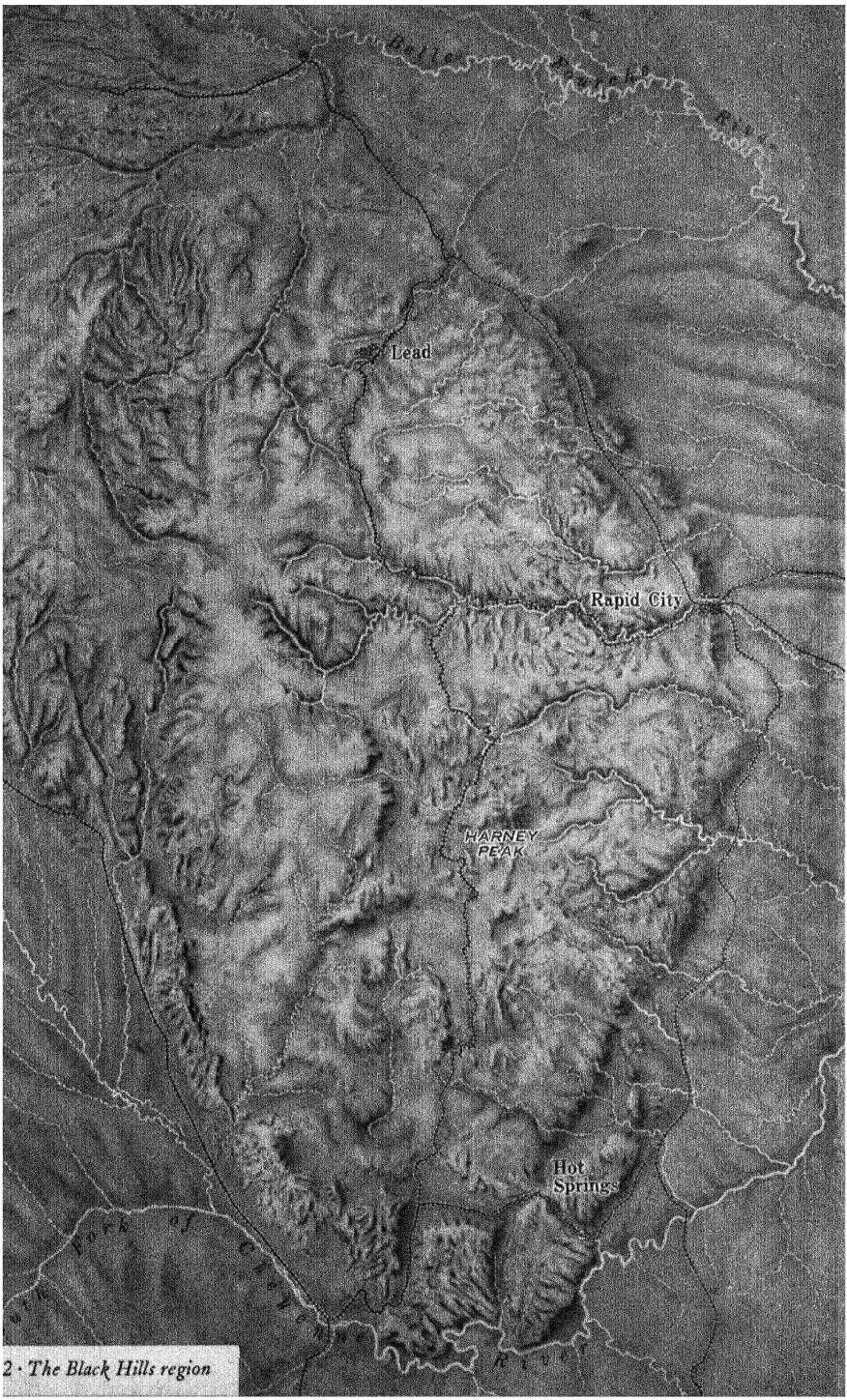
An illustration of interrelationship—the Black Hills. We can easily recognize on good relief maps or in well-selected pictures, or, better still, by field observations, that the Black Hills rise somewhat abruptly from the surrounding plains. See Figure 2. There is a break in topography at the margin of this province which is obvious to the most casual observer who visits that part of our country. Thus the boundaries of this area, based on contrasts in topography, are readily determined.

He who looks more deeply into the study of the natural environment may recognize that in the neighboring plains the rock formations lie in a nearly horizontal position. They are sandstones, shales, conglomerates, and limestones. In the foothills those same sedimentary formations are bent upward and at places stand in a nearly vertical position. Precisely where the change in topography occurs, we find a notable change in the geologic structure and thus discover an explanation for the variation in relief.

The Black Hills are due to a distinct upwarping, or doming, of the crustal portion of the earth. Subsequent removal by stream erosion of the higher portions of that dome and the dissection of the core rocks have produced the present relief features. As erosion has proceeded, more and more of a complex series of ancient metamorphic rocks has been uncovered. That series consists of gneisses, schists, and great granite intrusions. The core rocks are of Pre-Cambrian age; the sediments that encircle the dome are in part Paleozoic and in part Mesozoic in age. Associated with the very old rocks of the core and, at places, with the sedimentary strata, there are a number of later intrusions which have cooled and formed solid rock. They have produced minor domes about the northern margin of the Black Hills.

With the elevation of this part of our country there came an increase in rainfall in the area, and with the increase in elevation and rainfall came contrasts in relief, in soils, and in vegetation.

As we pass from the neighboring plains, where the surface is monotonously level, and climb into the Black Hills area, we enter a land-



2 · *The Black Hills region*

scape having great variety in the relief. In the foothill belt, at the southwest, south, and east, there are hogback ridges interrupted in places by *water gaps*, or gateways which have been cut by streams that radiate from the core of the Hills. Between the ridges there are roughly concentric valley lowlands. On the west side of the range, where the sedimentary mantle has not been removed, there is a plateaulike surface and an absence of hogback ridges. Here erosion has not proceeded far enough to produce the land forms common to the east margin. In the heart of the range we find deep canyons, rugged intercanyon ridges, bold mountain forms, craggy knobs, and other picturesque features. See Figure 3. The range has passed through several periods of mountain growth and several stages, or cycles, of erosion.

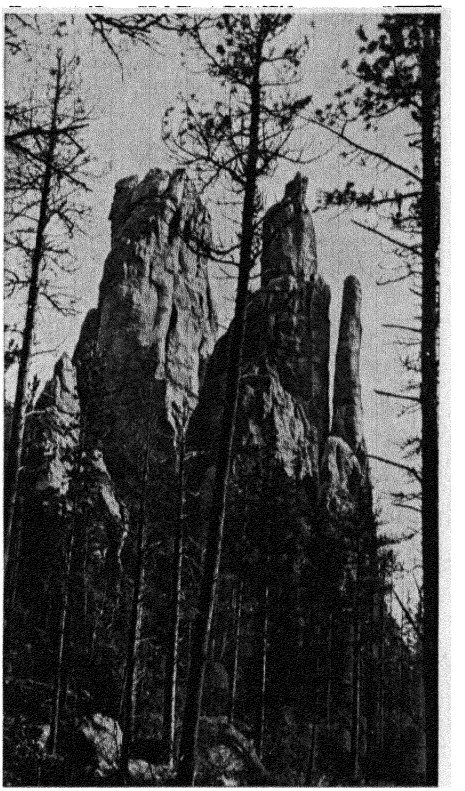
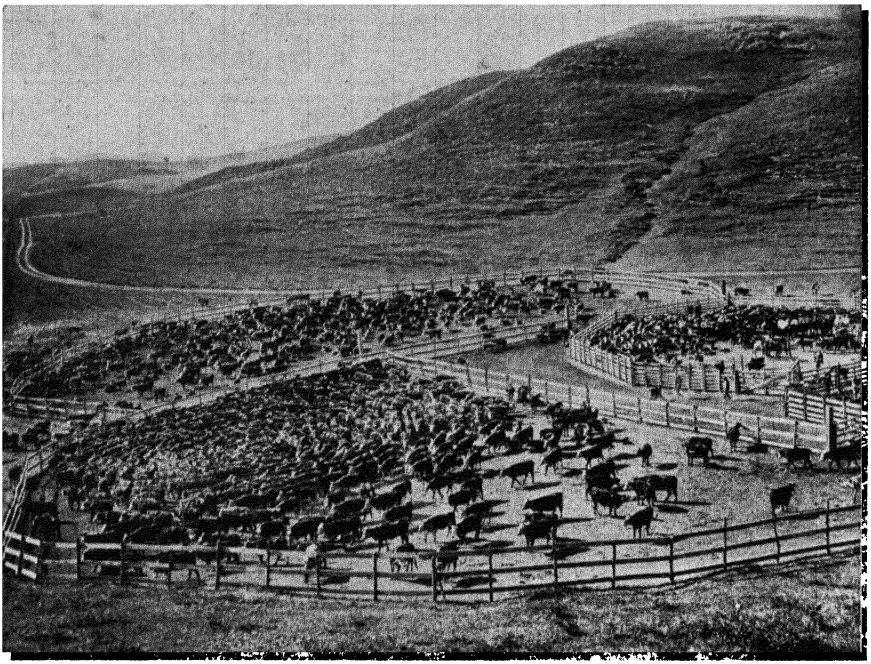


Figure 3 · Cathedral spires of pink granite in the Harney Peak section of the Black Hills

The rainfall of the Black Hills area is somewhat greater than that of the brown, seared, semiarid plains regions, and evergreen trees survive among the hills. We leave a land of sagebrush and grasses to enter one of forests. The dark-colored evergreen trees suggested to early settlers the name Black Hills. As we enter the area we pass from a land of cattle ranches (Figure 4) and some seminomadic shepherds to a land where forestry, mining, general farming, and recreational activities give character to the life of the people. In color and form, in topography, climate, vegetation, and economic opportunities, the Black Hills stand out conspicuously as a distinct geographic unit.

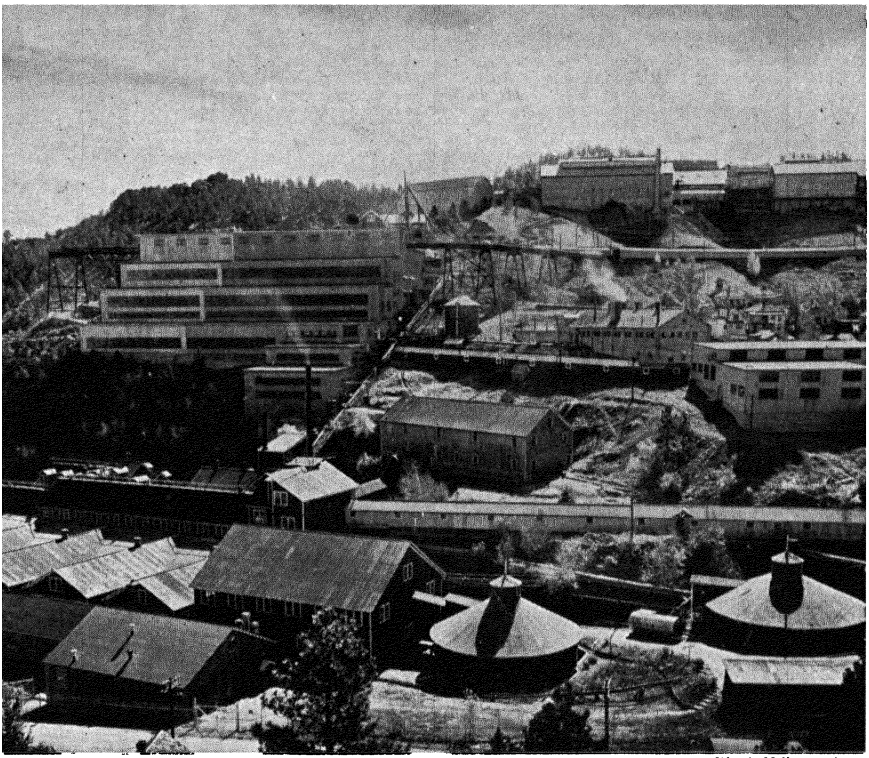


Ewing Galloway, N Y.

Figure 4 · A cattle roundup on a ranch near the Black Hills

The human drama. When progressive pioneer people enter a region, they look about in order to determine the most-favored occupations in that part of the world. Each habitat serves as a stage setting where a human drama is to be enacted. The actors wonder what their roles should be. Each wishes to know what part he is to play.

In the Black Hills some of the early pioneers washed gravels in the stream beds in the hope of making important discoveries. They found pebbles of tin ore and a number of gold nuggets. Placer mining was begun. Camp cities appeared at several places. Some men scrambled over the hillsides looking for indications of the original sources of gold and tin ores. They searched for mineralized zones or veins where work might be done at a profit. In time good ore bodies were located. Mining centers were established; mining towns developed; great stamp mills and concentrating plants were erected; and, before many years had passed, all the social and economic complexity of an active mining industry gave character to the life in that particular section.



Black Hills Studios

Figure 5 · A section of Lead, South Dakota, showing stamp mills and a cyanide plant that are typical of a progressive gold-mining camp

The forests of the upland area furnished mine timbers, building material, and fuel for the settlers. Some of the lands in the hills proved to be valuable for general farming, and the mining communities furnished ready markets for the farm products. Much later the beauty of the landscape attracted tourists from distant parts of the country, and pleasure resorts were provided and recreational grounds were set aside in the midst of the hills. As the years passed a cultural pattern developed in the Black Hills which is distinctly different from that in the surrounding plains. See Figure 5.

A résumé. Thus the natural geographic provinces, or regions, based upon contrasts in relief, serve as logical, practical, and convenient units

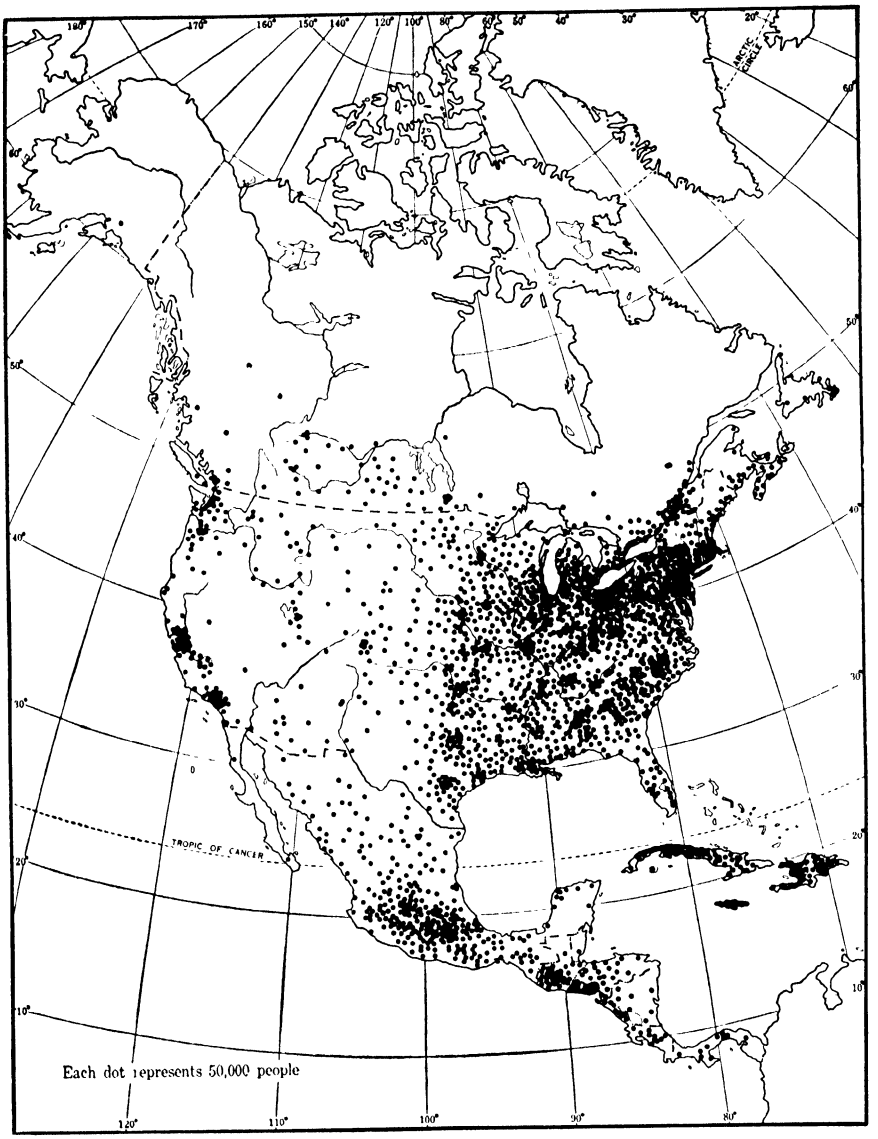


Figure 6 · Distribution of people in North America

of study, and by carrying out thorough regional treatments we should come to an intelligent and sympathetic understanding of the human life in the various parts of the continent. We should recognize that the inhabitants of each region have their own peculiar social and economic

problems and, through the sale and distribution of their products, a tie-up with national and international problems. The distribution of people on a continent is determined chiefly by geographic conditions, and Figure 6 should prove to be of increasing interest as we proceed with our studies.

In this volume it is proposed to describe and interpret the physical features of the continent and thus to provide a background, or basis, for complete regional studies that should be undertaken by all who wish to understand thoroughly the influence of environment upon the economic and cultural development in the different parts of North America. An approach to the human drama in each province will be included in order to emphasize some of the relationships between the physical and cultural phases in the study of geography.

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GEOLOGIC CALENDAR
FOR NORTH AMERICA

Arranged Primarily for Students of Physiography

		PHYSIOGRAPHIC CONDITIONS	OROGENIC TIMES	SPECIAL LAND SURFACES
PSYCHOZOIC OR RECENT ERA (20 million years)	POSTGLACIAL PERIOD	Most of continent above the sea Some uplift at northeast and along Pacific coast Glaciers shrinking Vigorous stream action and great floods Winds very active in arid and semiarid areas Ground waters continuing their work Waves and shore currents very active Volcanism in cordilleran region Mountain growth continuing in West		Mississippi and Yukon bottom lands developing Great deltas made Lacustrine plains exposed Dune areas developing
	PLEISTOCENE PERIOD	Morainic mantle deposited Thousands of lake basins formed Great lakes in Basin Region Ice-front lakes Drainage disarranged Rivers flooded by glacial waters Several interglacial stages Great canyons of West excavated Numerous alpine glaciers in high mountains Huge ice sheets in north half of continent Volcanism in West	Cascadian	Morainic lands Bare rock surfaces with soil swept away Outwash plains Valley trains
CENOZOIC OR MODERN ERA (60 million years)	PLIOCENE	Mountain growth in Cordilleran Provinces from southern Mexico to Alaska General uplift in Eastern Highlands Volcanism in Cordilleran Provinces Sierras and Basin Ranges refaulted Erosion to peneplanation in parts of West Sedimentation on Pacific coast Sedimentation among mountains and on Great Plains	Revolution	Late Tertiary peneplains pp. 305, 390, and 448
TERTIARY GROUP OF PERIODS	MIOCENE	Vast outpouring of lavas in Idaho, Oregon, and Washington Volcanic explosions in Rocky Mountains and elsewhere in Cordilleran Provinces Sea advances over California coastal areas Sedimentation on Atlantic Coastal Plain Sedimentation among mountains of West Vigorous erosion in high mountains Erosion in most parts of continent		Columbia and Snake River Plateau p. 408 Mid-Tertiary peneplain p. 124 Tertiary cycle-end-surface p. 309
	OLIGOCENE	Some regional uplift near close of period in West Sedimentation on Gulf Coastal Plain Local sedimentation among mountains of West Erosion in high mountains of West		Early Tertiary erosion surfaces
	EOCENE	Sedimentation on Coastal Plain Sedimentation among mountains of West Active erosion in high mountains Alpine glaciation in Rocky Mountains Volcanism at places in West Mountain growth continuing	Laramide Revolution	pp. 302 and 404

		PHYSIOGRAPHIC CONDITIONS	OROGENIC TIMES	SPECIAL LAND SURFACES
MESOZOIC OR MEDIEVAL ERA (110 million years)	UPPER CRETACEOUS PERIOD	Growth of Rocky Mountains Uplift of much of intermontane plateaus of West Uplift of much of eastern half of continent Uplift and arching of Appalachian Highlands Mesa Verde sandstone deposited (A widespread mesa-capping) Dakota sandstone deposited (A great hogback maker) Sea covers Atlantic and Gulf Coastal Plain Province Volcanism in Rocky Mountain Province and central Mexico Sea advances covering Rocky Mountain and most of Great Plains provinces	Laramide Revolution	Cretaceous peneplains pp. 124 and 248
	LOWER CRETACEOUS OR COMANCHIAN PERIOD	Fresh water deposits east of Appalachian Highlands Fresh water deposits in Montana, Wyoming, and British Columbia Sea advances over Pacific margin of continent Sea covers much of Mexico and Great Plains Sea advances from Gulf of Mexico and Arctic Ocean	Mountains rise in	
	JURASSIC PERIOD	Intrusion of immense batholiths near Pacific border Mountain making from Central America to Alaska Jurassic beds now exposed at Zion Canyon National Park were deposited Continental deposits in Great Plains and in Far West Volcanism important in Far West Sea advances along Pacific border A long period of erosion in most of continent	Pacific Borderlands Province	
	TRIASSIC PERIOD	Some "Painted Desert" formations of this age More red beds formed Arid climate (salt and gypsum precipitated) Triassic Lowland of East receives fresh water sediments and lavas Continent rising (eastern half becomes land)		
PALEOZOIC OR ANCIENT ERA (*Continued*)	PERMIAN PERIOD	Appalachian mountain making Granitic intrusions in New England Glaciation in Boston area Many red beds formed Kaibab limestone, rim rock at Grand Canyon of this age Arid climate (salt and gypsum precipitated) Sea advances into Texas, New Mexico, and Arizona, and later in Great Plains and Cordilleran Provinces	Appalachian Revolution	
	CARBONIFEROUS PERIOD — PENNSYLVANIAN	Period of crustal unrest Great fresh water swamps develop in East where coal measures form Sea covers much of continent several times	Crustal disturbances	
	CARBONIFEROUS PERIOD — MISSISSIPPIAN	Red wall in Grand Canyon of this age Great limestones accumulated Sea advances over much of East and Far West Continent rises above sea at close Crustal movements in Southern Appalachians and in Colorado, Utah, New Mexico, and west Texas Continuance of mountain folding in Acadian region		

		PHYSIOGRAPHIC CONDITIONS	OROGENIC TIMES	SPECIAL LAND SURFACES
PALEOZOIC OR ANCIENT ERA (330 million years) *(Continued on preceding page)*	DEVONIAN PERIOD	Mount Royal and Monteregian Hills in St. Lawrence Lowland of this age Volcanism in New England–Acadian Province Mountains in Acadia folded Sea readvances and covers nearly 40 per cent of continent but withdraws at close of period	Acadian Mountains	
	SILURIAN PERIOD	Continent nearly free of sea water at close Niagara limestone, widespread in interior of continent, is formed Sea advances and retreats twice in period		
	ORDOVICIAN PERIOD	Mountain making in East from Pennsylvania to Gaspé Peninsula Near close of period sea withdraws Sedimentation in epicontinental sea Sea readvances and covers much of continent	Taconic Mountains	
	CAMBRIAN PERIOD	Sea withdraws in part at close of period Sedimentation takes place Sea advances over portions of continent		
PROTEROZOIC ERA (500 million years)	TAKEN TOGETHER AS PRE-CAMBRIAN TIME	Most of the rocks of these very ancient eras of geologic time have been profoundly altered by metamorphic processes. During each mountain-making period they have been subjected to tremendous pressure. Whenever volcanism has occurred the molten magmas have necessarily passed through these older underlying rocks.		Very old erosion surfaces truncate Proterozoic rocks at places. One shown in the Grand Canyon of the Colorado. p. 367
ARCHEOZOIC ERA (500 million years)		Where the rocks are exposed at the surface today they exhibit marked complexity, and when eroded produce notable variety in topography. In high mountain areas they produce great ruggedness. They are appropriately referred to as the *Fundamental Complex* or the *Pre-Cambrian Complex* See Figure 58.		Old-age erosion records are commonly found at surface of Archeozoic complex. One below Proterozoic and above Archeozoic rocks exposed in Grand Canyon of the Colorado. Figure 187

II

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THE ATLANTIC AND GULF COASTAL PLAIN

A General Description

A typical coastal lowland. The lowland bordering the Atlantic coast of the United States and Mexico is one of the most clearly defined physiographic provinces of the continent. It extends from Cape Cod southward to the peninsula of Yucatan and inland to the margins of a variety of provinces all of which rise distinctly higher than the general level of the Coastal Plain.

Very few topographic features relieve the monotony which is characteristic of extensive areas in this lowland province. Broad, flat-bottomed valleys, with bordering bluffs that range from 20 to 50 feet in height, provide the only relief features throughout much of the area. For mile after mile the surface is so remarkably level that highways and railways follow straight lines. The outer margin of this province has been beneath the ocean waters during or since the Pleistocene Ice Age, and the entire province has been under sea waters in relatively recent geologic time. From many of the best outlook points the present surface appropriately resembles the floor of an ancient sea.

On Cape Cod and on the islands south of New England and westward to Staten Island a morainic mantle has given a gently rolling surface to the landscape, with occasional hills that rise to 100 feet, and at a few places to about 200 feet, above their surroundings. In New Jersey two low ridges, and in the Carolinas and Georgia a belt of hills near the inner margin of the plain, break the uniformity of the surface. In Florida there is a picturesque hilly belt in the central portion of the peninsula where the relief commonly varies from 100 to about 200 feet. Low ridges parallel the coast line in Alabama, Mississippi, and Texas, and each ridge is bordered on the landward side by a lowland belt. Where rivers have cut through these ridges their valleys are usually 200 to 300 feet deep. Low marine terraces border the coast, and sand dunes fringe the seaward margin of the plain at many places. Near Tampico, in Mexico, there is an isolated volcanic plug that rises conspicuously above the lowland. See Figure 7. The region is predominantly a lowland plain that slopes gently to the sea.

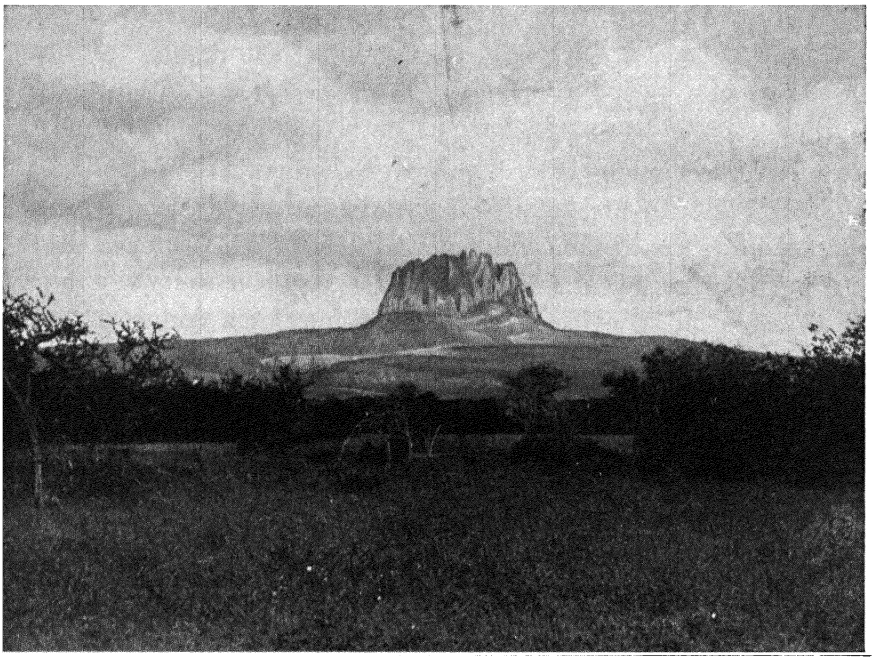


Figure 7 · A volcanic plug on the Coastal Plain near Tampico, Mexico. This is a unique feature of this lowland province

The landscape from the air. When seen from the air, the pine forests that cover a large portion of the Coastal Plain are conspicuous. They give to much of the landscape a dark-green color. When to their extent is added that of the swampy lands, one is impressed with the relatively small amount of land under cultivation in the region. Nevertheless, agriculture is the dominant occupation of the people living in this province. Each spring the blossoms of fruit trees beautify many of the hillsides, and during the autumn most of the plowed fields throughout the Southern States are whitened by millions of cotton bolls.

The coast line is dotted with resorts where throngs of people gather during the summer season in the northern portion and during both summer and winter in the southern portion. Charleston, Savannah, and Jacksonville are conspicuous concentrations of population near the mouths of rivers; and near the shores of the Gulf of Mexico we find Tampa, Mobile, New Orleans, Galveston, Tampico, and Veracruz.

At the inner edge of the Coastal Plain we see another chain of important cities, but the towns and villages throughout most of the province have comparatively small populations. There are no large cities in its midst; all the larger settlements are at its inner or outer margins.

The inner boundary. The inner boundary of the Coastal Plain crosses Massachusetts near the Cape Cod Canal; and from there, westward to New York City, it is located just south of the mainland of New England and north of Nantucket, Martha's Vineyard, and Long Island. Southwestward from New York City the boundary line crosses New Jersey to Trenton and is prolonged through Philadelphia to the western outskirts of Wilmington, Baltimore, and the District of Columbia. It then passes through the cities of Richmond, Columbia, Augusta, Macon, and Columbus. In Alabama it is a few miles north of Montgomery.

Approaching the Mississippi, the inner boundary of the province swings northward into the interior of the continent to a position near the southern end of Illinois, and southwestward from southern Illinois it skirts the boundary of the Interior Highlands of Missouri and Arkansas. See the map opposite page 12.

In Texas the inner boundary of the Coastal Plain is somewhat irregular and indefinite, but it may be traced a few miles west of Fort Worth, Austin, and San Antonio, and thence along the southern margin of a clearly defined escarpment, due to the Balcones Fault, to the Rio Grande. In Mexico the inner margin of the plain is sharply defined at the base of the Sierra Madre Oriental.

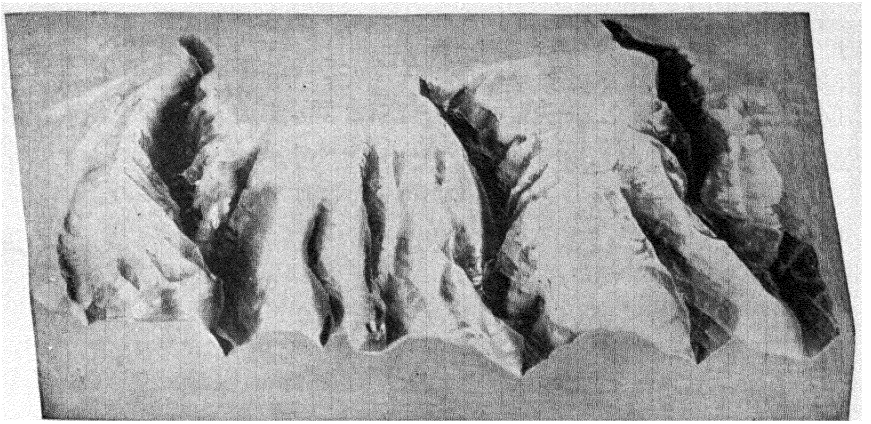
The elevation at the landward margin of the Coastal Plain varies from sea level at New York City to 1000 feet at the Rio Grande. The variations are irregular. In Maryland the inner margin of the plain is about 300 feet above tidal waters, in Georgia about 800 feet, at Little Rock, Arkansas, about 360 feet, and at Austin, Texas, about 700 feet above the sea.

The fall line. Southwestward from the valley of the Hudson to central Alabama, where the lowland which we are describing comes in contact with the Piedmont Upland of the Appalachian Highlands, the inner boundary of the Coastal Plain is appropriately designated the *fall*

line. Numerous streams from the older land lying to the west and northwest cross the lowland plain. Where these streams pass from the older and harder rocks of the uplands to the loose, unconsolidated, and younger sediments of the plain, there are falls or rapids in their channels.

These falls or rapids in the major streams determined the sites of many early settlements at the inland margin of the province because they marked the head of continuous navigation from the sea. They represented the upstream termini or transshipment points where travel and transportation were interrupted. Trenton and Philadelphia were established near the rapids in the Delaware and those of the Schuylkill respectively. Wilmington, Baltimore, and Washington, D. C., were early located near the fall line. The location of the city of Washington was not determined by the adventures of settlers, but the site selected for the national capital happens to be just east of the Falls of the Potomac. Early settlers in Virginia who moved inland along the James River paused at the rapids where Richmond is now located. From the small seventeenth-century settlement the present-day capital city of Virginia has developed. Many of the villages which grew up at the fall line in the Carolinas and Georgia have become important manufacturing centers during the recent industrial development in that part of the country. The water power that first attracted the miller has now, through the aid of the hydroelectric engineer, become a source of power which is contributing to modern industrial growth.

The seaward boundary. The outer boundary of the Coastal Plain is the present shore line. Where the sea waters meet the land we might expect to find a very well defined boundary, but it is more appropriate to think of this outer edge of the province as one which is constantly changing in its character and position. The work of shore-line currents, of waves, of corals, and of streams causes a constant succession of changes. The rising and sinking of sea level relative to the land changes the outline of the continent. All estuaries are drowned river mouths due to the lowering of the land relative to sea level. When formed they are soon changed by the deposition of sediments or by the accumulation of vegetable growth. No other physiographic boundaries represented on the map of North America are subject to so many minor



Photograph of model prepared by Francis P. Shepard

Figure 8 · Submarine canyons off the New England coast

modifications, within comparatively short periods of time, as are the coast lines of the continent and of neighboring islands.

The continental shelf. Seaward from the Atlantic and Gulf Coastal Plain there is a zone, or belt, where shallow waters rest upon a so-called *continental shelf.* This shelf is probably but the submerged border of the coastal lowland. It varies in width from a few miles to more than 100 miles and may be traced on the coast charts from Newfoundland to Central America. The depth of waters over this coastal feature increases seaward to about 100 fathoms, or 600 feet. At its outer margin the sea bottom drops off abruptly to abysmal depths of several thousand feet. We shall find, when we consider the Pacific coast, that a similar but much narrower shelf borders the western margin of the continent.

From all that is yet known, most of the surface of the shelf on the Atlantic side of the continent and in the Gulf of Mexico is smooth, with a gentle slope away from the present shore line. It is a remarkable fact, however, that at a number of places, and notably near the outer margin of the shelf, deep, steep-sided troughs have been discovered which resemble gorges or canyons cut by streams in a land surface.

Francis P. Shepard[1] is now carrying on studies of the submarine floor

[1]Francis P. Shepard, "Submarine Valleys," *Geographical Review*, Vol. 23 (1933), pp. 77–89.

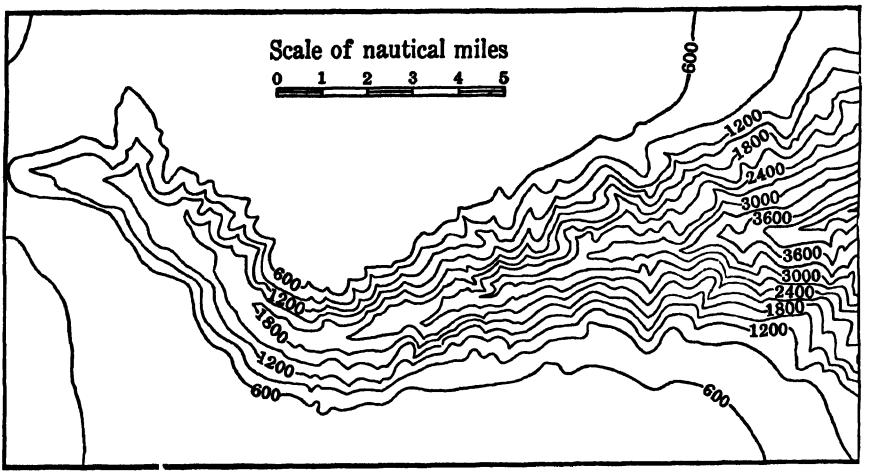
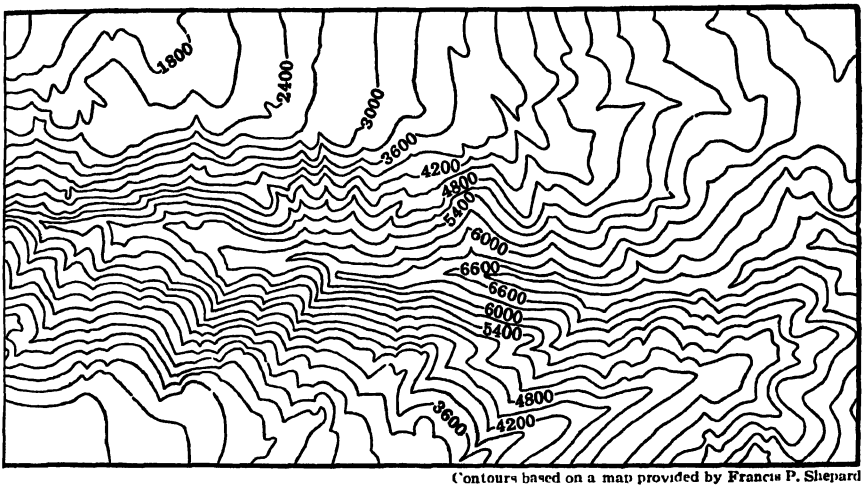


Figure 9 · Submarine canyon at the margin of the

which borders the continent, and has presented evidence of many deep canyon troughs in the continental shelf. He describes some near the outer margin of Georges Bank, south of Nova Scotia, as thousands of feet deep and comparable to the great canyons in the western part of our country. See Figure 8.

Seaward from the mouth of the Hudson River a deep trench was long ago discovered. See Figure 9. In places this trench is much like a river gorge, with a depth of about 4000 feet below the general submarine land surface. It has been traced seaward to a depth of 7000 feet. This submarine feature is commonly interpreted as a valley cut during an earlier geologic period when the continental shelf was above sea level. Three canyons smaller than the one opposite the mouth of the Hudson have been discovered off the coast of New Jersey, and there are submarine channels opposite Delaware and Chesapeake bays and at several places farther south.

In an unpublished paper presented by the late A. C. Veatch and Paul A. Smith at the meeting of the Geological Society of America in December, 1938, evidence was presented of two periods of subaerial erosion for the continental shelf opposite the mouth of the Hudson River. They describe, in addition to the deep canyon mentioned above, a broad flat-bottomed channel 10 miles wide and with a depth of about



Contours based on a map provided by Francis P. Shepard

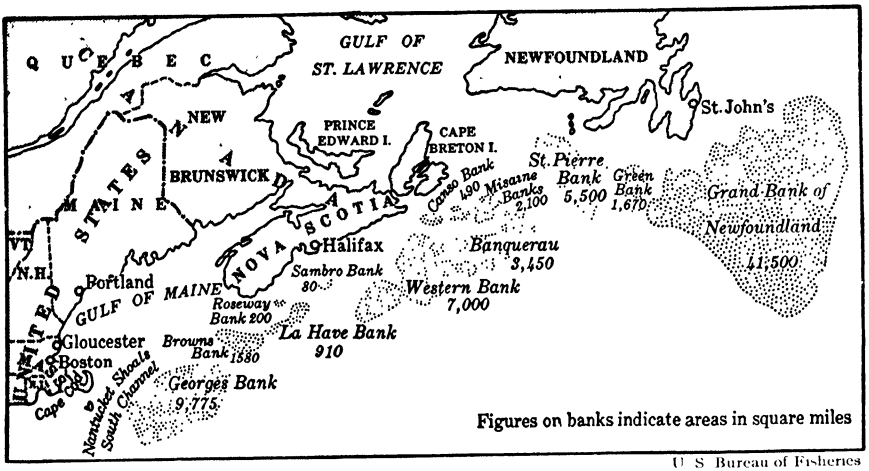
continental shelf opposite the mouth of the Hudson River

35 fathoms. At a depth of 43 fathoms there is a large delta associated with this channel. The broad channel and the deep submarine canyon farther out at sea are taken as evidence of the two stages of stream erosion.

D. W. Johnson[1] has shown from a study of marine charts that certain ridges similar to those commonly found at places in the topography of the Coastal Plain south of New York Harbor are present beneath the sea waters in the Bay of Maine. The great fishing banks which lie south of Nova Scotia and Newfoundland may represent a still further northeastward extension of the Atlantic Coastal Plain. See Figure 10.

The offshore submarine topography suggests that the portion of the lowland plain now under water at the eastern margin of North America formerly stood above sea level, and that the Atlantic coast at one time followed approximately the outer margin of the continental platform. But this explanation requires that we believe the lands to have been several thousand feet higher than they are today. If that were so, what became of about half of the ocean waters during that period? It is one of the fascinating fields of investigation in which much more work must be done before a solution can be anticipated.

[1]D. W. Johnson, *New England-Acadian Shoreline.* New York, 1925.



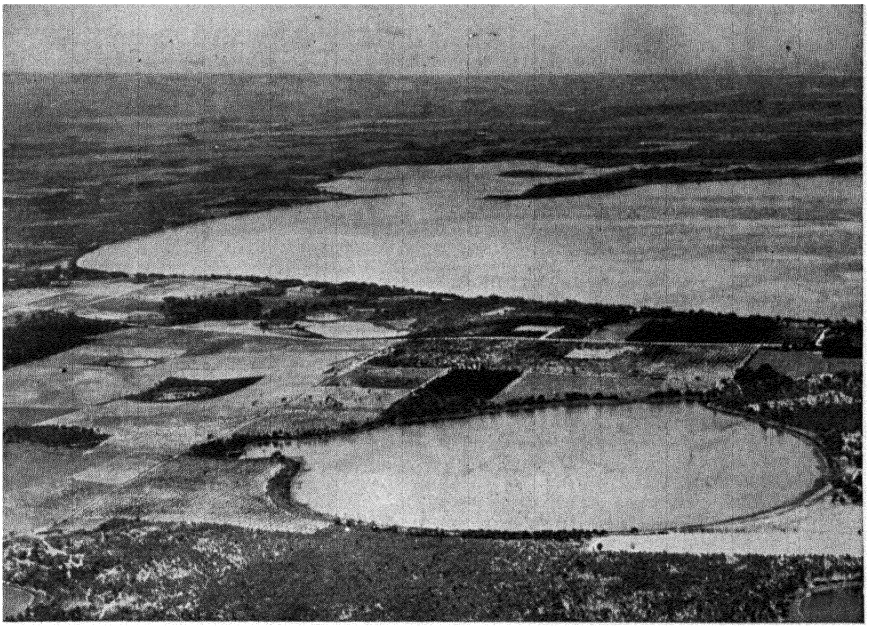
U. S. Bureau of Fisheries

Figure 10 · The great fishing banks northeast of Cape Cod, which may represent an extension of the Atlantic Coastal Plain

Lakes, ponds, and lagoons. Among the glacial deposits in the northern portion of the plain there are many undrained depressions where rain water has accumulated and formed lakes or ponds. Barrier beaches have led to the formation of many shore-line lakes. This process is well illustrated on the south shore of Martha's Vineyard.

Southward from New York Harbor long, narrow tidal marshes or lagoons are common. The Dismal Swamp of Virginia and North Carolina, with its remarkable network of lagoons, is less than 20 feet above the sea and has an area of at least 1500 square miles. In the midst of this swamp is Lake Drummond, which is from six to ten feet deep.

In central Florida there are thousands of sinkholes partly filled with water which add greatly to the scenic attractiveness of the peninsular portion of that state. In some sections at least half the surface is occupied by depressions. See Figure 11. At Silver Springs underground waters come to the surface and form a beautiful pool. Each day hundreds of visitors, in glass-bottomed boats, see the water bubbling through the sands at the bottom of the pool. They are fascinated by the huge turtles and myriads of subtropical fish playing about in the clear waters or dashing in and out among delicate leaves or branches of water-loving plants that mantle the nearly vertical walls of the sinkhole. This belt of sinkholes extends northward into southern Georgia.



Aero-Graphic Corporation

Figure 11 · Lakes in the central portion of the peninsula of Florida

The St. Johns River in Florida occupies a lagoon, and farther south many coastal lagoons are included with the Everglades in an area which may be set aside as a national park. The Everglades are so near sea level and have so little slope that water stands over much of the park area a large part of the time. The swamp lands of southern Florida occupy nearly 6000 of the 7000 square miles in that part of the state. The forested portions of southern Florida are the higher lands in the midst of the great swamp. Lake Okeechobee fills a large shallow basin embracing about 700 square miles. Its surface elevation varies with the seasons but is usually about 20 feet above the sea. From the biological standpoint the southern part of Florida is a natural wonderland and should be maintained as a sanctuary. In addition to its vast mangrove marshes and rookeries, where literally millions of water-loving birds make their homes, it contains the only tropical forest in continental United States.

Bordering the shores of the Gulf of Mexico, lagoons and tidal marshes give character to the outer portion of the Coastal Plain. All these par-

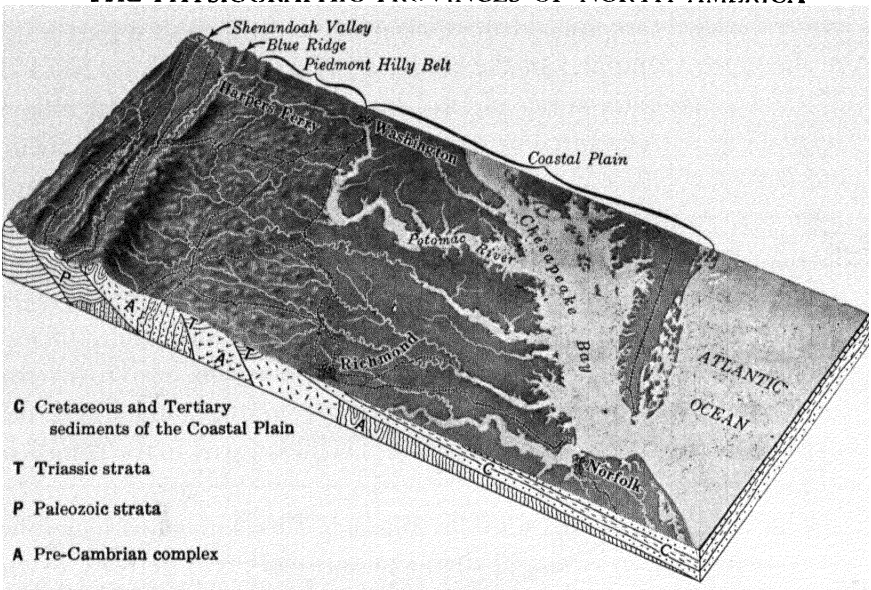


Figure 12 · A block drawing including belt of terrain extending from the Shenandoah Valley to the Atlantic coast line. The Blue Ridge and Piedmont hilly belt, or upland, are shown at the left. The fall line extends from near Washington southward through Richmond, and from that line eastward the lands all belong in the Coastal Plain Province. Diagrammatic structure sections, based on the publications of the Virginia Geological Survey, but somewhat simplified, are shown on two sides of the block

tially submerged areas near the coast are gradually being filled by sediments and by the growth and decay of vegetable matter. In the broad bottom lands of the major stream courses, particularly in the flood plain of the Mississippi River, there are numerous old channel lakes, and in the delta of the Mississippi there are several lakes. See Figure 15.

Materials and structure. The materials of the Coastal Plain consist, for the most part, of unconsolidated sands, gravels, clays, and marls. Locally there are beds of limestone rich in phosphate, and at other places there are layers of coral rock. Along the coast of Florida for 250 miles south of St. Augustine large quantities of shells are partially cemented into a rock called *coquina.*

Some of the strata of the plain that outcrop far inland from the coast contain shells of marine animals, which indicates that the sediments in

which the shells are imbedded accumulated while the salt waters rested on the present land area of the plain; other strata contain no fossils at all; and a few carry traces of land life. The fragmental materials of the plain were transported by rivers from the older lands farther inland and deposited either in the sea or on the land surface after the retreat of the sea. At many places a mantle of sand and gravel was spread over the plain by streams after the sea water retreated.

In the diagram shown in Figure 12, the formations appear as layers of sediments dipping gently seaward. The oldest formation outcrops farthest inland, and in a general way the surface belts nearer the coast represent the outcropping edges of successively younger strata. The monotony of relief in this lowland province is due in part to the simplicity of the underlying structure.

The exposures in many of the roadside cuts and in various other excavations give evidence of frequent advances and retreats of the shore line. Whenever the sea retreated, rivers excavated shallow valleys in the new land; and when the sea readvanced, the old valleys were filled with sediments. The resulting *unconformities* in structure record interruptions in sedimentation.

The Evolution of the Present Topography

Establishment of drainage.[1] As the ocean waters began to withdraw a narrow Coastal Plain came into existence as a land area. That plain must have appeared much as the coastal mud flats of today appear at low tide. The rivers from the older land lengthened their courses seaward across the low, flat alluvial plain. The gradients of the channels across this new-made land were very low, and the streams soon began to meander and thus to develop broad bottom lands associated with their channels. As the withdrawal of the sea waters continued and the streams were forced to lengthen their courses still more, some of the independent streams of the older land surface undoubtedly united. This process has been labeled *ingrafting of streams.* See Figure 13.

[1]Frequent reference should be made to the map at the back of this book which shows the land forms of the United States.

Rains fell upon the new land, and in time more river valleys were developed. The exact location of new drainage lines on a recently emerged sea bottom is determined by the irregularity of the surface or by the inequality of the surface materials in their resistance to erosion. Embryonic river systems originate as gullies, and the gullies grow by headward erosion during, and for a short time after, each rainfall. They pass through the stages of ravinehood to valleyhood. In this manner new valley lines were established at many places on the Coastal Plain. Their location and development were consequent upon the slope of the surface and the character of the materials encountered. Such a stream pattern is called *consequent drainage.*

The gullies that formed at the seashore had a distinct advantage in growth over those that may have begun at some place inland on the Coastal Plain. The material removed in the cutting of a gully must be disposed of. If it is deposited on the land at the mouth of a gully, it forms an alluvial fan, which tends to block or shift the course of the stream. If the waste material is carried to the sea and there disposed of by waves and shore currents, it does not interfere with the erosional work of the stream. Thus the consequent drainage lines which were successful in the conquest of the new land area probably began as small gullies at the shore line. By working headward they have come in time to include large areas of land in their drainage basins.

Dismemberment of streams. When a seashore is submerged and the marine waters advance inland, forming great estuaries such as Chesapeake Bay, the branches of a major stream are cut off. This process is called the *dismemberment of streams.* See Figure 13. The James, Rappahannock, and Potomac rivers, former tributaries of the Susquehanna, became independent streams when the Coastal Plain adjoining Chesapeake Bay was submerged. The sinking of the coastal lands and the consequent drowning of the river mouths characterize much of the Atlantic margin of the continent and account for most of the major irregularities of the coast and for all the better harbors. Numerous cases of dismemberment occurred as the larger estuaries along the Atlantic coast were formed. The larger bays along the coast of the Gulf of Mexico are due to a sinking of the land. They are estuaries.

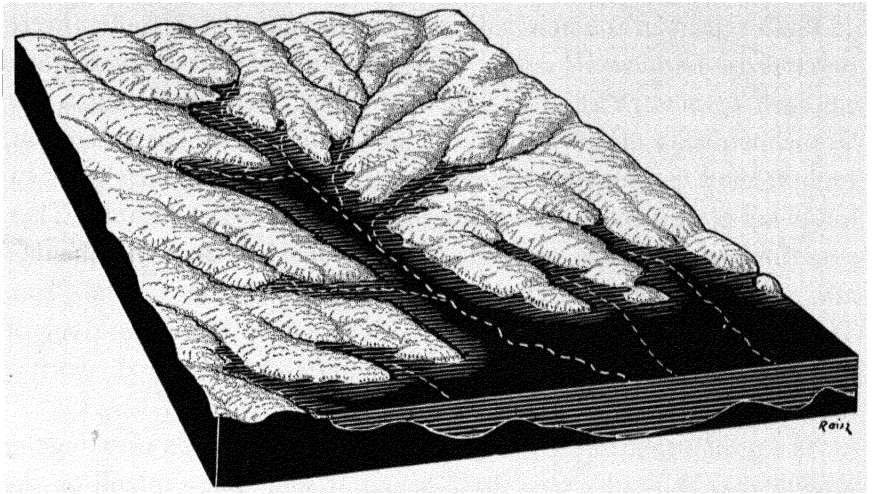


Figure 13 · When the sea advances on a land area, the river mouths are drowned and become estuaries. Dismemberment occurs wherever tributaries are cut off from the main stream and provided with independent outlets. When the sea withdraws, the ingrafting of streams is almost certain to take place

The base plain of erosion. The valleys which developed within the coastal province are all shallow. They cannot be otherwise, for sea level at the mouth of a stream system determines the depth of stream cutting at that point. Inland from the shore line the streams cannot lower their courses even to sea level, for every stream bed must slope seaward. The gently inclined plain below which a stream cannot erode its valley is the *base plain of erosion.* Deep valleys are therefore impossible in this province because the surface of the Coastal Plain is comparatively near the base plain of erosion.

The stages in valley development. Youth, maturity, early old age, and the various intermediate stages in the life history of valleys in coastal lowlands are illustrated over and over again in this physiographic province. Youth is illustrated by thousands of V-shaped gullies that are just beginning their life histories. Such youthful forms are commonly observed near the coast or in the tributaries of the older streams. Valleys that have reached the mature stage of development are broader and more open, with a characteristic U-shaped form. They are usually farther inland in that part of the Coastal Plain that has long been subject

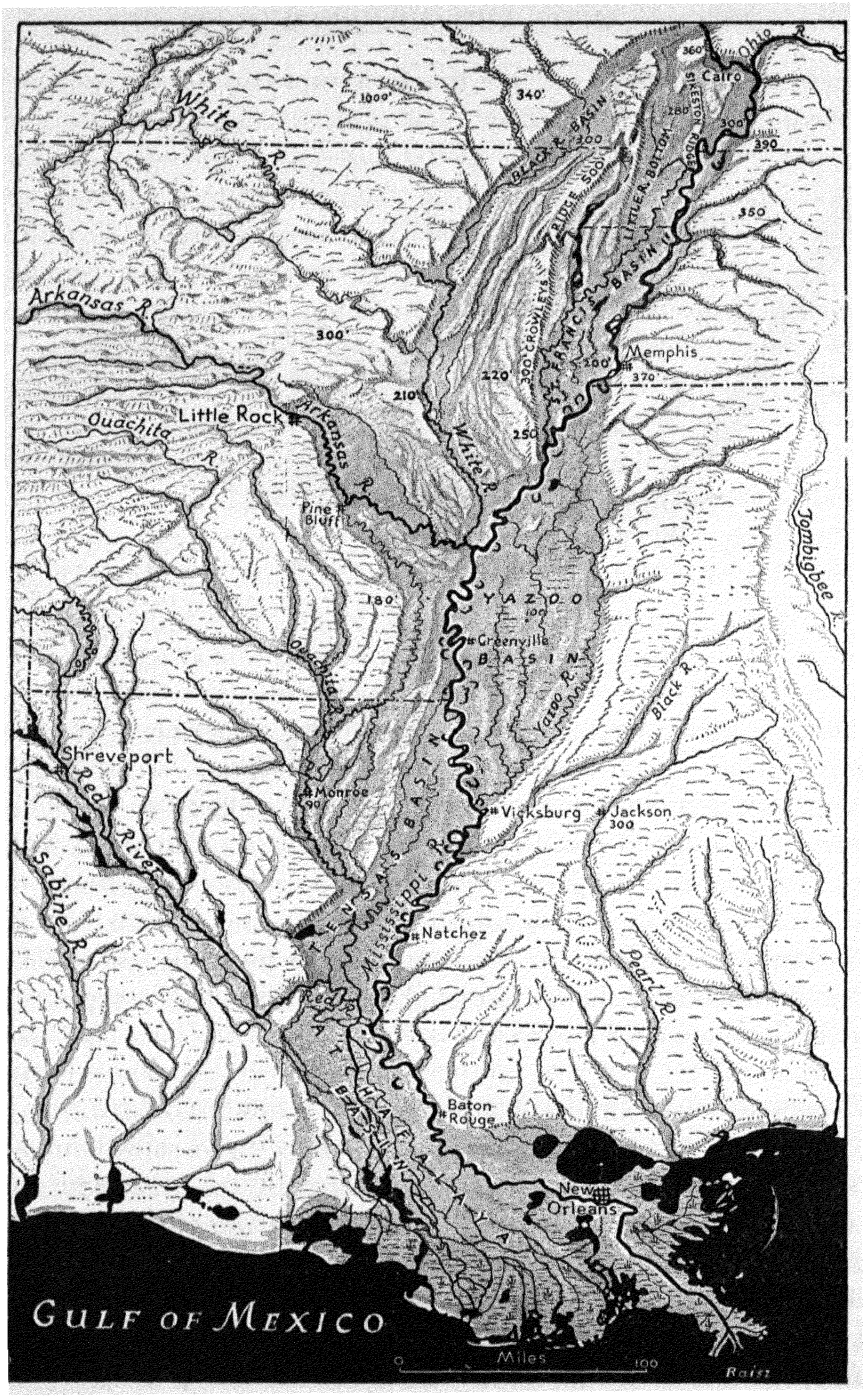


Figure 14 · The lowlands and delta of the Mississippi River

to stream erosion. There are not many examples of old-age valleys in this province. However, the flood plain of the Mississippi furnishes one of the best examples of old age in the world. The stream is working on a low gradient in a broad alluvial plain. It swings back and forth across its flood plain in great meanders, shifts its course from time to time, deposits sand bars in its channels, builds up natural levees along its banks, deposits a thin layer of alluvium on its flood plain during each period of overflow, and develops at its mouth an extensive delta. See Figures 14 and 15.

The lowlands of the Mississippi. The Mississippi River lowland from Cairo, Illinois, to the Gulf of Mexico is 50 to 70 miles wide and about 600 miles long. The actual channel of the river from Cairo to the Gulf is about 1000 miles long. This lowland belt is one of the most remarkable alluvial lands in the world. It contains 30,000 square miles below the flood level, and in 1927 floods actually covered 20,000 square miles of this area. At the east and west it is bordered by bluffs that rise to a height of from 100 to 200 feet. Through the trough thus formed the Mississippi River each day is transporting millions of tons of the best top-soil material and dumping most of it into the Gulf of Mexico. This waste of material presents a problem in conservation of tremendous significance to the nation. If the material could be saved and spread out upon this river lowland, an ideal agricultural region would be provided. The rainfall here is adequate and the length of the growing season perfect for the production of a wide range of crops. Millions of people could make their homes on this land and be self-supporting. The area is much larger than the Po Valley of northern Italy, which is the most prosperous section of that country. It is comparable in size and fertility to the Ganges Lowland of India, where millions of people are now living.

At the north these bottom lands are divided, by an upland called Crowley Ridge, into the Little River Lowland on the east and the Black River Lowland on the west. A little farther south, on the east, is the St. Francis Basin. From Memphis to Vicksburg the Mississippi River swings far to the west and helps to define the Yazoo Basin, which is drained by the river of the same name. See Figure 14.

West of Vicksburg, on the right bank of the master stream, is the

Tensas Basin, drained by the Tensas River. Farther south, on the same side of the trunk channel, is the Atchafalaya Basin, drained by a river of the same name which flows directly into the Gulf of Mexico. The Red River is a branch of the Atchafalaya.

It is believed that for a time the Mississippi followed the present course of the Black River on the west side of Crowley Ridge and there joined the White River. Later, and probably at a flood period, the Mississippi found a pass across Crowley Ridge and followed about the same course that the St. Francis River follows today. Still later, the master stream found a route through Crowley Ridge farther north and joined the Ohio near the present site of Cairo. At that time the Ohio River crossed southern Illinois ten to fifteen miles north of its present course through what is now called Cache River Sag.

All the streams on the Mississippi River lowland flow on very low gradients. The bed of the trunk channel from Cairo to the Gulf declines less than six inches per mile. In the normal work of building up their flood plains the rivers repeatedly overflow much of the lowland area and each time deposit a thin layer of silt. Each stream tends to meander and to shift its course. Again and again the Mississippi River has abandoned a channel and left an *oxbow* lake in the area of its flood plain. With each overflowing, the natural levees which develop on the banks of such streams have become higher and the back-swamps more poorly drained. Frequently the master stream has broken through a natural levee during a high-water stage and caused terrific damage.

Since 1880 our national government has been attempting to control the waters of the master stream and to prevent disastrous floods by building artificial levees; but in 1927, after many millions of dollars had been spent on this program, there occurred one of the most destructive floods in the history of the lowland. When artificial levees are built on top of natural levees and the river is not allowed to overflow, there is a tendency at places for the stream to deposit a part of its load on the bed of the channel and thus continually to raise the level of the water.

A much better plan of flood control is the storage of flood waters in reservoirs established at numerous localities in tributary streams. If settling basins could be defined and protected by dikes or levees and the flood waters turned into one after another of these basins and there

ponded, the stream load of soil material would be deposited and a fertile land would gradually be built up.[1] After the dangerous period of high waters had passed, gates could be opened allowing the waters in the settling basins to flow back into the trunk channel. Thus, little by little, one section after another of the great lowland would be built high enough for settlement and agricultural development. Upon completion of the work the flood control should be entirely dependent upon storage reservoirs in the tributary basins. Great floods should be prevented, and the loss of rich soil material should be reduced to an unavoidable minimum.

The delta of the Mississippi. Downstream from Baton Rouge the lands built by the river and its distributaries are commonly thought of as the delta of the Mississippi. See Figure 15. Here the surface features do not differ much from those of the lowlands farther upstream. There are natural levees bordering each channel, stream meanders, backswamps, cutoff lakes, and many large areas that are not as yet built up above sea level. Fresh waters have replaced the sea waters in these low places and formed lakes Pontchartrain, Grand, Salvador, Lake des Allemands, and many smaller lakes.

Various studies have been made of the amount of load taken to the Gulf of Mexico by the Mississippi River. Long ago the amount of material held in suspension was measured and the statement was made that each year the river deposited in the Gulf enough material to cover a square mile to a depth of 268 feet. More recently, officers of the Louisiana Survey have stated that the river carries 1,000,000 tons each day to the sea. "In the 30,000 years since the glaciers started their slow retreat from the North American continent, the Mississippi has brought to south Louisiana enough sediment to bury the entire state (48,000 square miles in area) to a depth of one hundred and eighty-eight feet"[2]; but we cannot as yet know how much North American soil is being taken away by this river, since we have not measured the material rolled along the bottom and that carried in solution.

[1] W. W. Atwood, "Saving the Silts of the Mississippi River," *Bulletin of the Geological Society of America*, Vol. 28, (1916).

[2] H. V. Howe, R. J. Russell, and J. H. McGuirt, "Physiography of Coastal Southwestern Louisiana," *Louisiana Geological Survey Bulletin*, No. 6 (1935), pp. 1–72.

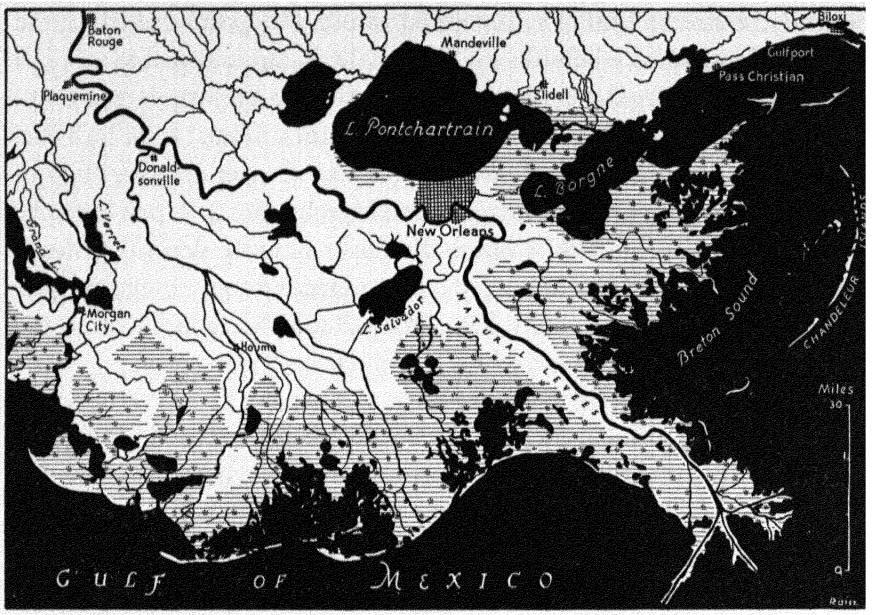


Figure 15 · The delta of the Mississippi River, with excellent examples of distributaries, natural levees, delta lakes, tidal marshes, and offshore sand reefs

At the outer margin of the delta, deposition is taking place opposite each of the river mouths. The bird-foot end of the main stream has claws, or fingers, 20 to 25 miles long. Bordering each finger the natural levees rise a few feet above the water and are from one to four or five miles wide. These outer bird-foot "passes" advance seaward about 300 feet each year. Within a mile or two of the outer ends of these passes "mud lumps" frequently rise within a few hours or a few days to elevations two to ten feet above the river and present a serious problem in the navigation of the Mississippi. Water-loving plants soon get started in the new-made lands of the delta and tend to protect it from the action of storm waves. Salt islands that rise as much as 150 feet above the marshy parts of the delta occur at several places. They have a domal structure and commonly contain rock salt. Some of them contain sulphur and petroleum.

The depth of sediments in the delta is not known, but it has been estimated to be as much as 30,000 feet. As the material accumulates, the land sinks because of the weight of this load. East and west of the

delta, where river-building is not going on, the land is drawn down somewhat by the sinking delta and is being encroached upon by the sea. The contest between the river and the sea is continuous, but during the ages that have passed the river has won, and has built the land seaward. In this way virtually all the lands of Louisiana have been made. The state of Louisiana is much indebted to the Mississippi River.

Only one other river that flows into the Gulf of Mexico is able to build a delta. That stream is the Apalachicola. There also delta-building is sufficiently rapid to overcome the work of waves and shore currents and the effects of sinking due to loading of the sea bottom. At no place along the Atlantic seaboard is there a river that brings sufficient material to the ocean to form a delta. The material that is brought to this coast is disposed of by waves, undertow, and shore currents.

Cycles of erosion. When a landscape is entirely devoid of river valleys, from the standpoint of its erosional history it may be thought of as representing extreme *youth*. Even after a number of valleys have been excavated, if broad interstream areas are undissected, the region as a whole is still in its youthful stage of erosion. As stream work continues and the valleys deepen and widen, and as more and more tributary valleys are excavated, there comes a time when the entire landscape is reduced to slope. At this stage the region as a whole may properly be referred to as *mature*.

As erosion continues, the valleys become broader, the flood plains wider, the interstream ridges are dissected into hills, and the hills become lower and lower. The landscape is passing through stages of late maturity and early old age, and in time may be spoken of appropriately as representing the *old-age* stage. If nothing interferes with the work of degradation by streams and associated agencies, such as ground water and winds, the land in time will be reduced to the base plain of erosion, and a cycle of erosion will have been completed. A gently rolling surface developed at a very late stage in a cycle of erosion is called a *peneplain*, and, as the word implies, it is nearly a plain. The peneplain stage represents the extent to which streams have commonly gone in their work of degradation before some interruption has occurred. At times during the erosional history of a given area the land may have

been uplifted, depressed, glaciated or buried beneath flows of lava. Some climatic change may have occurred which has disturbed the orderly sequence of events that would have led to the development of the final, or base-leveling, stage. Whenever an uplift occurs the streams are rejuvenated and a new cycle of erosion is begun. Thus most cycles of erosion are interrupted, and widespread, well-developed peneplains are rare. Partially developed peneplains appear as bench lands, and they have been called *straths* or *strath terraces.* Stream-cut surfaces in certain of the lowland belts between the uplands of the Coastal Plain province which have been recognized as peneplains should be called straths. Into these surfaces the streams have entrenched their valleys, and that is evidence of a new cycle of erosion.

The marine terraces that border the Atlantic and Gulf coast are at most places extremely young. Farther inland mature stages of erosion are represented at various localities, and at the inner margin of the Coastal Plain there are some examples of river valleys that have reached old age.

The influence of structure and inequality in resistance. We have already discovered that the streams which cross the Coastal Plain flow over the outcropping edges of gently inclined strata. Since the strata dip seaward at angles greater than the inclination of the base plain of erosion, the streams flow over the older formations near the inner margin of the plain and over successively younger outcropping strata until the present shore line is reached. As no two formations offer exactly the same resistance to the processes of weathering and erosion, it is therefore not surprising that there are a few low ridges or belts of higher land on the Coastal Plain. In New Jersey the belt which extends diagonally across the state from Raritan Bay to Delaware Bay is such an upland. In Alabama, Mississippi, and Texas resistant strata produce well-marked uplands and consequently a belted Coastal Plain. See map in pocket at end of book.

In each locality where the belts are well-defined the uplands have gentle slopes seaward and much shorter, steeper slopes on the landward side. Such asymmetrical forms are called *cuestas.* The inner lowland north of the main cuesta upland in Alabama and Mississippi

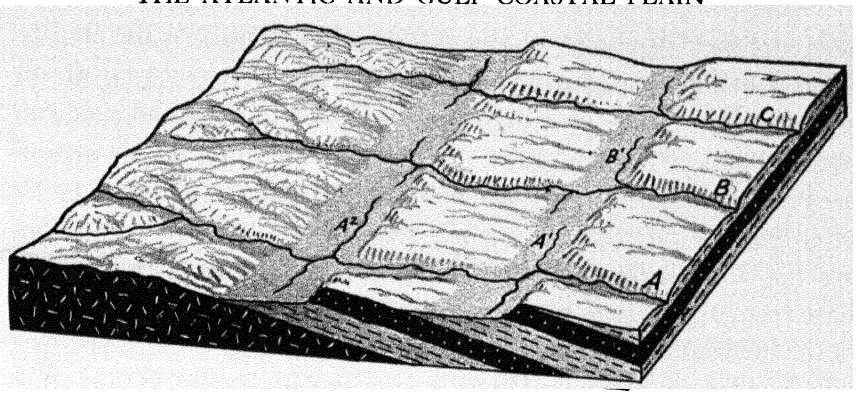


Figure 16 · A drainage pattern where inequality in resistance to stream erosion has resulted in the development of cuestas, water gaps, and inner lowlands

is 20 to 25 miles wide and several hundred miles long. It is known as the Black Belt and is one of the richest farmland belts in the South. The name came from the black soil which formed as large quantities of vegetable humus were added to the disintegrating limestone.

In Texas there are four well-developed cuesta uplands that are roughly parallel to the coast. Each of these upland belts is bordered on the landward side by a lowland. See Figure 116, page 238.

Stream piracy; water and wind gaps. In the Atlantic and Gulf Coastal Plain of North America there is sufficient inequality in mate-

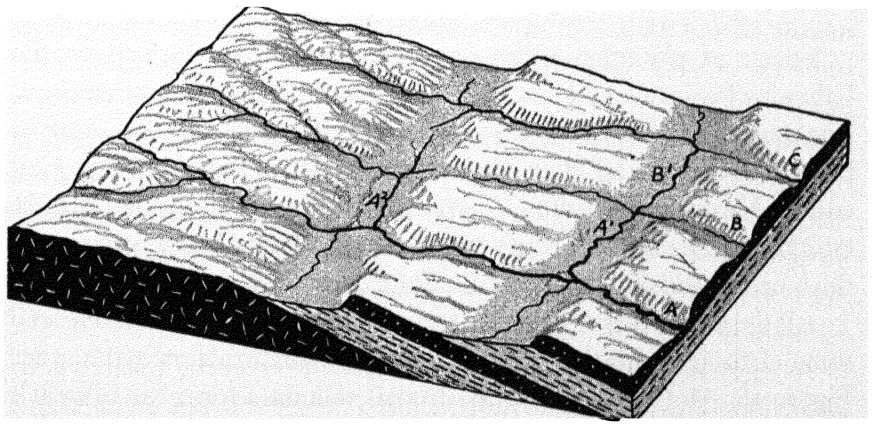
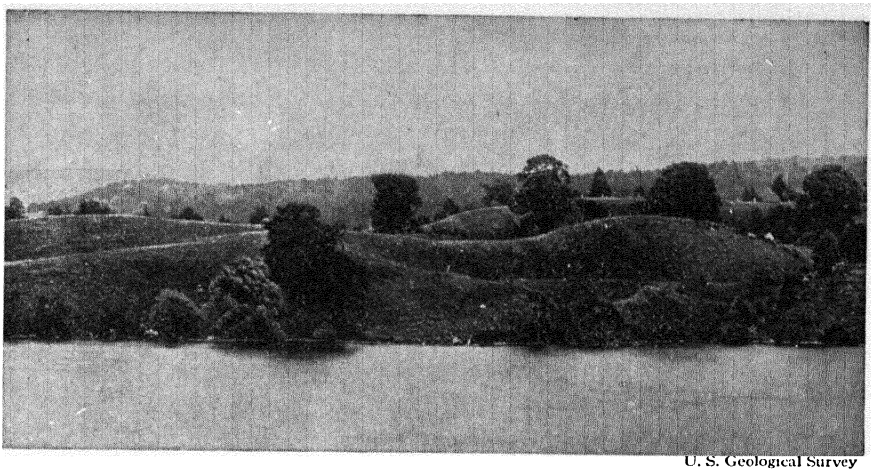


Figure 17 · The same area as is shown in Figure 16, with the drainage pattern further developed, with evidence of stream piracy and three wind gaps

rials to cause stream piracy and certain adjustments to structure. In Figures 16 and 17, *A*, *B*, and *C* represent three well-established stream systems. No two of the streams have identical volume and gradient, and therefore they differ in cutting powers. Assuming that Stream *A* is the most powerful stream in this region, it will erode more rapidly than the other two, and its tributaries upstream from the water gaps will lower their courses in the less resistant layers more quickly than the tributaries of *B* or *C* at work in the same belts. It is possible, therefore, for Stream *A*-1 to work headward, tap Stream *B*, and divert that water into its own drainage system, thus committing *stream piracy*. This process of beheading streams has occurred at several places in the coastal lowlands. The Alabama River crosses a cuesta belt through a water gap, and upstream from that point it has beheaded several rivers. When stream piracy has occurred, the additional supply of water secured by the capture will make possible a still more rapid lowering of the stream bed of *A*. As a result of this change, certain tributaries of *B* can cut more deeply, and *B*-1 may work headward until it reaches Stream *C*. If its channel is lower than that of *C*, another case of piracy will occur. The former water courses of streams such as *B* and *C*, abandoned in the resistant layer or cuesta belt, and the narrows in the courses which were formerly water gaps, become *wind gaps*. Wind gaps therefore may be interpreted as evidence of stream piracy. Stream piracy is one type of stream adjustment.

Effects of glaciation. The great ice sheets which formed on the Labrador Peninsula and spread radially from that center covered New England, most of the Maritime Provinces of Canada, and the northern portion of the Coastal Plain. Frontal moraines are found on Cape Cod and on Nantucket, Martha's Vineyard, Block, Long, and Staten islands. On the continental shelf south of New England and Nova Scotia there must be considerable glacial drift. See Figure 74 on page 156.

All the hilly lands of Staten Island are parts of a frontal moraine, and some of those of northern New Jersey are morainic in character. See Figure 18. On Long Island two frontal moraines form the hilly belt at the north margin of that land mass and separate to form the two eastward-extending prongs of the island. An outwash plain extends



U. S. Geological Survey

Figure 18 · Terminal moraine topography in northern New Jersey

southward from the southernmost moraine to the lagoons near the Atlantic border of Long Island. The outwash plain was built by waters carrying large quantities of fine materials as they issued from beneath the margin of the ice. An outwash plain on Martha's Vineyard originated in a similar manner beyond a frontal moraine; likewise a sand and gravel plain was formed on the south side of Cape Cod. This plain is definitely related to a frontal moraine that includes all the higher bouldery lands of Cape Cod. A pitted outwash plain was developed in the northward-extending arm of Cape Cod. This special type of outwash owes its origin to the deposition of sand and gravel about masses of ice which later melted and caused numerous depressions or pits in the surface of the plain.

Study Figure 19, showing Cape Cod in relief. The land northwest from the Cape Cod Canal near Sandwich is structurally and physiographically part of New England. The surface in all that portion near Plymouth is mantled with glacial deposits, and the numerous lakes and ponds are due to glaciation. The lands extending eastward from the Cape Cod Canal and then northward are part of the Atlantic Coastal Plain. That land is mantled with glacial deposits,—in fact, is composed almost entirely of them. The belt or ridge of higher land extending eastward from Sandwich is a frontal moraine. The flat lowland extending southward from that moraine is an outwash plain composed of

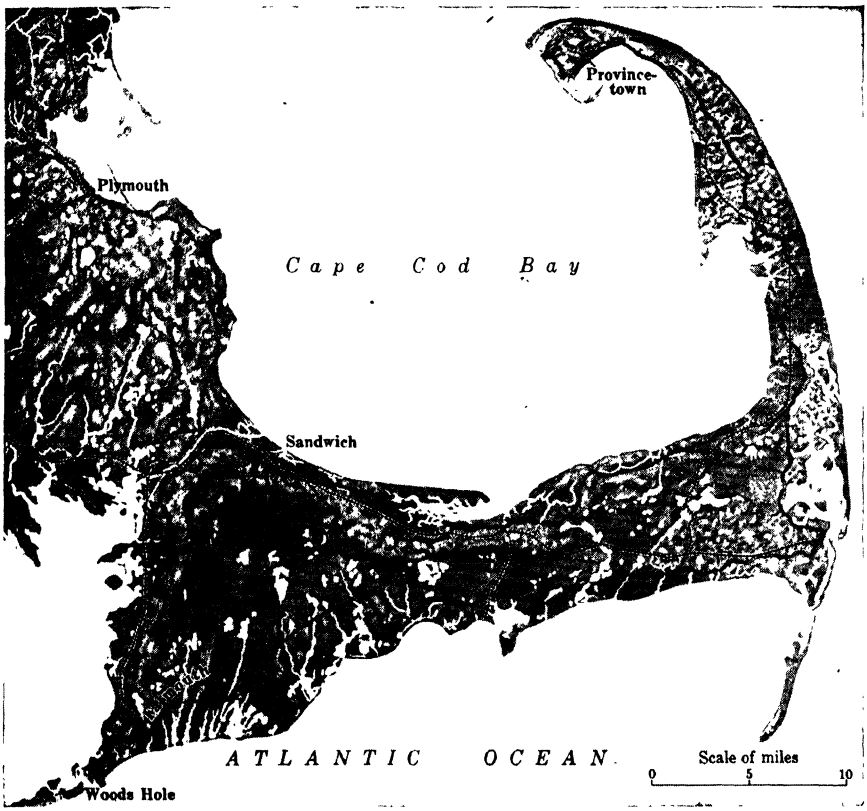


Figure 19 · A relief map of Cape Cod

sands and gravels. In the surface of that plain there are many depressions containing lakes or ponds. The northward-extending arm of Cape Cod is composed chiefly of glacial deposits in which there are large quantities of sands and gravels washed out from the margin of the retreating ice lobes. The ridge or belt of rough country extending southward from the Cape Cod Canal to Falmouth is an inter-lobate moraine. About the margin of Cape Cod there are numerous shore-line features that are due to the post-glacial work of waves and littoral currents. There are sand and gravel spits, hooks, islands, offshore reefs, and barrier beaches. The harbors at Plymouth and Provincetown are protected by offshore deposits. The region is one of special attractiveness for field studies in physiography, and also a favorite vacation land.

Movements of the land. The presence of submerged valleys in the continental shelf and the drowned river mouths in the Middle Atlantic States prove that the margin of the continent has been depressed relative to sea level. Delaware and Chesapeake bays, the estuarine mouths of all the smaller streams of New Jersey, and the "sounds" along the coast of North Carolina all owe their origin to the depression of the land or the rise of the sea water. Farther south along the coast of Georgia and Florida, and westward along the Gulf of Mexico, abundant evidence of changes in the level of the sea water relative to the land is provided in drowned river mouths. Tampa Bay, Mobile Bay, and some of the shallow indentations on the coast of Texas are estuaries. The "Ten Thousand Islands" on the west coast of Florida are due to sinking of the land.

The presence of marine sediments near the inner edge of the Coastal Plain is sufficient evidence to prove uplift of the land relative to sea level; furthermore, old shore lines and marine terraces on the Coastal Plain indicate that in recent times there has been uplift of the land.

C. W. Cooke[1] has described a series of seven terraces on the Coastal Plain which stand at elevations up to about 270 feet above mean tide level of today and extend several miles inland. These terraces have been recognized at various places between New Jersey and Florida, and there are similar terraces along the Gulf coast. The inner edges of these terraces are marked at places by old shore-line features such as low cliffs, sand bars, and beaches. The very low, flat lands immediately adjoining Chesapeake Bay indicate that there has been some uplift of the land or a sinking of the sea level since the submergence which caused this estuary. Certain of the maps selected for laboratory study and listed at the end of this chapter illustrate this feature.

In searching for an explanation of these various terraces which record so many changes in the elevation of sea water, Cooke favors the "Glacial Control Theory" and makes the following statement: "It has long been recognized that the alternate accumulation and melting of the polar ice caps during Pleistocene time must have resulted in fluctuations of sea level because of the great volume of water piled up on the land in

[1]C. W. Cooke, "Seven Coastal Terraces in the Southeastern States," *Washington Academy of Sciences Journal*, Vol. 21 (1931), pp. 503–513.

the form of ice during the glacial stages and restored to the sea during the interglacial stages."

Daly[1] has estimated that the melting of the last ice sheets that rested on North America and northwestern Europe during the great Ice Age of the Pleistocene period must have raised the level of the ocean water about 260 feet. The formation of continental ice sheets during each stage of glaciation must have meant the withdrawal of vast amounts of water from the sea and the lowering of coast lines about all continents and islands. The return of the waters following the melting of the ice sheets forced the ocean to advance upon the land areas and to develop new shore-line features.

If changes in climate and the consequent accumulation and melting of vast quantities of ice on the lands do not account for these changes in sea level relative to the land, we must assume that the uplift and depression of the land account for them. It seems unlikely, however, that the land could have been frequently uplifted or depressed without suffering notable deformation in structure.

The broad lowland trough occupied by the Mississippi flood plain below Cairo is due in part to sinking of the land. Evidence of somewhat recent sinking in this belt is recorded in Reel Foot Lake in northwest Tennessee. The basin of that lake is 20 miles long and about 20 feet deep, and it was formed at the time of earthquakes which occurred in 1811 and 1813. In Texas there is marked evidence of faulting at the Balcones Escarpment at the west margin of the Coastal Plain. There is other evidence of faulting in the midst of the coastal plain of Texas east of Austin.

Development of the Shore-Line Features

Cape Cod. Material gathered by shore-line currents along the eastern margin of Cape Cod, especially during southeast storms, has been carried northward and deposited in the form of a curved sand bar, or spit, which has grown longer and longer until today it nearly encloses, as a great hook, the harbor of Provincetown. See Figure 20. Southwest

[1] R. A. Daly, *The Changing World of the Ice Age.* New Haven, 1934.

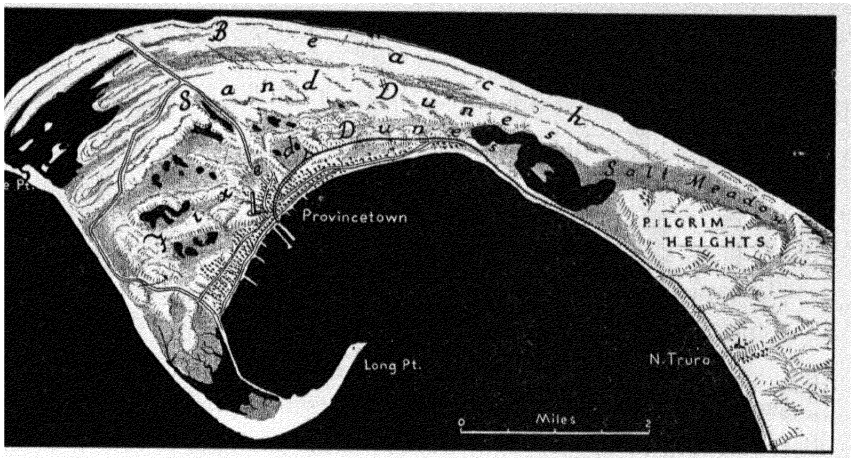


Figure 20 · The Provincetown end of Cape Cod. Pilgrim Heights are composed of glacial debris, and their northward margins are ancient sea cliffs. All the land to the westward of Pilgrim Heights is composed of shore-line or wind-blown materials

storm winds within Cape Cod Bay have developed another sand spit which has grown in a westerly direction from Pilgrim Heights. Between these two spits and just north of Pilgrim Heights there is a lagoon, but farther west the shore deposits from the two directions have united and developed a land mass approximately a mile in width and three miles in length. The winds have taken sands from these spits and piled them into dunes. The dune-building continues today, and the more youthful dunes are constantly migrating. The older ones have become anchored by vegetation.

On the outer margin of Cape Cod, east of North Truro and Truro, the ocean waves have encroached upon the land and developed a *sea cliff*, which rises approximately 120 feet above mean tide level. Offshore from this cliff *submarine bars* may be detected. It is evident that erosion has forced this cliff to retreat several hundred yards. Beneath the shallow waters east of the cape there is a *marine terrace*, which is the result in part of wave cutting and in part of wave building.

At the southeast corner, or elbow, of Cape Cod, in the vicinity of Chatham, an elaborate system of sand bars, spits, and lagoons has been produced by southward-moving littoral currents which are particularly strong when northeast storms strike the easternmost land of the cape.

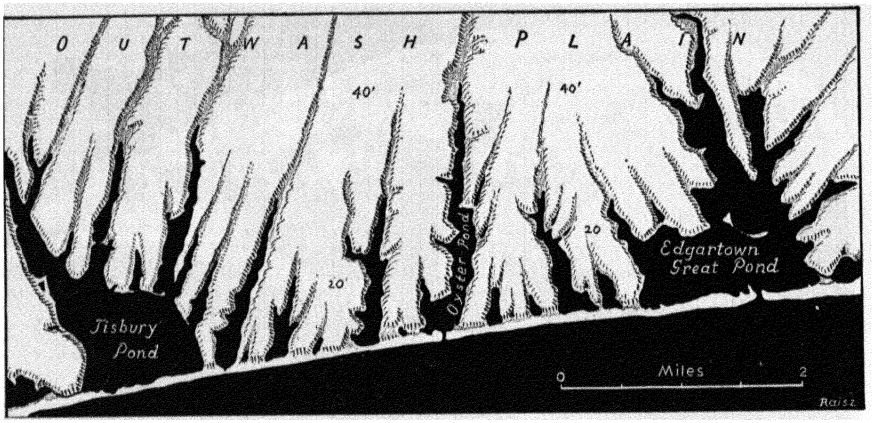


Figure 21 · The barrier beach that has caused the formation of several shore-line lakes along the south margin of Martha's Vineyard

Nantucket and Martha's Vineyard. Few places in the world offer better examples of shore-line lakes or ponds that have been closed in by *barrier beaches* than do the south shores of Nantucket and Martha's Vineyard. Edgartown Great Pond and Tisbury Pond on Martha's Vineyard are good examples of shore-line lakes, and there are many others on these islands. See Figure 21.

Long Island. Most of the south shore of Long Island is bordered by *sand reefs*, which have been built up by waves and shore currents. The trend of the currents along the coast is commonly toward New York Harbor; consequently the free ends of the beaches are to the westward. Fire Island Beach, Rockaway Beach, and Brighton Beach (Coney Island) have curved spits, or hooks, at their western ends. Inland from the south-shore beaches of Long Island a network of tidal inlets and stream channels parallels the coast in a broad marshy belt. See Figure 22.

The New Jersey beaches. Opposite Rockaway Beach, at the southern entrance into the lower bay of New York Harbor, is Sandy Hook. See Figure 23. The form of this coastal feature indicates that there have been several stages of growth as the northward-moving shore currents have deposited sands and gravel. The topography of Sandy Hook is char-

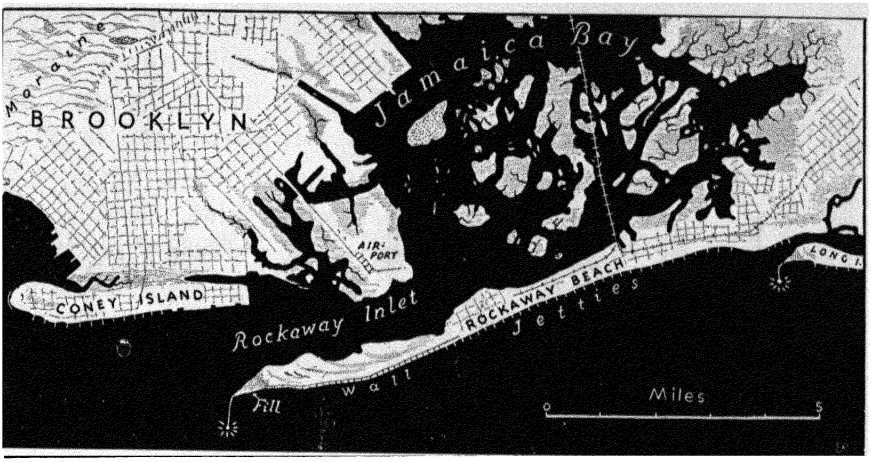


Figure 22 · The south shore of Long Island where the littoral currents have built a series of offshore sand reefs

acterized by sand dunes throughout most of its length. The sea cliffs bordering the Atlantic and Navesink highlands were formed earlier than Sandy Hook. They are now protected by the offshore sand deposits.

Farther south an almost continuous line of sand reefs fringes the New Jersey coast. In the vicinity of Ocean Grove and Asbury Park they are located near the mainland, but in the vicinity of Atlantic City and southward to Cape May a belt of salt marshes from five to six miles wide intervenes between the outer sand reefs and the mainland. The salt marshes are crossed by a network of channels navigable for small boats.

Sand dunes are commonly present on the New Jersey beaches, but where settlements have grown up the dunes have been removed and the material has been used to fill in the salt marshes, thereby extending the land available for building sites.

Cape Henry. At the southern entrance to Chesapeake Bay, in the vicinity of Cape Henry, there is an excellent example of a coast line made smooth and regular by the deposits left by shore currents. The successive stages in the development of Cape Henry are clearly indicated by crescentic lines of dunes nearly parallel to the present shore line of the cape. See Figure 24.

The beaches of the Carolinas and Georgia. The northeast storms which strike the coast of North Carolina set up a shore current which carries more or less sand and gravel southward. Southeast storms tend to develop littoral currents that move northward and carry sand and gravel with them along the shore. These alternating currents build sand bars which in time develop into sand reefs and in some cases form *cuspate forelands.* Cape Hatteras and Cape Lookout are examples of such sharp-pointed forelands. Farther south, offshore sand reefs mantled with many dunes parallel the coasts of South Carolina and of Georgia. Through the salt marshes which intervene between the sand reefs and the mainland there is a network of channels utilized today by fishing and pleasure boats.

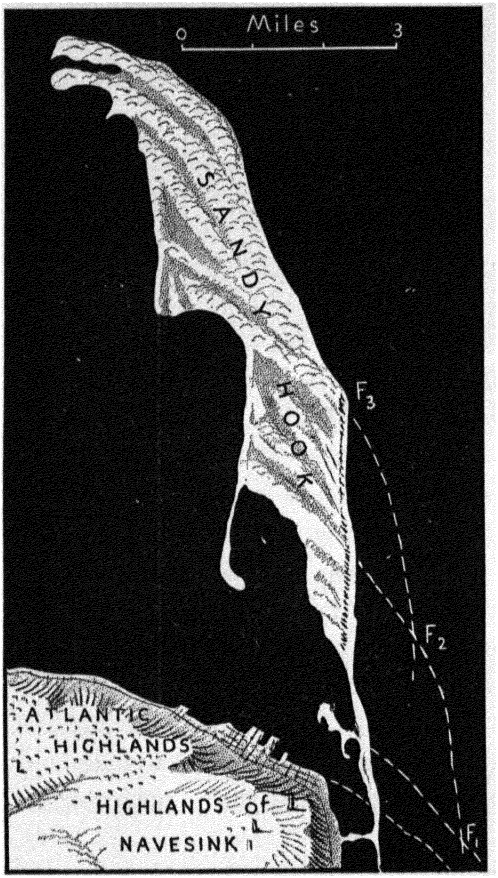


Figure 23 · The broken lines suggest outer margins of the land at stages in the development of Sandy Hook. Little by little the loose materials of the beach have been carried northward

Florida beaches. The Florida beaches include most of the types thus far described and, in addition, a number of coral reefs. Off the coast where the waters are clear, where the depth is not more than 120 feet, and where the sea temperature does not fall below 68 degrees Fahrenheit, corals live and carry on their work of building reefs. As the mass of coral skeletons approaches the surface of the sea, storm waves break the delicate branches of the coral structures,

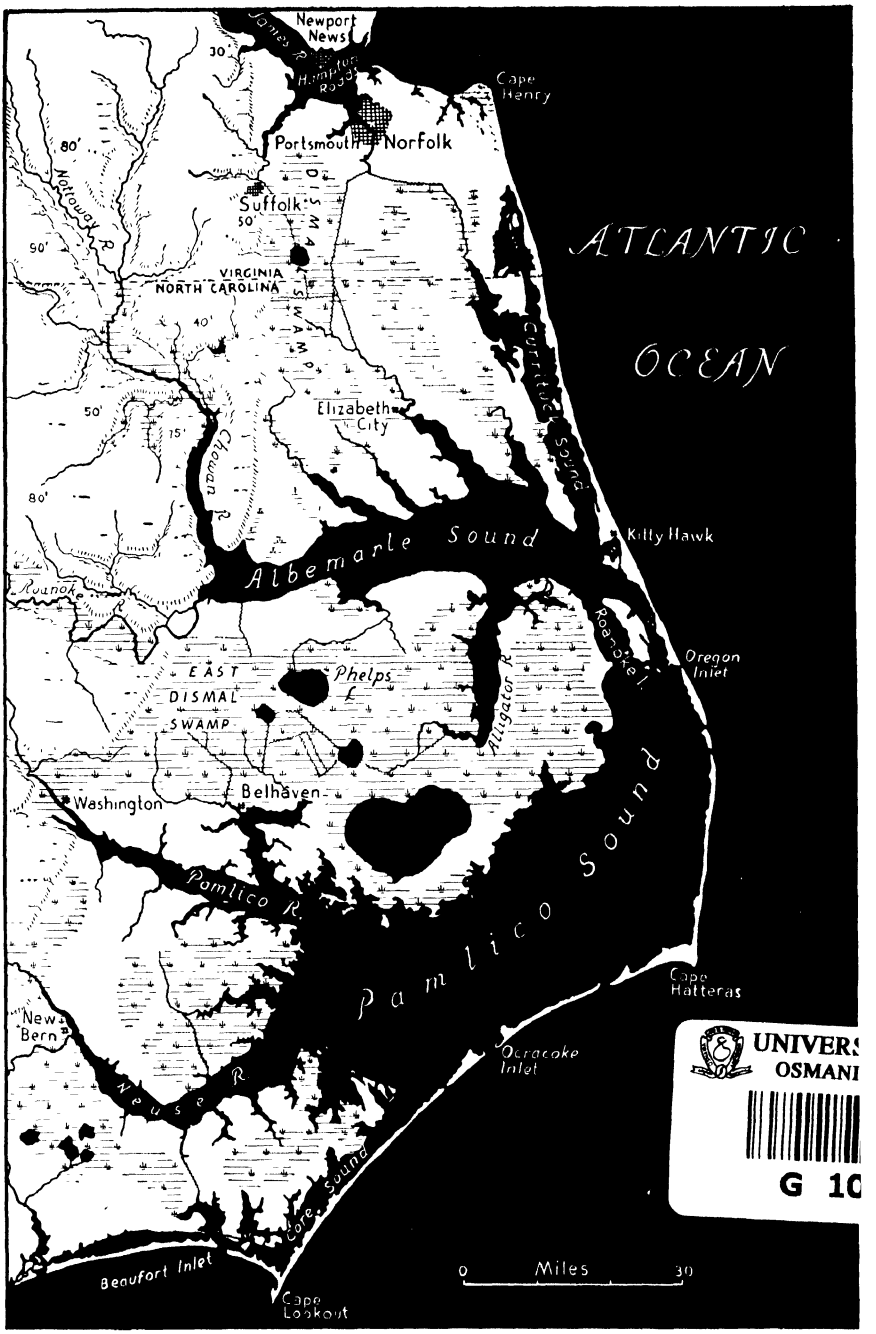


Figure 24 · The coast from Cape Henry to Cape Lookout, with excellent examples of sand reefs, cuspate forelands, lagoons, estuaries, ancient sea cliffs, and shoreline swamps

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heap up the fragmental material, and grind some of it into sand. Gradually the reef reaches the surface of the sea; seeds of salt-water plants take root on this new-made land, floating material becomes lodged on the reef, and in time the mass comes to be a few feet above sea level.

Coral reefs often form danger zones at sea, but they may provide shelter for ships in time of storm, and, where their area is sufficient, they may become the sites of villages or pleasure resorts. The Bahama Islands, off the east coast of Florida, are coral islands, and the Bermuda Islands are composed of coral sands, from the local beaches, which have been formed into dunes and cemented into a soft limestone. Active coral reefs fringe the shores of both these groups of islands.

The Texas coast. Sand reefs parallel the entire coast of Texas from the Sabine River to the Rio Grande. They are less interrupted by inlets than are the beaches at any other place along the eastern seaboard of North America. Padre Island, which extends northward from the mouth of the Rio Grande, is unbroken for more than 100 miles. Between the low sand islands and the mainland are shallow lagoons which expand into bays of considerable size in the partly closed estuaries of the Nueces and Trinity rivers and in Galveston and Matagorda bays.

The Gulf coast of Mexico. Southward from the Rio Grande the Coastal Plain of Mexico is fringed by low offshore sand and gravel beaches and occasional coral reefs. Just south of Tampico a well-developed cuspate foreland, called Cape Rojo, projects into the Gulf. The coast line is very irregular near Veracruz and Puerto Mexico, and farther east, along the margin of Yucatan, there are sand spits, hooks, barrier beaches, and coral reefs.

Work of the winds. Wherever large quantities of dry sand occur along the outer margin of the Coastal Plain, the winds have piled the sand into low hills. These sand hills, or dunes, are among the most prominent relief features in this landscape, although they rise but 50 to 100 feet above their surroundings. Among the dunes there are numerous small undrained depressions. The topography of a sand-dune area commonly consists of hills, short ridges, and low places without out-

lets. In many respects such a topography resembles that of a morainic area, but the materials are very different.

The northern end of Cape Cod is composed largely of sand dunes. See Figure 20. Provincetown was started on a sand-and-gravel beach, but, as it has grown, the houses have been built farther and farther inland on the tops of sand dunes. Race Point lighthouse on Cape Cod, overlooking the southern route into Boston Harbor, rests upon sand dunes as youthful and barren as many of the dunes in the Sahara Desert.

Accumulations of wind-blown sands form chains of dunes on most of the beaches from Long Island southward to Florida and westward bordering the Gulf of Mexico.

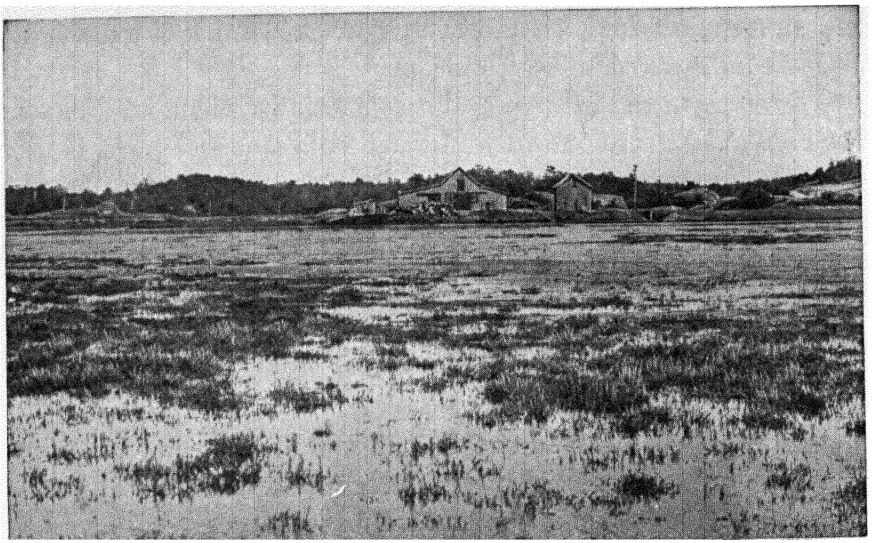
Most of the shore-line features described in the preceding pages are illustrated on the topographic maps which have been selected as the basis of laboratory work to be carried on in connection with the study of this chapter.

A Brief Summary of the Physical History

The Atlantic and Gulf Coastal Plain of North America is an extensive lowland that has been alternately above and below sea level. This physiographic province is composed for the most part of unconsolidated sand, gravel, clay, and morainic debris. Rivers brought to it much of the material which is there today, and rivers are responsible also for most of its topographic features. In addition to the phenomena of stream erosion, the work of waves, shore currents, winds, ground waters, glacial ice, and reef-building corals is illustrated in this province. There is abundant evidence of recent changes in the level of the land relative to the sea in both the submerged and the elevated portion of this continental margin.

Settlement and Utilization of Lands

Among the adventurers who left the Old World and came to our Atlantic coast there was a company in a small and much overcrowded boat that has since become very famous. That boat first dropped anchor in the harbor at the north end of Cape Cod near the present site of



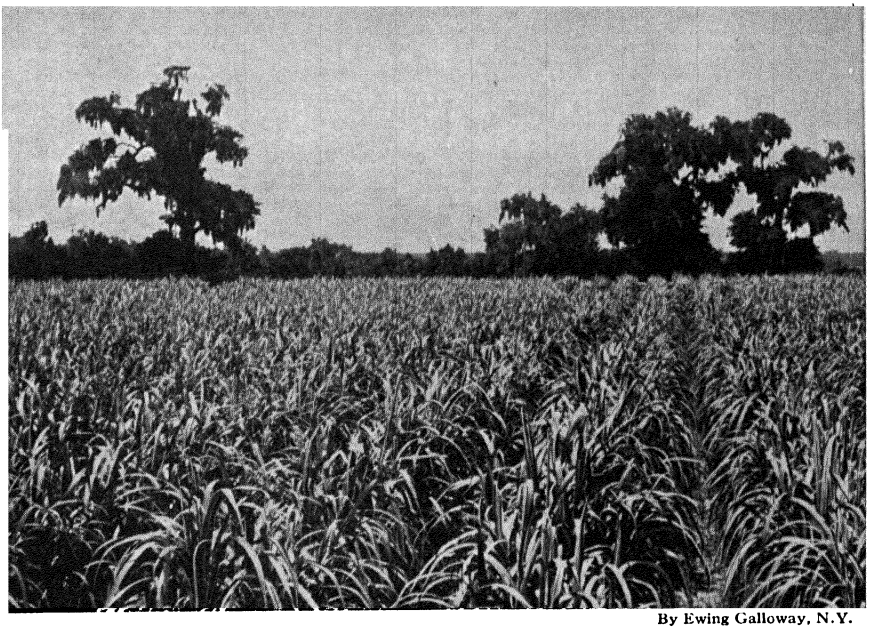
Photograph by W. Elmer Ekblaw

Figure 25 · A flooded cranberry bog on Cape Cod

Provincetown. After preparing and signing a covenant, the company sailed westward across Cape Cod Bay to the place now called Plymouth and there established a colony.

Other colonists who approached the coast south of the mouth of the Hudson River moved inland and located near the landward margin of the Coastal Plain. Several of the early British settlements in Virginia, the Carolinas, and Georgia were inland from the coast. The Spanish and French colonists who came to the Gulf coast have left an indelible impression upon the cultural development in that part of the Coastal Plain. Ponce de Leon, who early visited Florida in search of the fountain of perpetual youth, was the forerunner of thousands with the same hope who each year frequent the bathing beaches of that land of sunshine and warmth.

The nearly level land surfaces of the Coastal Plain are used chiefly for agriculture and forestry today. See Figures 25, 26, and 27. Here are produced lumber and turpentine, an abundance of fruit and vegetables, large quantities of raw material for the cotton textile industries of this and many other countries, and tons of fish and shellfish. The health and recreational resorts of this province are also invaluable to the nation.



By Ewing Galloway, N.Y.

Figure 26 · A field of sugar cane on the delta lands of Louisiana

As more and more people have come to live on the Coastal Plain and large markets have developed in neighboring provinces, some of the people in the province have turned their attention to the use of resources beneath the soil. Almost every formation has proved to be of some value. Some of the sands have led to the development of the glass industry; others are used as molding sands in foundries. The clays are used in the manufacture of pottery; the marls and phosphate rocks have proved to be very good fertilizers; and the gravels serve as road-building material or roofing supplies, or, when mixed with sand and cement, produce concrete. In the sediments of the Gulf coast valuable supplies of oil and sulphur have been discovered, and these products now reach many of the markets of the world.

The Coastal Plain is a very neatly defined physical unit. It has its own characteristic agricultural and industrial activities; in many respects its social and recreational life is peculiarly its own; and there is no doubt that it is playing an important role in the economic life of the United States and Mexico.



Official Photograph U S Army Air Corps

Figure 27 · The land-use pattern on the natural levee bordering the Mississippi River near New Orleans, Louisiana

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SELECTED LIST OF TOPOGRAPHIC MAPS FOR THE ATLANTIC AND GULF COASTAL PLAIN

All maps listed for Laboratory Exercises, unless otherwise indicated, are published by the United States Geological Survey, Washington, D. C.

Barnstable, Massachusetts
Chatham, Massachusetts
Falmouth, Massachusetts
Martha's Vineyard, Massachusetts
Plymouth, Massachusetts
Provincetown, Massachusetts
Wellfleet, Massachusetts
Yarmouth, Massachusetts

Moriches, New York
Riverhead, New York
New York City and Vicinity, New York–New Jersey
Southeast of New York Bay[1]

Atlantic City, New Jersey
Great Egg Harbor, New Jersey
Trenton, New Jersey–Pennsylvania

Choptank, Maryland
Patapsco, Maryland
Patuxent, Maryland
Tolchester, Maryland

Cape Henlopen, Delaware
Cedar Creek, Delaware
Rehoboth, Delaware

Cape Henry, Virginia
Hampton, Virginia
Mathews, Virginia
Newport News, Virginia
Smithfield, Virginia
Williamsburg, Virginia
Yorktown, Virginia

Cape Fear, North Carolina (No. 150)[2]
Cape Hatteras, North Carolina (No. 1232)[2]
Cape Lookout, North Carolina (No. 1233)[2]
Coharie, North Carolina
Four Oaks, North Carolina

Edisto Island, South Carolina
Manning, South Carolina
Mayesville, South Carolina
Wadmelaw Island, South Carolina
Warrenville, South Carolina
Augusta, South Carolina–Georgia

Hephzibah, Georgia
Irwinton, Georgia
Milledgeville, Georgia
Oliver, Georgia
Folkston, Georgia–Florida
Moniac, Georgia–Florida
Sapelo Island to Amelia Island, Georgia–Florida (No. 157)[2]
Clarks Hill, Georgia–South Carolina
Shirley, Georgia–South Carolina

Cape Canaveral, Florida (No. 161)[2]
Citra, Florida
De Funiak Springs, Florida
Interlachen, Florida
Jacksonville, Florida
Lawtey, Florida
Mayport, Florida
Niceville, Florida
Ocala, Florida
Orange Park, Florida
Palatka, Florida
Palm Valley, Florida
Panasoffkee, Florida
Macclenny, Florida–Georgia

Epes, Alabama
Montgomery, Alabama
Tuscaloosa, Alabama

Mississippi Sound, Alabama–Mississippi (No. 1267)[2]

Bayou Sara, Louisiana
Colfax, Louisiana
Donaldsonville, Louisiana
East Delta, Louisiana
Mississippi River, Louisiana (No. 194)[2]
Pollock, Louisiana
West Delta, Louisiana
Alluvial Valley of the Mississippi River[3]

Greenwood, Mississippi
Meridian, Mississippi
Schlater, Mississippi
Natchez, Mississippi–Louisiana
Vicksburg, Mississippi–Louisiana

Memphis, Tennessee–Arkansas

Advance, Missouri
Morley, Missouri
Cape Girardeau, Missouri–Illinois

Thebes, Illinois–Missouri
Cairo, Illinois–Kentucky–Missouri

Little Rock, Arkansas

Antlers, Oklahoma

Aransas Pass, Texas
Austin, Texas
Brackett, Texas
Burnett Bay, Texas
Corpus Christi, Texas
Deepwater, Texas
Fauna, Texas
Galveston, Texas
Laguna Vista, Texas
La Porte, Texas
La Sal Vieja, Texas
Morgan Point, Texas
Mouth of Rio Grande, Texas
Palmito Hill, Texas
Park Place, Texas
Port Isabel, Texas
Saltillo Ranch, Texas
Settegast, Texas
Uvalde, Texas
Virginia Point, Texas

[1]Chart I-B from Special Paper No. 7, Geological Society of America.
[2]Published by the United States Coast and Geodetic Survey, Washington, D.C
[3]Published by the Mississippi River Commission, Vicksburg, Mississippi.

III

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THE APPALACHIAN HIGHLANDS
THE NEW ENGLAND–ACADIAN DIVISION

A General Description

The province as a whole. Most of the bolder relief features in the eastern part of North America are found in the group of physiographic provinces included within the Appalachian Highlands. The Blue Ridge, the various mountain ranges in and near the Great Smoky Mountains National Park, the Appalachian ridges extending from central Alabama to the Hudson Valley, the Catskill Mountains, the Green Mountains, the White Mountains, the Notre Dame Mountains north of New England, the Shickshock Mountains of the Gaspé Peninsula, and the Long Range of Newfoundland are all within this highland area. Associated with the mountain ranges there are extensive areas of deeply dissected plateaus, certain uplands with gently rolling topography, and, in New England and Acadia, a coastal hilly belt.

For convenience in study this large area will be divided into two parts: the New England-Acadian, or Northeastern, Division and the Southwestern Division, which comprises the portion between the Hudson Valley and central Alabama.

The extent of the Northeastern Division. The New England-Acadian region includes a narrow strip of eastern New York State, nearly all of New England and the Maritime Provinces of Canada, the islands in the Gulf of St. Lawrence, and Newfoundland. On the northwest this province reaches to the St. Lawrence Valley Lowland, and on the southeast and east to the Atlantic Ocean. In southern New England this region is limited at the inner margin of the Coastal Plain. At the west it extends to the margin of the Hudson Valley-Champlain Lowland.

An amphibian landscape. Flying over the New England-Acadian region of the Appalachian Highlands in an airplane, one is impressed with the large number of lakes, ponds, swamps, and man-made reservoirs. Thousands of little lakes and many of considerable size lend variety and beauty to the landscape. Most of these inland bodies of fresh water are centers of pleasure and recreation. Their shores are

lined with summer homes or camps. Bathing beaches, diving platforms, sails, and the throbbing of internal-combustion engines testify to their popularity. In many respects the life as well as the landscape is amphibian. See Figure 28.

Most of the villages and towns of the region depend for their water supply upon surface waters that have been ponded in the neighboring drainage basins, whereas large reservoirs established in rural districts furnish adequate supplies of water for the metropolitan areas. Many of the mills and factories rely in part upon ponded water for power.

The region is bordered by salt waters on the south and east and on the northeast by the brackish waters of the St. Lawrence River. These waters have long played an important role in the occupations of many of the inhabitants in this part of the continent. Fishing villages are located near many of the lesser harbors along the coast, and a little before daybreak each morning the silence of the night is broken by thousands of explosions from the boats used by the fishermen as they go out to visit their lobster traps and fishing nets or to start the day's fishing.

A forested region. Another impressive characteristic of this region is the widespread distribution of forests, and of cutover lands where a fairly good start toward reforestation is being made. Throughout the area the forests are extensive, and logging camps, wood-pulp mills, and lumber mills are numerous. Certain of the streams are still used for the transportation of logs.

Each autumn the leaves of the deciduous trees begin to lose their green colors and take on brilliant shades of red or yellow or deep rich tones of brown. For three or four weeks, beginning late in September, the landscape is strikingly beautiful. Few areas in the world have such extensive forests of mixed hardwoods and softwoods, and therefore few can compete with this region in autumnal coloring. The maples, dogwoods, birches, and oaks vie with one another in adding to the beauty of the landscape. Thousands of visitors come to New England at this time of year just to see the autumn colors. Special excursion trains are sent from the large cities into the more mountainous sections, and the highways are crowded with automobiles.



Official Photograph U. S. Army Air Corps

Figure 28 · An aerial view of Lake Winnipesaukee from a position above Wolfeboro, New Hampshire. This is one of the largest and most beautifully situated glacial lakes in New England. The shores are dotted with summer homes and recreation grounds



Figure 29 · Skiing in Vermont

The cultural pattern. The villages and towns nestled among the trees in the New England-Acadian region, and the connecting highways winding in and out among lakes, ponds, marshes, and hills, form a complex cultural pattern. Areas which are under cultivation or are used as pasture lands commonly appear along the highways as small rectangular clearings in the almost continuous forest cover. The seaports and the numerous manufacturing communities inland from the coast suggest the active industrial and commercial life in this physiographic province. Almost continuous chains of industrial plants and stream reservoirs help to define the valleys of the Blackstone and Merrimack rivers. In the Connecticut, Housatonic, and Androscoggin valleys all the larger settlements are located near mills that either use or formerly used water power developed by ponding the streams.

The seashore, the mountains, and the peaceful rural districts attract thousands during the summer vacation periods, and the "snow trains" of the winter season, bound for the mountains, are crowded with enthusiastic lovers of skiing, tobogganing, and snowshoeing. The winter landscape has become a very valuable asset in this part of the continent. See Figure 29.

Major Relief Features

The Green Mountains. The most conspicuous topographic features in the New England-Acadian region are old, worn-down mountain ranges. Those west of the Connecticut Valley, in Vermont, Massachusetts, and Connecticut, are known as the Green Mountains, although in Massachusetts and Connecticut they are commonly referred to as the Berkshire Hills. This belt of mountains includes Mount Mansfield, in Vermont, with an elevation of 4364 feet above sea level, and a number of peaks having elevations of over 3500 feet. The general summit elevation of the Green Mountains in Vermont is between 3500 and 3800 feet above sea level. Mount Greylock, in the Berkshire Hills of western Massachusetts, is the highest mountain in that state, having an elevation of 3505 feet. In northern Massachusetts the crest of the Berkshire Hills is about 2300 feet above sea level, but it declines to the southward, and near the Hudson River it has an elevation of but 1500 feet.

The Taconic Range. West of the Berkshire Hills and the Green Mountains as far north as Brandon, Vermont, there are a number of north-south upland ridges known as the Taconic Mountains. Their summits reach elevations varying from 1800 to 2000 feet. These ridges are composed of schists that were formed by the compression and metamorphism of very early Paleozoic sediments. Mountain-making movements are recorded in this range at the close of Ordovician time.

The White Mountains. East of the upper Connecticut Valley are the White Mountains. They are conspicuous topographic features in New Hampshire, but in Massachusetts and Connecticut they have been so much subdued by stream erosion and glaciation that the region appears as an upland with a gently rolling surface. Above that upland surface in southern New Hampshire is the classic example of a relief feature which owes its prominence to superior resistance to erosion. This is Mount Monadnock, which rises 3166 feet above the sea and about 2000 feet above its immediate surroundings. See Figure 30. In Massachusetts, Mount Watatic and Mount Wachusett rise a few hundred feet above the upland surface; they also are true monadnocks.

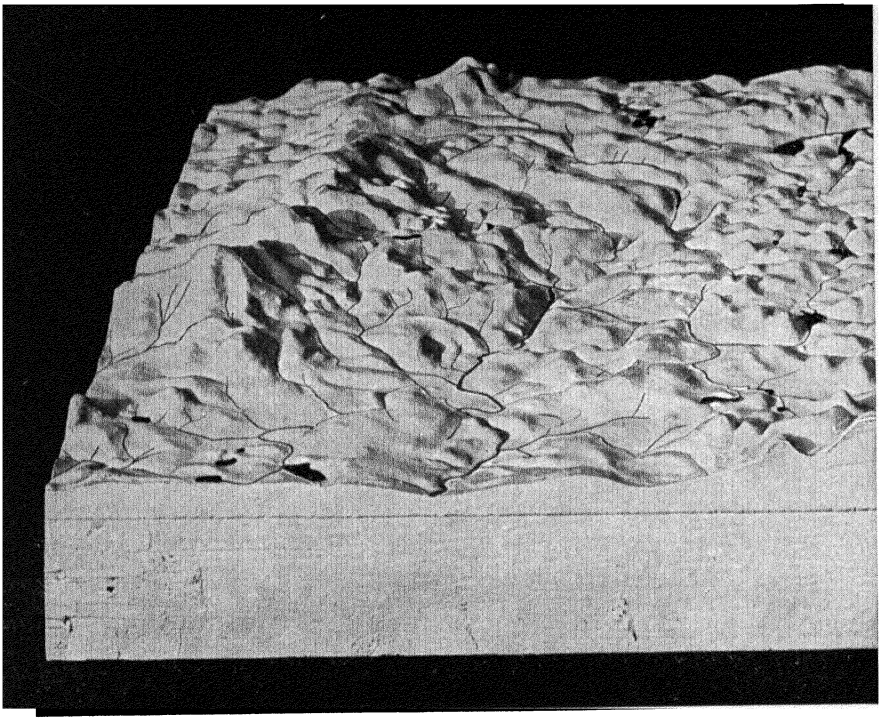
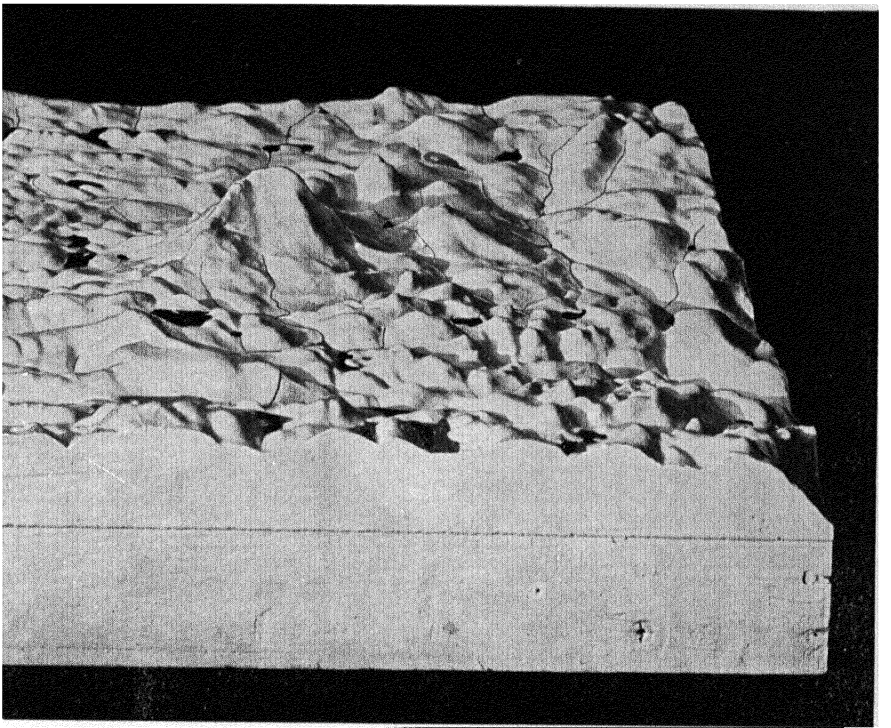


Figure 30 · Relief model of Mount Monadnock

The boldest and most picturesque features of the White Mountains are in the Presidential Range, located in the central part of New Hampshire. In that range there are a number of strikingly beautiful peaks which rise to elevations of over 5000 feet. They include Mount Jefferson, Mount Madison, Mount Adams, and Mount Monroe. The best known of the group is Mount Washington, the highest mountain in the New England-Acadian region, with an elevation of 6293 feet. In the vicinity of the Presidential Range there are several U-shaped gorges that were deepened and widened by glacier ice. See Figures 31 and 32.

Northward and northeastward from central New Hampshire the White Mountain belt is represented by many prominent relief features, but the range becomes much less conspicuous in northern Maine and in New Brunswick. Mount Katahdin, with an elevation of 5273 feet, is one of the outlying mountain forms in the eastern part of Maine. See Figure 36.



Model made under direction of Wallace W. Atwood, Jr.

and vicinity in southern New Hampshire

The Canadian and Newfoundland ranges. The northward extension of the Green Mountains is represented in Canada by a number of low ranges south of the St. Lawrence River, called the Caledonia, Boundary, and Notre Dame mountains, and by the Shickshock Range of the Gaspé Peninsula. The summits of these ranges have been softened or subdued through very long periods of weathering and erosion. At the northwestern margin of Newfoundland there is a mountainous region known as Long Range. The general elevation of these mountains is from 2000 to 2200 feet above sea level.

The lowlands. The Connecticut Valley Lowland and the lowland associated with the Annapolis-Cornwallis Valley of Nova Scotia are the most extensive areas of nearly level land within the Northeastern Division of the Appalachian Highlands. At a number of places near the coast there are narrow marine terraces where there is very little relief

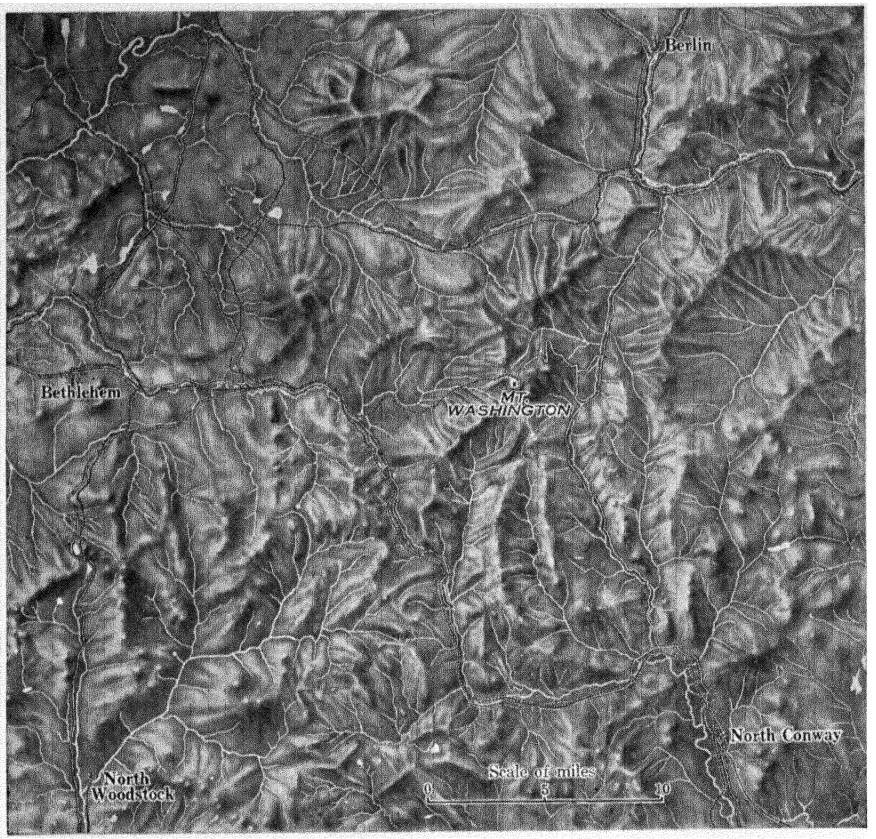


Figure 31 · Mount Washington is in a maturely dissected and glaciated area

in the topography, and about the margins of the Maritime Provinces and the Gaspé Peninsula there are narrow coastal lowlands.

The uplands and the Coastal Hilly Belt. An upland, or plateau, with a gently rolling surface, occupies much of the northern part of Maine and extends into the Maritime Provinces. Throughout most of the Coastal Hilly Belt, which extends from the Hudson Valley to the Gulf of St. Lawrence, the relief is from 200 to 300 feet. However, the Blue Hills, south of Boston, are exceptional in that they rise 500 feet above their surroundings; and the major elevations on Mount Desert Island and on the neighboring mainland are conspicuous because they rise nearly 2000 feet above the bordering lowlands.



Fairchild Aerial Surveys, Inc.

Figure 32 · The Presidential Range in the White Mountains of New Hampshire. The summits have been subdued by continental glaciation, and the small cirques have been modeled by valley glaciers

Structure and Materials

The hard rocks. Throughout the highland areas of this region the underlying rock formations, which are of Pre-Cambrian and Paleozoic age, have been repeatedly disturbed by mountain-making movements in the crustal part of the earth. At many places the strata have been distinctly folded, broken, and crushed. There are vast areas of meta-

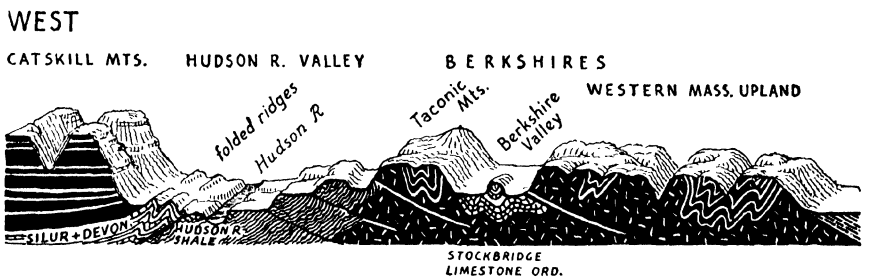
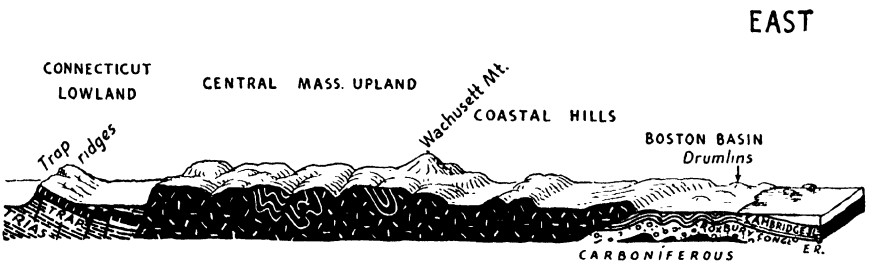


Figure 33 · Block drawing of a belt extending from Boston Basin on the east structure section is shown

morphic rocks, such as gneisses, schists, slates, quartzites, and marble, within this area. They indicate that many profound changes have taken place in the rock materials here. Large areas of granitic rock tell us that huge masses of molten material have risen toward the surface of the earth at various times in the past and, upon cooling, have formed solid rocks. The Presidential Range in the White Mountains has been carved out of a huge granitic mass of rock, and many of the lower mountains and hills of New England are composed of granite. See Figure 32. Certain headlands on the coast of Maine and many islands off that coast are also of granite. Great sheets of lava indicate that at several places molten material has been poured out upon the surface of the land.

The coarsely crystalline rocks now at the surface must have cooled deep in the earth, where crystallization proceeded slowly and continuously through long periods of time and thus permitted the growth of large crystals of feldspar, quartz, mica, hornblende, augite, tourmaline, and many other minerals. The metamorphic processes which transformed ancient crystalline rocks or very old sedimentary formations into schists also took place far below the surface of the earth. We are probably safe in assuming that the crystallization of certain of the magmas which formed the granites now exposed at the surface, and the metamorphism which produced certain of the schists now at the surface, took place under a load of at least five miles of rock. See Figure 33.

In the Connecticut and Annapolis-Cornwallis valleys there are red sandstones, shales, and conglomerates of Triassic age. These rocks are younger than the formations that make up the highland belts. Associated with the Triassic sediments there are a number of sheets of ba-



to the Catskill Mountains at the west. A generalized and much simplified on the near side of the block

saltic lava. These dark-colored lavas have been upturned along with the sandstones, shales, and conglomerates of the lowland, and since they are more resistant to erosion than the sedimentary formations with which they are associated, they have come to form low mountain ridges. See Figure 34. The Holyoke Range, including Mount Tom and Mount Holyoke, and the various north-south ridges that extend from central Massachusetts to the vicinity of New Haven, in Connecticut, are composed of the lava. North Mountain, at the margin of the Annapolis Valley, has the same origin.

In the Gaspé Peninsula and in portions of New Brunswick and Nova Scotia the sedimentary formations are but gently deformed, but at no locality are they resting in their original positions. In the mountain ranges of Newfoundland the rocks have been folded and crushed and throughout most of that island there is evidence of great deformation of the underlying foundation materials.

The glacial drift. A mantle of glacial drift obscures the underlying rocks in most of the New England-Acadian region and accounts for many of the minor details in the surface features. The only portion of the region thus far known to have escaped the effects of glaciation includes a part of the Gaspé Peninsula and an adjoining section in the province of New Brunswick, although a portion of northwestern Newfoundland also may have escaped glaciation. Detailed studies have not been made of the effects of glaciation in Newfoundland, but it is known that an independent ice cap formed on that island, and it is safe to infer that a large part of the island has been affected in some way by

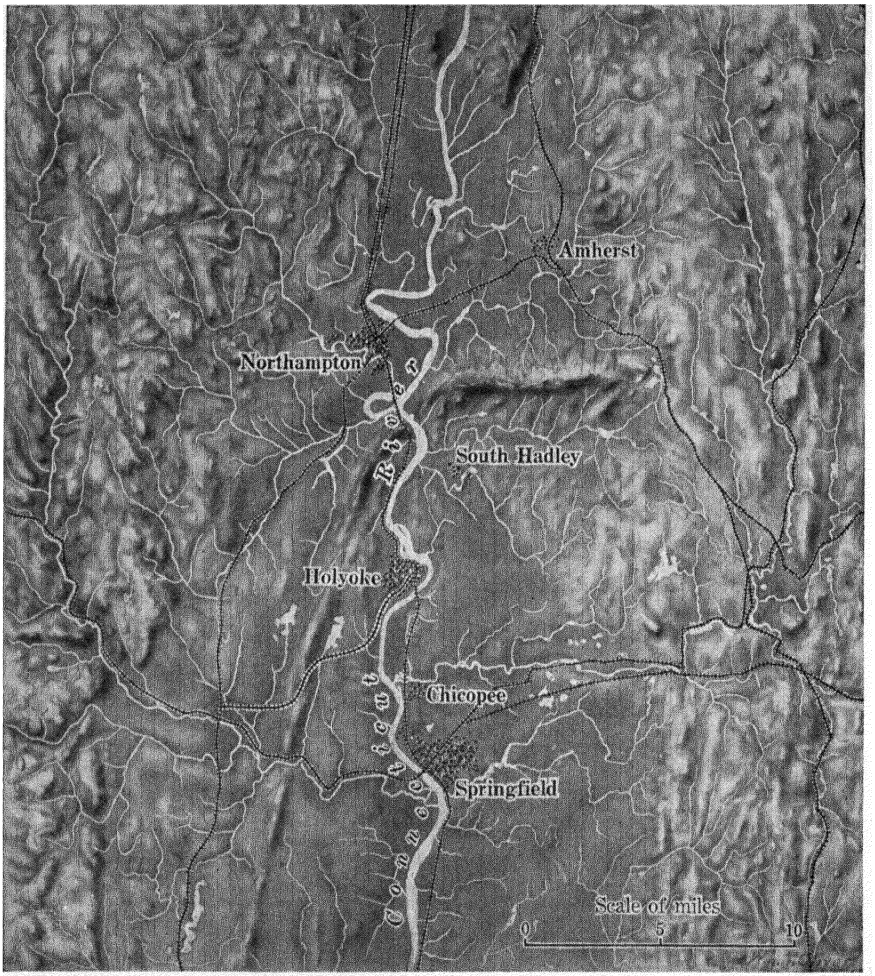


Figure 34 · The Holyoke Range rises conspicuously above the floor of the Connecticut Valley Lowland in western Massachusetts

ice action. A study of the distribution of certain plants led Fernald[1] to believe that much of northwestern Newfoundland as well as the Gaspé Peninsula were never covered by great ice sheets. He finds plant societies in those sections that have not been disturbed by glaciation. Field studies in New Brunswick and the Gaspé Peninsula by the author of this book support Fernald's discoveries in that area.

[1]M. L. Fernald, "Persistence of Plants in Unglaciated Areas of Boreal America," *Memoirs of the Gray Herbarium of Harvard University*, Vol. 2 (1925), pp. 239–242.

Development of the Topography

A great physical revolution and the opening of a long erosion period. A gigantic physical revolution at the close of the Paleozoic era, which affected the entire area of the Appalachian Highlands and, in fact, the entire eastern half of North America, opened a long story of erosion in the New England–Acadian region. See Chart on page 20. The rock formations which constitute the foundation of the region were uplifted and deformed. If all the materials which have been removed from the present surface were replaced, the land surface would undoubtedly rise at least five miles into the air. This is one of the regions of old, worn-down mountains where the agents of weathering and erosion have been at work for many millions of years.

The upward movement and deformation were undoubtedly exceedingly slow. Perhaps they were so slow that, had there been people living in the region at the time, they might not have realized that any change in elevation relative to sea level was taking place. As soon as any land mass rises above sea level the agents of weathering and stream erosion begin their work of destruction. One should not assume, therefore, that at any time there were mountains five miles high in this part of the continent. The relief of today may be as great as the relief of any previous period. But there is a probability that there were very lofty mountains in this region at certain periods in geologic history.

Local disturbances caused the formation of the troughs in which the Triassic sediments and lavas accumulated, and, later, other local disturbances uplifted these rock formations and at places broke and tilted them. During all this time erosion continued throughout most of the region. Many cycles of erosion may have been completed or partially completed, but of these we shall never know very much. In time the streams produced a remarkable surface, which is preserved to this day on the higher lands in this part of the continent. That surface must have been, when developed, near the base plain of erosion, for at no other horizon can running water develop such a widespread area of gently rolling topography. The period of time during which that surface was developed will be referred to as the first cycle of erosion. It is the earliest cycle well recorded in the present landscape.

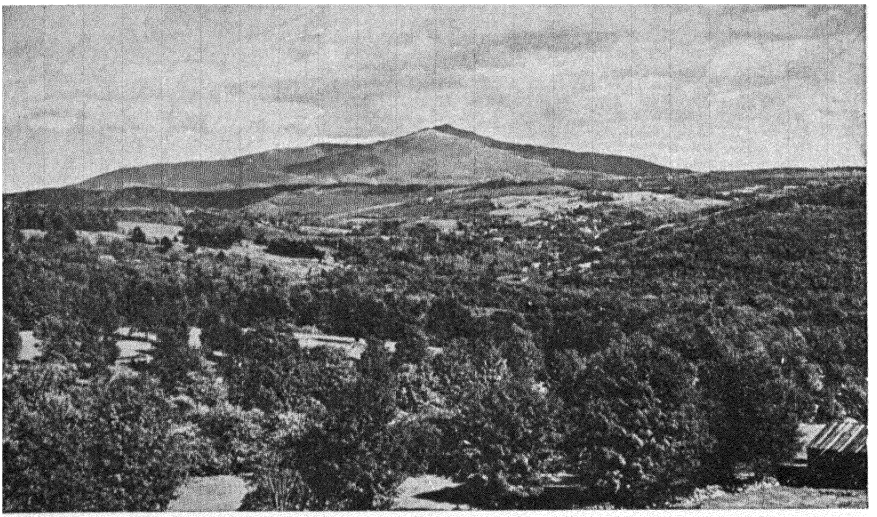


Figure 35 · Mount Monadnock, New Hampshire. This is the classic example of a mountain mass that rises conspicuously above an old-age erosion surface because of its superior resistance to all agents of disintegration and erosion. The summit elevation is 3166 feet, and the general elevation of the peneplain about the base of the mountain is from 1500 to 1700 feet above sea level

The summit peneplain. Here we find a considerable portion of one of the most remarkable and widespread old-age erosion surfaces in the world. We shall encounter remnants of this surface southwestward in the Appalachian Highlands as far as central Alabama and also in portions of the Interior Highlands of Missouri and Arkansas. There are remnants of this same surface on the flanks of the Adirondack Mountains and at many localities in the Laurentian Upland. When developed, this gently rolling erosion surface probably extended to the Arctic Ocean at the northeast, at least as far as central Alabama and Arkansas at the south, and westward to the eastern margin of the Great Plains. Large portions of that surface, however, have been destroyed during subsequent cycles of erosion.

Davis[1] long ago carefully described and interpreted the upland erosion surface in New England as a summit peneplain and correlated it in age with the Schooley or Kittatinny surface recorded at or near

[1]W. M. Davis, "The Physical Geography of Southern New England," *National Geographic Society Monographs*, Vol. 1, No 9 (1895), pp. 269–304.

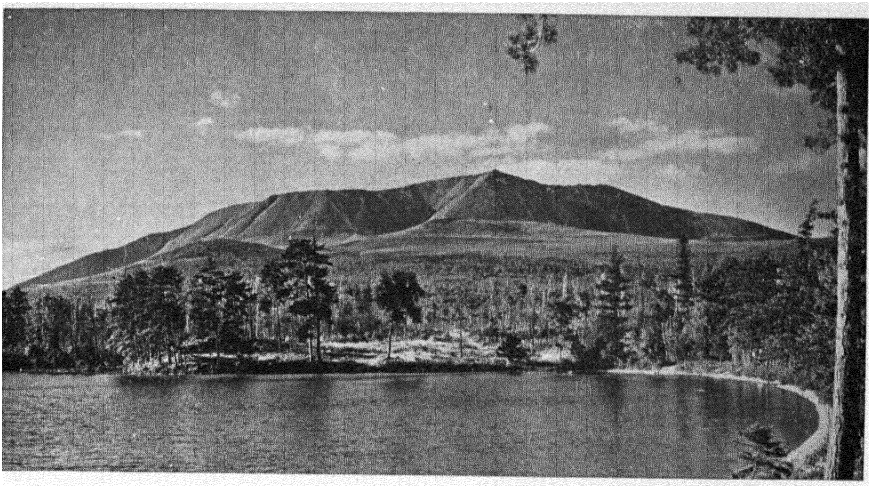


Figure 36 · Mount Katahdin. This is one of the isolated mountains in the eastern part of Maine that rises conspicuously as a monadnock above an old but much dissected erosion surface. The summit elevation is 5273 feet. The small amphitheatral basins are glacial cirques

the summits of the mountain ranges in the Southwestern Division of the Appalachian Highlands.

Above this New England peneplain there rose several conspicuous topographic features. Some were hills, but others were of sufficient magnitude to be called mountains. Most, if not all, of these features remain to this day as conspicuous elements in the topography. They include all the higher summits in the White Mountains and in the Green Mountains. Mount Mansfield, Mount Greylock, Mount Wachusett, Mount Watatic, Mount Monadnock, and Mount Katahdin are in this group. Their presence today as conspicuous relief features testifies to the superior resistance of the rock formations within them. They are, however, but roots or stumps of much higher mountains of an earlier day. In fact, all the hills and mountains in this region are the roots of what were once loftier mountains. See Figures 35 and 36.

In northern Connecticut the remnants of this old erosion surface are about 1500 feet above sea level. The surface rises gradually to the north until it is about 2000 feet above tidal waters at the southern boundary of Vermont and New Hampshire. At certain outlook points on the slopes of Mount Monadnock, a magnificent view of this ancient erosion

surface may be obtained. To the south is the gently rolling upland surface of the Central Highlands of Massachusetts. That surface is a part of the summit peneplain. Mount Wachusett, northwest of Worcester, and Mount Watatic, near Fitchburg, appear in this view, and they rise conspicuously, as monadnocks, above the general level of the highland surface. To the southwest is the remarkably even sky line of the summit in the Berkshires, with Mount Greylock standing out as a monadnock form. To the west the ranges of the Green Mountains exhibit in their summits the monotony characteristic of remnants of old peneplains wherever they are found in the world. The summits of the Shickshock and Long ranges are probably parts of this same peneplain.

The second cycle of erosion. With the uplift of the Schooley Peneplain, the cycle of erosion during which that surface was developed closed and a new cycle opened. The streams were rejuvenated and began their work of reducing the lands toward the newly established base plain of erosion. Valleys again passed through the stages of youth and maturity and in time became broad and open. Many of the streams developed meandering courses. Considerable areas of land were reduced to the next peneplain horizon.

The evidences of this cycle of erosion are found today in broad benches distinctly below the summit peneplain and hundreds of feet above the present channels of the stream courses. In the valley of the Deerfield River, as viewed from the Mohawk Trail where that route crosses the Berkshire Hills of western Massachusetts, there are upland benches which were developed during this second cycle of erosion. See Figure 37. In many of the tributary valleys of the Connecticut this intermediate stage in the development of the erosion topography in New England can be detected.

In other sections in the Central Highlands of Massachusetts, and at places in the Green Mountains and in the White Mountains, there are many short ridges and hills that correspond to one another in elevation and are distinctly below the Schooley erosion surface. They represent an incompleted cycle of erosion and should be correlated with the old-age surfaces which are well-preserved near Harrisburg, Pennsylvania, and southward at many places in the Appalachian Highlands.

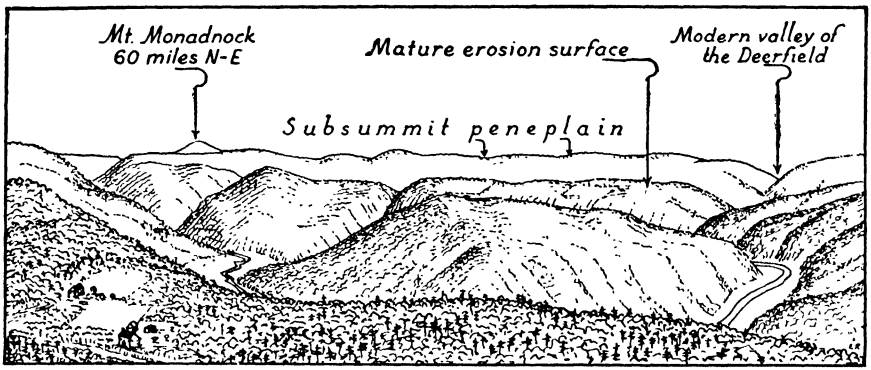


Figure 37 · A sketch based upon photographs taken from the Mohawk Trail where it crosses the Berkshire range. Looking eastward, we see the summit peneplain of New England (the Schooley), certain bench lands sufficiently broad to attract settlers who there have cultivated fields, and, below that intermediate surface, the modern valley of the Deerfield River

The third cycle of erosion. There is no question that a third cycle of erosion was introduced before the first of the great ice sheets came into this region. The streams throughout the New England–Acadian region have cut their channels well below the intermediate, or Harrisburg, benches that were developed during the second cycle. There are many examples of deeply entrenched meanders in which the streams have lowered their channels several hundred feet below the bench levels developed during the preceding cycle. The Deerfield, Millers, Westfield, and Chicopee river systems of western Massachusetts illustrate these features admirably. The larger lowlands associated with the major valleys such as the Housatonic, Connecticut, Merrimack, Kennebec, Penobscot, and Annapolis, which are all located in belts of weaker rock, were probably excavated at this time. Their present topographic features, however, were not developed during this cycle of erosion. Those features are chiefly of glacial or post-glacial stream or lacustrine origin. See Figure 38.

A possible fourth cycle of erosion. The possibility of subdividing what has been referred to as the third cycle of erosion into two stages is suggested by a number of topographic features in the vicinity of the

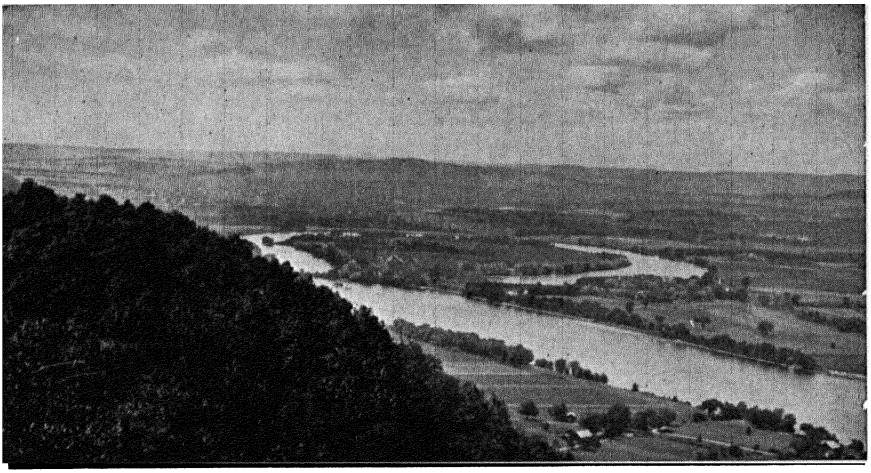


Figure 38 · The Connecticut River north of the gap through the Holyoke Range. This view is taken from the summit of Mount Holyoke and shows the well-defined oxbow now detached from the main channel of the river

White Mountains. The field problem is exceedingly difficult because of the heavily forested condition of the landscape and the presence of a mantle of glacial drift, which adds to the difficulty of correlating erosion surfaces developed during preglacial time. The problem is made even more difficult because this portion of the continent was depressed relative to sea level during the Ice Age and has risen since the melting of the ice. The fact that the amount of uplift has not been the same in all parts must be given consideration in working out the very late stages in valley development. When the ice had but partially disappeared and the land was still low, portions of the stream courses were drowned, more than they are today. At that time they were being filled with sediments. Marine clays are present in shore-line terraces of this age. With uplift of the land the streams at once went to work at clearing out the recently deposited alluvium. Many of them are today engaged in that work or in removing glacial deposits.

It is reasonable to believe, however, that the entire belt of Appalachian Highlands from Newfoundland to Alabama has passed through the same major stages of erosion. In the Southwestern Division, beyond the area where the stream-erosion history was interrupted by glaciation, there are four distinct cycles of erosion recorded in the topography.

Marine terraces. Some years ago Barrell[1] identified as marine terraces a series of eleven bench levels extending from the southern margin of Connecticut northward into Massachusetts. Most of these terraces must have been developed during preglacial time. A few of the lower ones were interpreted as being of postglacial age. If we accept Barrell's theory that these terraces are of marine origin, their presence means that southern New England must have been depressed below the waters of the ocean and etched by wave action at several horizons as the sea withdrew. If the sea was over the land, sediments must have accumulated offshore. In that event a remnant of those marine sediments, or at least a few shells of sea animals, should have been discovered somewhere in this area. In company with Barrell the author examined the field evidence, and must admit that he was not convinced of the marine origin of the so-called benches. The field problem has been made exceedingly difficult because several incompleted cycles of erosion followed the development of the summit peneplain and several glacial episodes occurred during the Pleistocene period. There is no doubt about the low marine terraces near the coast.

Glaciation

During the third or possibly the fourth cycle of stream erosion, when dissection of the land had proceeded beyond the stage of youth, the advance of a huge continental ice sheet gradually put a stop to the work of running water throughout most of the New England–Acadian region. See Figure 74, page 156.

While that ice sheet was moving slowly southward there must have been periods when great floods characterized the southward-flowing streams. The invading ice modified many of the surface features by erosion. Hard rock hills like Mount Monadnock were severely worn on the north side. Then the advancing ice steepened the rock walls on the south slope by plucking huge masses of rock from that side. Thus many of the preglacial features were made asymmetrical, with their steeper faces to the south or southeast. See Figures 39 and 40.

[1] J. Barrell, "The Piedmont Terraces of the Northern Appalachians," *American Journal of Science*, 4th Series, Vol. 49 (1920), pp. 227–258.

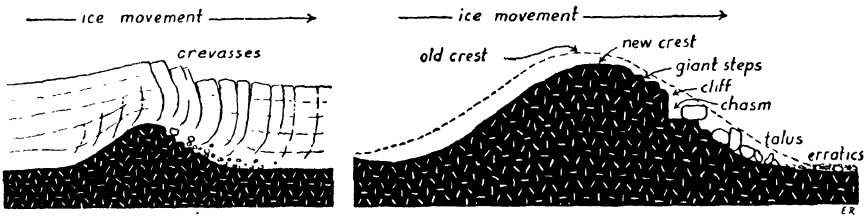


Figure 39 · Diagrams to illustrate the action of ice in moving over a mountain mass. The stoss side is rounded and polished, while the lee slope is made rugged by plucking. Many of the great blocks plucked from the mountainside are left as talus near the base. (Drawn by Erwin Raisz and used by courtesy of the New York Academy of Sciences)

The summit of Mount Monadnock is severely glaciated. Polished, grooved, and striated surfaces are abundant on that mountaintop. All loose material has been swept away, and examples of plucking are numerous, particularly on the southern face of the mountain. Many of the bare rock surfaces in New England and Acadia were smoothed, polished, and striated by the rock-shod glacier as it moved slowly southward. The summits of Mount Washington and Mount Katahdin carry unmistakable evidence of glaciation.

Valleys were deepened and widened, and lateral scarps were so cleared of all loose material that they now appear as nearly vertical walls approximately parallel to the direction of ice movement. On Mount Desert the ice so deepened the preglacial valleys that they all became U-shaped troughs. See Figure 41. Long and Jordan ponds and Eagle and Echo lakes now occupy the deeper portions of these old valleys. Somes Sound is deeper than the other troughs and is open to the sea. It now has all the characteristics of a fiord, but the walls are neither so steep nor so high as those of the more famous fiords in other parts of the world.

Many of the lesser physical features in the landscape of the New England–Acadian region are composed of morainic material left by the ice or of sands and gravels deposited by glacial waters. The major relief features in this part of the continent, however, are all due to the underlying hard rock formations. At many places the glacial mantle is but a thin veneer.

The White Mountains, the Katahdin group, and the Green Moun-

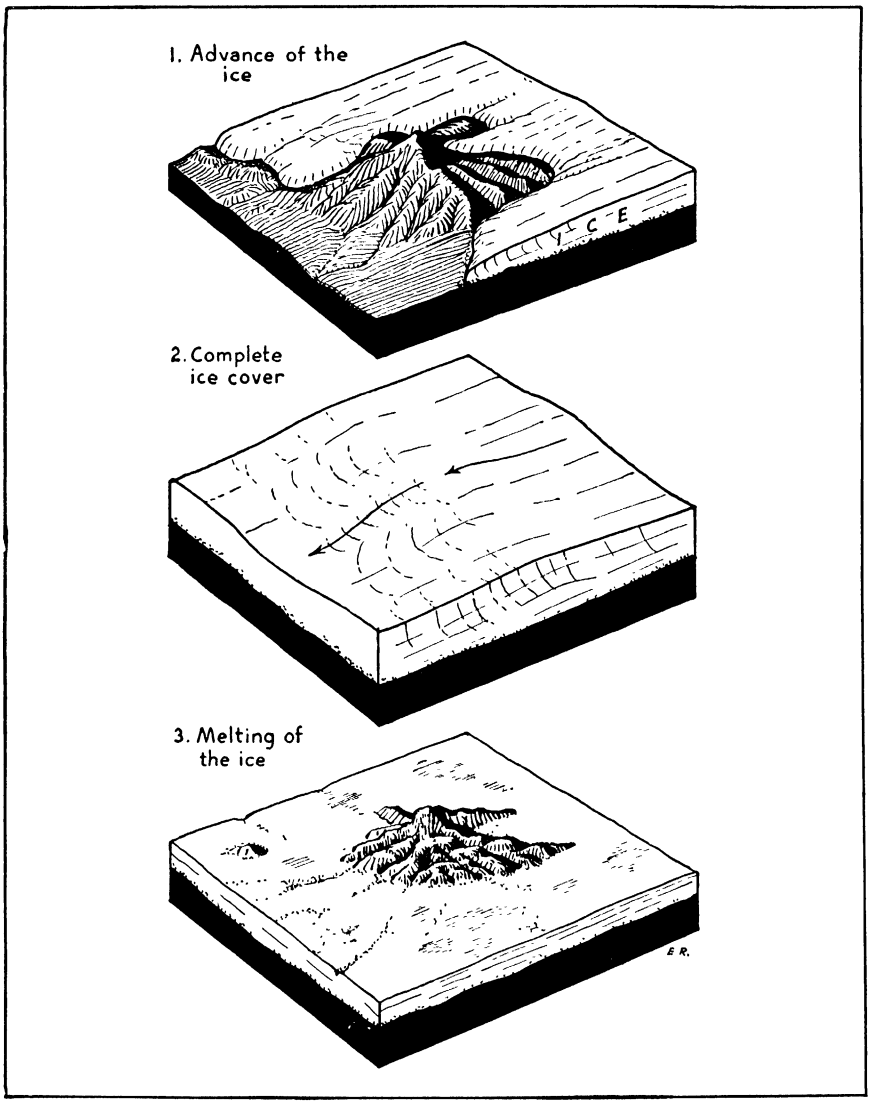


Figure 40 · The behavior of a continental ice sheet in the vicinity of an isolated mountain mass

tains were centers of alpine glaciation during the Ice Age. The local valley glaciers may have formed before the arrival of the continental ice sheets or they may have formed after the retreat northward of those sheets of ice. It is possible that they formed both before and after the

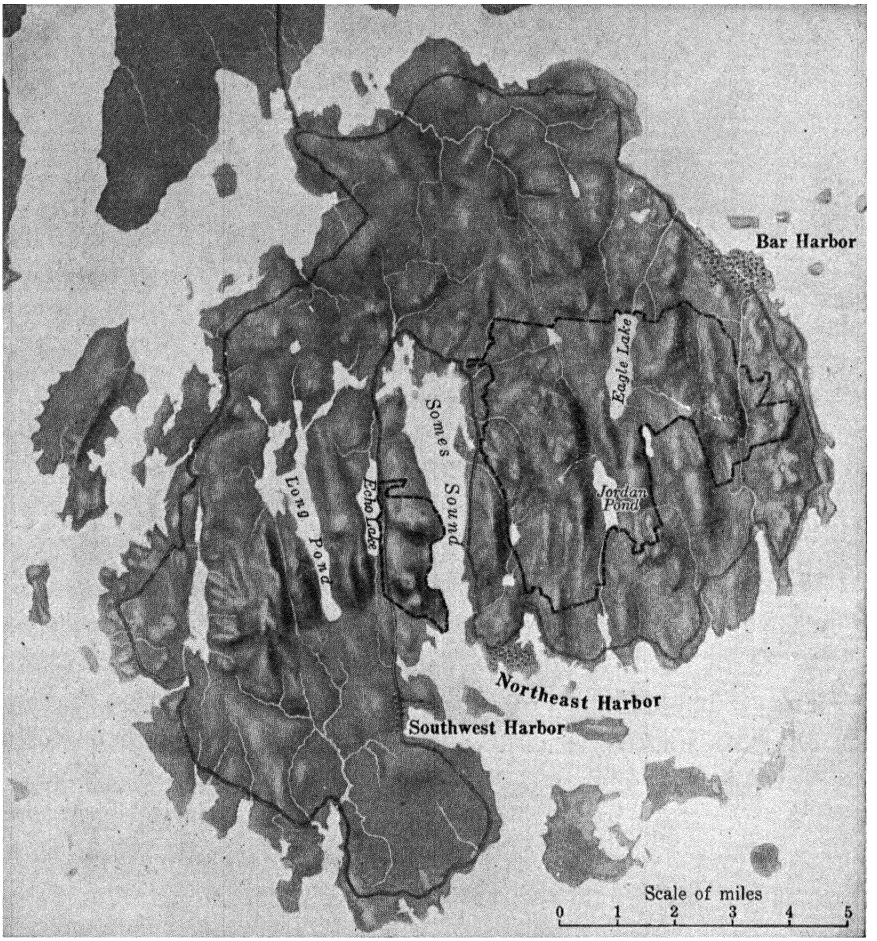


Figure 41 · The southeast portion of Mount Desert Island, where the views from the hilltops are very picturesque, is included within Acadia National Park

presence of the continental ice. The chief evidence of the small alpine glaciers is the *cirques*, or amphitheatral basins, that were excavated at the heads of the valleys which contained such tongues of ice.

The origin and movement of great ice sheets will be considered in detail when the Laurentian Upland is studied. In the chapter on the Central Lowlands a fuller description of glacial deposits will be presented than is given in this chapter, since in that province most of the surface features in the landscape are of glacial or fluvioglacial origin.

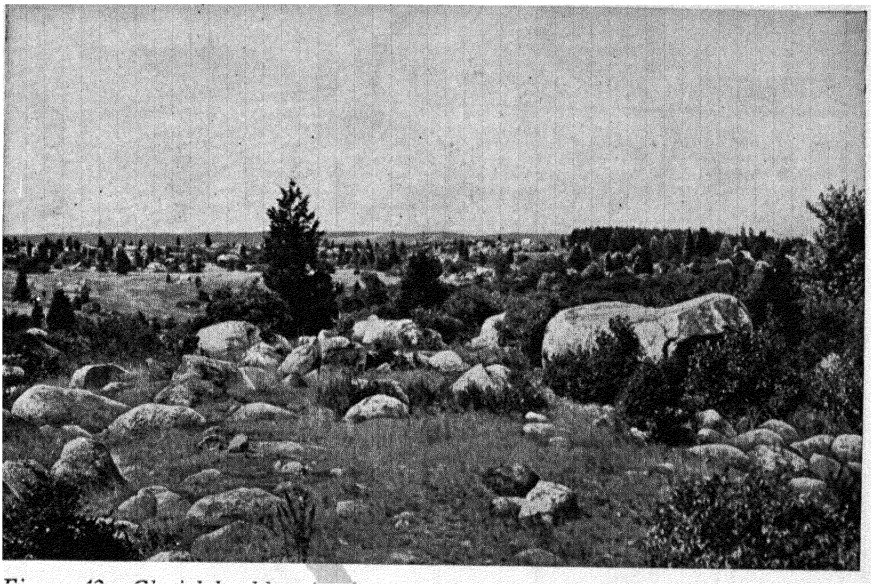


Figure 42 · Glacial boulders in the ground moraine at Cape Ann, Massachusetts

The frontal moraines. Well-defined frontal moraines, with their characteristic hilly or hummocky topography, exist on the islands south of New England and on Cape Cod but are not present as continuous belts farther north. Among the old, worn-down mountains and in the uplands there are small areas where morainic forms have the characteristic topography of a deposit laid down at or near the margin of the ice. Alden[1] has indicated the location of many such patches of moraine in the central part of Massachusetts.

The ground moraine. Any deposit, thin or thick, of unstratified glacial material that is not a part of any other special variety of moraine may be classified as *ground moraine.* Throughout most of the area now under consideration the ground moraine, which commonly varies up to 30 or 40 feet in thickness, modifies but slightly the underlying rock topography. Most of it was undoubtedly left when the last great ice sheet melted, and has been but little modified since that time. See Figure 42.

[1]W. C. Alden, "The Physical Features of Central Massachusetts," *U. S. Geological Survey Bulletin,* No. 760 (1924), pp. 13–105.

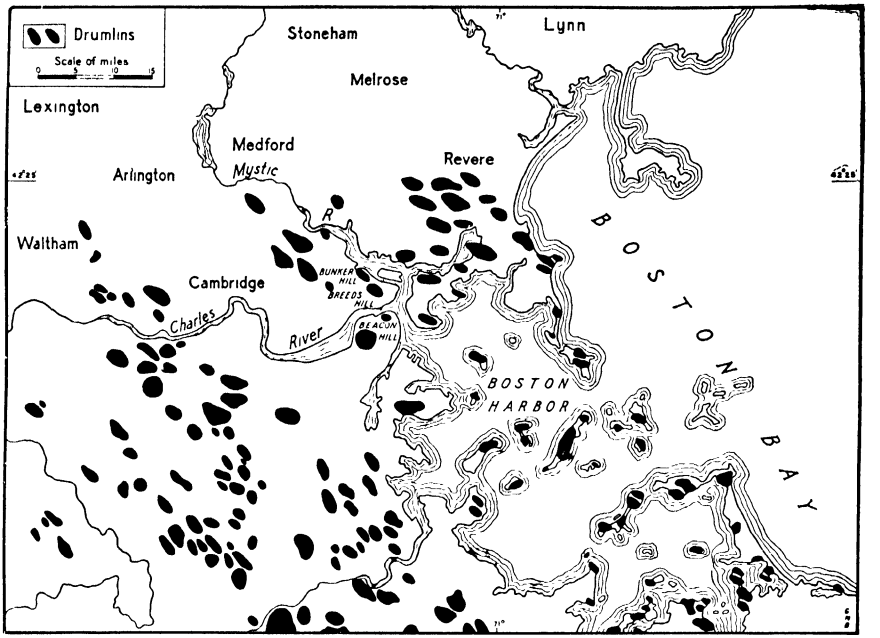


Figure 43 · The larger and more conspicuous drumlins in the vicinity of Boston. They include several of historic interest

Drumlins. In Boston, Yarmouth, and Halifax harbors and in Mahone and St. Peter's bays there are numerous elliptical hills of unstratified morainic material called *drumlins.* Their longer axes are parallel to the direction of ice motion, and their larger and higher ends are to the north. The glacial striae on exposed bedrock surfaces near by are approximately parallel to these longer axes and thus the drumlins help to indicate the general direction of ice movement. Other hills of similar form and origin are scattered somewhat widely through southern New England. See Figure 43.

Deposits left by glacial waters. In addition to the unstratified glacial debris, there are many examples of fluvioglacial deposits which are distinctly stratified. Where streams issued from beneath the ice, these deposits developed local *outwash plains.* Hundreds of *eskers* have been identified in the midst of other glacial deposits within this region. These are long ridges of sand and gravel, which vary in length from

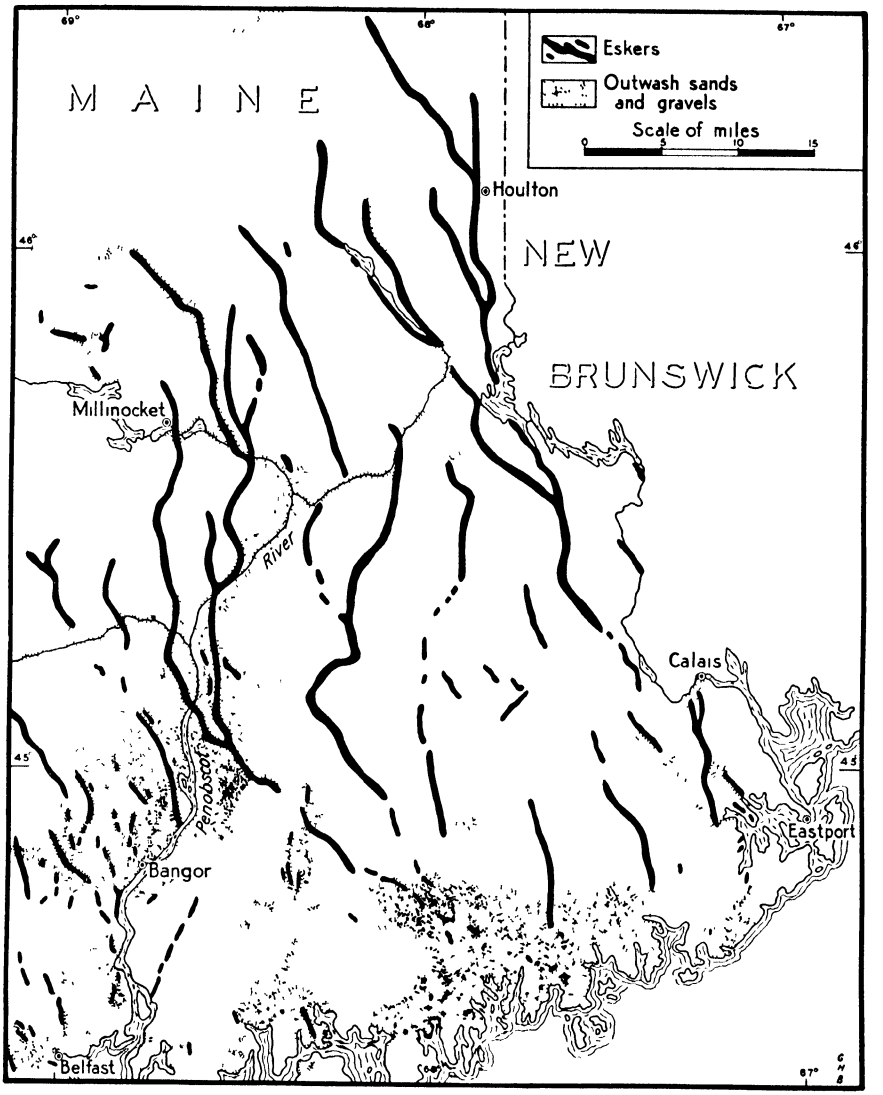


Figure 44 · The eskers and outwash deposits in the southeastern part of Maine

a few hundred yards to at least 20 miles. The longest and most conspicuous eskers thus far discovered in North America are in Maine. They are clearly shown on the Passadumkeag topographic sheet for that state. See Figure 44. In the midst of the morainic areas there are many hills of distinctly stratified sand and gravel called *kames.*

Stagnant ice. During the recessional stages of the last great ice sheet in this region many masses of stagnant ice appear to have remained for some time after the margin of the great ice sheet had retreated far to the north. Such stagnant masses of ice blocked the courses of streams and caused the formation of temporary lakes or ponds. They were not dynamic agents as were the true glaciers which were always grinding up material and constantly contributing vast quantities of sand, clay, and gravel to the waters issuing from beneath their margins. No continuous supply of debris could have come from the stagnant ice masses. The most they could contribute was the amount of material which they held when they became isolated from the parent moving mass. The lakes caused by blocks of this ice were distinctly ephemeral. In their basins lacustrine deposits accumulated, and at places about their margins faint shore-line features were developed.

Stagnant ice was a conditioning factor which helped to determine many of the local types of deposition of stream-borne material. When valley troughs were occupied by such ice, streams may have been located at the sides in the spaces between the ice and the valley walls. There the streams appear to have deposited sands and gravels, for today we find benches of such material on the side slopes of the New England valleys. These benches are called *kame terraces.* Flint[1] made a detailed study of the glacial deposits in the Connecticut Valley and presented a full statement of his views of the influence of stagnant ice.

Ice-front lakes. As the margin of the great ice sheet retreated northward, there were many places where water accumulated between the ice front and some rock ridge, a stagnant block of ice, or a morainic mass. These were generally small and ephemeral lakes. At a number of places in the larger lowland valleys the land at the south may have risen somewhat as it became free from ice. An ice-front lake covered the flat lands in the bottom of the Housatonic Valley south of Pittsfield, Massachusetts. Near Sudbury, Massachusetts, and Nashua, New Hampshire, there are old lake bottoms where the waters must have been held in by ice dams at the north.

[1] R. F. Flint, "Stagnation of the Last Ice Sheet in New England," *American Journal of Science,* 5th Series, Vol. 22 (1931), pp. 174–176.

The largest and most interesting ice-front lake was in the lowlands of the Connecticut Valley. That lake extended northward from Middletown, Connecticut, to a little beyond Greenfield, Massachusetts. The portion that was south of the Holyoke Range is called Lake Springfield, and the part that was north of that range is spoken of as Lake Hadley. The shore lines of the Connecticut Valley lake are shown clearly at a number of places by old beaches and lake cliffs, and especially well by deltas at the mouths of streams that came from highlands on the east or west. See Figure 34.

On the bottom of this lake beautifully laminated clays were deposited by the waters that issued from the melting glacier. The layers of clay differ slightly, each alternate one being of a little coarser material than the intervening layer. The layers of coarser particles are interpreted to represent the summer seasons, when the ice was melting rapidly. The layers of finer particles represent the winter seasons, when there was very little melting and consequently very little current in the waters issuing from beneath the glacier. Each pair of layers, or *varves*, represents a year, and thus the deposition of these clays served as a self-recording timepiece. Antevs,[1] an expert in reading such records, states that this lake must have existed for some 4000 years. During that time the ice front retreated from about the present location of Hartford, Connecticut, to a position near the site of St. Johnsbury, Vermont. From a study of the Connecticut Valley varves and those deposited under like conditions in other ice-front lakes, he estimates that the last great ice sheet in North America began to retreat about 25,000 years ago.

In time the great load of ice melted away at the north, and as the land rose, the ice-front lakes were drained. When the streams, like the Connecticut, became located on the old lake floors they cut into the lacustrine deposits, and as they lowered their channels they developed terraces at several horizons.

In the Connecticut Valley the varved clays have become valuable in the manufacture of bricks and certain kinds of paper. The sand and gravel about the shores of the lake and especially in the deltas are ex-

[1]E. Antevs, "The Recession of the Last Ice Sheet in New England," *American Geographical Society, Research Series*, No. 11 (1922), pp. 1–10.

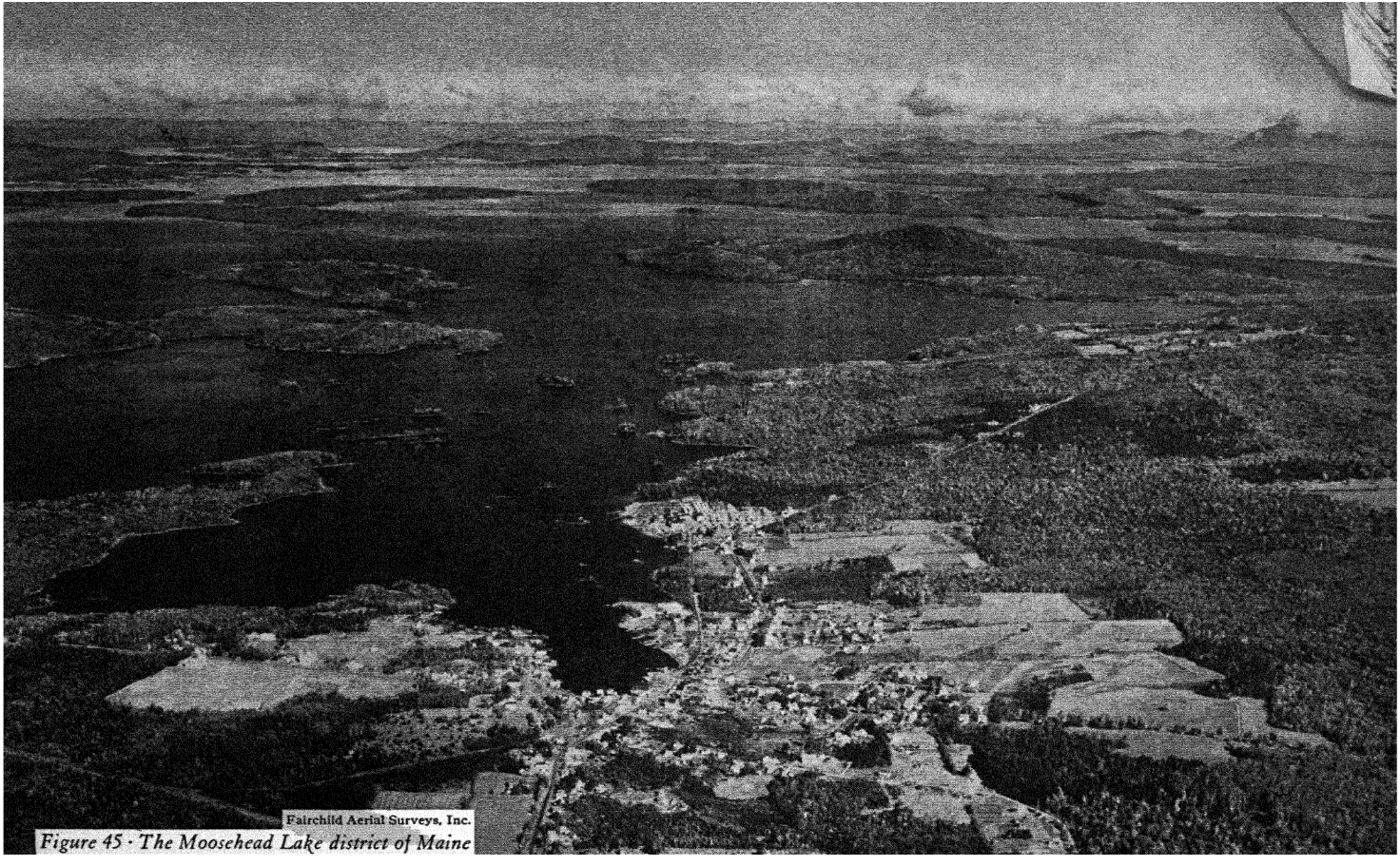


Figure 45 · The Moosehead Lake district of Maine

cellent building materials. The broad river terraces underlain with clays are good farming lands, and at intervals they serve as the sites of cities and towns.

Disarrangement of drainage. Since the disappearance of the last continental ice sheet from the New England–Acadian region, the streams have been forced to adjust themselves to conditions that differ greatly from those developed during preglacial time. Thousands of ponds, lakes, marshes, and swamps were formed as rain waters or waters from the melting ice and snow accumulated in undrained depressions in the landscape. All the old stream courses contained more or less debris, and some of them were so deeply filled at places that the streams were forced to find new courses. See Figure 45.

The drainage of the Androscoggin illustrates the difficulties which beset a single river in finding its way from the interior highland area to the coast. That stream, which starts directly toward the Atlantic Ocean, repeatedly turns away from the ocean and follows a circuitous route many times longer than the preglacial channel must have been. In its wanderings the river has encountered hard rock ledges at many places and has developed falls and rapids. Its valley is broad and open at certain places and narrow and gorgelike at others. Like most of the valleys of the New England–Acadian region, it illustrates the disarrangement of drainage that has furnished much of the water power in this part of the continent.

Post-glacial stream erosion. Lakes, ponds, and marshes, which are indicative of youth in the drainage of almost any region, are an indication that the present drainage system of the New England–Acadian region is in a youthful stage. They are features of brief duration in the erosion history of a landscape, and their ephemeral nature is due chiefly to the work of the streams. In time, rivers either lower the outlets of such depressions until the basins are drained, or they fill the basins with sediment and thus cause extinction. The growth of aquatic plants has aided in the extermination of many of the small lakes.

The numerous falls and rapids in the drainage lines of this region are another indication of extreme youth. Most of the streams are en-

gaged in clearing away the glacial debris from their courses. At a few places streams are cutting notches or gorges in the solid rock formations.

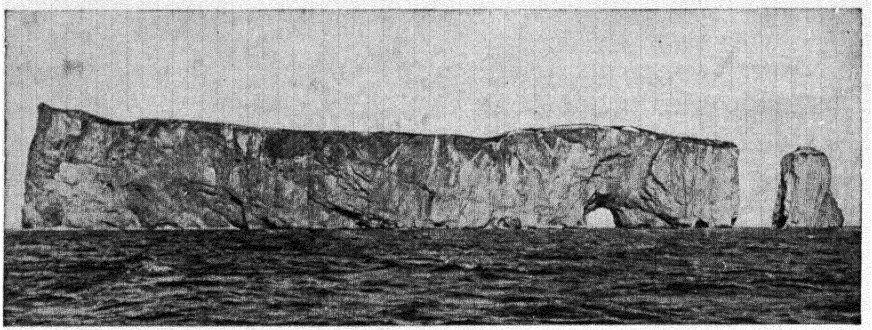


Figure 46 · Percé Rock, near the eastern end of the Gaspé Peninsula. Sea cliffs, a shore-line pillar, and a great rock arch due to wave erosion are beautifully illustrated

The rock gorges excavated since the ice left are very small. In many of them the streams are still working out potholes below falls. This is still another indication of extreme youth.

Coastal Features

Resulting from submergence. The larger indentations in the coast line of this region are a result of partial submergence. As the ice melted, the sea advanced over the coastal lowlands and into the downstream portions of all river valleys. The stream mouths are drowned and thus present excellent examples of estuaries. Countless islands offshore, which are the tops of partly submerged hills or low mountains, add to the picturesqueness of the coast. See Figure 41.

Resulting from emergence. A number of marine terraces along the Atlantic coast of New England and others bordering the St. Lawrence River and the Gulf of St. Lawrence indicate that certain parts of the coast have risen since the melting of the ice sheets. Recent marine deposits extend inland from the coast of Maine for at least 80 miles and to heights of 500 feet. Post-glacial shore lines along this coast are 300 to 400 feet above the tidal waters of today. In the valley of the St.

Lawrence River the old shore lines have elevations that range up to 630 feet above the river. Many of these terraces are used as farm lands; others are the sites of villages; and smaller ones are crowded with summer homes.

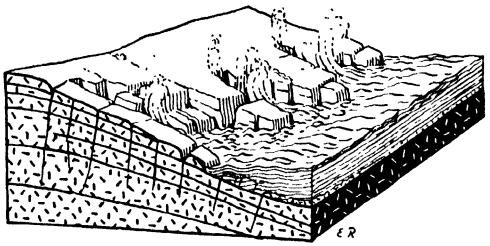


Figure 47 · A block drawing of the Thunder Hole shore line of Mount Desert Island. (Drawn by Erwin Raisz and used by courtesy of the New York Academy of Sciences)

Resulting from wave erosion. Sea caves, wave-cut cliffs and benches, picturesque scarps, arched rocks, and shore-line pillars all testify to the active work of waves.

Percé Rock, off the southeast coast of the Gaspé Peninsula, is a long narrow island composed of limestone, bounded by cliffs 150 to 300 feet high and pierced by an opening large enough to allow small boats to pass through. A tall chimney rock rises at the seaward end, and a sand bar, uncovered at low tide, unites the island to the mainland. See Figure 46.

On the seaward side of Mount Desert Island there are bold, rocky, picturesque cliffs where the waves are constantly at work. During storm periods the southern side of the island presents spectacular scenes in the attack of the ocean waves upon the land. At many other localities along the Atlantic coast of this part of the continent, good examples of sea caves, sea cliffs, and wave-cut benches may be found. See Figure 47.

Resulting from deposition. A variety of beaches border the coastal margins of the region. On the shores of the Bay of Fundy, Chignecto Bay, and Minas Basin, spits, forelands, hooks, and bay-mouth bars are numerous. Cuspate forelands and cuspate bars fringe the northeastern coast of New Brunswick, northern Prince Edward Island, and the Bras d'Or of Cape Breton Island. Vast mud flats and marshes occupy the heads of many of the basins and small estuaries. The "sea coast prairies" of the Maritime Provinces of Canada are tracts of great fertility which were in part reclaimed from the sea. They provide rich farm lands.



Fairchild Aerial Surveys, Inc.

Figure 48 · A view of Marblehead Neck from a position above Marblehead. The island is tied to the mainland by a sand and gravel bar

At several places islands have been tied together or tied to the mainland by sand bars. When the continental ice sheet disappeared and the waves and shore currents began their work in the vicinity of Marblehead, Massachusetts, they found a large rocky island a little offshore. The attacks of the waves upon this island provided the shore currents with some debris, and currents following northward along the coast of the mainland brought additional material. Little by little a sand bar formed what is now called Marblehead Neck. The special type of sand bar which ties an island to the mainland is sometimes called a *tombolo*. See Figure 48.

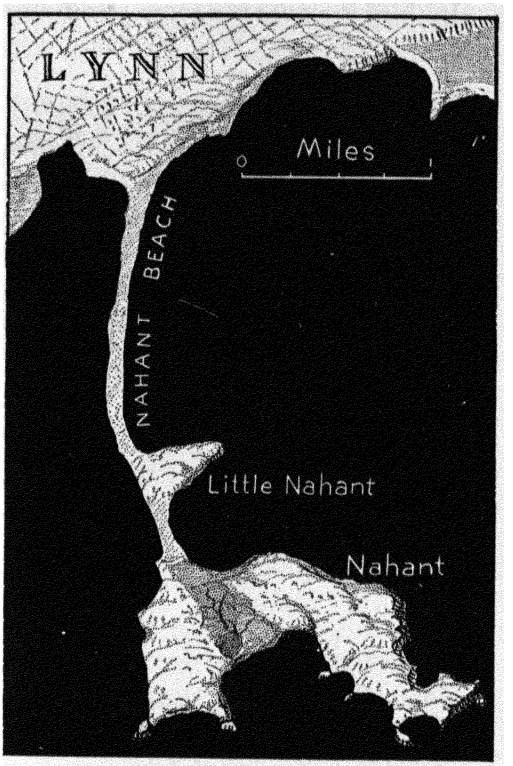


Figure 49 · The sand and gravel beaches that have tied Little Nahant and Nahant to the mainland are tombolos

In the vicinity of Nahant Bay, at the north margin of Boston Harbor, there were formerly two islands, Big Nahant and Little Nahant. Shore-line deposition tied Big Nahant to Little Nahant, and the latter to the mainland. They are now land-tied islands. See Figure 49.

At the south margin of the entrance to Boston Harbor there was at one time a group of drumlins rising above the sea water which were exposed to wave action immediately upon the retreat of the continental ice sheet. Some of these islands have been partially removed, and others have been completely truncated a few feet below sea level by the action of waves. Materials gathered by shore currents have formed sand and gravel beaches which have tied a chain of the remaining drumlins together and formed Nantasket Beach. See Figure 50.

A Brief Summary of the Physical History

In thinking over the more significant factors in the evolution of the physiography of the New England–Acadian region, it must be kept in mind that this region is the northeastern portion of the Appalachian Highlands. The underlying rock structures reflect great variety and complexity. There is abundant evidence in this part of the world of ancient mountains which have been removed. The prominent topographic features of today in New England and Acadia are but the roots or stumps of the loftier mountains of an earlier time.

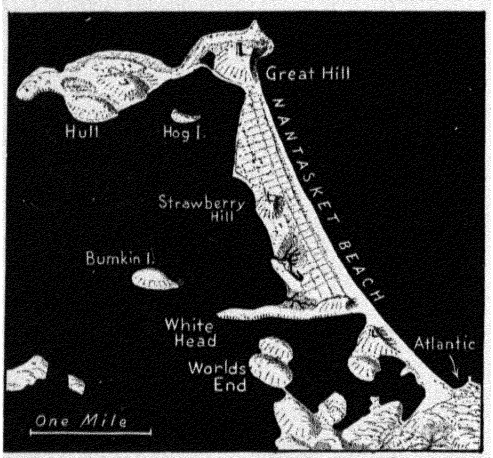


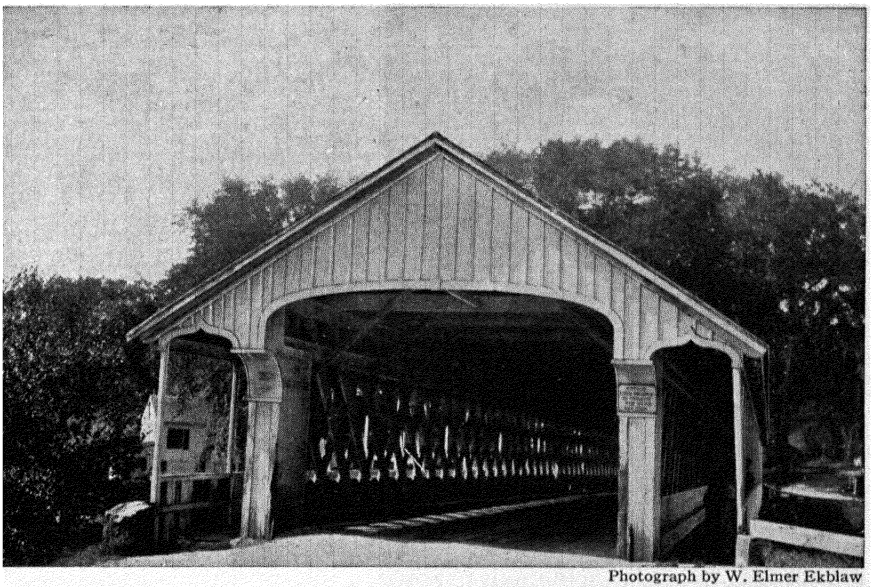
Figure 50 · Nantasket Beach and a nest of drumlins

All the major relief features are due to the superior resistance to erosion of hard rock formations exposed at the surface at various places within the region. One well-developed peneplain is represented by the remarkably even-crested summits of many of the ranges and upland areas. Above this peneplain rise several monadnocks. The preglacial stream-erosion history is subdivided into three or four cycles. Continental glaciation has played so important a part that an interpretation of the present physical features of the landscape cannot be made without recognition of the work of ice and of waters associated with glacial ice.

Changes in sea level relative to the land are recorded about the margin of the region, both on the seaward side and in the valley of the St. Lawrence. Certain evidence indicates that there has been submergence along the coast in comparatively recent times, and other evidence indicates that there has been some uplift even since the disappearance of the last ice sheet. The present shore-line features reflect intense activity by waves and shore currents.

An Approach to the Human Drama

The New England–Acadian region is full of historic interest. To this part of the New World came representatives of the vikings and



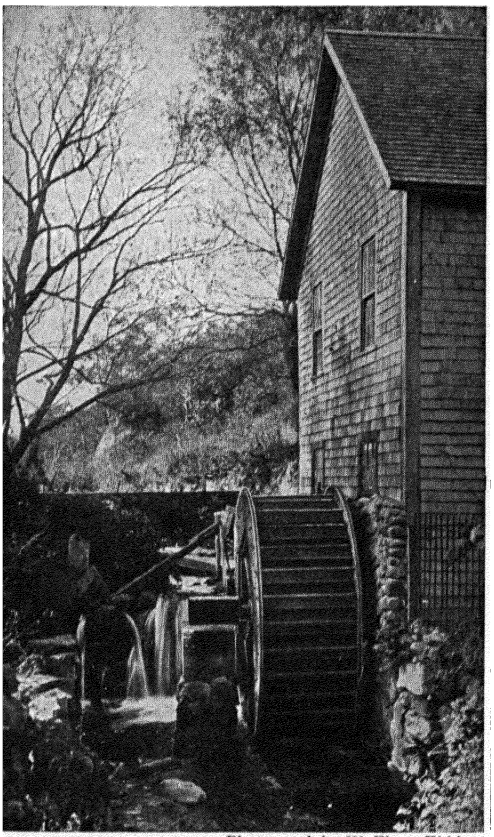
Photograph by W. Elmer Ekblaw

Figure 51 · A sample of the covered bridges which were formerly common in New England. This one crosses the Ashuelot River in southwestern New Hampshire

of the early British and French explorers, and here occurred many events of great importance in the early history of Canada and of the United States.

The first settlers found a dense forest wilderness over most of the area. After securing the timber necessary for the construction of homes, for firewood, and for other uses, many of the colonists turned their attention to lumbering, and some of them turned to bridge building. See Figure 51. Much more lumber was produced than was needed at home, and the surplus was offered in foreign trade in exchange for manufactured goods. Many wooden ships were constructed for the commerce between the colonists and the people of the Old World, and some were used along the coast, providing the easiest means of communication between the settlements near the Atlantic border of the New World.

The offshore fisheries, and especially those on the banks south of Nova Scotia and Newfoundland, early attracted many adventurous souls, and such huge quantities of food were produced there that a large surplus was available for shipment to other lands. Thus the forests and the fisheries early led the New England and Acadian settlers into world commerce.



Photograph by W. Elmer Ekblaw

Figure 52 · An old mill wheel at East Brewster, Massachusetts, suggestive of the simple beginnings of industrial life in New England

Farm lands were available, and in the earlier days, before there was competition with the better farm lands in the interior of the continent, many of the New England and Acadian farmers were reasonably prosperous. There was no great mineral wealth discovered by the colonists, but in more recent years the coal and iron in the Maritime Provinces have come to play an important role. The asbestos deposits just north of Vermont in the Canadian lands now produce 80 per cent of the world's supply of that mineral. Building stones are abundant. New England has provided some of the best granites, slates, and marbles found on the continent.

The water power of the region was early recognized as of great economic importance, and at strategic points small mills were constructed where the direct falling of water turned wheels and generated power. See Figure 52. Textile and flour mills, metal works, and many wood-working industries were established near waterfalls. As time passed, the water power was used in generating electricity, and then

some of the manufacturing plants were erected at more convenient places. Numerous special lines of industry became established. The manufacture of cotton or woolen cloth, of shoes, hats, chairs, paper, toys, silverware, watches and clocks, and articles of clothing became centered in certain communities.

With the rise of industrialism and the opening up of the great farming lands in the interior of the continent, general farming in this part of the New World decreased. Today the farming industry here is highly specialized. Dairy farming, poultry-raising, truck farming, and orcharding can be carried on successfully because of the markets which are furnished by the manufacturing and commercial centers close by.

The larger cities are near the coast, where favorable harbor facilities have determined their locations. New Haven, Providence, Boston, Portsmouth, Portland, Halifax, and St. John's are good examples. Other prosperous cities, such as Holyoke on the Connecticut, Lowell, Lawrence, Nashua, and Manchester on the Merrimack, and Auburn and Lewiston on the Androscoggin, are located where water power is available. Most of the inland towns and villages throughout the region are located where there is some water power available to help in the establishment of manufacturing industries. A few villages are located in the midst of areas of good farming lands, or near an unusual supply of good building stone where quarrying is actively carried on, or within easy reach of certain coal, iron, or asbestos mines.

Parallel with the industrial and commercial development in this province there was an enthusiastic movement in education. Here, in 1636, Harvard, oldest college in the United States, was founded; and as the decades passed more than a hundred colleges, universities, engineering schools and teacher-training institutions were established. Some of these have had a remarkable growth, and many of them have come to play an important part in the educational work of the nation. Boston boasts of having established the first public library in America that was authorized by state legislation. At Lexington, Massachusetts, the first school for training teachers was opened. The examples of those cities have been followed throughout the New World.

The province has also been a leader in the development of recreational facilities and public reservations. Worcester, Massachusetts,



Photograph by W. Elmer Ekblaw

Figure 53 A prolonged New England house in the little village of Tully, north of Athol, Massachusetts

boasts that it was the first city to set aside a park to be maintained at public expense. State parks, state forests, bird sanctuaries, recreational grounds, and camps for young people are widely distributed throughout the region. The seacoast, the mountains, the shores of beautifully situated lakes, and even the old farms attract thousands of vacationists each year. See Figure 53. Many of the towns and villages owe their prosperity during recent years to the scenic or recreational attractiveness of their locations. Most of the nationally famous sailing races take place along the coast of New England. The mountain areas have become popular winter resorts. Trails and storm shelters have been built and are maintained by enthusiastic mountain climbers. "Ski trains" leave the larger cities for the mountains each week end during the colder months of the year.

Many of the cultural traditions within the United States and Canada originated in this part of the continent and migrated westward as the frontier crossed the Appalachian Highlands, the interior plains, and, in time, the high cordilleran provinces of the Far West.

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SELECTED LIST OF TOPOGRAPHIC MAPS FOR THE NEW ENGLAND–ACADIAN DIVISION OF THE APPALACHIAN HIGHLANDS

Nova Scotia (N. L.–20)[1]
Bras d'Or, Nova Scotia[2]
Sydney, Nova Scotia[2]

Acadia National Park, Maine
Bath, Maine
Boothbay, Maine
Boyd Lake, Maine
Bryant Pond, Maine
Buckfield, Maine
Eastport, Maine
Fish River Lake, Maine
Great Pond, Maine
Houlton, Maine
Katahdin, Maine
Mooseleuk Lake, Maine
Musquacook Lakes, Maine
Passadumkeag, Maine
Penobscot Bay, Maine
Portland and Vicinity, Maine
Saponac, Maine
Smyrna Mills, Maine
Stratton, Maine

Crawford Notch, New Hampshire
Franconia, New Hampshire
Monadnock, New Hampshire
Mt. Chocorua, New Hampshire
Mt. Washington, New Hampshire
Penacook, New Hampshire
Peterboro, New Hampshire
Ossipee Lake, New Hampshire
Winnepesaukee, New Hampshire
Wolfeboro, New Hampshire
Gorham, New Hampshire–Maine
North Conway, New Hampshire–Maine
Portsmouth, New Hampshire–Maine
Claremont, New Hampshire–Vermont
Keene, New Hampshire–Vermont
Mt. Cube, New Hampshire–Vermont
Whitefield, New Hampshire–Vermont

Burlington, Vermont
Camels Hump, Vermont
Hyde Park, Vermont
Island Pond, Vermont
Milton, Vermont
Montpelier, Vermont
Mount Mansfield, Vermont
Hanover, Vermont–New Hampshire

Ayer, Masachusetts
Boston and Vicinity, Massachusetts
Gloucester, Massachusetts
Manomet, Massachusetts
Northampton, Massachusetts
Granville, Massachusetts–Connecticut
Palmer, Massachusetts–Connecticut
Springfield, Massachusetts–Connecticut
Providence, Massachusetts–Rhode Island
Greenfield, Massachusetts–Vermont
Greylock, Massachusetts–Vermont
Hawley, Massachusetts–Vermont

Charleston, Rhode Island

Guilford, Connecticut
Meriden, Connecticut
Middletown, Connecticut
New Haven, Connecticut
Niantic, Connecticut
Saybrook, Connecticut
New London, Connecticut–New York
Stonington, Connecticut–Rhode Island–New York

Berlin, New York–Massachusetts–Vermont

[1]Published by the Department of the Interior, Ottawa, Canada (scale 1:1,000,000).
[2]Published by the Department of National Defence, Canada (scale 1:63,360).

IV

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THE APPALACHIAN HIGHLANDS

THE SOUTHWESTERN DIVISION

A General Description

A region of varied relief. In the province we are now to study we shall find great variety in the topography and many notable relief features. Here there are mountain summits that rise a little more than 6000 feet above the sea, bold ridges notched at intervals by deep water gaps, gorges 2000 to 3000 feet deep, torrential streams with beautiful waterfalls, and broad lowland valleys between mountain ridges. The contours have been softened or subdued through long periods of weathering and erosion. Through the central portion of the province there is a well-defined zone of old, worn-down mountains which have had a remarkable history.

When seen from the air, this division of the Appalachian Highlands is readily divided into four subprovinces. At the southeast is the Piedmont Upland, with a gently rolling or hilly surface, and at the northwest is the deeply dissected Appalachian Plateau. Between these two subprovinces all the bolder topographic features are mountains. At the east are the Older Appalachians and at the west the Newer Appalachian Mountains, or the Ridge and Valley subprovince. See Figure 54 and refer frequently to the map at the end of this book.

The boundaries. The fall line described in Chapter II as defining the northwest margin of the Atlantic Coastal Plain extends along the eastern margin of the Piedmont Upland from Alabama to New York City. Farther north the eastern boundary of this division of the Appalachian Highlands is at the western margin of the New England–Acadian province or at the west base of the Taconic Range as far north as Brandon, Vermont, and from there on at the west base of the Green Mountains. Low, west-facing escarpments in Tennessee and eastern Kentucky are accepted as the western margin of the Appalachian Plateau in that section. In Ohio the western boundary line is indefinite because there the edge of the plateau is so dissected that it fades out gradually through a hilly belt into the Central Lowlands of the continent.

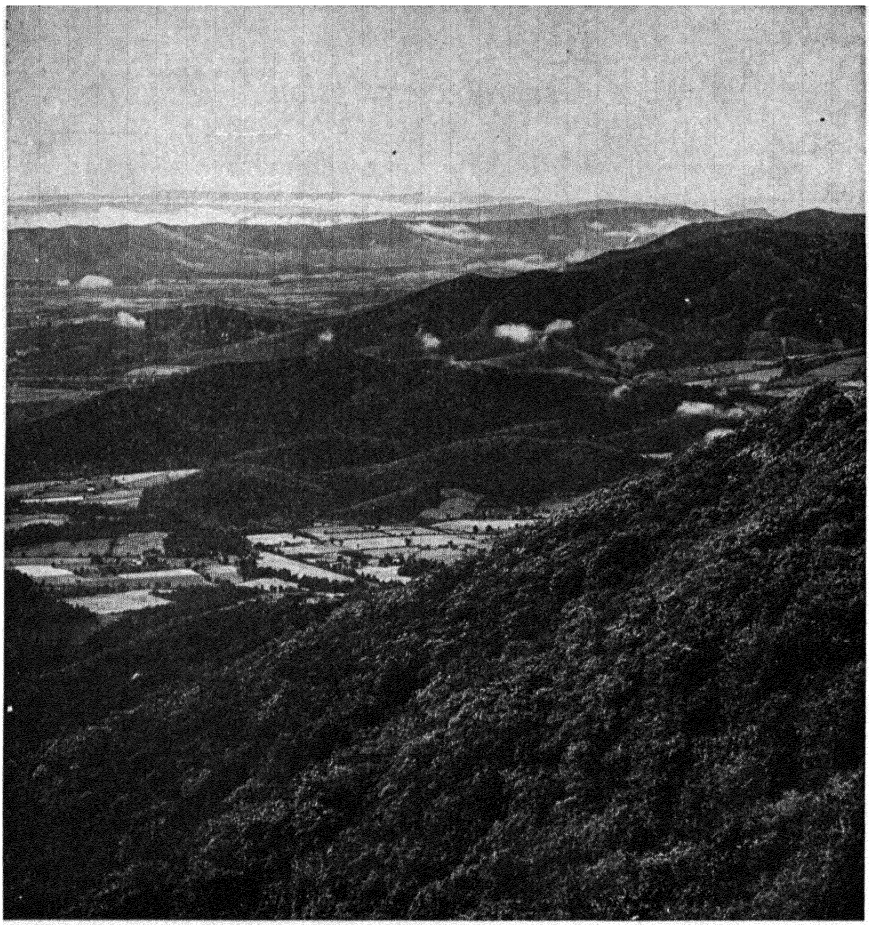


Figure 54 · Looking northward along the Blue Ridge across the valley of the Shenandoah to the even-crested ridges of the Newer Appalachian Mountains. The agricultural lands in the foreground are small benches on the slope of the Blue Ridge

At the north the boundary of the province follows for many miles a bold escarpment which crosses northwestern Pennsylvania and central New York State. On clear days this escarpment can be seen from the south shore of Lake Erie, in Pennsylvania, and, farther east, from the highways which border the New York Barge Canal.

Near Albany the boundary line crosses, somewhat arbitrarily, the valley of the Mohawk River to the east base of the Adirondack Moun-



Official Photograph U S. Army Air Corps

Figure 55 · The Highlands of the Hudson, with West Point in the foreground

tains and continues northward to the lowlands that border the St. Lawrence River. The Hudson Valley–Champlain Lowland is thus included in the province, for it is the northward extension of the Ridge and Valley subprovince of the highland area. At the south the Appalachian Highlands reach to the inland margin of the Gulf Coastal Plain in Alabama.

The Subprovinces

The Piedmont Upland. The foothill subprovince which borders the Appalachian Mountains on the east is a zone, or belt, of hilly country composed, for the most part, of very old (Pre-Cambrian) rock formations, in which the summits commonly rise to elevations of from 1000 to 1200 feet at the inner margin and decline seaward somewhat uniformly to the inland border of the Coastal Plain. This belt is about 50 miles wide at the north; in the Southern States it varies from 100 to 125 miles in width. At a few places monadnocklike hills rise from 300 to 400 feet above the general summit elevation. Stone Mountain, near Atlanta, Georgia, is a good example of one of these monadnocks.

The Older Appalachian Mountains. Adjoining the Piedmont Upland on the northwest and extending from the Hudson Valley to central Georgia there is a nearly continuous chain of mountain ranges known as the Older Appalachians. These ranges are composed, for the most part, of Pre-Cambrian rock formations that have been compressed and highly metamorphosed during several periods of mountain-making movements. The Highlands of the Hudson and the Highlands of Northern New Jersey, the Musconetcong, Lehigh, and South mountains in Pennsylvania form the northern portion of this chain. See Figure 55. Northeastward for 50 miles from the valley of the Susquehanna River there are no mountains at the west margin of the Piedmont Upland. Here the Ridge and Valley region adjoins the Piedmont Upland. The Blue Ridge of southern Pennsylvania, Maryland, Virginia, and North Carolina, the Great Smoky, Black, and Unaka ranges of North Carolina and Tennessee, and the Cohutta Mountains of Georgia are all parts of the Older Appalachian Mountains.



Figure 56 · Looking westward from the Blue Ridge across the Shenandoah Valley to the even-crested ridges of the Newer Appalachian Mountains

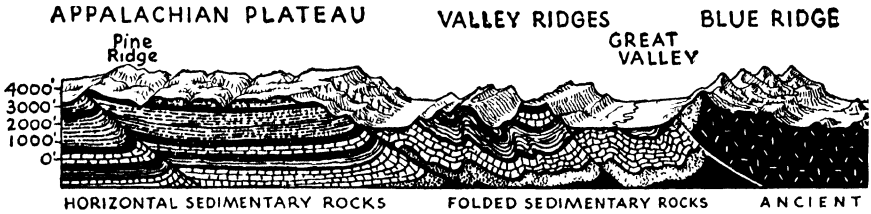
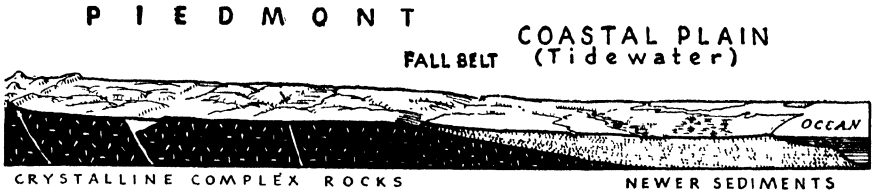


Figure 57 · Diagrammatic structure section through the

The summit elevation of these mountains varies from less than 1000 feet in the south to over 6000 feet in the region of the Great Smoky Mountains National Park. The Black Mountains of western North Carolina include Mount Mitchell (6711 feet), the highest peak in eastern United States, and other summits of approximately the same elevation. Among the higher peaks in the vicinity of Mount Mitchell are Black Brothers (6690 feet), Balsam Cone (6645 feet), Mount Gibbs (6611 feet), and Clingman's Dome (6419 feet). The Older Appalachian Mountains attain altitudes of from 3000 to 4000 feet in southern Virginia and descend to altitudes ranging from 1500 to 2000 feet in southern Pennsylvania. In the Highlands of the Hudson the summit elevation is about 1500 feet.

The Newer Appalachian Mountains. West and northwest of the Older Appalachian Mountains are the nearly parallel and remarkably even-crested ridges of the Newer Appalachians. These mountains are composed of younger (Paleozoic) rocks, which are much less altered structurally than are those of the older mountain system. In some places they rise 2000 feet above the adjacent lowlands, attaining summit elevations of from 3000 to 4000 feet above the sea.

A composite lowland called the Great Appalachian Valley is located for the most part between the westernmost ranges of the Older Appalachians and the easternmost ridges of the Newer Appalachians. It is made up of the Kittatinny, Lebanon, Cumberland, Hagerstown, Shenandoah, Tennessee, and Coosa valleys. This lowland has provided a fairly continuous highway of travel and many broad, gently rolling areas of good farming lands. Other long, narrow valleys alternate with parallel ridges westward to the base of the bold escarpments which mark the eastern face of the Appalachian Plateau. See Figures 56, 61, and 63.



State of Virginia with the associated relief features

The Appalachian Plateau. Bordering the Newer Appalachian Mountains on the west and northwest is the Appalachian Plateau, a belt of varying width, composed of Paleozoic strata. The eastern boundary of this plateau is sharply defined by the Allegheny Front at the north and the Cumberland Escarpment at the south. The western and northern boundary is the inland margin of the Appalachian Highlands, which was described on page 109. The summit elevations within the plateau vary from about 2000 feet in central Tennessee to 3500 feet in southeastern Kentucky, and to 3000–4000 feet in West Virginia. In western Pennsylvania the summit of the plateau is about 2000 feet above the sea.

Portions of the Appalachian Plateau have been described as mountainous, so deeply and irregularly has the surface been dissected by stream erosion. In a few cases, as in the valley of the Kanawha River, the streams are from 1000 to 1500 feet below the plateau surface. The Catskill Mountains of eastern New York State are the result of the deep dissection of another portion of this plateau region.

Materials and Structure

In the Piedmont Upland and the Older Appalachian Mountains. Figure 57 presents a simplified and somewhat generalized structure section across the Southwestern Division of the Appalachian Highlands from the northwest to the southeast. In the two eastern subprovinces, the Piedmont Upland and the Older Appalachian Mountains, the rock formations consist of gneisses, schists, slates, quartzites, and many other metamorphic rocks, all of which have been greatly deformed by mountain-making movements. Most of the hard rock formations within these two subprovinces are of Pre-Cambrian age. They are a part of

the fundamental complex of rock formations upon which the continent has been built. This complex is widespread at the surface in the Laurentian Upland, and it appears in the cores of many Western mountain ranges and in the depths of many great canyons. See Figures 58 and 59.

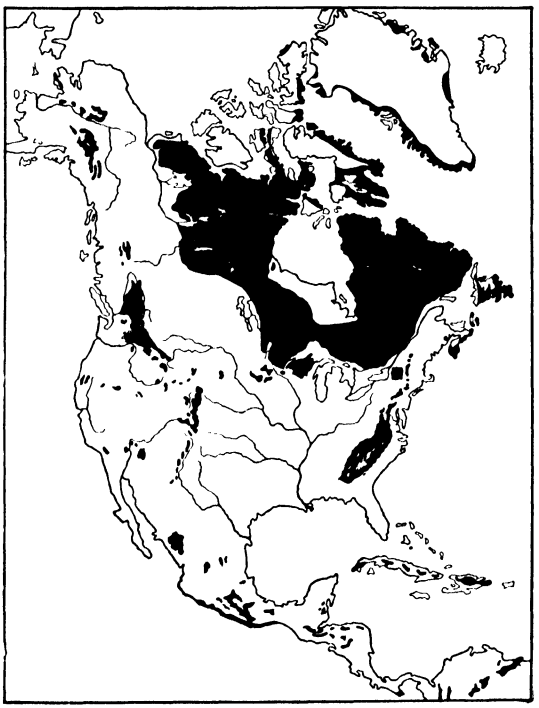
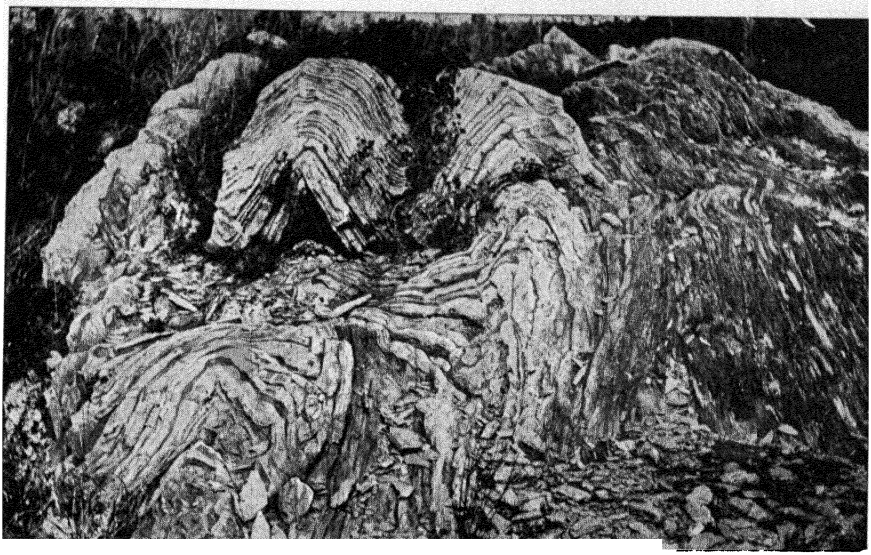


Figure 58 · Areas in North America where the Pre-Cambrian rock complex is at the surface or mantled with glacial drift. (Reprinted by permission from "Historical Geology," Part II, by Schuchert & Dunbar, published by John Wiley & Sons, Inc.)

Erosion of a narrow band of weak rocks in the midst of the crystallines of the Piedmont Upland has caused a lowland belt which extends from the vicinity of New York City southwestward into Virginia. The formations in this belt, which are commonly of a deep-red color, are of Triassic age, and among geologists this zone is referred to as the Triassic Lowland. The formations are closely related to similar formations of about the same age which explain the location of the Annapolis-Cornwallis Valley and the Connecticut River Lowland in the New England-Acadian region. The underlying strata of the Triassic Lowland consist of sandstones and shales interbedded with conglomerates and coal.

Associated with the sedimentary rocks there are several ridge-making layers of very resistant dark-colored rock of igneous origin. They resemble in origin, composition, and color the ridge-makers in the Connecticut River Valley, and here, as there, they are called trap rock. Certain of the igneous layers in this lowland belt were poured

out on the surface as lava flows. They have been tilted by down faulting, and some now form the Watchung Mountains of New Jersey. One sheet



U. S. Geological Survey

Figure 59 · Closely folded beds of limestone in the Piedmont Upland near Lancaster, Pennsylvania

was forced in between other layers of rock as a sill, and since being upturned and in part uncovered it has come to form the Palisades of the Hudson, which extend northward from Hoboken at least fifteen miles on the west side of the river. Huge masses of the trap rock continue to fall from the east-facing escarpment and thus maintain a precipitous wall which, at places, is very picturesque.

Much of the surface of the Triassic Lowland shows the characteristics of an old-age topography, with meandering rivers and broad bottom lands near the base plain of erosion.

In the Newer Appalachian Mountains and the Appalachian Plateau. The rock formations in the two western subprovinces are of Paleozoic age. They consist of a great series of sediments estimated to be 30,000 feet thick at some places. These sediments have been cemented and now form sandstones, shales, conglomerates, limestones, beds of iron ore, and extensive seams of coal. In the Newer Appalachians these

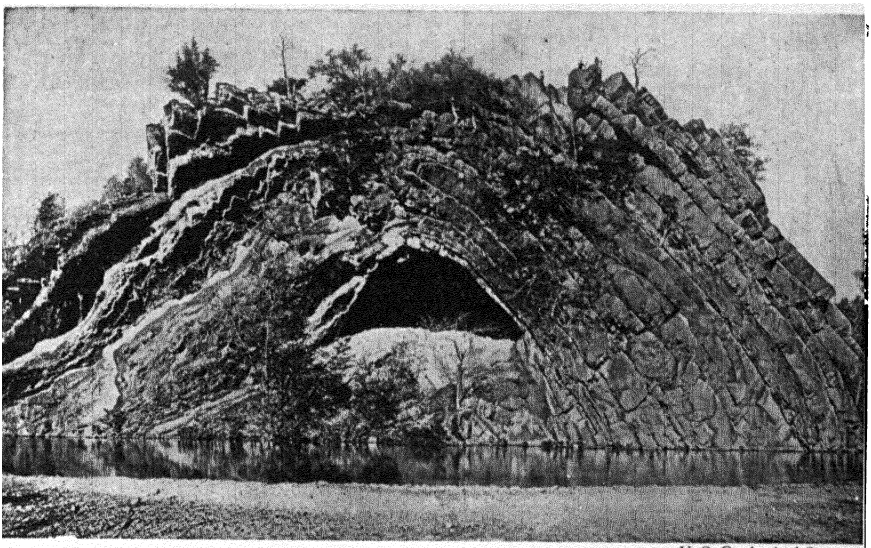
rocks have been greatly disturbed by folding and faulting. In the Appalachian Plateau they are nearly horizontal, dipping but gently to the westward.

A study of Figures 57 and 61 should make it perfectly clear that the great differences in relief, which serve as the basis for dividing the Southwestern Division of the Appalachian Highlands into subprovinces, are definitely related to the differences in the nature and structure of the underlying rock formations.

The Appalachian type of structure. The term "Appalachian structure" has been applied to the distinctive type of deformation found in the Newer Appalachian Mountains. Because of the fact that the term conveys a definite and significant concept in geologic and physiographic literature, brief explanations of the constituent forms are here given.

In the typical Appalachian structure, strata of sedimentary rocks have been compressed into long, narrow folds generally parallel among themselves and sometimes overturned and overthrust. When the powerful compressive forces were applied in the eastern portion of North America at the close of the Paleozoic era, the old land mass, Appalachia, was pushed against the strata which had accumulated to great depths in the inland sea to the west. Those strata were too weak to resist compression, and as a result long anticlinal arches and synclinal troughs were formed. The axes of these folds extend from northeast to southwest. In most instances the axes are not horizontal, but are so warped that they pitch or decline in one direction or the other. The folds are not all symmetrical, for in many cases one side is much steeper than the other. These structural conditions are all reflected in the modern topographic features. They have caused cigar-shaped mountains, canoelike ridges, and zigzag mountains. See Figures 60, 61, and 63.

Most of the structure sections of the folded Appalachians reveal a number of dislocations or breaks in the strata where the beds have been thrust upward over the planes of fracture. See Figure 61. At some places huge blocks of the mountainous mass have been moved northwestward over fault planes for several miles. The faulted structure has caused the repetition of outcrop of certain strata, and thus a series of parallel mountain ridges is sometimes found to be the result of the out-



U. S. Geological Survey

Figure 60 · An anticlinal fold in the Appalachian Mountains of Maryland

cropping of a single layer of resistant rock at several places. An understanding of the evolution of the present forms of the Newer Appalachian Mountains is not possible unless due consideration is given to the underlying rock structure.

An interpretation of the structures. The physical history of the Southwestern Division, as interpreted from the structural relations, may be divided into three major periods. During the first period there existed an extensive land area which included the present Older Appalachian Mountains, the Piedmont Upland, and much land farther to the east and northeast. In geologic literature that ancient land mass is called Appalachia. Eastward from Appalachia lay the deep basin of the Atlantic Ocean; westward there was a shallow interior sea in which slow sinking must have accompanied the accumulation of sediments. Through long periods of time Appalachia supplied vast quantities of sediments which were washed from the projecting land mass into the adjacent bodies of water. The sediments carried eastward have never been lifted out of the ocean to be exposed as dry land, but those carried to the west now form much of the interior of the North American continent.



Figure 61 · A diagrammatic structure section from the Unaka Range westward

The second major period in the physical history of this region came at the close of the Paleozoic era, when the area was uplifted and the rock strata were deformed. That was one of the major physical revolutions in the history of the continent. The waters of the interior sea retreated slowly; and west of the ancient land of Appalachia, in the belt of the Newer Appalachians of today, the rocks were folded and faulted as they rose. In the plateau west of the Newer Appalachians the rock strata were uplifted and inclined gently to the northwest. It was during this same revolution that the New England–Acadian province was uplifted.

Following the uplift and mountain-making came the third major period, which may be thought of as the physiographic period. It has been characterized chiefly by stream erosion. Continental ice has affected the landscape in the northern portion, and locally, especially in the south, the work of underground water has modified the surface of the land. During this period, which has continued to the present day, the relief features which we see have been carved out of the uplifted mass of rock. The events of this period will be treated in the next section.

Development of the Present Land Forms

Establishment of drainage. As the Appalachian province rose at the close of the Paleozoic era, the streams in Appalachia to the east were rejuvenated. Because they were higher above sea level their cutting power was increased. These streams crossed a land in which there is great variety in the nature and resistance of the rock formations. They undoubtedly followed the natural tendency and tried to maintain their old courses as they lowered their channels. Those working in the less resist-



to the Mississippi River, with associated relief features shown in perspective

ant zones must have advanced more rapidly in the work of erosion than those cutting into harder rocks, and there may have been many cases of adjustment to structure through piracy. For the most part, however, the drainage patterns were inherited from a previous period of erosion.

As the gigantic mountain folds formed and, together with the plateau at the northwest, rose above the waters of the inland sea, all processes of disintegration and erosion were inaugurated in those sections and new drainage patterns were developed.

In the plateau, where the surface was comparatively smooth and sloped gently to the west, the location of the drainage lines was determined by inequalities in the surface which led to the concentration of the runoff after each rain. Here a consequent drainage was established with *dendritic* patterns.

In the region of folded mountains the stream courses were established at first in the synclinal troughs. While those streams were at work lowering their channels to the base plain of erosion, tributary streams flowing down the sides of the adjoining anticlines began their work of dissection. Little by little, as the tributary streams removed the surface-capping and notched the crest lines of the anticlines, the smooth, archlike forms of those early Appalachian Mountains became serrated, and in time the entire topography became distinctly roughened.

The history of the drainage changes here was long and complicated. There may have been several cycles during that very long period of erosion and the sea may have advanced over the region more than once. It is generally believed that the first drainage lines west of the Older Appalachian Mountains were toward the interior of the continent. Today the major streams from the Hudson to the James flow eastward. Such a reversal of drainage is difficult to explain unless we assume that the sea did advance over at least the northern portion of the province, and re-

mained long enough to receive a considerable amount of sediments. Later when the sea retreated a new consequent drainage would have developed, and if the land were tilted seaward the new drainage lines would have been to the eastward.

The new stream channels would have been lowered quickly through the mantle of loose marine sediments and superimposed upon the underlying harder rocks. In this way the stream courses that are transverse to the structural grain of the Newer Appalachian Mountains may be explained. This hypothesis has been presented and defended by Johnson.[1]

As erosion continued, the rock layers that stand at various angles came to outcrop in parallel bands or belts. The streams that were located in the weaker, or less resistant, formations had a great advantage over those located in the stronger rocks. Where streams crossed the grain of the structure they were forced to cut through layers of varying resistance. This meant that the more powerful streams repeatedly committed piracy. Old channels were abandoned, water gaps became wind gaps, the resistant rock layers probably came to stand out as bold ridges in that ancient landscape, and in time *trellised* drainage patterns undoubtedly were evolved. There must have been many longitudinal valleys and a few transverse valleys. Such a drainage pattern may be thought of as *adjusted* to structure. The larger longitudinal valleys were in the weaker rocks; the transverse valleys crossed the stronger rock formations, and at these places had narrows or water gaps.

Development of the Schooley Peneplain. After many millions of years of persistent work, the streams carried away nearly everything that stood above a certain base plain of erosion in this part of the continent and produced a gently rolling surface, parts of which we can see in the mountains today but which when developed were not much above sea level. Remnants of that surface now form most of the even crest lines of the ridges of the Newer Appalachians throughout the mountain belt from the Hudson River to central Alabama. Other remnants are present in the Older Appalachian Mountains, and in the Appalachian Plateau. See Figures 56 and 63.

[1] D. W. Johnson, *Stream Sculpture on the Atlantic Slope: A Study in the Evolution of Appalachian Rivers.* Columbia University Press, New York, 1931.

The broad, flat-topped summit area of Schooley Mountain in northern New Jersey was long ago recognized as a portion of this ancient stream erosion surface, and the name Schooley Peneplain has been suggested as a label for the surface as a whole.[1] The even crest line of Kittatinny Mountain is part of this old land surface, and the name of that mountain has also been suggested for the peneplain.[2] On the map that is shown in Figure 62 the remnants of that peneplain in northern New Jersey are clearly defined. If a similar map were prepared for the entire Appalachian Highland province, the peneplain remnants would be found to be widespread. Throughout the belt of the Newer Appalachians they are conspicuous features today.

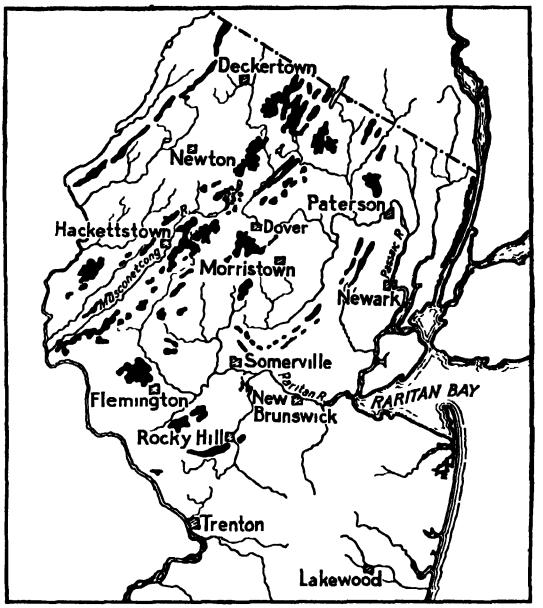


Figure 62 · The extent and distribution of the Schooley Peneplain remnants in northern New Jersey

Late stages in the development of a peneplain. Near the close of a cycle of erosion, when the land surfaces are near sea level, the valleys are old and the stream gradients gentle. At intervals the sluggish, meandering rivers which are completing the final work of peneplanation deposit a mantle of alluvial material on their broad flood plains just as the lower Mississippi is doing today. A cycle-end surface is made up of low intervalley areas with thick residual soils, of some areas where ancient rock structures are being truncated, and of large areas where

[1] W. M. Davis, "The Rivers and Valleys of Pennsylvania," in *Geographical Essays*, pp. 413–484. Ginn and Company, Boston, 1909.

[2] R. D. Salisbury, "The Physical Geography of New Jersey," *New Jersey Geological Survey, Final Report, No. 4* (1898), 170 pages.

alluvial waste is accumulating. There may be a few relief features that rise conspicuously above the general level of the landscape. They are monadnocks.

The conditions just described should be kept clearly in mind as we approach the problems which the streams in the Appalachian Highlands may have encountered when a new cycle of erosion was inaugurated. These conditions are assumed by Meyerhoff and Olmsted[1] in explaining the present drainage patterns in the Appalachian Mountains.

The age of a peneplain. An old-age erosion surface, or peneplain, is younger than the youngest beds eroded in the process of its development and older than the oldest beds that rest upon it. Such a surface is of about the same age as the rock formation made or laid down during the last stage in the development of the erosion surface. The youngest beds truncated by the Schooley Peneplain are of Triassic age. The surface, therefore, was developed in post-Triassic time; but that is a very long period. As yet no marine sediments have been found resting on this peneplain, and therefore its exact age cannot be determined. For a long time the Cretaceous sediments in the neighboring Coastal Plain province were believed to have accumulated as the work of developing the Schooley Peneplain was being completed. For that reason this old erosion surface has been referred to over and over again in the literature of geomorphology as the Cretaceous Peneplain. Today the accuracy of this correlation is doubted and there is a tendency to believe that the Schooley Peneplain was not completed until mid-Tertiary time and perhaps not until near the close of the Miocene.[2]

The closing of the Schooley Peneplain cycle. The long period of erosion during which the first generation of New Appalachian Mountains and much of the rock material of the Appalachian Plateau and the Piedmont Upland were removed and the Schooley Peneplain was developed, was brought to a close by a renewal of uplift. This time the lands of the entire province rose as a single low arch, or elongated dome.

[1] H. A. Meyerhoff and E. W. Olmsted, "The Origins of Appalachian Drainage," *American Journal of Science*, Vol. 32 (1936), pp. 21–42.

[2] E. W. Shaw, "Ages of Appalachian Peneplains," *Bulletin of the Geological Society of America*, Vol. 41 (1930), pp. 695–700.

There was no intense deformation such as characterized the physical revolution at the close of the Paleozoic era. In the central portion of the mountain area the amount of uplift varied from 1000 to about 3000 feet. To the north, south, east, and west the uplift was much less.

The opening of the second long cycle of erosion. With this uplift all streams in the region were rejuvenated and a new cycle was inaugurated. Signs of rejuvenation normally appear first in the lower courses of the main streams and migrate slowly upstream and into the tributary courses as the influence of rejuvenation in the main stream passes the mouths of the tributaries.

If old streams were flowing seaward on the Schooley Peneplain when that surface was uplifted, they should have cut downward through the alluvial filling in their own valleys when they were rejuvenated, and in time into the solid rocks. The tendency would have been for those streams to hold their old courses; but as the downward cutting proceeded, many new adjustments to structure must have taken place. The streams that found their courses on the less resistant strata widened and deepened their valleys more rapidly than did the streams that were forced to cross and recross the most resistant rocks. As adjustments took place, more and more of the stream courses came to be located on the weaker strata. Some of these adjustments were due to piracy, and some were due to lateral shifting of stream channels down the dip of the more resistant strata.

The reappearance of mountain ridges. Little by little, as erosion proceeded, the hard, upturned layers of the folds came to stand out again and this time form the ridges that we see today. Their long, even crests, of approximately the same elevation, are portions of the Schooley Peneplain. They are really monadnocks rising above the second widespread erosion surface of the Appalachian region.

Where the mountain ridges are parallel they may be accounted for by the truncation of an anticline or a syncline in which the axis is horizontal. A single resistant layer of rock that appears in adjoining folds with pitching axes will produce, after erosion, a zigzag arrangement of mountain ridges such as those illustrated in Figure 63. The ridges



Figure 63 · At the northwest is a portion of the Appalachian Plateau.

that join and form canoelike ends are the results of erosion of pitching anticlines or pitching synclines. Where these united ridges have cigar-like terminations, they owe their form to a resistant layer in an anticline that pitches or slopes gently toward the new base plain of erosion. The ends of the pitching synclines, where the canoe-shaped forms appear, are abrupt or steep.

These contrasts in topography are illustrated in Figure 63, and are also well shown on many of the topographic maps of the Newer Appalachian Mountains. Such topographic features permit the well-trained student of topography to interpret the underground rock structures on the basis of a good contour map.

The Harrisburg Peneplain. During each cycle of erosion the streams are all working to reduce the lands to a base plain of erosion. Given time enough, they will accomplish that work; but the time required is long, and the work is usually interrupted before it is completed.

During the second cycle in the Appalachian Province considerable



Drawing by Renshawe, Courtesy U. S. Geological Survey

The balance of the area is in the belt of folded rocks in Pennsylvania

areas were reduced to the peneplain stage, but a large amount of work remained to be done. The upland surface east of Harrisburg is a portion of the erosion surface that was being developed in the second cycle; so is the rolling upland near Chambersburg, Pennsylvania, and so are the extensive farm lands of the Shenandoah Valley in Virginia. In the region of the Great Smoky Mountains many of the high basinlike areas are interpreted as parts of the so-called Harrisburg Peneplain, and the same is true of much of the upland surface in the Piedmont belt and parts of the Appalachian Plateau.

The names Harrisburg, Chambersburg, and Shenandoah have all been used in describing this old-age erosion surface, and they are all equally good, but we will use the name Harrisburg here. Remnants of this partial peneplain may be easily recognized in the field and on many of the topographic maps selected for the map exercises to accompany this chapter.

The long, ridgelike mountains and all the higher summits in the Great Smokies rise above the Harrisburg surface. In many places they

rise as much as 2000 feet, and in some places fully 3000 feet, above the base plain toward which the streams were reducing the country. They are all monadnocks of the second cycle.

Strath terraces. During many cycles of erosion the work of the streams has been far from completed when an interruption has occurred. It is unfortunate that in the literature of geomorphology many bench levels, or partially developed erosion surfaces, below summit peneplains and well above the modern valley floors have been called peneplains. If the term "strath terraces" proves to be acceptable, it may be applied to any number of partially developed erosion surfaces which have been called peneplains in the past. The term "peneplain," meaning "nearly a plain," should be reserved for those few surfaces that were developed during the very long periods of stability when the work of removing a land mass which stood above the base plain of erosion was nearly completed.

Probably there is no example in the world of a large land surface that was completely reduced by streams to the base plain of erosion. Earth movements commonly occur too frequently to permit streams to complete the work of a cycle of erosion. We need a new term to describe erosion surfaces that record the work of streams interrupted long before the peneplain stage was reached.

The third cycle of erosion. While the second, or Harrisburg, cycle of erosion in the Appalachian area was proceeding, the region was uplifted for a third time. There was no pronounced deformation of the area, but, rather, a broad, general arching. The amount of uplift varied, but nowhere did it exceed a few hundred feet. It was enough, however, to initiate the third cycle of stream work.

Valley-deepening began again, and many of the streams that had established meandering courses retained those winding channels as they cut downward toward the new base plain of erosion. This resulted in a large number of the *entrenched meanders* which characterize the dissected areas of the Harrisburg surface. They are examples of old-age rivers in young valleys. They demonstrate rejuvenation. The present valley of the Conodoguinet Creek, west of Harrisburg, contains

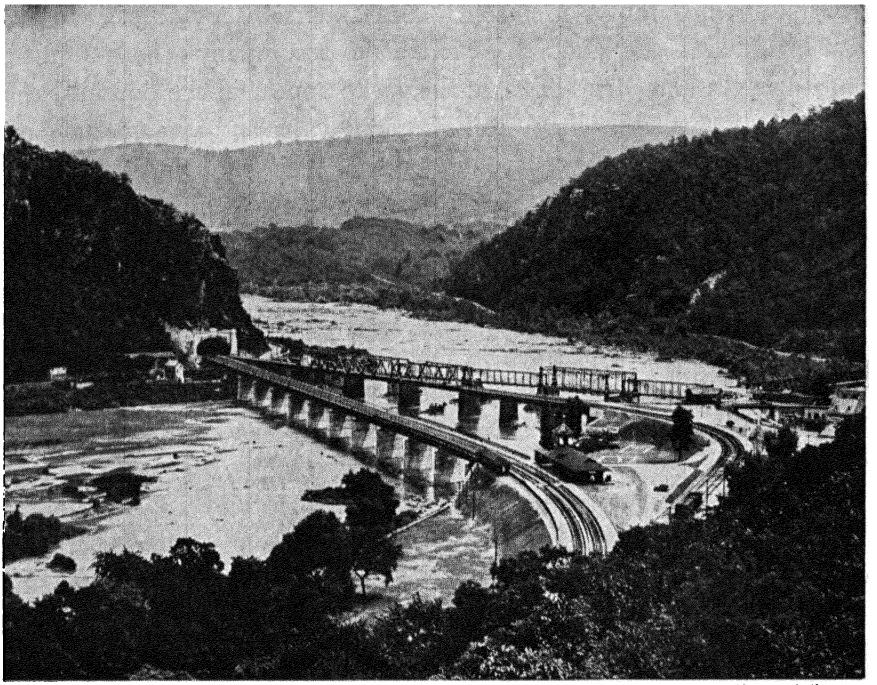
several good examples of entrenched meanders. Many other examples are included in the laboratory exercises to accompany this chapter.

In time a new series of plains began to appear in the bottom lands of the major valleys. These plains became wider and longer, and some of the interstream areas were obliterated. The third erosion surface, known as the Somerville in New Jersey, the Worthington in Pennsylvania, and the Coosa in southern Tennessee and Alabama, was produced. These are old-age erosion surfaces developed in another interrupted cycle. They are limited to the valleys that were being cut in the less resistant rock formations. In many valleys such plain surfaces were not developed, and, with rejuvenation, streams went on with the work of deepening, and for this reason the third cycle of erosion is not well recorded in portions of the province.

The present valleys. Before very extensive removal could take place during the third cycle of erosion, a fourth regional uplift occurred and forced the streams to begin cutting still deeper into the rock masses. This uplift inaugurated the fourth and present cycle of erosion. The modern stream valleys which have been cut below the Somerville-Coosa Plain represent the work accomplished during this last cycle. Few of those valleys have advanced far beyond the stage of youth. In many of the valleys the work of the third and fourth cycles is represented in what appears to be the modern valley.

Water gaps and wind gaps. As erosion advanced, those streams that were forced to cut through the stronger layers developed water gaps, such as the Delaware Water Gap and the six gaps in the Susquehanna above Harrisburg, in the Potomac at Harpers Ferry, and in the valleys of many other major streams in the Appalachian region.

Some streams that were being forced to cut through the resistant layers were so greatly delayed that they were beheaded by piratical streams working in rocks of less resistance, and the water gaps which they were developing became wind gaps. All the water gaps, many of the wind gaps, and most of the attractive scenic features of the Appalachian belt are the result of the work of the streams during the second and third cycles of erosion.



From Ewing Galloway

Figure 64 · The Harpers Ferry gap cut through the Blue Ridge by the Potomac River

The Potomac River cuts across the structure, whereas its tributaries—Black Creek, Sleepy Creek, and Sidling Hill Creek—join the Potomac nearly at right angles. The tributary streams flow through valleys which correspond with the strike of the weaker layers of rocks in the belt of folded structure. The main stream has cut a magnificent water gap through the Blue Ridge at Harpers Ferry. See Figure 64.

Early in the history of the Shenandoah River, when its drainage basin was much more restricted than at present, there were several streams, including Beaverdam Creek, Goose Creek, and Rockfish Creek, which rose in the mountains west of the Blue Ridge, flowed east at right angles to the course of the Shenandoah, and crossed the Blue Ridge through separate and distinct water gaps. Beaverdam Creek flowed through Snickers Gap, and Goose Creek through Manassas Gap. See Figure 65.

The downward cutting in the upper courses of these small streams, in the section west of the Blue Ridge, could not exceed the lowering of

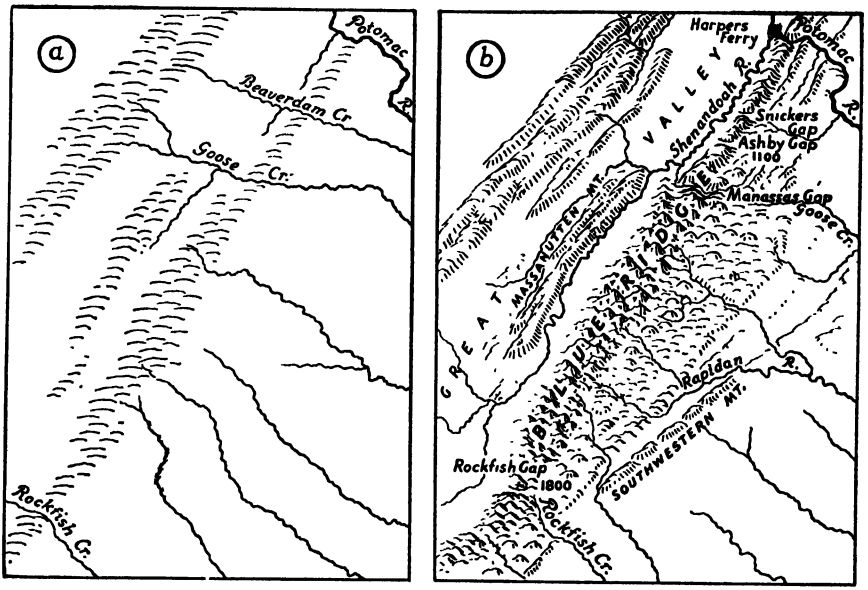


Figure 65 · Sketch maps to illustrate the changes in drainage due to piracy committed by the Shenandoah River: (a) represents a possible drainage pattern before piracy occurred; (b) represents the drainage pattern and relief features of today

the channels at the points where the streams crossed the Blue Ridge. But the Shenandoah could lower its course more rapidly than could the smaller streams to the south, since it was a tributary of the Potomac, a large and powerful river that had cut deep into the Blue Ridge. The Shenandoah worked headward along the line of less resistance in the depression west of the Blue Ridge and eventually beheaded one after another of the weaker streams. Thus Beaverdam Creek was beheaded by the Shenandoah, and Snickers Gap was abandoned. The abandoned water gap became a wind gap. Likewise, when Goose Creek was beheaded by the Shenandoah, Manassas Gap became a wind gap. In time the headwaters of the streams that flowed through Brown and Rockfish gaps were diverted into the Shenandoah River, and Brown and Rockfish water gaps became wind gaps.

From Sunbury to Harrisburg the Susquehanna is an outstanding example of a transverse stream. In a distance of 40 miles it has incised six deep, narrow water gaps. Where it cuts through Kittatinny Moun-



U. S. Geological Survey

Figure 66 · The Delaware Water Gap from the south. The even crest of Kittatinny Mountain is a remnant of the Schooley Peneplain. The rolling uplands to the right and left are parts of the Harrisburg erosion surface. The present valley, with its flood plain and terraces, represents the work of the third and possibly the fourth cycle of erosion in this province

tain and again through Second Mountain, the valley bottom is hardly wider than the river bed, and the cliffs rise from 800 to 1000 feet above the river. See map at the end of this book.

The walls of the famous and picturesque narrows cut by the Delaware River through Kittatinny Mountain rise about 1000 feet above the river. See Figure 66. The Juniata River has formed no less than ten water gaps through the hard, ridge-making, upturned strata of the Appalachian Mountains of eastern Pennsylvania. Shear zones due to faulting may have determined the locations of some of the water gaps.

Stream piracy in the Catskill Mountains. In the Catskill Mountains several examples of stream piracy have been discovered. The Kaaterskill and Plaaterskill streams, on the eastern escarpment of the Catskill Mountains, have stolen the headwaters of streams that flow westward

and follow very long and circuitous routes to the Mohawk River. Other cases of stream capture may be expected in this vicinity, for the streams which flow eastward down the steep, short slopes to the Hudson have a great advantage over the rivers of the western slope, which flow over long and gentle gradients. These cases of piracy are included in the map study exercises to accompany this chapter.

Dissection of the Appalachian Plateau. The history of stream erosion in the Appalachian Plateau is in some respects more simple than the history of river work in the Ridge and Valley section where the layers of rock were tilted, folded, and faulted. In the Appalachian Plateau the sedimentary layers, in a broad general way, dip westward into the interior of the continent, but at many places there are anticlinal folds and shallow synclinal troughs in the structure of this subprovince. Some of the anticlinal folds are so short that they are more appropriately described as low domes.

As stream erosion proceeded in this part of the Appalachian Highlands a simple dendritic pattern of drainage developed over considerable areas, but where the strata were arched or folded in any way the structure soon influenced the topography in the development of cuestalike ridges. Some of these are now locally described as mountains. They have come to be from 1000 to 2000 feet above the neighboring stream beds, which have been lowered as this portion of the Appalachian Highlands was raised each time that the other portions of the highland area were uplifted.

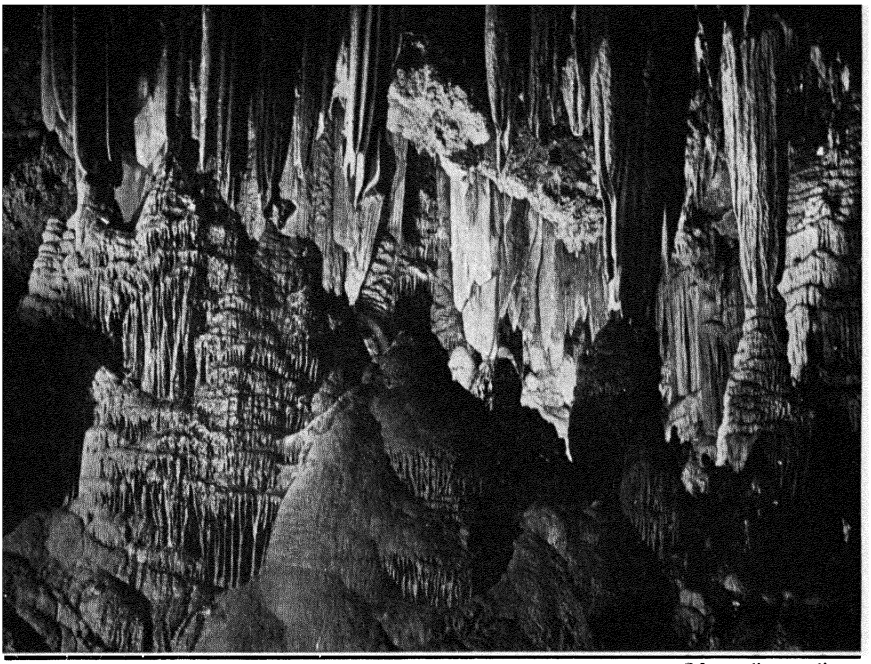
In general, the surface of the plateau reaches its greatest elevation near its eastern margin; and in that section there are, at various localities between Tennessee at the south and New York at the north, broad flat-topped areas that have been interpreted as parts of a peneplain and tentatively correlated with the Schooley erosion surface that has been recognized farther east and northeast in the Appalachian Highlands.

With each uplift of the land in this region the streams were rejuvenated, and at many places they developed broad strath terraces. Attempts have been made by various field workers to recognize stream-cut benches that can be correlated with the Harrisburg erosion surfaces

farther east. Many ridge crests and benches have been called Worthington in age. Such correlations are always difficult to make and are subject to error. There are so many strath terraces in this province that some of them should undoubtedly be credited to resistant strata and be called stripped plains. Furthermore, the streams may not have had sufficient time to develop broad flat-bottomed valleys during the interrupted cycles which are well represented by the strath terraces in the Ridge and Valley section. If a valley is not developed beyond maturity before rejuvenation takes place, the deepening in the next cycle is almost certain to remove all evidence of the earlier and uncompleted cycle. Under such conditions the valleys become deeper and deeper but do not retain evidence of the successive stages that may have subdivided the erosion history.

Underground drainage. Since there are extensive areas of limestone in the belt of the Newer Appalachian Mountains and in the Appalachian Plateau, it is not surprising that waters sinking into the ground have formed, through solution, many subterranean passageways. Numerous caves have been discovered, and undoubtedly more will be found. At places the subsurface limestones have been honeycombed by the work of underground waters.

In many localities the solution of the limestones has led to the development of large rooms and circuitous passageways which, when taken together, form curiously shaped labyrinths. In these underground realms, waters carrying lime in solution have been dripping from the ceilings for centuries. As the drops of water strike the floors of these underground rooms and passageways, evaporation takes place and the lime in solution is precipitated. Little by little, pillars of crystalline lime are formed, which in time grow to be great columns. Such forms are *stalagmites.* At places, some of the waters coming to the roof of a cave evaporate before dropping, and the lime in solution is left clinging to the ceiling. Little by little, a beautiful icicle-like form of crystalline lime grows longer and longer. Glistening clusters and long fringes of these pendant forms develop. They are *stalactites.* Some stalactites have grown in length until they have joined the pillars that were forming directly below them, and thus stalacto-stalagmite



© Luray Caverns Corp.

Figure 67 · Stalactites and stalagmites in the Cathedral Caverns at Luray, Virginia. Some of the crystalline columns are about ten feet in diameter

columns have been formed that reach from the floor to the ceiling. In some places waters which evaporated on the walls of these subterranean labyrinths have left delicate crystal forms that suggest a coating of frost. A combination of various crystal formations has given to these underground passageways a fairyland beauty. See Figure 67.

Where the roofs of caves have become weak as a result of solution and surface erosion, they have collapsed and sinkholes have been formed. These depressions are locally called *coves*. Many large undrained hollows in the southern portions of the Newer Appalachian Mountains and Appalachian Plateau owe their origin to such processes. Where numerous undrained sinkholes characterize the surface of a region, the term *karst topography* may be used. Wherever a narrow remnant of the roof of a subterranean passageway remains, there we find a natural bridge. This is, however, but one of the ways in which natural rock bridges are accounted for.

The Work of the Continental Ice Sheets

Extent of glaciation. The great continental ice sheets which formed on the eastern part of the Laurentian Upland invaded the northern portion of the Southwestern Division of the Appalachian Highlands. At the position of maximum advance the ice left a thin mantle of morainic material. The frontal moraine located on Long Island and Staten Island continues westward into New Jersey and thence northwestward into Pennsylvania and southern New York State. From here it turns to the southwest and crosses a corner of Pennsylvania into Ohio. See Figure 88. Within the area covered by the ice, the hilltops have been somewhat reduced and some of the valleys have been deepened by ice erosion. The entire area has been mantled with glacial drift.

Drainage changes. The deposition of debris by the ice was so irregular that drainage within the glaciated area has been generally disarranged. Many of the preglacial valleys were blocked at intervals by moraines which have ponded the surface waters and formed lakes. Most streams have been forced to cut new valleys. In New York State, the Finger Lakes are in preglacial river valleys modified in part by ice erosion and blocked by ice deposition. About their margins there are old shore lines and hanging deltas that record higher levels of the lake waters. For a time during the retreat of the last ice sheets these lakes drained southward into the Susquehanna. See Figure 100. Their drainage is now northward into Lake Ontario. In northwestern Pennsylvania the drainage, which was formerly northward, has been forced southward into the headwaters of the Ohio. As the ice advanced, those streams were ponded, and they overflowed to the southwest near the margin of the great ice sheet, and in time formed the headwaters of the Ohio drainage system.

Lake Passaic. In northern New Jersey the retreating front of the ice sheet ponded the upper waters of the Passaic River and there caused the formation of a large body of water known as Lake Passaic. The basin of that lake is shown on a topographic map as a broad flat, almost completely enclosed by mountain ridges. On the east and south

Watchung Mountain rises about 300 feet above the lake plain, and the mountain ridges to the west rise still higher. Preglacial drainage of the southern part of this basin flowed through the now drift-filled Short Hills Gap in Watchung Mountain, while another river system left the basin through an outlet near Paterson. The advancing ice blocked first one and then the other of these outlets, causing the formation of Lake Passaic.[1] The lake drained for a time through Moggy Hollow, at the southwest, into the Raritan River and continued to use that outlet until the ice front had retreated far enough to uncover the Paterson outlet. The Short Hills Gap is closed by glacial drift, and the basin has since been drained by the stream which flows through the gap at Paterson.

Valley trains and outwash plains. The Hudson, Delaware, Susquehanna, and Ohio valleys contain vast quantities of sand and gravel that have been washed out by streams issuing from the glacier. Those deposits are *valley trains.* Today, since the streams have dissected the old flood plains made by the glacial waters, the valley trains appear as terraces. Where the waters issuing from the glacier did not follow distinct valley routes, but spread out and deposited their sands and gravels near the terminal moraine, great *outwash plains* were developed. The level land on which Plainfield, New Jersey, is located is a good example of such a plain.

The Hudson-Champlain trough. The northern portion of the Ridge and Valley region, including the lowlands between the Taconic and Green mountains on the east and the Catskills and Adirondacks on the west, is known as the Hudson-Champlain trough. The underlying rock structure here is due to a complex folding and faulting of sedimentary layers, but most of the surface features in this lowland belt are due to glacial and lacustrine conditions. Stagnant ice has probably been an important factor in the last stages of the Ice Age in this trough. There is a complex of morainic and lacustrine deposits, of lake and stream terraces, of outwash sands and gravels, of kame terraces, and of deltas.

[1]R. D. Salisbury *et al.*, "The Glacial Geology of New Jersey," *New Jersey Geological Survey, Final Report, No. 5* (1902), 802 pages.

For a time Lake Albany occupied a large portion of the trough, and farther north in the Champlain Basin there was another lake which discharged southward into Lake Albany. In these lakes extensive deposits of clays accumulated. Clay terraces border Lake Champlain for five or six miles inland and rise nearly 100 feet above the lake. Sandy terraces rise still higher, even to 500 feet above the present level of Lake Champlain, and sand and gravel deltas occur at all levels formerly reached by the lake waters. This ice-front lake probably drained southward as long as the continental glacier blocked all outlets to the St. Lawrence.

Lake Albany may have been due to a block of stagnant ice combined with glacial drift in the gorge at the Highlands of the Hudson. In this lake thick deposits of clays accumulated, and above those deposits there are sands and gravels, and various delta formations. Some of the clay deposits are varves like those in the Connecticut Valley.

In Chapter VI will be found an account of a temporary drainage from the Great Lakes by way of the Mohawk and Hudson rivers to the sea and the appearance of salt or brackish waters in at least a part of this lowland trough.

A Brief Review of the Physical History

At the close of the Paleozoic era, when the rock formations of the entire Appalachian Highlands region were uplifted and in part folded and broken, a long period of stream erosion was inaugurated. The details in the history of that erosion are very complex and may never be known, but it is certain that after many millions of years had passed the generation of mountains formed at that time was removed, and a widespread gently rolling surface near the base plain of erosion was produced. That surface is now commonly called the Schooley Peneplain, and it is represented in this province by numerous even-crested ridges and various basins and flat surfaces. Following successive uplifts, three later cycles of erosion were inaugurated, but in no one of them was the work far advanced. They must therefore be thought of as partial, or incompleted, cycles of erosion.

During the four cycles of stream work recorded in this province, there were many adjustments of the stream courses to the underlying rock structure. These adjustments were accompanied by numerous cases of piracy. The stronger strata, upturned in the folded mountain area, have come to stand out as long, even-crested ridges that have at places a zigzag pattern. Through these ridges numerous water gaps have been cut, but some of them, because of stream piracy, have become wind gaps.

The Piedmont Upland has been subdued after more than one cycle of erosion to a gently rolling surface, and that surface has been uplifted and dissected. Most of the Older Appalachian Mountains are bold and picturesque, with slopes too steep for cultivation but carrying heavy forest covers. They form a group of monadnocks that in their higher summits rise above the oldest erosion surface that can be recognized. In the belt of the Newer Appalachian Mountains there are many broad valley lands suitable for farming, and numerous mountain ridges clothed with forests. In the Appalachian Plateau most of the surface is maturely dissected. The valley walls are steep, and most of the settlements are on the valley floors.

At the far north of the province continental glaciation has affected a portion of the area; and at many places, more notably at the south, underground water has affected the surface drainage and the topography. The work of surface streams continues to be the most significant geomorphic process within the province. Many of the details in the topographic features are traceable to structural conditions and variety in the underlying rock materials.

An Approach to the Human Drama

This highland belt has played a very important role in the history of the United States of America. Undoubtedly it delayed migration westward and thus helped to concentrate the colonial settlements on the Atlantic seaboard. This led to the development of unity and strength, which was necessary when the effort was made to establish an independent nation.

The routes of migration through this province which were followed by pioneers as the American frontier moved westward are of special interest. There was but one route which avoided the mountain barrier; that was northward by way of the Hudson to the present site of Albany, and thence westward in the valley of the Mohawk to the lowland bordering the Great Lakes. Many pioneers followed that route. Others traveled upstream in certain of the valleys of Pennsylvania and then climbed over the divide and entered drainage lines leading to the Ohio. The valley of the Potomac served some of the westward-moving bands. One of the earliest routes, which became very popular, led southward through the Great Appalachian Valley to Cumberland Gap. That old river channel was used in moving westward into the drainage lines which led the immigrants to the blue-grass country of Kentucky. The entire Appalachian Mountain region is rich in historic landmarks and legends. See Figure 68.

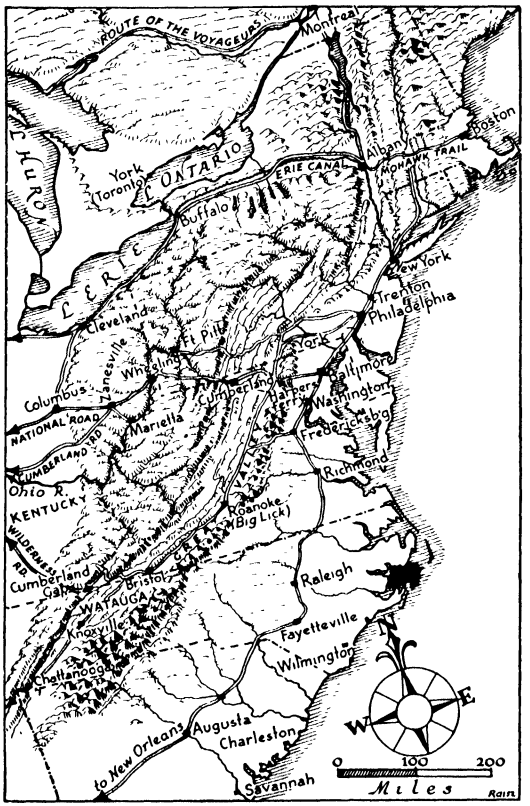


Figure 68 · Routes followed by many of the pioneers who moved westward through the Appalachian Highlands. The Erie Canal did not become available until 1825. The route westward from Montreal is through the Laurentian Upland

In the early days of settlement, the Appalachian area was undoubtedly heavily clothed with a mixed forest of hardwoods and softwoods. Today most of the mountainsides are forested, and many of the steeper slopes of the lower relief features retain their forest cover. The entire

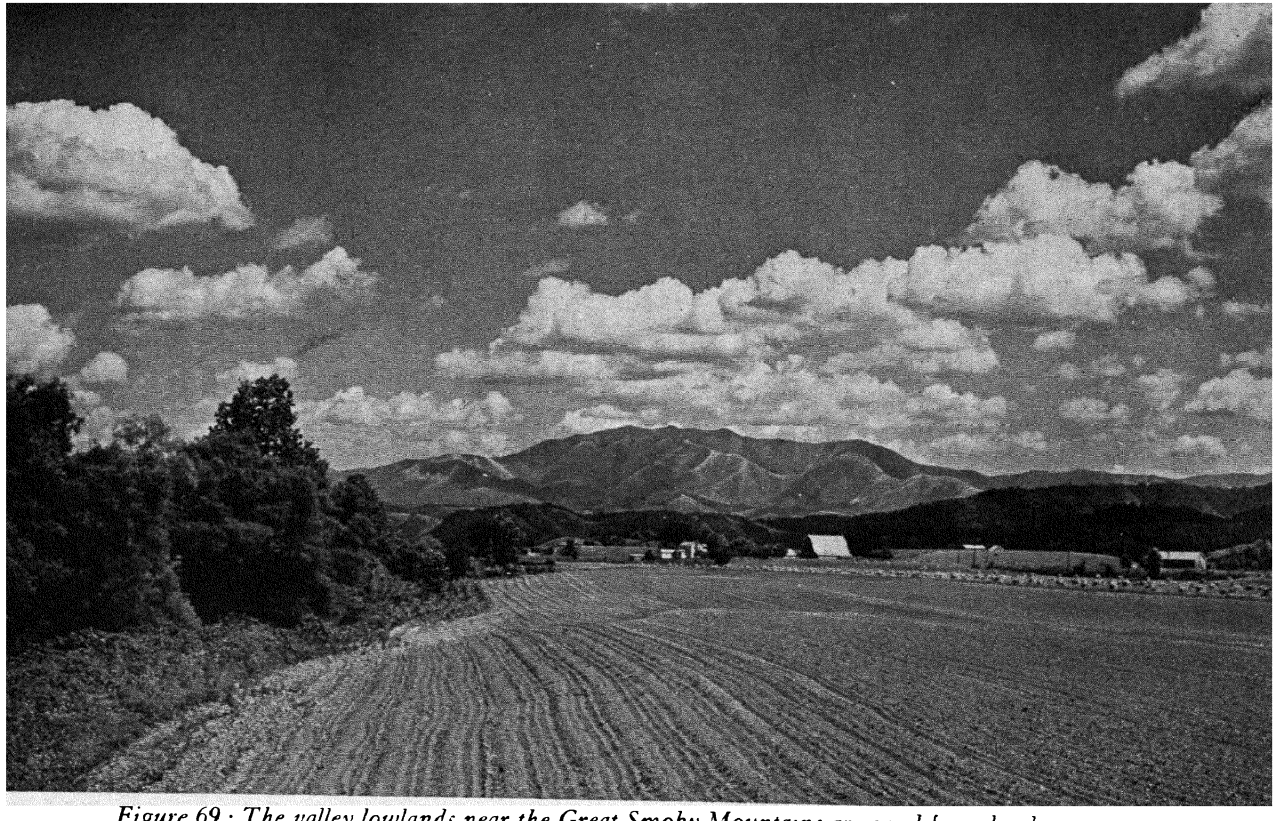
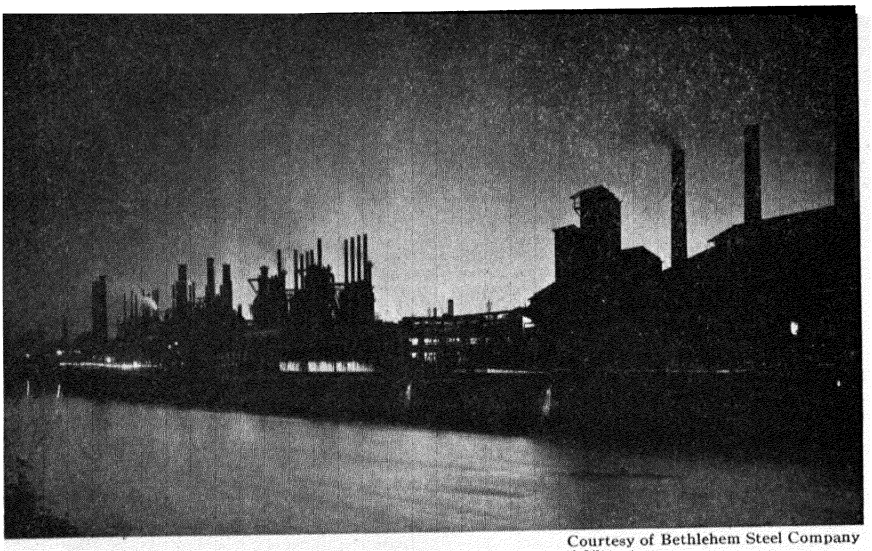


Figure 69 · The valley lowlands near the Great Smoky Mountains are good farm lands



Courtesy of Bethlehem Steel Company

Figure 70 · Natural resources found beneath the soils in this province led to the development of a huge steel industry

province is adequately watered for agriculture, and the growing seasons are such that good crops can be produced wherever the slope of the land is suitable for cultivation. Much of the land on the uplands of the Piedmont Belt is now used for farming. Between the long and nearly parallel ridges of the mountain zone there are valley lowlands with extensive fields under cultivation. In the Appalachian Plateau the cultivated lands and most of the population are concentrated in the valleys.

The northern portion of the Southwestern Division of the Appalachian Highlands is included in the hay-and-pasture belt of the continent, and there dairy farms are conspicuous. The central portion is a part of the corn-and-winter-wheat region, and toward the south the lands are included in the cotton belt. See Figure 69.

As the settlers poured into this part of the continent and the human drama proceeded, men found vast resources such as coal, iron ore, petroleum, natural gas, and limestone beneath the soil. Hundreds of coal-mining and oil-producing centers have been developed. Coking furnaces pour forth their dense smoke, and blast furnaces, especially in the Pittsburgh and Birmingham sections, suggest the great industries

which owe their success to natural resources found in the underlying rock formations. See Figure 70.

With the development of science and engineering, the use of iron and steel and of mineral fuels became very important, and the Southwestern Division of the Appalachian Highlands has played and continues to play a leading role in the great industrial dramas of the New World. Here, for a long time, was centered the manufacture of locomotives and steel rails that were demanded as the age of railroad construction proceeded. From the rolling mills in this province came the steel bands that helped to bind together the near and distant parts of the North American nations. From the machine shops in this region came the powerful engines that transported passengers, mail, raw materials for industry, foods, and the manufactured products of the factories and mills. No invention in which science and technology have united has been of greater service in the growth of the leading nations of North America than the railroad.

For a long time most of the coal, natural oil, and natural gas used in North America came from the Southwestern Division of the Appalachian Highlands. Most of the anthracite coal mined in the continent still comes from Pennsylvania, and large quantities of soft coal, petroleum, and natural gas are produced in the province. In many of the Piedmont cities of the Carolinas and Georgia, where water power could be used, textile mills have been built.

The natural resources of this province have been of fundamental importance in the growth of industrial enterprises in North America and the development on this continent of one of the two great manufacturing regions of the world.

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SELECTED LIST OF TOPOGRAPHIC MAPS FOR THE SOUTHWESTERN APPALACHIAN HIGHLANDS

Albany, New York
Amsterdam, New York
Auburn, New York
Baldwinsville, New York
Berne, New York
Catskill, New York
Clyde, New York
Cohoes, New York
Geneva, New York
Genoa, New York
Ithaca, New York
Jamestown, New York
Kaaterskill, New York
Ovid, New York
Schenectady, New York
Schunemunk, New York
Troy, New York
Watkins, New York
Weedsport, New York
West Point, New York
Ramapo, New York–New Jersey
Tarrytown, New York–New Jersey

Hackettstown, New Jersey
Somerville, New Jersey
Plainfield, New Jersey–New York

Bedford, Pennsylvania
Bellefonte, Pennsylvania
Berlin, Pennsylvania
Broad Top, Pennsylvania
Brownsville, Pennsylvania
Centre Hall, Pennsylvania
Eagles Mere, Pennsylvania
Everett, Pennsylvania
Hollidaysburg, Pennsylvania
Howard, Pennsylvania
Huntingdon, Pennsylvania
Hyndman, Pennsylvania
Laporte, Pennsylvania
Lock Haven, Pennsylvania
Meadville, Pennsylvania
Philipsburg, Pennsylvania
Pittsburgh, Pennsylvania
Townville, Pennsylvania
Williamsport, Pennsylvania
Windber, Pennsylvania
Wind Gap, Pennsylvania
Delaware Watergap, Pennsylvania–New Jersey
Philadelphia and Vicinity, Pennsylvania–New Jersey–Delaware
Warren, Pennsylvania–New York

Frederick, Maryland
Washington and Vicinity, Maryland–District of Columbia–Virginia
Antietam, Maryland–Virginia–West Virginia
Pawpaw, Maryland–West Virginia–Pennsylvania

Chagrin Falls, Ohio
Chillicothe, Ohio
Mentor, Ohio
Roxabell, Ohio
Marietta, Ohio–West Virginia
Parkersburg, Ohio–West Virginia

Beckley, West Virginia
Durbin, West Virginia
Fayetteville, West Virginia
Milton, West Virginia
Saint Albans, West Virginia
Spruce Knob, West Virginia
Hancock, West Virginia–Maryland–Pennsylvania
Guyandot, West Virginia–Ohio
Bruceton, West Virginia–Pennsylvania
Morgantown, West Virginia–Pennsylvania

Healing Springs, Virginia
Max Meadows, Virginia
Roanoke, Virginia
Salem, Virginia
Speedwell, Virginia
University, Virginia
Arringdale, Virginia–North Carolina
Critz, Virginia–North Carolina
Emporia, Virginia–North Carolina
Stuart, Virginia–North Carolina
Falling Springs, Virginia–West Virginia

Burnside, Kentucky
Monticello, Kentucky

Briceville, Tennessee
Standingstone, Tennessee
Wartburg, Tennessee

Pisgah, North Carolina–South Carolina
Saluda, North Carolina–South Carolina
Asheville, North Carolina–Tennessee
Great Smoky Mountains, North Carolina–Tennessee
Mt. Mitchell, North Carolina–Tennessee

Tate, Georgia
Warm Springs, Georgia

Bessemer Iron District, Alabama
Birmingham, Alabama
Vandiver, Alabama
Yolande, Alabama

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THE LAURENTIAN UPLAND

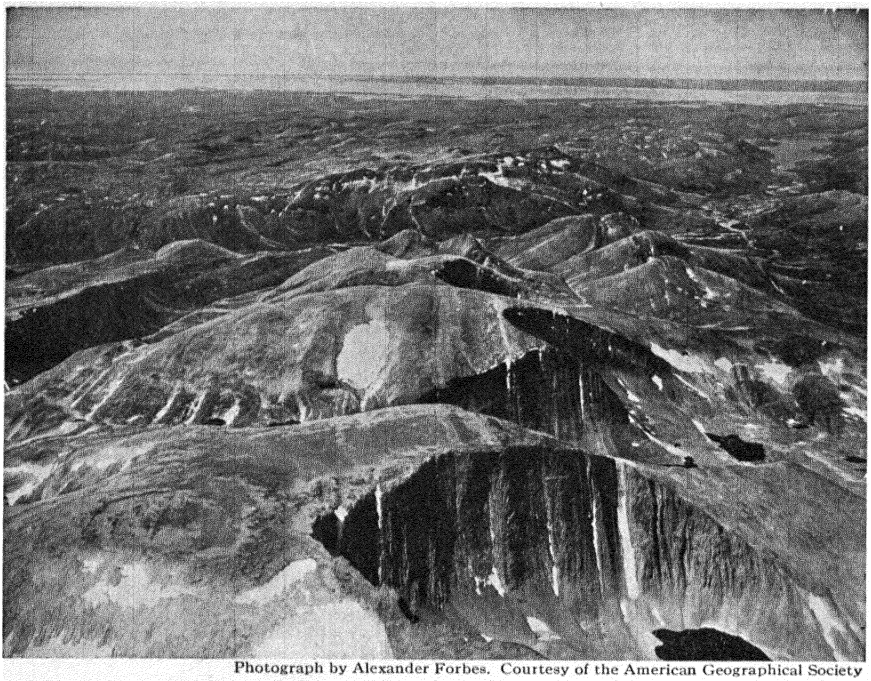
A General Description

Location. To the north and northwest of the Appalachian Highlands stretches the great area of the Laurentian Upland. It nearly surrounds Hudson Bay and the Hudson Bay Lowlands. Most of this province lies in Canada; but a portion is in Labrador; and the Adirondack Mountains of New York State and the highlands south and west of Lake Superior in Minnesota, Wisconsin, and Michigan, which are southern extensions of this great upland region, are within the United States. See the map opposite page 12 and the one at the end of this book.

The boundaries. The Laurentian Upland extends northward to the Arctic Ocean, eastward to the Atlantic, and westward to the interior plains of the continent. The western boundary is very near Lake Winnipeg and crosses Great Slave Lake and Great Bear Lake. The southern boundary of the province borders the lowlands of the St. Lawrence Valley and those of the Great Lakes region.

The landscape from the air. When seen from an airplane this province appears as an extensive area of softened hill contours with a few low, rounded mountains and thousands of lakes and swamps. Like the New England–Acadian region, it is an amphibian landscape. Here water is abundant, and the chief highways of travel are on the rivers and lakes. Most of the human activities in the region are concentrated along the water courses. The inhabitants are good boatmen and many of them are fishermen. The southern half of the province is covered with a dense evergreen forest; and the northern half is in the tundra belt, where shrubs, mosses, grasses, and flowering annuals provide a luxuriant and at times a beautiful, though dwarfed, mantle of plant life.

Throughout thousands of square miles in this upland province the sky line is monotonously even. Near the west and south margins the summit elevations rise from 1300 to 1700 feet above the sea. At the east, on the Labrador coast, the summits are about 2000 feet above sea level. From these outer areas the upland surface slopes gently downward,



Photograph by Alexander Forbes. Courtesy of the American Geographical Society

Figure 71 · The northeast spur of the central range of North Labrador. Four distinct glacial cirques appear in the foreground

usually only one or two feet per mile, toward the shore lines of Hudson Bay, thus forming a huge, shallow, saucerlike depression.

A few scattered monadnocks rise 100 to 200 feet above the general level of the upland. The so-called Laurentide Mountains, which rise abruptly to an elevation of about 2000 feet above the lowlands bordering the St. Lawrence River, are but the dissected margin of the upland. They do not rise conspicuously above the lands farther north. At the northeast, however, there is an old, worn-down mountain range that extends from Labrador northward for 2000 miles into Ellesmere Island. In northern Labrador this range is known as the Torngak Mountains. Their summits rise 4000 feet above the sea, being the highest known points in eastern Canada. See Figure 71. This range of mountains and their northward extension have been studied but little. Members of some of the arctic exploring parties have reported on the location of the mountains on Baffin Island and on Ellesmere Island.

The higher peaks of the Adirondacks form a group of monadnocks at the southern margin of the Laurentian Upland in New York State. They rise to elevations of about 5000 feet above the sea. Near the west end of Lake Superior the Mesabi and Penokee ranges, which are famous for the iron ore they contain, are monadnocks that rise above the general level of the upland surface.

Materials and structure. The foundation of the Laurentian Upland consists of an ancient complex of highly metamorphosed rocks of Pre-Paleozoic age. On most of the hilltops and in most of the stream gorges, gneisses, schists, slates, or quartzites appear at the surface. These rocks have been tightly compressed and greatly deformed. In most cases their textures and compositions are so altered that their origins are obscure. In many hills, at many of the exposures along stream courses and along the shore lines of the ocean, granites, diorites, basalts, and other intrusive rocks may be seen. There are scarcely any unaltered sedimentary rocks within the region. Figure 72 shows a typical cross section from Hudson Bay southward through the Laurentian Upland. The section is extended into the lowlands of the southern peninsula of Michigan to show the structural relationship at that margin of the province.

The surface materials within this province are, for the most part, of glacial origin. They consist of vast quantities of morainic debris and of deposits of sand and gravel left by waters issuing from continental ice sheets.

The Hudson Bay Lowlands are not part of the Laurentian Upland. See map opposite page 12. In structure and physiographic history they are similar to the Central Lowlands of the continent, which are treated in Chapter VI. They are composed of nearly horizontal Paleozoic strata, which overlie the Pre-Cambrian complex.

The Preglacial Physical History

A very ancient period of erosion. The presence of the coarsely crystalline granitic rocks at the surface of the Laurentian Upland, and the exposures of gneisses and schists similar to those in the Piedmont Up-

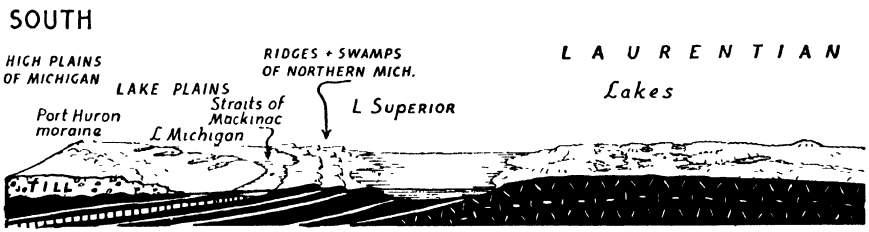
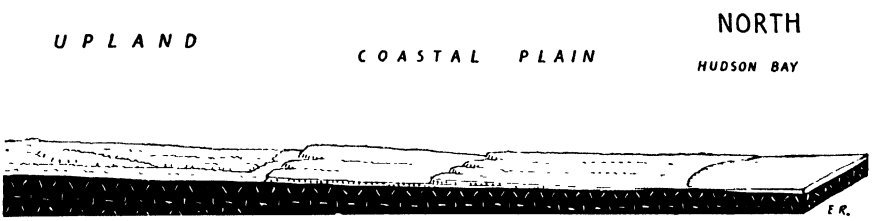


Figure 72 · Diagrammatic structure section extending southward from

land and in the Older Appalachian Mountains, indicate that during an ancient cycle of erosion vast quantities of rock, miles in thickness, were removed from this region. The crystallization of the molten magmas that formed the granitic rocks and the changes that produced gneisses and schists certainly took place beneath a great load of earth material. The truncated edges of the highly folded rocks in this complex series of very old formations also indicate that huge masses of rock which formerly occupied this region have been carried away by agents of erosion. Furthermore the peneplain buried beneath the Paleozoic sediments about the margin of the province demonstrates that this ancient period of erosion must have been a very long one. It was probably subdivided into several cycles. See Figure 72.

Advance of sea waters. After the close of the long Pre-Cambrian period of erosion, the sea advanced over much of the Laurentian Upland. In time hundreds of feet of conglomerate, sandstone, shale, and limestone accumulated in that sea. At the close of this period of sedimentation, all the lands in the area were uplifted, and the physiographic chapter in the history of the region began. This uplift was a part of the great physical revolution which we have found recorded in the history of the Appalachian Highlands, although here the movement presumably took place somewhat earlier than it did farther south in the continent. See page 120.

Development of the Laurentian Peneplain. With the uplift of the land at the close of the Paleozoic era, another long period of weathering and stream erosion was inaugurated in this part of the continent. Mil-



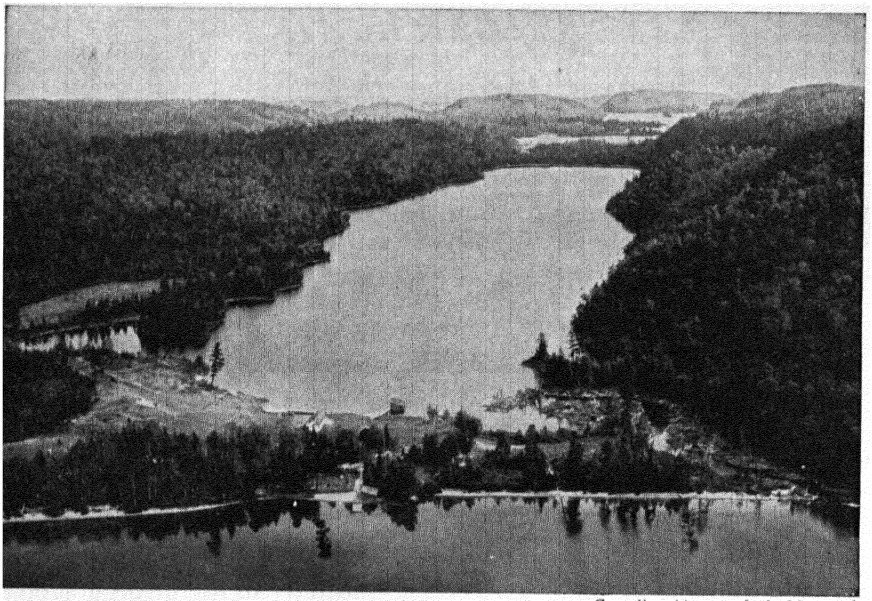
Hudson Bay into the state of Michigan, with associated relief features

lions of years passed, during which most of the mantle of Paleozoic sedimentary rocks that overlaid this area was removed. In time the Laurentian region was again reduced to a gently rolling surface not very high above sea level. That erosion surface, which is called the Laurentian Peneplain, is represented today by the monotonously even summits common to most of this upland province.

The hills and mountains which rise distinctly above the general level of the upland surface are true monadnocks. They have resisted erosion more effectively than the lands about them. They are residual masses similar in their physiographic origin to the White Mountains and Green Mountains of New England and the Great Smokies of North Carolina.

The Laurentian Peneplain was probably developed during the long period of post-Paleozoic stability in the eastern portion of the continent when the Appalachian Highlands were lowered by stream erosion to a surface of slight relief. If this hypothesis is correct the old-age erosion surface near the summit of the Laurentian Upland is of about the same age as the Schooley Peneplain, which we have recognized at so many places in the Appalachian Highlands. See Figure 73.

Some have urged that considerable areas within the Laurentian Upland may be portions of the Pre-Cambrian erosion surface which have been little modified since uncovering took place. According to that hypothesis such areas are parts of a resurrected peneplain. If, however, they have been modified at all since they were resurrected, and it seems probable that they have been, it is appropriate to classify them with the other surfaces of the Schooley Peneplain. If this surface could be proved to truncate infolded Paleozoic sediments in the midst of the upland area or if the surface could, with certainty, be traced beyond the upland



Canadian Airways, Ltd., Montreal

Figure 73 · The Laurentian Upland in the Lake Shawinigan district in the Province of Quebec. The sky-line surfaces are parts of the Laurentian Peneplain. The lake basins are in preglacial valleys in which there are morainic deposits

across Paleozoic or younger rock formations, this much-debated problem would be solved. Such evidence would demonstrate that this peneplain is not the Pre-Cambrian erosion surface. There may be a narrow belt about the margin of the province where the Pre-Cambrian peneplain has been uncovered recently and has been but little modified.

Uplift and rejuvenation. After the development of the summit peneplain in this province, and long before the glacial period, the region was uplifted and the rivers were rejuvenated. The quickened streams again began the work of valley-deepening and, as in the Appalachian Highlands, that work may have proceeded through two or three cycles of erosion before it was interrupted by the formation of great continental ice sheets. Certainly the upland was deeply dissected; large basinlike areas were excavated and a complex network of drainage lines was established before the ice began to form and move over the landscape. The details of the preglacial erosion history are now so obscure that they may never be worked out.

The Great Ice Age

Evidence of glaciation. We have encountered abundant evidence of continental glaciation in each of the provinces which we have thus far studied. We know that the great ice sheets of North America modified the topography, soils, drainage, and distribution of plant and animal life, and even affected the elevation of the land relative to the sea, in a large part of the continent. Heavy terminal and recessional moraines, widespread ground moraines, hundreds of drumlins, polished, grooved, and striated rock surfaces, striated stones in the morainic deposits, lacustrine sediments deposited in ice-front lakes, sand and gravel laid down by streams that issued from the melting ice, and numerous examples of disarranged drainage all testify to the former presence of glacier ice in the northern and northeastern portions of the United States and in the eastern and southern portions of Canada and Labrador. Later we shall have occasion to refer to the gigantic alpine glaciers in the high mountains of the west and to another center of great ice sheets in the cordilleran portions of Canada. It is appropriate that we now give attention to the origin and movement of the huge masses of ice that formed in the Laurentian Upland.

Centers of snow accumulation and ice formation. Data accumulated during the last one hundred years indicate that somewhere east of Hudson Bay in the midst of the Labrador Peninsula a number of great ice sheets formed during the Ice Age, and that similar ice sheets developed in the Keewatin area west of Hudson Bay. There may have been a third center, located south of Hudson Bay and north of the Lake Superior basin, where snows accumulated and formed ice sheets. That center of accumulation has been called the Patrician. A small independent ice cap formed in Newfoundland.

During each stage of the Ice Age, the two or three distinct ice caps that formed on the Laurentian Upland spread radially, and in time covered most of the northeastern part of the continent. See Figure 74. The Greenland ice cap was undoubtedly larger than it is today, and each of the islands in the Arctic Archipelago was nearly covered with ice.

The centers where the snows accumulated to form the great ice

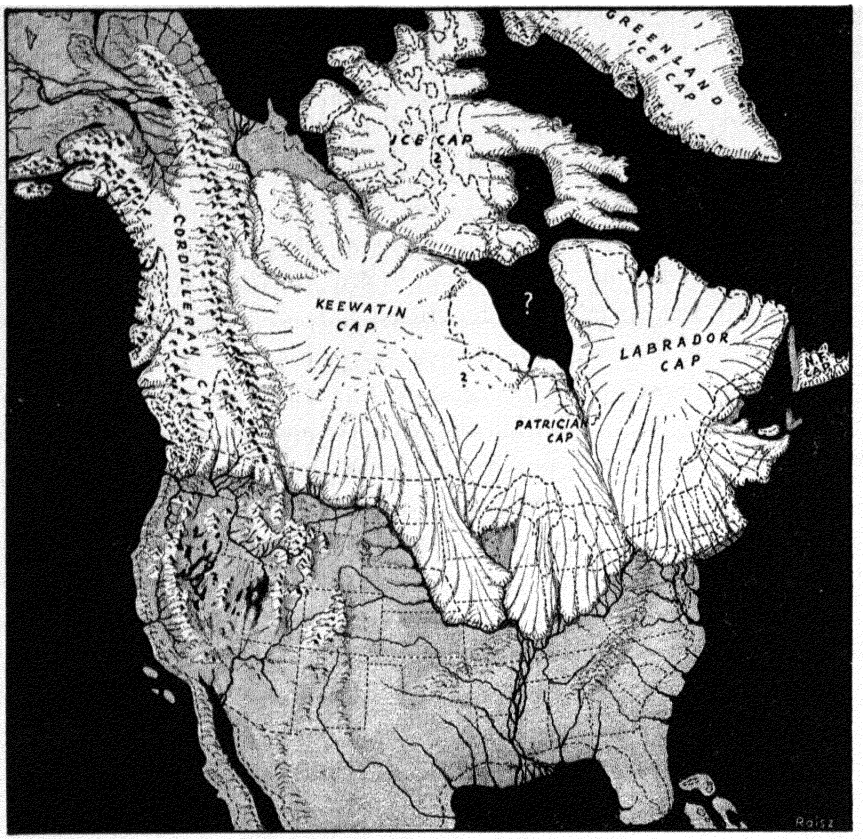


Figure 74 · North America during the Pleistocene ice age. There were several centers of snow accumulation where ice formed; great lakes existed in the western plateau portion of North America and in portions of Alaska; there were lakes at various places bordering the south margin of the ice sheet; huge rivers flowed southward from the ice within the United States, and the margin of the continent was somewhat extended

sheets have been ascertained from the distribution of glacial debris and the direction of glacial striae on the rock surfaces over which the ice moved. In general, the ice motion was radially outward from the centers of great accumulation, but locally the direction of movement was modified by topographic features.

There may have been other centers of snow accumulation and of ice formation than are shown in Figure 74. Recent observations in Green-

land indicate that there are at least four centers in the huge ice sheet on that island. Those who have an opportunity to visit any portion of the Laurentian Upland should try to make careful observations of the distribution of drift and of the direction of glacial striae on rock surfaces. Little by little, new data may accumulate which will be welcomed by all who are interested in this subject.

The formation of an ice sheet. When the climate was such that more snow fell during a winter season than melted in the following summer, a miniature perennial snow field came into existence. If that snow field was enlarged during succeeding years, it became in time so great that the pressure within the mass of snow caused the formation of ice. The ice formed first at the base of the snow field and became more extensive and thicker as the snow field grew in size. As the great dome of ice became larger, the pressure within the mass caused motion. As soon as motion began a true glacier existed. *Any large body of ice moving slowly over a land surface is a glacier.* Unless all the conditions in this definition are fulfilled, the ice mass is not a glacier. See Figure 75.

The one necessary condition for the formation of a true glacier may be reduced to the simple phrase "snow enough." Enough snow must fall during a winter season so that some is left over when the next winter season sets in. A perennial snow field is thus formed. As the years pass, snow must accumulate until a very large mound develops. With enough snow, the pressure at the base of the field becomes sufficient to force the air from between the particles of snow and cause the formation of glacier ice. The tiny ice particles in the snowflakes become so compressed that they form a solid mass. Melting at the surface of the snow field, caused by the heat of the sun's rays, produces water which, upon trickling through the snowbank, occupies the intergranular, or intersnowflake, spaces and, upon freezing, helps to form a solid body of ice.

Great elevation favors the accumulation of perennial snow fields and the formation of glaciers, but that condition is not essential. Glaciers are common today in high latitudes even at low elevations; and in low latitudes, even at the equator, they form at high altitudes. There is no other absolutely essential condition for the formation of a glacier but enough snow.

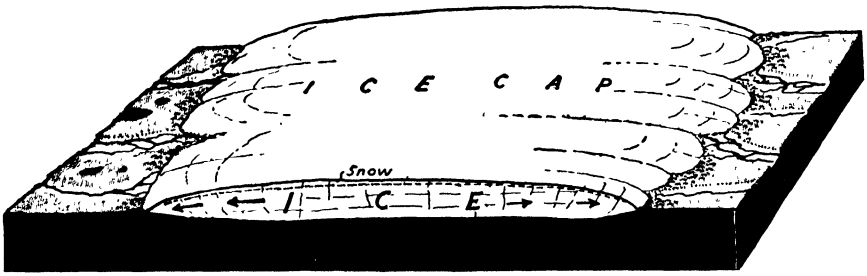


Figure 75 · A diagrammatic section of an ice cap at an early stage in development

The beginnings of motion. When the ice mass had sufficient volume and weight to cause motion, spreading began and a tendency to flatten out the great dome of ice was inaugurated. The motion was presumably very slow. According to observations of the present-day ice sheets, the forward motion may have been but three or four feet a day. In certain localities where tongues of ice advanced through valley troughs, as they do today from the main mass of the Greenland ice cap, the motion may have been considerably greater than in the parent mass. The concentration of ice in such a trough results today, at certain localities near the coast of Greenland, in motion of from 30 to 40 feet in twenty-four hours. In most places the motion in the great ice caps was probably not more than 10 feet a day.

The ice motion was probably greater during the summer seasons than during the winter seasons. Periods of heavy precipitation of snow and periods of unusually light snowfall must have affected the rate of motion of the glaciers.

Influence of topography on ice motion. It is certain that the topography of the surface over which the ice moved affected the rate and direction of its motion. Where there were no obstructions, the advancing ice must have spread somewhat evenly and uniformly over the landscape. Minor topographic features such as low hills or shallow depressions did not greatly affect its onward movement. Steep-walled canyons transverse to the course of the ice were crossed after they became filled with blocks of ice broken from the advancing front of the glacier.

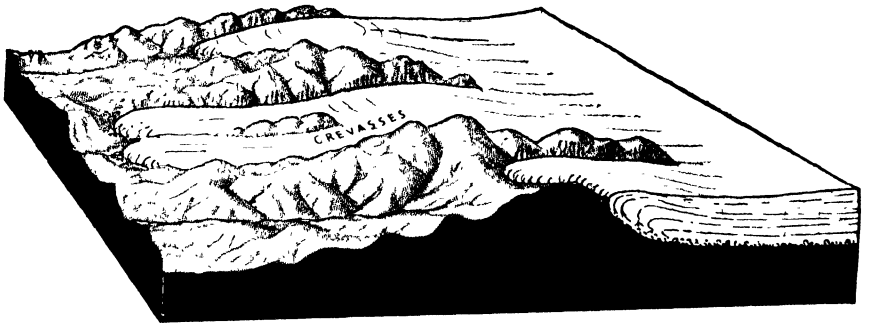


Figure 76 · An ice sheet advancing through a mountain region

Where the ice encountered hills or mountains, it tended at first to move around them. If the ice divided as it approached an isolated mountain form and then completely surrounded it, as suggested in Figure 76, the mountaintop rose as a nunatak, or island, in the field of ice. Such features exist today on the coast of Greenland. If the ice continued to advance, the mountain or hill may have been entirely covered. The systems of striae on the rock surfaces of Mount Monadnock, in New Hampshire, indicate that for a time the ice moved around that mountain and later passed over its summit. See Figure 40, page 87.

It is evident that the topography, whether it was that of a plain or a hilly country, a mountainous landscape, a land of broad, open valleys or of canyons, did not stop the ice. It may have slowed up motion in some places, but the huge moving mass, which may have been miles in thickness at the center of accumulation, moved irresistibly over the landscape. It filled valleys and in time buried mountains. The Laurentide, Adirondack, and White Mountains have been covered by ice.

Detailed studies of the monadnocks and mountain ranges of the Laurentian Upland have not yet been made. The Torngak Mountains of northern Labrador present a fascinating problem for field investigation. They may not have been covered by the ice sheets, but they undoubtedly contained valley glaciers. A study of the glaciation of the Laurentide Mountains should yield important results. Investigation of the behavior of ice on the Labrador coast, or about the margins of Hudson Bay, would undoubtedly produce valuable data. Some scientists think that the Keweenaw Peninsula and small areas north of lakes

Superior and Huron were never glaciated. Perhaps there were several other small areas elsewhere that escaped being glaciated. The Laurentian Upland offers many attractive opportunities for those who enjoy scientific field investigations.

The disappearance of the ice. The close of the Ice Age was due to a slow climatic change which reversed the conditions that caused the formation of the glaciers. Less and less snow fell each year and finally the amount added was not sufficient to offset the amount of melting that was taking place at the margins. Little by little the ice sheets shrank in size and the margins appeared to retreat. As long as the ice sheets existed as true glaciers the ice was moving outward from the centers of accumulation, but the melting at the margins meant that the ice sheets were gradually becoming smaller.

Just as the growth of the continental ice sheets was very slow, so also was their disappearance very slow. In time, however, the huge masses of ice melted away. No remnants of the great ice sheets which formed on the Laurentian Upland have been discovered. The small ice caps on certain of the far-northern islands and the Greenland ice cap are remnants of ice sheets that were much larger during the Ice Age, but they are not parts of the ice sheets that formed on the Labrador Peninsula or in the Keewatin area. See Figure 77.

The new landscape. With the disappearance of the ice, areas of bare rock surfaces were exposed, and the country between those areas was strewn with ice-borne debris. Much of that material is of a true morainic nature, consisting of boulders and stones of various sizes, indiscriminately mingled with clay, sand, and gravel. Much of it is appropriately called boulder clay or till. All unassorted glacial deposits may be called *till*. Associated with the unassorted heavy bouldery deposit, which was left wherever it melted out of the ice, there are vast quantities of assorted material. This material consists of sand and gravel which were carried by waters issuing from the melting ice. As in the physiographic provinces farther south in the United States, there are in the Laurentian Upland outwash plains, valley trains, eskers, and kamey areas.

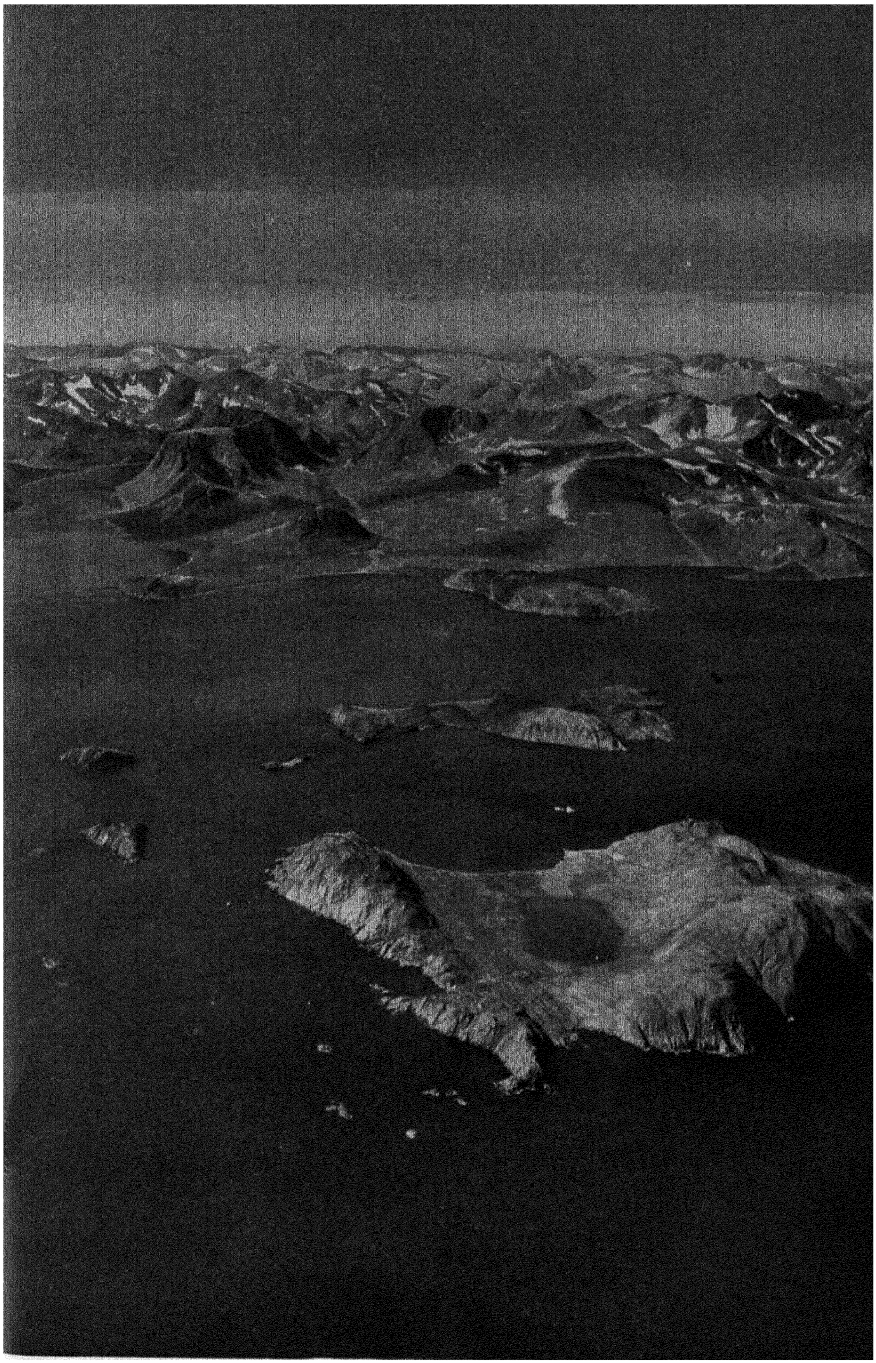


Figure 77 · The east coast of North Labrador in the Tetragona district. The region was long subjected to stream erosion, later to severe glaciation, and the land has been depressed relative to sea level

Water from the melting ice and snow, as well as rain water, filled the many depressions that were without outlets in this recently glaciated upland. Thousands of lakes, ponds, and swamps were thus formed. The streams found the old river valleys blocked with morainic material at many places, and therefore were forced to follow new routes. Lake levels rose until the waters overflowed and ran from one low place in the landscape to another. No orderly arrangement of drainage lines could be established. Thus the valleys in this region today do not have the normal gradients of stream courses. They do not become wider and deeper from their sources to their mouths. They are constricted at many points, and at some places they widen out into lakes. Falls and rapids occur at frequent intervals in these disarranged river courses.

The loading and unloading of the continent. Much interest has been shown in the extent and thickness of the ice which formed on the North American continent and in northwestern Europe during the great Ice Age. We know the areal extents somewhat accurately, but the thickness is difficult to determine except where the ice moved along the side of some mountain mass and failed to surmount the summit. About the margins of the area invaded by the North American ice sheets there is some definite evidence of the thickness of the last of the great ice sheets. In eastern Pennsylvania and near New York City it was about 900 feet thick; in northeastern Pennsylvania from 1200 to 1500 feet, and where it passed alongside the Catskill Mountains it was between 3000 and 4000 feet thick. The last ice sheet may not have surmounted Mount Washington, which is over 6000 feet above the sea, but the summit of that mountain carries erratics which indicate glaciation during an earlier ice advance. In the region of the St. Lawrence Valley, in the White Mountains, in the Green Mountains, and in the Adirondacks the ice was probably nearly 6000 feet thick. Where the ice surmounted the Baraboo ranges in central Wisconsin it must have had a thickness of at least 800 feet.

Since movement from the center of a great ice dome requires some slope to the upper surface of the ice it is reasonable to assume that ice which moved from the vicinity of James Bay to the coast of New England exceeded 6000 feet in thickness. Furthermore, there is evidence

that when the ice cap was largest and thickest the rock floor beneath it was about 2400 feet lower than it is today. At that time the rock floor about the margins of the ice-covered area was approximately at its present level. This being the case, the ice which formed in the Laurentian area first had to fill a deep bowl and then steepen its surface sufficiently to give a slope that would force the ice outward over the hills and mountains to the east and southeast.

Studies in northwestern Europe, where similar glaciers formed during the great Ice Age, indicate that the ice over the Scandinavian Peninsula and Finland was at least 2400 feet thick. Furthermore, there is evidence that there was a great depression in Fennoscandia under the last ice sheet. Since the disappearance of the ice the land at the center of accumulation, where the weight was probably greatest, has risen between 600 and 700 feet, and the amount of uplift has decreased rapidly to the rim of the great bowl caused by the weight of ice.

In North America the huge bowl in the Laurentian Upland has been nearly annulled by upheaval. At the margin of this bowl there is some very definite evidence of recent earth movements. Shore lines about the Great Lakes are tilted, being somewhat higher at the north than at the south, which means an uneven movement in that part of the continent. Gutenburg,[1] who has carried out a study of the tilting of the continents of Europe and North America, indicates that the tilting in progress today between Chicago and the northeastern part of the Great Lakes region is about two fifths of an inch each year. Leverett and Taylor,[2] in their report on the Great Lakes region, have included evidence of land tilting since the disappearance of the ice sheets.

About the shores of James Bay there are elevated beach lines and recent marine clays 400 and 500 feet above the salt water. Post-glacial marine terraces along the coast of Labrador are 1500 feet above the sea, and on the banks of the St. Lawrence River there are similar terraces about 600 feet above tidal waters. In the bays and fiords of the Arctic Archipelago old strand lines up to 860 feet above the present shore lines have been reported. Along the coast of New England and Acadia

[1] B. Gutenburg, "Tilting Due to Glacial Melting," *Journal of Geology*, Vol. 41 (1933), pp. 449–467.

[2] F. Leverett and F. B. Taylor, "The Pleistocene of Indiana and Michigan and the History of the Great Lakes," *U. S. Geological Survey Monograph*, No. 53 (1915), 529 pages.

there are shore features which indicate that the lands in that part of the continent were recently lower relative to sea level than they are today. The continent appears to have been uplifted more at the north than at the south. It may naturally be thought that there should be some compensating depression somewhere to the south, and the evidence of recent sinking about the margin of the Atlantic and Gulf Coastal Plain is significant.

The dimensions of the last ice caps in North America and northwest Europe have been estimated as follows:

Region	*Area (Square Kilometers)*	*Average Thickness (Meters)*	*Volume (Cubic Kilometers)*
Labrador-Keewatin . . .	9,000,000	2400	21,600,000
Cordillera, North America	2,500,000	800	2,000,000
Europe	3,500,000	1600	5,600,000

Adding to these figures estimates for the volume of ice in other parts of the world in excess of the present volume of ice, Daly[1] finds that the volume for the last Pleistocene ice caps is 34,300,000 cubic kilometers. Daly has estimated also that the melting of the last Pleistocene ice caps raised the level of the ocean at least 260 feet. If this was true after the melting of the last great ice sheets similar changes in sea level occurred after the melting of each of the three earlier sheets of ice. These studies lead to the conclusion that during each glacial stage the sea must have retreated from the lands producing the effects of continental uplift along the shores; and that during each stage of deglaciation the sea must have risen producing the effects of continental sinking along the shores of all land masses. If these variations in the elevation of the sea relative to the land were each time approximately 260 feet and world-wide, their significance has an important bearing on the explanation of recent geomorphic conditions along coast lines.

Changes in the glaciated area since the disappearance of the ice. During the relatively short time since the last ice sheets disappeared from northern North America few topographic changes have taken place.

[1] R. A. Daly, *The Changing World of the Ice Age.* Yale University Press, New Haven, 1934.

Drainage lines are gradually becoming better and better established. New soils are forming on the rock surfaces which were left bare by the ice. Thousands of years will pass, however, before the rocks break down and deep, fertile soils form. In the moraine-covered areas soils have formed and vegetation has become well established. Many of the plants and animals that were driven southward by the advancing ice are represented here again.

About the margins of lakes many minor changes have taken place. Lake cliffs and wave-cut terraces have resulted from wave erosion. Small beach ridges, spits, hooks, sand bars, and barrier beaches have been formed. About the shores of many of the small lakes little ridges, or ramparts, have been forced up by the lake ice. When the surface waters of these small lakes freeze over completely and the temperature continues to fall, the ice contracts and either withdraws from the shores or cracks. In either case lake waters rise at the margins or in the great open cracks and freeze. When the temperature rises, the ice expands, and causes a thrust toward the shores of the lakes. During a winter season the temperatures may change from 20 or 30 degrees below zero to as many degrees above zero. With each fall in temperature the ice contracts, and with each rise in temperature it expands, thus causing a recurrence of thrusting against the margins of the lakes. Boulders on the beaches are frozen into the ice and thrust outward, forming what are known as *boulder ramparts.* Such ridges are found about the margins of many of the lakes in this upland province and in the northern portions of the Central Lowlands of the continent. See Figure 78.

The Adirondack Mountains

Materials and structure. In the northeastern portion of New York State the area of crystalline and metamorphic rocks, with a hill and mountain topography, is one of the southern extensions of the Laurentian Upland into the United States. This is known as the Adirondack Mountain area, and its connection with the larger expanse of similar rock formations and similar topography at the north is through the zone of the Thousand Islands in the St. Lawrence Valley. In the

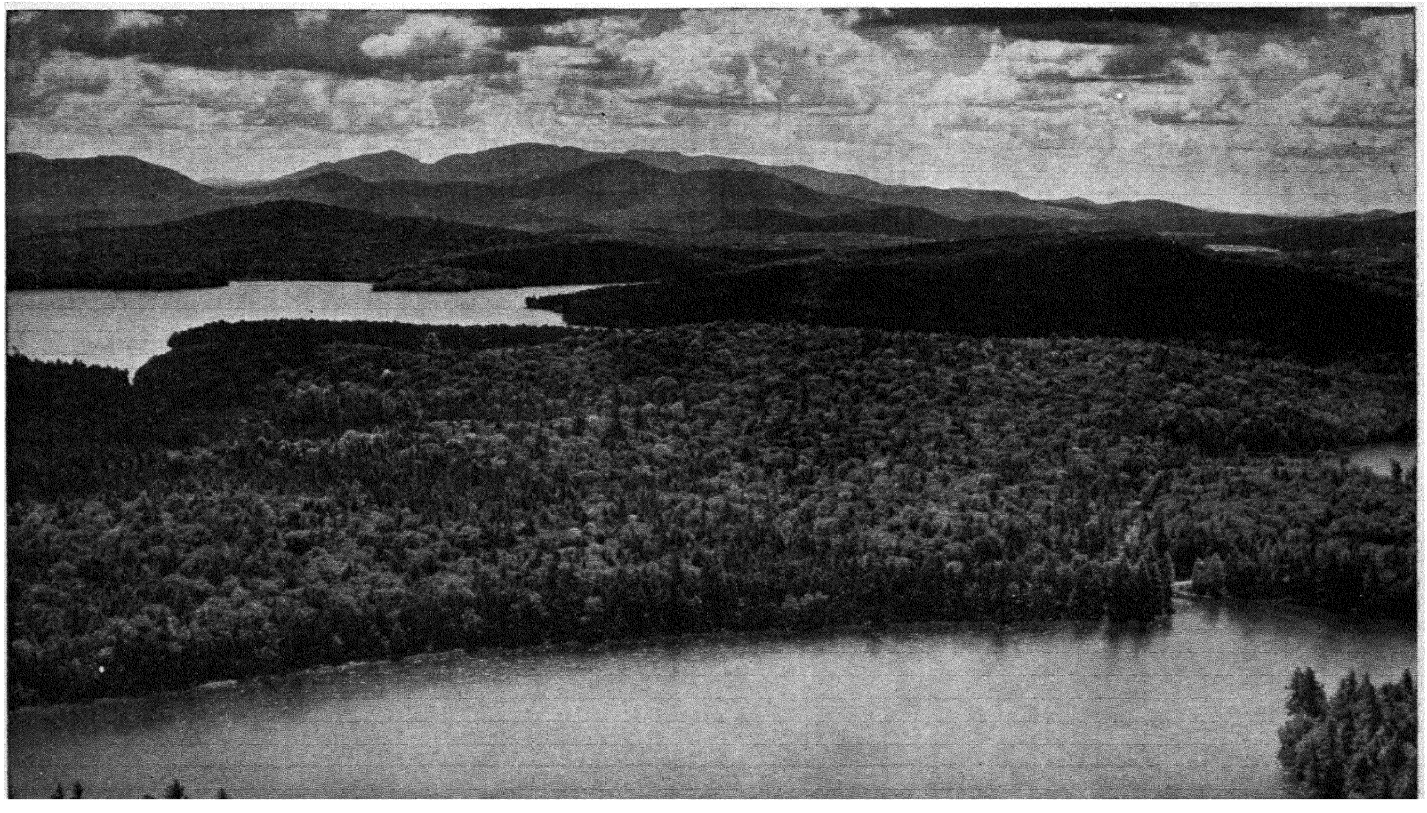


Photograph by Buckley. Courtesy of the Wisconsin Geological Survey

Figure 78 · A boulder rampart on the shore of Lake Mendota, photographed soon after it was formed. This is not within the St. Lawrence Upland, but the photograph illustrates a feature that is widespread in the glaciated parts of North America

midst of this mountainous region there are huge masses of granite and syenite, and to the east there is a large body of dark-colored, coarsely crystalline, intrusive rock (gabbro), locally known as the Adirondack batholith. The rocks throughout the entire mountain area are believed to be of Pre-Cambrian age. Near the eastern margin of the range the rock formations have been broken by faulting into a series of rectangular blocks, and many of the bolder relief features in this section are the uplifted margins of fault blocks. About the margin of the mountains there are upturned sedimentary strata of sandstone, shale, and conglomerate. They were deposited in the Paleozoic sea which presumably covered most if not all of this highland region. See Figure 79.

Stream erosion. In the Adirondack region, as in the Canadian portion of the Laurentian Upland, there is evidence of a very long period



Fairchild Aerial Surveys, Inc.

Figure 79 · The upper Saranac Lake district in the Adirondacks

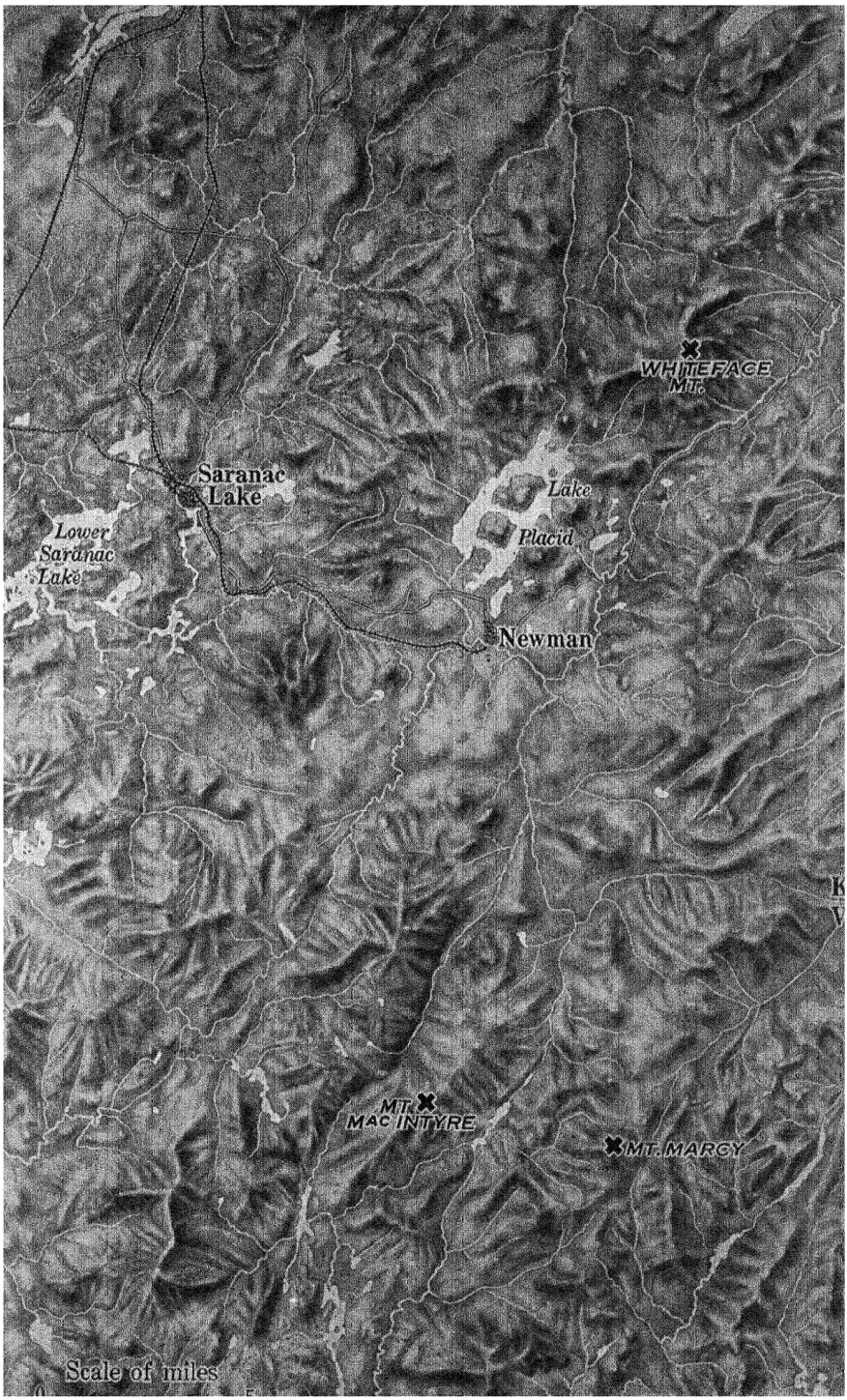
of erosion which preceded the advance of the Cambrian sea. The erosion surface developed during that period is being uncovered as the sedimentary strata about the margins of the mountains are worn away. Where recently exposed, that old surface descends somewhat steeply below the upturned overlapping sedimentary layers.

Here too there was pronounced uplift at the close of Paleozoic time. In this section a huge dome was formed, and on the surface of that dome a consequent radial drainage pattern was established. Stream erosion continued through a very long period and produced a gently rolling erosion surface. This surface is today well preserved on the western flank of the Adirondack Mountains, and at places on the northern and southern margins of the mountain area. It appears to be part of an old peneplain which has been uplifted and dissected. In the western half of the range the sky line is about 2000 feet above sea level and comparable to the surfaces which we have described in the New England area and in the major portion of the Laurentian Upland. Furthermore, it is in approximate agreement in elevation with remnants of the Schooley Peneplain in the adjoining provinces to the east and south.

All the higher peaks among the Adirondacks are monadnocks, that rise above this peneplain horizon. Two of the peaks have an elevation of over 5000 feet; Mount Marcy is 5344 and Mount MacIntyre is 5112 feet above the sea. There are at least ten other peaks with elevations of over 4000 feet. Whiteface is one of the most conspicuous of these, with a summit elevation of 4872 feet. The summits of these mountains have been softened during long periods of weathering and stream erosion and also during several stages of glaciation. See Figure 80.

With the uplift of the subsummit peneplain (Schooley) in the Adirondack Mountains and the rejuvenation of all streams, a new cycle was inaugurated. As dissection continued, wide valleys were developed in the major stream courses; and their former flood plains may possibly be correlated in age with the Harrisburg erosion surfaces which have been recognized at various places in the Appalachian Highlands.

These Harrisburg surfaces are now high above the present stream channels; and that means there was, in this mountain region, another period of uplift and rejuvenation of streams and further dissection of the land before continental ice sheets invaded this region.


WHITEFACE
Mt.
Saranac
Lake
Lake
Placid
Lower
Saranac
Lake
Newman
MT.
MAC INTYRE
MT. MARCY
Scale of miles

Glaciation. As the ice sheet from the Labrador center east of Hudson Bay spread southward and crossed the St. Lawrence Valley the advancing edge came in time to the north margin of the Adirondack Mountain region. This area of pronounced relief must have affected the movement of the ice. One lobe presumably moved eastward through the Lake Champlain trough, and another around the western margin of the mountains. The ice that moved directly toward the center of maximum relief may have been somewhat stagnated by this great physical obstruction and the upper layers of the ice may have moved over the lower layers and in that way surmounted the summits of the range.

Detailed field studies in New York have demonstrated that as the period of deglaciation advanced, the ice mantle on the high mountain area disappeared before the ice in the lowlands to the east and west had melted away. For a time the bordering masses of ice appear to have blocked the drainage flowing radially from the mountains and to have caused a series of lakes which changed frequently in elevation, becoming lower and lower as the ice melted away and new outlets were available. In these lakes alluvial sediments accumulated. At the margins of certain of the ice lobes and between the ice and the neighboring valley walls kame terraces were constructed. In many of the lakes sand and gravel were deposited as deltas, and as the waters stood at lower and lower levels faint shore-line features were engraved upon the landscape. Later in the history of ice-melting, outwash deposits were spread over the floors of many of the valleys bordering this mountain region. The lacustrine and outwash conditions in this range during the closing stages of the Ice Age account for the abundance of sand and gravel deposits in the valleys of the Adirondack Mountains.

The present lakes. The larger lakes in this mountain region, such as Tupper, Placid, Saranac, Raquette, and Cranberry, are due to morainic obstructions in valleys. Eight morainic dams in a preglacial valley account for the Fulton chain of lakes. There are about two thousand lakes and ponds in the region, and most of them owe their existence to glaciation in one way or another. Some of their basins may have been deepened by glacial erosion, but most of them were formed by ponding or blocking by morainic dams.

Alpine glaciers. As in the White Mountains, the Green Mountains, and the Catskills there were in the Adirondack Mountains valley glaciers which formed either before or after, or both before and after, the presence of the great continental ice sheets. The evidence of this type of glaciation is here, as in the other mountain regions of the east, chiefly cirques and U-shaped troughs that were excavated by the tongues of ice that formed near the summits of the mountains. Giant Washbowl on Giant Mountain, several cirques on the north slope of Sentinel Range, and one on Whiteface Mountain are generally recognized as good examples of the catchment basins where snows accumulated and formed alpine glaciers.

The Superior Upland

Materials and structure. In that portion of the Laurentian Upland which extends southward and westward from Lake Superior into the United States, the Pre-Cambrian crystalline and sedimentary rocks have been tightly compressed and severely metamorphosed. Here the structures indicate that the great folds if replaced would reach the heights of lofty mountains. In this section the evidence of Pre-Cambrian peneplanation is abundant and at the southern margin of the area Paleozoic sediments rest upon that peneplain.

The Duluth and Superior escarpments near the west end of Lake Superior are the result of faulting, and the earth block between these escarpments has fallen. The lowland just south of the Keweenaw Peninsula is another down-faulted area, and the bold escarpment at its northern margin is the result of faulting. The mountain ranges in which the rich copper and iron deposits have been discovered are due to the superior resistance of certain upturned layers in the folded structure of the Pre-Cambrian formations.

Stream-erosion history. The Paleozoic sediments that now appear about the southern margin of this area undoubtedly once extended much farther than they do today. They have been stripped off during a long period of stream erosion, and as they were removed the very ancient

Pre-Cambrian peneplain was uncovered. Since the uncovering of the core rocks, stream erosion has continued and has reduced much of the landscape to a new peneplain horizon. This post-Paleozoic erosion surface is represented by the even sky lines common throughout this section today, and it is believed to be of about the same age as the Schooley Peneplain. It has been referred to as the Superior Peneplain, and the use of that term is recommended by some in order to avoid commitment as to the age and correlation of this surface of erosion.

Since the development of this subsummit erosion surface there has been sufficient uplift to permit dissection to the depth of several hundred feet. Most of this work of erosion was accomplished before the opening of Pleistocene time, for the ice that advanced into this section found a number of low mountain ranges and many deep valleys. Here this period of stream work may have been subdivided into two or more cycles of erosion as it was in the Appalachian Highlands.

Glaciation. Into the Superior Upland moved huge lobes of ice from the Patrician and Keewatin centers. Most of the work was accomplished by the ice from the Patrician center. That ice moved through the trough now occupied by Lake Superior and southward and westward into the lands now included in the northern peninsula of Michigan, northern Wisconsin, and eastern Minnesota. A few miles west of Lake Superior the ice from the Keewatin center that advanced southward into Iowa spread eastward even into a part of the area that once had been covered by the ice from the Patrician center.

The great ice sheets that invaded the Superior Uplands left a large amount of drift. Here there are great belts of terminal and recessional moraines and elsewhere a heavy mantle of ground moraine. A few small areas have but a thin mantle of glacial debris. Among the moraines there are hundreds of undrained depressions now occupied by lakes or ponds. In many of the outwash plains there are pits that are now occupied by lake waters.

Lake Superior occupies a trough that is 1290 feet deep, and at its maximum depth 690 feet below sea level. The basin could not have been lowered so much below sea level by running water, and it is believed by most investigators that much of the depth is due to glacial

erosion. There are structural conditions about the margins of this lake which suggest that this trough may be due in part to down folding.

As the ice began to retreat from the west an ice-front lake, which has been called Lake Duluth, came into existence. That lake drained southward by way of the Kettle River to the St. Croix River, and thence to the Mississippi. Lake Duluth became larger and larger as the ice front retreated eastward, and in time the waters abandoned the St. Croix outlet and flowed near the margin of the ice into Lake Chicago. Today there are shore lines as high as 425 feet above the present level of Lake Superior. This record will be referred to again in Chapter VI when the history of the Great Lakes is considered in more detail.

The St. Lawrence Valley Lowlands

The lowlands bordering the St. Lawrence River, which were covered by the waters of the Champlain Sea, are of special interest both from the physical and the cultural points of view. They occupy an area of weak rocks between the strong rock formations of the Laurentian Upland at the northwest, the New England Upland at the southeast, and the Adirondack Mountains at the south. See the map at the end of this book.

In each of the neighboring higher lands, remnants of the Schooley Peneplain are preserved. In the St. Lawrence Lowlands, a region of less resistant formations, the upland surface has been removed and a lower plain of erosion has been developed that may be of the same age as the Harrisburg surfaces. This lower surface is well shown west of Montreal, and it extends eastward a little beyond Quebec, where it dips below the waters of the St. Lawrence estuary. The site of the city of Quebec and the Plains of Abraham, immediately west of the city, are a part of this surface. The abandoned stream channel northwest of Quebec was formerly occupied by the St. Lawrence River. The Ottawa Valley and the valley of the St. Lawrence below Montreal are probably preglacial. The present course of the St. Lawrence from Lake Ontario to Montreal is of post-glacial origin. Here the channel is shallow and interrupted by numerous rocky and very picturesque islands.

The Monteregian Hills are volcanic necks, or plugs, that rise conspicuously above the lowland plain in the vicinity of Montreal. They are composed of great masses of very resistant volcanic rock. Mount Royal, in the city of Montreal, rises a little more than 700 feet above the lowlands, and some of the hills to the southeast, across the St. Lawrence River, rise 1400 to 1700 feet above their surroundings. See Figure 81.

This lowland bordering the St. Lawrence is now the most densely populated part of the Dominion of Canada. Here people have found favorable conditions for the development of agriculture, manufacturing industries, and shipping. Here they have developed three of their largest and most important cities, and here they have established the capital of the dominion. This small lowland area has thus become one of the chief cultural centers of Canada.

A Brief Review of the Physical History of the Laurentian Upland

The Laurentian Upland province is about 1,000,000 square miles in extent. Throughout most of its area it is composed of an ancient and complex series of rock formations. This ancient complex was reduced by erosion to a peneplain in Pre-Cambrian times, submerged, for the most part, during the Paleozoic era, buried beneath layers of sandstone, conglomerate, shales, and limestones, and again uplifted high above the sea. Since then, stream erosion working through millions of years has again reduced the area to a surface of slight relief, and that surface (probably a part of the Schooley Peneplain) has been elevated and dissected. The complexity and variety in the present topography of this upland is due, in large measure, to the variety in underlying rock formations.

The Laurentian Upland is of special interest because in it are located the centers where the snows accumulated which led to the development of the largest continental ice sheets that ever existed in North America. The movement from those centers was radially outward until more than half the continent was covered with ice.

The preglacial stream-erosion topography of the Laurentian Upland has been modified by glacial erosion and by the deposition of debris



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Figure 81 · Looking northeast over the city of Montreal. Mount Royal, with its heavy forest mantle, is in the middle ground

from the melting ice. Today this region, although composed of very old rock formations, presents the appearance of physiographic youth. Drainage is much interrupted and imperfect; there are thousands of lakes, ponds, and swamps; waterfalls and rapids are common in most of the stream courses; and the soils are youthful.

Economic Development of the Laurentian Upland

Location. Since most of the Laurentian Upland is north of latitude 45° and in the northeastern portion of the continent, the climate of the region is characterized by long, severe winters and short, warm summers. If it were located in the same latitude at the western margin of a continent where winds that have passed over a great ocean approach the land, as in the case of northwestern Europe, the climatic conditions would be notably different. The bleak, desolate, almost uninhabited lands of this province are in the same latitude as northwestern Europe. In fact, all but the Mediterranean region of Europe is as far north as the southern margin of the Laurentian Upland. The Scandinavian Peninsula, where nine million people live, is in the same latitude as the sparsely populated tundra wilderness in the northeastern part of North America. The importance of location is strikingly illustrated in the settlement and economic development of this province.

Rainfall. The average yearly rainfall in the southeastern portion of the Laurentian Upland varies from 20 to 40 inches, but very little of the area receives more than 30 inches. In the latitude of Hudson Bay there is an east-west belt where only 10 to 20 inches of rain falls yearly, and farther north the annual precipitation is less than 10 inches. See map opposite page 6. If the far-northern portion of the province were in a region where evaporation was rapid, it would certainly be a semi-desert landscape.

Growing season. Near the southern margin of the Laurentian Upland the average length of the growing season is about 90 days. Farther

north the growing season becomes so much shorter that the production of cereal grains and many of the food crops is impracticable if not impossible. Very little agriculture is carried on anywhere within the province because of unfavorable topography, drainage conditions, and temperatures.

Vegetation. The southern third of the Laurentian Upland is covered with a coniferous forest, consisting chiefly of pines, spruces, and hemlocks. Farther north the coniferous forest is classified as subarctic. As a result of decreasing rainfall and decreasing length of growing season the trees in most of the area are more and more stunted as the distance from the equator increases. A tundra vegetation mantles the far-northern portion of the province, including the Arctic Archipelago. There the vegetation consists of grasses, mosses, and shrubs, with many perennial flowering plants.

The natural resources below the soil. In the lands bordering Lake Superior vast resources of iron and copper have been discovered. Here are located the richest iron mines in the world. In the Adirondack Mountains there are smaller deposits of iron ore. To the northeast, where Labrador adjoins Quebec, a large iron ore deposit has been discovered. North of Lake Huron, in the Sudbury region, there is an area in which is produced, on the average, about 80 per cent of the world's supply of nickel. In that same region copper, lead, and zinc have been discovered. A little farther north, in the Cobalt region, silver and arsenic have been discovered. Between the Cobalt region and James Bay there are other deposits of copper and zinc as well as gold deposits. Indications of gold, copper, and zinc have also been found in localities in the vicinity of Lake Winnipeg. Still farther away, in the Northwest Territories, valuable mineral deposits have been discovered.

The human drama. Five hundred years before Columbus made his historic journeys across the Atlantic, Norsemen visited the coast of what is today called Labrador and drifted southward to the New England region. Later, during the sixteenth and seventeenth centuries, many French and British came to the region of the Gulf of St. Law-

rence. Some sailed their vessels up the St. Lawrence in the hope of finding the "Northwest Passage" and of coming in time to the land of India. The name Lachine, given to the rapids in the river at that time, suggests the mistaken ideas of some of those early adventurers who thought they were in China. At the head of navigation for ocean-going vessels a settlement was founded on the St. Lawrence. This grew in time to be the beautiful city of Quebec. For many decades it served as the chief seaport for trade with the people in the St. Lawrence drainage basin.

Some of the adventurous pioneers from France landed on the banks of the lower St. Lawrence and there established homes at the margin of the Laurentian Upland. They cultivated the soils near the river, and did a little fishing, lumbering, and hunting. The upland furnished timber and firewood, provided pasture lands, and served as a good hunting ground. The pioneers worked out a subsistence type of agriculture and a very simple type of community organization closely associated with the church. Year after year they saw the vessels from the homeland pass by en route to Quebec and again on the outward journey. These settlers were left to carry out a little drama by themselves. See Figure 82.

For more than a century these settlements on the lower St. Lawrence were more or less isolated, while Quebec, standing at the headwaters of ocean navigation, was developing into an important port. The isolation led to the preservation of the French language and of many ancient customs. Here developed the nucleus of the French-speaking communities of Canada, which today furnish about a third of the total population of the dominion. Here the parish type of organization is still maintained, in which the village priests assume a large amount of responsibility in the care of the people. Up the St. Lawrence from Quebec few of the inhabitants live in the Laurentian Upland proper, but, rather, at the margin or on the bordering lowlands. They depend in part upon the resources of the upland, however.

When the river channel above Quebec was deepened and certain obstructions were removed, Montreal became the head of navigation for ocean-going vessels and Quebec lost its position of importance as the leading seaport of eastern Canada. Then the communities of the



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Figure 82 · Farm lands and the town of Murray Bay located below Quebec on the north bank of the St. Lawrence. The Laurentide Mountains appear in the distance

lower St. Lawrence became even more isolated. Not until recent years, with the advent of good roads and motor cars, have these people had many visitors from other parts of the world.

Today the average density of population in the Laurentian Upland is less than two people per square mile. This means that there are thousands of square miles in the region with no permanent settlement whatsoever. We must think of this region as a wilderness, forested in part and moss-covered in part. Trappers and hunters visit many of its most desolate parts. Here the Hudson's Bay Company maintains a number of trading stations where native Indians and trappers may exchange pelts for articles of clothing or food. Exploring parties search through the wilderness with magnetic needles, hoping to find more iron resources like those in the Lake Superior region. There are a few small mining towns in the region. On the shores of beautiful lakes cabins have been built to which sportsmen retreat for periods of rest and recreation. Canoeing and fishing expeditions follow the water courses for hundreds of miles.

The great forest mantle of the Laurentian Upland early furnished timber and firewood for the pioneers who settled about the margin of the province, and timber continues to be among the most valuable of all the natural resources of the region. Vast quantities of pulpwood are shipped from the upland to the more highly developed industrial sections of Canada and to the United States. Canada has now surpassed the United States in the production of wood pulp, 90 per cent of which comes from the Laurentian Upland. Many of the newspapers and other publications issued in the United States are today dependent upon paper manufactured from Canadian wood pulp.

The ponded waters and disarranged drainage lines of this upland region furnish a vast amount of water power, some of which has been developed for industrial and domestic uses. Canada ranks next to the United States in the development of its water power. Of the potential eighteen and a half million horse power available in the streams of Canada, 75 per cent is within the Laurentian Upland.

An examination of the regional map of North America will make it clear that between the lowlands of southeastern Canada and the interior-plain region west of Lake Winnipeg there is a great stretch of the

Laurentian Upland. For over a century that sparsely populated area, more than 1000 miles in width, furnished little possibility of trade or of passenger or freight business. These conditions prevented the construction of a transcontinental railroad in Canada by private capital.[1] Thus the two sections of this great British dominion which were attractive to settlers remained separated for a long time. Not until 1886, when the government of Canada subsidized the construction of the Canadian Pacific Railway, was this barrier crossed by any modern means of transportation. Since then other railways and a modern highway have been constructed over this area.

It is evident that the Laurentian Upland was long a liability in the economic development of Canada because it prevented free intercourse between the lowland regions of the east and the west where the population was becoming concentrated. Today, in addition to the improved transportation facilities, the mineral resources, to which reference has already been made, and the possibility of further discoveries of such resources, together with the forests, water power, and recreational attractiveness, now make this region a great asset to the Canadian people. In the future it may play a more and more important part in the economic development of the dominion.

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[1] W. A. Mackintosh, "The Laurentian Plateau in Canadian Economic Development." *Economic Geography*, Vol. 2 (1926), pp. 537–549.

SELECTED LIST OF TOPOGRAPHIC MAPS FOR THE LAURENTIAN UPLAND AND ADIRONDACKS

Gananoque, Ontario[1]
Mallorytown, Ontario[1]
English River, Ontario–Manitoba[1]
Arnprior, Ontario–Quebec[1]
Ottawa, Ontario–Quebec[1]

Belœil, Quebec[1]
Chibougamau, Quebec[1]
Granby, Quebec[1]
Lachine, Quebec[1]
Laurentides, Quebec[1]
Laval, Quebec[1]
Orford, Quebec[1]
Quebec, Quebec[1]
Ste. Agathe, Quebec[1]
Three Rivers, Quebec[1]

Fond du Lac, Saskatchewan[1]
Stony Rapids, Saskatchewan[1]

Duluth, Minnesota
St. Croix Dalles, Wisconsin–Minnesota
Superior, Wisconsin–Minnesota

Houghton, Michigan
Menominee Special Map, Michigan
Sagola, Michigan
Witbeck, Michigan

Ausable, New York
Bolton, New York
Chateaugay, New York
Glens Falls, New York
Hammond, New York
Lake Placid, New York
Long Lake, New York
McKeever, New York
Malone, New York
Port Leyden, New York
Saranac, New York
Schuylerville, New York
Tupper Lake, New York

[1]Published by Surveys and Engineering Branch, Department of Mines and Resources, Ottawa Canada.

VI

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THE CENTRAL LOWLANDS

A General Description

A favored region. The Central Lowlands of North America include an extensive area of slight relief in the interior of the continent. Here a vast expanse of nearly level land with fertile soils, a long growing season, and a favorable amount and distribution of rainfall, have combined to make this one of the best agricultural regions in the world. Furthermore, the primeval forests, the water resources, and the mineral wealth helped to make this part of the continent one of the really great manufacturing districts of the world. See the map opposite page 10 and the one opposite page 12.

The landscape from the air. Cruising at an elevation of from 2000 to 3000 feet over this gently rolling prairie section of the continent, we should be impressed with the widespread distribution of settlements, the high percentage of land under cultivation, the small percentage of land with its former forest cover, and the numerous great manufacturing and trading centers with large populations.

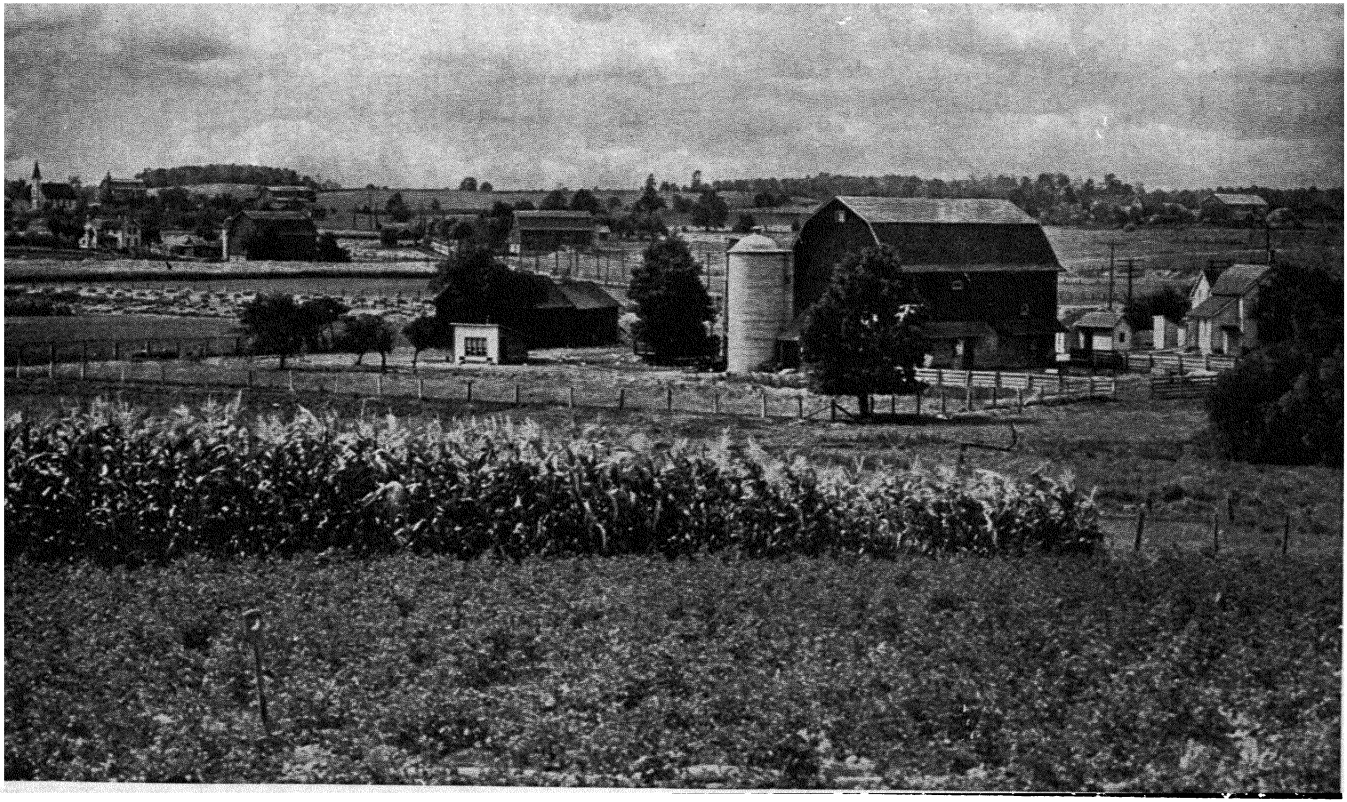
If we cross this province from south to north during midsummer, we see first the northern margin of the cotton belt, white with millions of cotton bolls nearly ready to be picked, and then the fields where winter wheat has been harvested and where corn, which is also grown here, is still standing. Next we pass over the greatest corn-producing area in the world, extending from central Ohio through Indiana, Illinois, and Iowa into Nebraska. Still farther north we look down upon the hay and pasture lands, with their great dairy farms; and far to the northwest, in Minnesota, the Dakotas, and the adjoining lands in Canada, we see a wonderful spring-wheat region. If we go northeastward, we shall find that many of the rural sections are used for intensive cultivation of fruit trees and grapevines. In the lands north and south of Lake Ontario and Lake Erie and throughout much of the southern peninsula of Michigan, the moderating influence of the waters of the Great Lakes lengthens the growing season just enough to favor the production of fruit. See Figure 83.

The vessels moving on the Great Lakes, the freight and passenger trains crossing the network of steel rails, the trucks and automobiles hurrying along the modern highways, the many planes flying through the air, and the factory chimneys belching forth great clouds of smoke, all emphasize the fact that we are flying over an active, densely populated manufacturing section.

If our cruising were done during midwinter, a very different picture would be seen. Most of the area would be covered with snow. Only the southern portion might be free of the white mantle, and there the winter wheat would give a touch of bright green to the landscape. Travel on the lakes would have ceased, and the railways and highways would not be so crowded as they are in the summer. The airways would be busy, however, and the manufacturing centers would be just as active as they are in the summer.

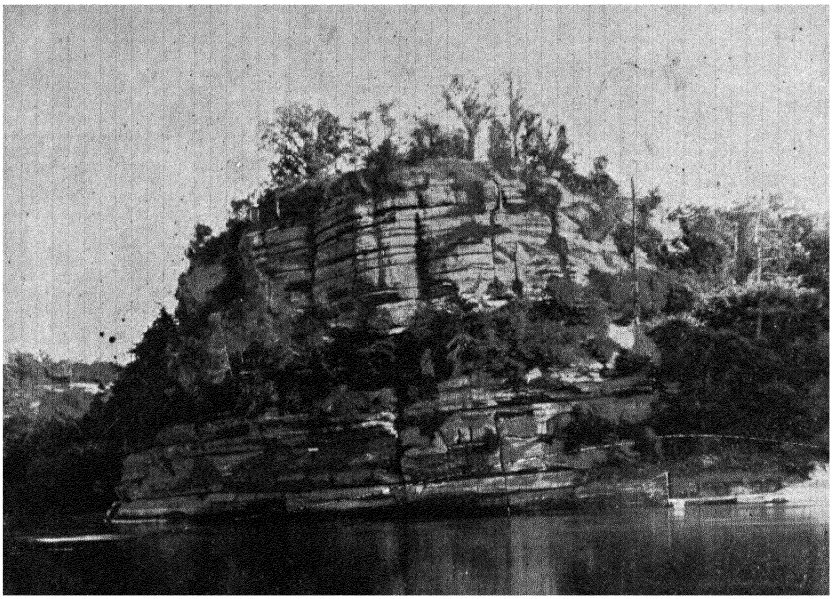
The boundaries. The Central Lowlands include most of the lands between the Appalachian Highlands at the east and the Great Plains on the west, the Laurentian Upland at the north and the Gulf Coastal Plain on the south. The exception is an area, in the midst of the continent, known as the Interior Highlands. That region will receive consideration as a distinct physiographic province in the next chapter.

To the east in Tennessee, Kentucky, and southern Ohio, the margin of the Appalachian Plateau is marked by a bold west-facing escarpment. In central Ohio the plateau gives way gradually through a zone of hills and low ridges to the interior plains. Farther to the north and east the boundary between the Central Lowlands and the Appalachian Plateau is also an escarpment. At the north a mantle of glacial drift obscures the geologic boundary and reduces the contrast in relief that one might expect to see when crossing from a lowland to an upland province. The west boundary is fairly well marked in the Dakotas and southern Canada by a distinct topographic break from the lowland to the Great Plains. Here the higher land to the west is known as the Missouri Plateau, or the Coteau du Missouri. Farther south, at many places on this western boundary, there are low east-facing escarpments that help to define the margin of the lowland province, but elsewhere the boundary is not clearly marked by any change in topography. Changes in the



By Ewing Galloway, N Y.

Figure 83 · A typical view in a well-developed farming section in the Central Lowlands. Taken near Rockfield, Wisconsin



Courtesy of Illinois State Geological Survey

Figure 84 · Starved Rock. This sandstone hill rises from the south bank of the Illinois River not far from La Salle and is included in a state park. It is one of the scenic and historic spots in this part of Illinois

soils and in the vegetation, resulting from increasing aridity to the westward in the continental interior, help to emphasize the geographic significance of the boundary which has been adopted. See the map at the end of this book and also the rainfall and climate maps opposite pages 6 and 8 respectively.

Materials and structure. The Paleozoic sandstones, limestones, conglomerates, shales, and coal extend in nearly horizontal positions westward from the Appalachian Plateau to the eastern margin of the Rocky Mountains. They are the foundation materials of the Central Lowlands. At the south they pass beneath the sediments of the Coastal Plain, and at the west beneath the surface formations of the Great Plains. At the north they overlap the Pre-Cambrian complex of the Laurentian Upland. The arrangement of the sediments in the north near the upland is similar to that on the present Coastal Plain. See Figures 84 and 72.

When the eastern part of North America was uplifted at the close of the Paleozoic era there was some buckling or deformation of the floor of the ancient inland sea. Structural domes are present in the bluegrass country near Lexington, Kentucky, and in the vicinity of Nashville, Tennessee, and there is a low anticlinal arch in the region about Cincinnati. In the southern peninsula of Michigan and in the central portion of Illinois the underlying structures are broad, saucerlike depressions, which are just the reverse of the low domes in Kentucky and Tennessee.

North of the Ohio and Missouri rivers most of the lands included in this province are heavily mantled with glacial drift. Here the debris left by the continental ice sheets has buried the underlying strata and obscured all but the bolder solid-rock features in the preglacial topography. However, the deposits left by the ice have produced a topography with as much variety and relief as that which they buried. In this part of the continent virtually all the topographic features are due, in one way or another, to glaciation.

The Subprovinces

The Lake District. In the northeast, bordering four of the Great Lakes (Michigan, Huron, Erie, and Ontario), is the subprovince which may be referred to as the Lake District. Its surface is mantled with recent glacial deposits that were left by certain great lobes of the Labrador and Patrician ice sheets or by waters that issued from these lobes of ice. Thousands of lakes, small ponds, and swamps give character to this landscape. Bordering the Great Lakes there are lacustrine plains and old shore lines that indicate the former extensions of those bodies of water. Later the history of the Great Lakes will be reviewed in some detail.

The Driftless Area. In the center of the northern portion of the Central Lowlands lies an area over which the continental ice sheets did not pass. It is called the Driftless Area and stands as an island surrounded by lands mantled with glacial drift. The greater part of this

area lies in southwestern Wisconsin, but small portions extend into the adjacent states of Illinois, Iowa, and Minnesota. Because it was not

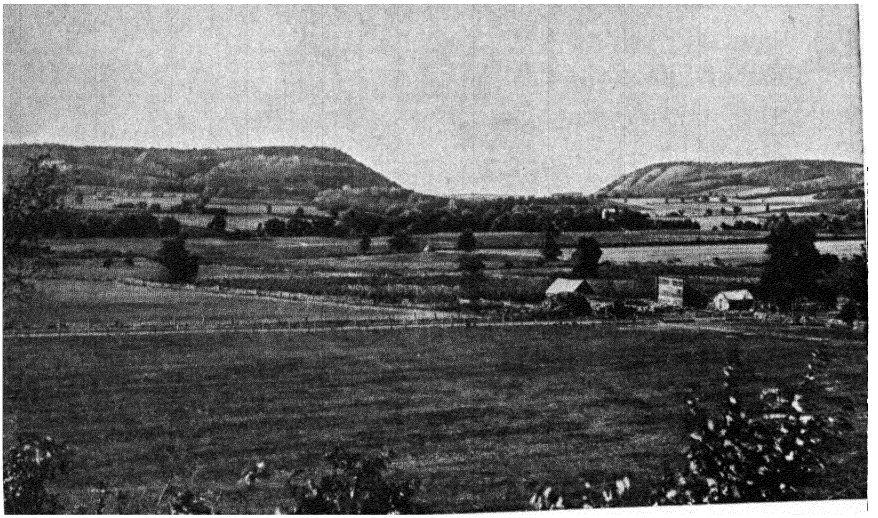


Figure 85 · The lower narrows of the Baraboo River near Baraboo, Wisconsin. The highland ridge in the distance is of Pre-Cambrian quartzite, and the water gap was probably cut and occupied by the Wisconsin River in preglacial time. The great ridge was a monadnock in the Pre-Cambrian landscape. It was deeply buried beneath Paleozoic sediments and has since been resurrected and become a monadnock in the present landscape

covered by the continental ice, this section differs from the surrounding territory in topography and soil and, as a consequence, in economic development. Here weathering and stream erosion have continued since the withdrawal of the shallow continental sea at the close of Paleozoic time. The lands have been dissected over and over again as one cycle of erosion after another has advanced through the stages of youth and maturity. Much of the overlying mantle of sedimentary rocks has been removed, and near Baraboo, Wisconsin, the upturned edges of an ancient syncline of Pre-Cambrian rock formation have been uncovered. See Figure 85.

The summit of the Baraboo Ranges suggests an old peneplain, but the correlation of that isolated surface with remnants of peneplains in other provinces, separated from the Driftless Area by hundreds of miles

of glaciated lands, is very hazardous. The present drainage pattern in southwestern Wisconsin is dendritic, just as would be expected in an unglaciated region of nearly horizontal strata. In portions of this section the summits correspond so closely in elevation that they have been interpreted as parts of a peneplain and the name Lancaster has been proposed for that surface.

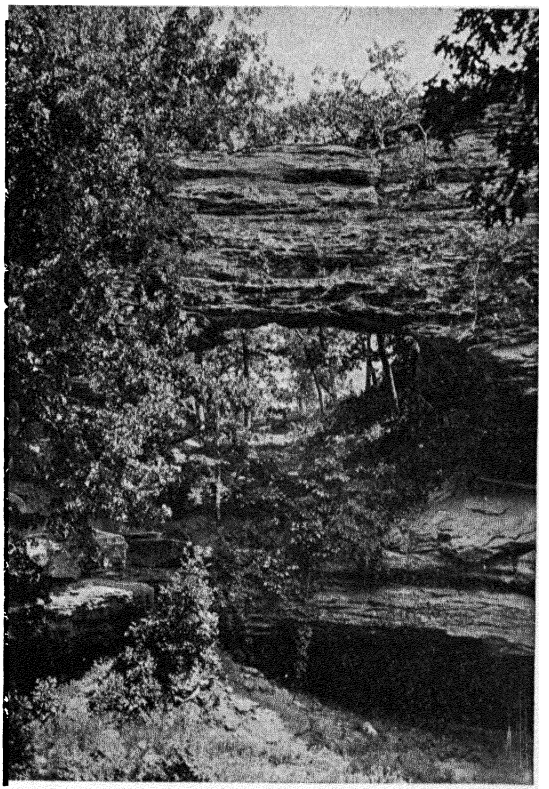


Figure 86 · A natural bridge in the Driftless Area near Denzer, Wisconsin. Such features are absent in the glaciated portion of the state

The use of a local name without any commitment as to a correlation with the erosion surfaces in the southeastern unglaciated section or in the Appalachian Highlands is wise, but we venture the opinion that the Lancaster surface is younger than the Schooley Peneplain. Since the development of the summit erosion surface there has been uplift, rejuvenation of all streams, and redissection of the land. Much of the landscape in the Driftless Area is in a mature stage of dissection and in certain portions it is even farther advanced. Many fantastic rock features are present in this subprovince that would not have withstood the onward advance of the great continental ice sheets, and they could not have developed in post-glacial time. The castlelike hills near Camp Douglas and Tomah, Wisconsin, are preglacial features that rise above a lowland developed in the first place by stream cutting and the various processes of weathering. See Figures 86 and 87.

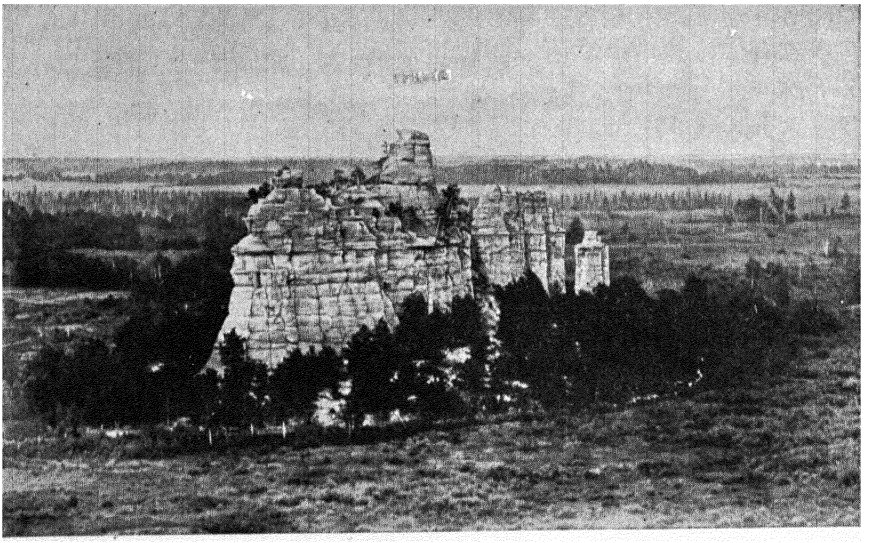


Figure 87 · Castle Rock near Camp Douglas, Wisconsin. This is one of the monadnock forms common in this section of the Driftless Area. They now rise above a plain which was covered by the waters of an ice-front lake

The Northwest Glaciated Division. The northwestern portion of the Central Lowlands is another region mantled with deposits of recent glacial drift and having an abundance of small lakes and ponds. The drift in this section was deposited by the ice sheets that formed in the Keewatin center of accumulation. The recession of the waters from an ancient lake in this subprovince left an extensive plain surrounding the present Lake Winnipeg and extending southward in the valley of the Red River into the Dakotas and Minnesota. The history of that ancient body of water, called Lake Agassiz, will be presented a little later, since the lake was associated with the closing stages of the great Ice Age.

In this division of the Central Lowlands the records of the preglacial erosion history are buried deep below the surface.

The Central Drift Plains. South of the three northern subprovinces lies a considerable area of drift-covered lands in which there are very few lakes. Much of the drift mantle in this section is older than that in the northern subprovinces and in the Laurentian Upland. It represents the work of the earlier ice sheets. Throughout the entire belt there

is a gently rolling surface, but there are more and larger valleys than in the areas mantled with the younger drift deposits. The preglacial erosion history in this section is obscured by the drift mantle. See Figure 88.

The Southeastern Unglaciated Division. Between the Appalachian Plateau and the Mississippi River lowland and south of the outermost terminal moraine of the continental ice sheets there is an area of low plateaus, cuestas, and karst topography that is a part of the Central Lowlands. Here most of the topography is due to stream erosion that has continued since the uplift at the close of Paleozoic time. The low domal structures in this section are reflected in the relief features. Cuesta escarpments face the Lexington plain and the Nashville Basin, and their associated uplands, sometimes plateaulike, slope gently away from the centers of maximum uplift.

Some of the higher rock surfaces in this region may represent the Schooley erosion cycle; but broader surfaces of gentle topography, such as the Lexington plain and the floor of the Nashville Basin, are much younger and may be of about the same age as the Harrisburg strath terraces in the Appalachian Highlands. Below the horizon of these broad erosion surfaces many of the streams with meandering courses are deeply entrenched. This indicates that there has been a period of uplift and rejuvenation since the close of the Harrisburg cycle.

In this division of the Central Lowlands and especially in central and western Kentucky and southern Indiana ground waters have dissolved vast quantities of an underlying limestone and developed a remarkable series of subterranean labyrinths. Marengo and Wyandotte caves in southern Indiana are widely known for the beauty of their crystal forms, and Mammoth Cave in Kentucky, now a national park, is one of the most famous caverns in the world. In Wyandotte Cave many of the stalagmites and stalactites have met, thus forming cylindrical columns. Such columns increase in diameter as the waters dripping over their sides evaporate and leave more lime. One of these columns, called "The Pillar of the Constitution," is at least 25 feet in diameter. Mammoth Cave has not been fully explored, but already 140 miles of subterranean passageways are known. Where passageways widen out,

great rooms, in some cases 100 feet in diameter and 40 to 50 feet high, are formed. In this section there are few surface streams but many sinkholes. The work of underground water has produced many square miles of karst topography.

The Southwestern Unglaciated Division. Southwestward beyond the margin of continental glaciation, the Central Lowlands extend through eastern Kansas, across Oklahoma, and into Texas. This section is often referred to as the Osage Plains. The absence of glacial features distinguishes it from the plains farther north. It is an area of low escarpments and plains in which the faintly inclined underlying strata have been beveled by stream erosion. Later uplift caused the streams to entrench their courses. This section has passed through several cycles of stream erosion.

A Brief Review of the Preglacial Physical History of the Central Lowlands

The old-age erosion surface beneath the Paleozoic sediments but exposed about the south margin of the Laurentian Upland extends southward and is buried below the present surface of the Central Lowlands. That very ancient peneplain records a long and undoubtedly very complicated history of erosion. Then the land sank, for the sediments of Paleozoic age, which consist of thousands of feet of sandstones, shales, conglomerates, and limestone, accumulated in a shallow inland sea. The beds of coal associated with those formations are evidence of extensive marshes that existed at intervals during the long period of sedimentation. The layers of salt that are included with the Paleozoic strata indicate that at times portions of the inland continental sea were cut off from the open ocean and evaporated.

When the great physical revolution at the close of the Paleozoic era which uplifted the Appalachian Highlands and the Laurentian Upland occurred, the interior of the continent was uplifted also, and the structural conditions within this province indicate that as uplift proceeded there was some gentle warping or folding of the strata.

Following the uplift and the withdrawal of the Paleozoic sea, streams became established in this interior province and began their normal work of dissecting the land. As erosion continued, the valleys grew wider, the divides lower, and the major irregularities of the land were presumably worn away. This portion of the continent was subject to stream work during the long period of stability when the Schooley Peneplain was being developed in the Appalachian Highland and in the Laurentian Upland. That same peneplain probably extended throughout the Central Lowlands, but it is exceedingly difficult to identify with certainty any remnants of that surface within this province. The uplift that closed the Schooley cycle probably affected the lands in this province, and it is reasonable to assume that surfaces were developed in the Central Lowlands comparable in age to the Harrisburg surfaces in the Appalachian Highlands. It is also reasonable to assume that the subsequent upwarpings that affected the Appalachian Highland provinces caused some uplift in the Central Lowlands. The great diastrophic movements that punctuated the physical history of the earth are commonly widespread in their influence.

In the southeastern unglaciated division of the Central Lowlands there are erosion surfaces that may, with some degree of confidence, be correlated with those in the neighboring province to the east. Accurate correlation of erosion surfaces in the Driftless Area of the upper Mississippi Valley with surfaces in provinces that are far removed, and separated from the Driftless Area by extensive tracts of glaciated terrain, is very difficult. The records of preglacial stream erosion within the glaciated portions of the Central Lowlands are forever buried. Even if we could discover the topography of the rock surfaces beneath the glacial drift we should not know how much that surface had been modified by ice erosion. The preglacial erosion history of those portions may never be known.

We may assume that there were well-developed drainage lines and a somewhat roughened topography in the interior of the continent when the Ice Age opened. The present relief features of the Driftless Area are a fair sample of what may have been somewhat widespread. The cuestas and low plateaus in the southeastern unglaciated division help us to imagine what may have been the topography before the great

ice sheets advanced southward into the territory of the United States. The Niagara escarpment, which is a great cuesta bordering the south shore of Lake Ontario and extending into the region of Georgian Bay and Lake Huron and appearing again in eastern Wisconsin, is suggestive of some of the preglacial topographic features of this province. See Figure 107 on page 223. The relief features of the Osage Plains at the southwest are also a sample of the topography that must have been present farther north near the western margin of the Central Lowlands.

We cannot be certain that the drainage was all southward to the Gulf of Mexico. Some of the preglacial drainage lines may have found an outlet to the northeast where the St. Lawrence Lowlands are now located, and, as we shall see later, some of the streams from the Rocky Mountains that now turn southward and become a part of the Missouri River may have flowed northward and northeastward into Hudson Bay. There is no doubt that the continental ice sheets profoundly disarranged the drainage within the Central Lowlands.

The Ice Age

The work of the ice sheets. No land surface in North America has been more profoundly modified by the work of continental ice sheets than has the northern two thirds of the province now under consideration. Here the scouring, grooving, striating, and polishing of bedrock surfaces by material frozen into the bottom of the ice are all illustrated. Here are found a remarkable series of terminal and recessional moraines, a vast amount of ground moraine, hundreds of drumlins, and a full assortment of fluvioglacial deposits. In this region many of the classic studies of T. C. Chamberlin,[1] R. D. Salisbury,[2] A. P. Coleman,[3]

[1]T. C. Chamberlin, "Glacial Phenomena of North America," in *The Great Ice Age and Its Relation to the Antiquity of Man*, by J. Geikie. New York, 1894. Pp. 724–774.

T. C. Chamberlin and R. D. Salisbury, "On the Driftless Area of the Upper Mississippi Valley," *U. S. Geological Survey, Annual Report*, No. 6 (1885), pp. 199–322.

[2]R. D. Salisbury, "Distinct Glacial Epochs and the Criteria for Their Recognition," *Journal of Geology*, Vol. 1 (1893), pp. 61–84: "The Drift, Its Characteristics and Relationships," *Journal of Geology*, Vol. 2 (1894), pp. 708–724, 837–851.

[3]A. P. Coleman, *Ice Ages, Recent and Ancient*. New York, 1926.

F. B. Taylor,[1] Frank Leverett,[2] W. C. Alden,[3] G. F. Kay,[4] and other pioneer students of glaciation in North America were carried out. The contributions of these men have been of the greatest significance in advancing our knowledge of ice work and in deciphering the history of the great Ice Age in the Western world.

Four, and possibly five, distinct sheets of ice advanced from the Laurentian Upland southward over the region of the Great Lakes and into the upper Mississippi drainage basin. See Figure 88. Each sheet of ice acted at places as a huge, rock-shod rasp, wearing away hilltops or gouging out deep troughs. Over most of the area invaded by the ice a mantle of loose material was deposited when the ice sheets melted away.

The first ice that entered this region must have found deep soils and a considerable thickness of disintegrated subsoil material. This loose mantle was removed completely in most places, reworked by the ice, and deposited as a layer of drift of very uneven thickness and with a topography characteristic of a morainic mantle. Each succeeding glacier picked up much of the earlier drift, worked that material over, and deposited another sheet of drift. During the long periods between the several advances of ice, weathering and erosion were going on and soils were formed, valleys were excavated, lakes were drained, and all the processes which affect land surfaces in regions of moderately heavy rainfall were in progress. Within this province the successive sheets of glacial drift have been recognized, and most of the names selected for these formations have come from here. Figure 88 shows the distribution of drift and the more conspicuous morainic belts which were developed at the margin of the ice within the United States.

Since there is no other province in North America in which the work of continental ice sheets is more significant and so well illustrated,

[1]F. B. Taylor, "A Short History of the Great Lakes," in *Studies in Indiana Geography*, by C. R. Dryer. Terre Haute, Indiana, 1894. Pp. 90–110.

[2]F. Leverett, "The Illinois Glacial Lobe," *U. S. Geological Survey Monograph*, No. 38 (1899), 817 pages: "Glacial Formations and Drainage Features of the Erie and Ohio Basins," *U. S. Geological Survey Monograph*, No. 41 (1902), 802 pages.

[3]W. C. Alden, "The Delavan Lobe of the Lake Michigan Glacier of the Wisconsin Stage of Glaciation and Associated Phenomena," *U. S. Geological Survey, Professional paper*, No. 34 (1904), 106 pages.

[4]G. F. Kay, "History of the Investigations and Classifications of the Pleistocene Deposits of Iowa," *Iowa Geological Survey*, Vol. 34 (1928), 67 pages.

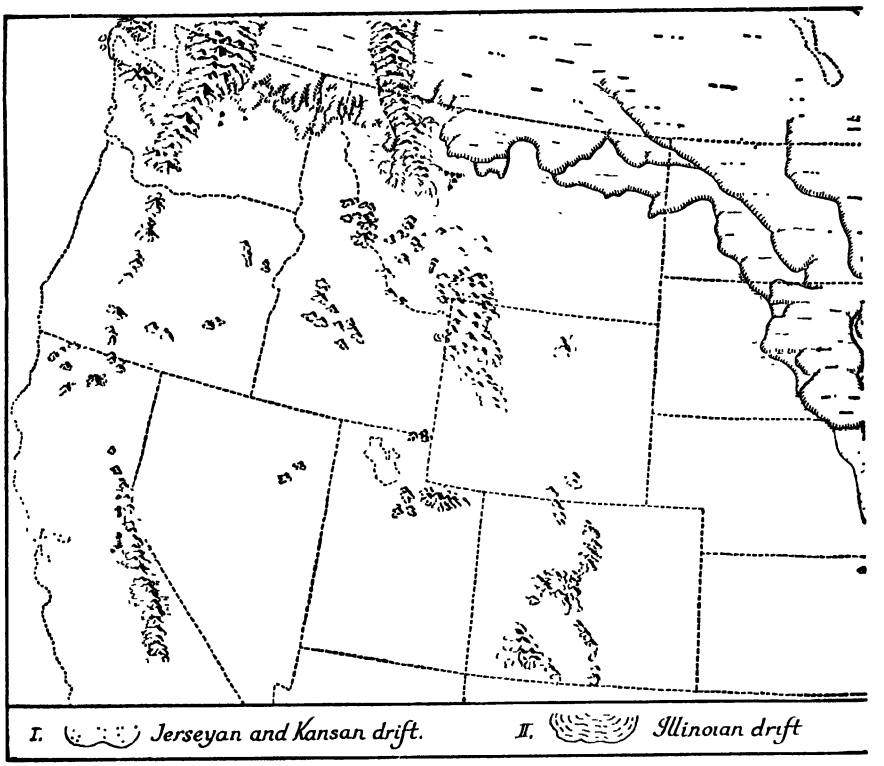
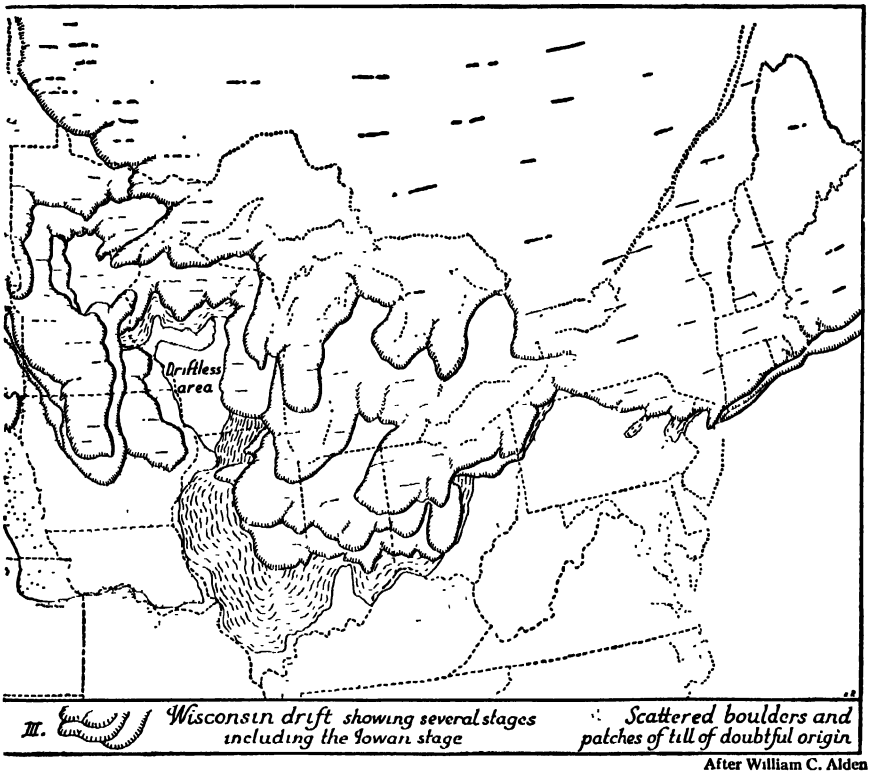


Figure 88 · The morainic margins of the various

it is appropriate for us to pause and consider with some care the nature of glacial drift and the characteristics of the various land forms left by the ice and waters associated with the melting of the great glaciers. These land forms are all illustrated on the topographic maps selected for the laboratory exercises which accompany this volume.

The chief characteristics of glacial drift. The three major characteristics of deposits left by glacial ice are physical heterogeneity, lithological heterogeneity, and lack of stratification.

A typical exposure of glacial drift reveals a great range in the size of materials. The rock material carried by the ice grades from the finest of impalpable dust to great boulders varying from 10 to 15 feet in diameter. Silt, sand, gravel, cobblestones, boulders, and huge angular



After William C. Alden

ice sheets that invaded the United States

blocks of rock may be found in a single exposure. This characteristic of the drift is *physical heterogeneity*. See Figure 89.

Upon examining the constituent stones in the glacial deposits within the upper Mississippi Valley or in other parts of northern United States, an observer will find rock fragments that differ greatly in their composition. It is not uncommon to discover in one exposure samples of sandstones, shales, conglomerates, limestones, granites, gneisses, schists, and numerous varieties of the less common igneous and metamorphic rock. Such variety results from the fact that the ice sheets, formed in the midst of the Laurentian Upland, gathered large quantities of igneous and metamorphic rocks from that surface and then moved southward over a region of great variety in sedimentary strata. Thus *lithological heterogeneity* is another marked characteristic of the formation.

A fresh exposure in drift deposited by ice exhibits unassorted material without the layers which would have been present had the material been deposited by water. It is an unstratified mass such as could well have developed as a result of the melting of the glacier and the consequent deposition of whatever was frozen into the ice. The *lack of stratification* of this till, or unassorted debris, is a third notable characteristic of the ice-deposited drift.

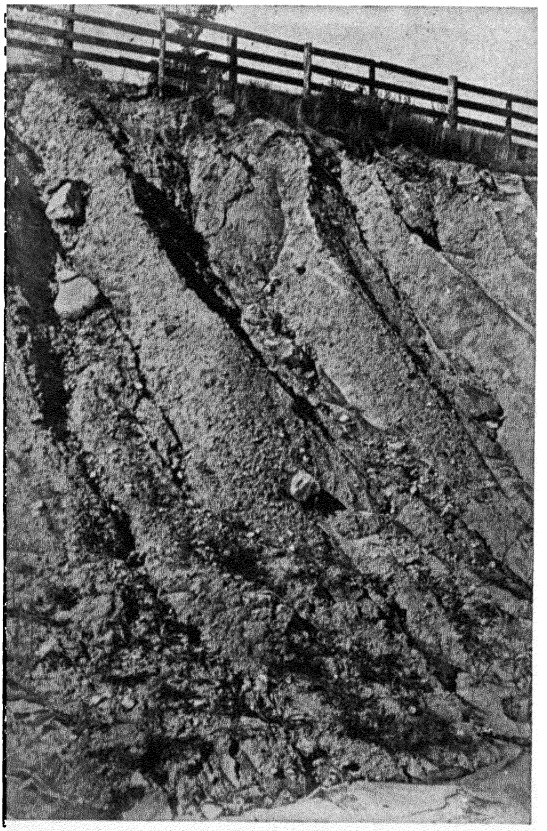


Figure 89 · A typical section in glacial drift exhibiting physical heterogeneity and absence of any clearly marked structure

Types of drift. There are but four distinct types of unstratified drift: terminal moraines, recessional moraines, ground moraines, and drumlins; and four distinct types of stratified material indirectly of glacial origin: outwash plains, valley trains, kames, and eskers. Minor modifications of the eight forms and many combinations may be anticipated in any glaciated region within the area affected by continental ice.

Terminal moraines. The surface features of the drift mantle vary from a gently rolling plain to a hilly region with numerous undrained kettlelike depressions. In Chapter III (p. 89) terminal moraines were defined as morainic material left by the ice at the margin of its position of maximum advance. Such belts commonly vary in width up to four

or even five miles and in relief from 100 feet to even 200 feet. The topography of a terminal moraine may often be described as hummocky, being made up of a succession of irregular hills and deep depressions. One such moraine in southern Wisconsin, a few miles west of Lake Michigan, was known to the farmers in that locality as the Kettle Range long before scientists visited the area and applied the term "kettle" to the small, steep-sided depressions common to frontal moraines. Some frontal deposits have been described as kettle moraines.

Wherever the ice remained for only a short time at its maximum position of advance, the morainic deposits at the outer margin of the glaciated area are not very thick. At these places a well-marked terminal moraine is absent and only a thin mantle of glacial drift is found. Such conditions exist at many places about the margin of the area invaded by the early ice sheets in Kentucky, Indiana, Illinois, and Missouri. There the outer limit of glaciation is difficult to locate.

Recessional moraines. The ice sheets did not retreat steadily, and wherever the outer margin of the ice remained for a considerable length of time recessional moraines were developed. These are frontal moraines just as truly as are the terminal moraines. Topographically they may be as well defined as the moraine left at the outermost position of the ice front. They are also belts of hilly, hummocky, kettle-hole topography where the relief is notably greater than in the surrounding drift-covered areas. On the lands just south of the Great Lakes there are many such moraines. See Figure 90.

Ground moraines. The gently rolling surface which characterizes the prairies of western Ohio, northern Indiana, most of Illinois, and Iowa is produced by ground moraines. As you know, this term may be applied to most of the mantle of glacial drift deposited directly from the ice (p. 89). See Figure 83.

Drumlins. Within the drift-covered country, especially in the central part of southern Wisconsin and in New York State south of Lake Ontario, there are a number of drumlins like those found in New England (p. 90). The origin of these hills of unstratified glacial drift is not



Leverett and Taylor, Courtesy of U. S. Geological Survey

Figure 90 · A diagrammatic representation of the ice border at several successive positions and the direction of ice movement in connection with each position

known. It seems reasonable to believe that they were made during the waning stages of glaciation, after the great continental ice sheets had lost their vigor. They may have been deposited partly in great fissures which formed in lobes of ice that were expanding and breaking along radial lines as the ice spread. This hypothesis was suggested by Alden,[1]

[1]W. C. Alden, "Radiation of Glacial Flow As a Factor in Drumlin Formation," *Geological Society of America Bulletin*, No. 22 (1911), pp. 733–734.

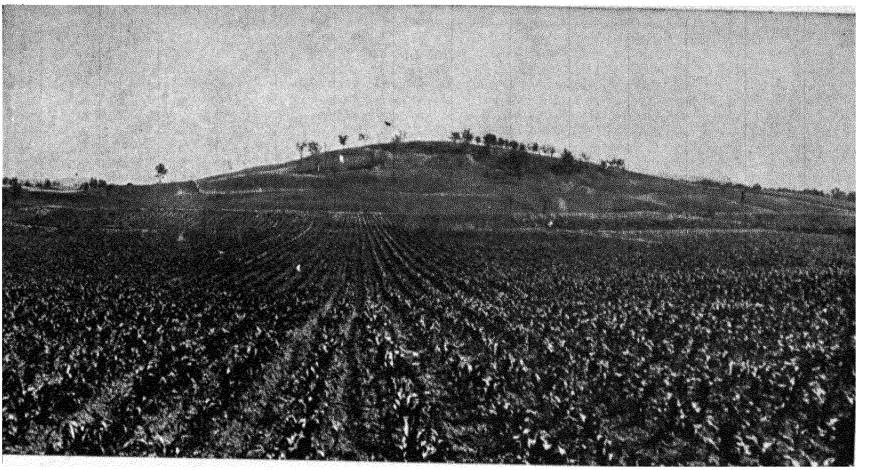


Figure 91 · One of the Wisconsin drumlins. Here the ice advanced from the left

who conducted a detailed study of the drift deposits in southern Wisconsin. They may have been deposited under the glacier and then smoothed and elongated by very slow-moving and none too vigorous ice. The fact that they are of unstratified material proves that they were deposited directly from the melting ice. See Figures 91, 92 and 93.

Outwash plains. The streams in this province which issued from the edge of the ice, carrying vast quantities of sand and gravel, built up a number of outwash plains, or morainic aprons. Such plains are well illustrated by Webster and Sauk prairies in central Wisconsin, which lie west of the terminal moraine and extend into the margin of the Driftless Area of the upper Mississippi Valley. See Figure 94.

Sometimes great blocks of ice were buried or partially buried in the sand and gravel of the outwash deposits. The final melting of these blocks left large pits or craterlike depressions in the otherwise smooth plain. Areas in which this occurred are known as *pitted outwash plains.* A good example is shown on the Whitewater sheet of the topographic maps of Wisconsin.

Valley trains. Wherever stream courses extended outward from the margin of the great ice sheets, sand and gravel accumulated in their valleys during the Ice Age. In the valleys of the Ohio, Wabash, Illinois,

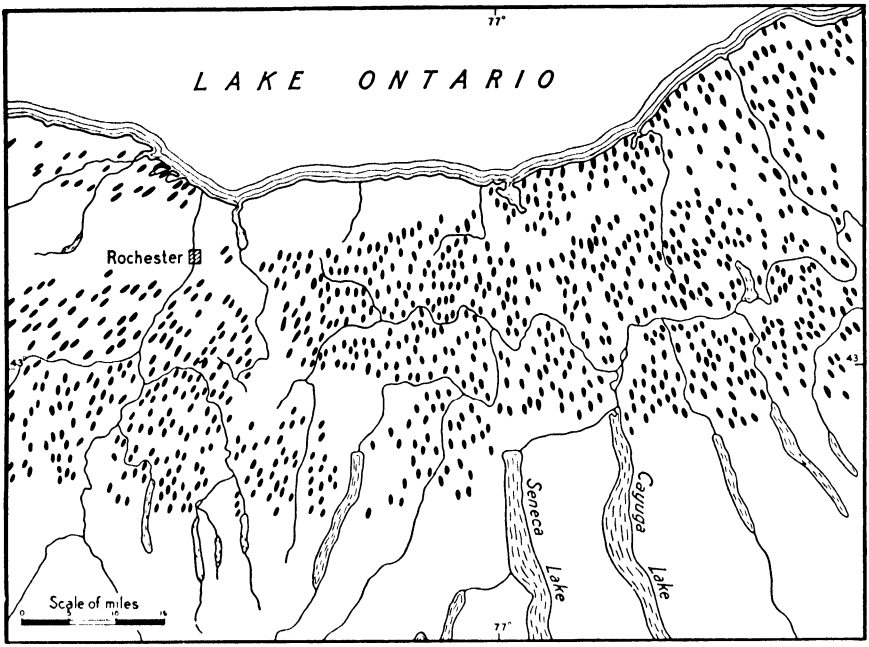


Figure 92 · Some of the drumlins in New York State

Wisconsin, and Mississippi rivers, and in many of the tributary courses, the fluvioglacial outwash deposits known as valley trains have developed. As in the case of the valleys of the Hudson, Delaware, Susquehanna, and Ohio rivers in the Southwestern Division of the Appalachian Highlands, these valley trains today appear as terraces.

Kames. There is no generally accepted theory as to how the hills of stratified sand and gravel of glacial origin known as kames were formed. It is clear that the materials were deposited by water and that the deposition took place while ice occupied the lower areas that now surround these hills. They were probably formed at or near the margin of the ice during a late stage in the melting away of the great glaciers.

At the margins of present-day ice sheets in the Far North, sand and gravel accumulate along the outer edge of the ice and are often deposited in lakes or ponds on the surface of a decaying ice sheet. When such ice finally melts, the sand and gravel now being laid down may be left as isolated hills or short ridges and so give rise to kames.

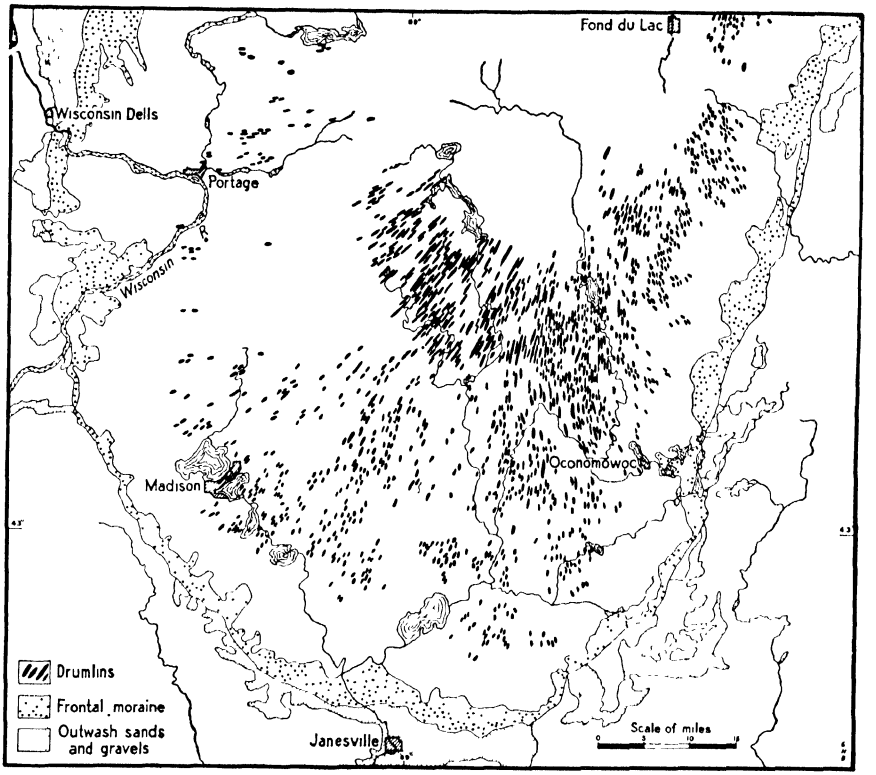


Figure 93 · Some of the drumlins in Wisconsin and the associated moraines and outwash plains at the margin of the Green Bay lobe. (After Alden)

Eskers. The retreating ice also left many eskers in this province. As in New England, the size and length of these ridges of sand and gravel vary (p. 91). In places they rise nearly 100 feet above their surroundings and range up to 500 feet in width at the base. Their crests are usually narrow and resemble old railroad embankments. The eskers may occur as straight ridges only a few rods long, or they may wind across a lowland area as sinuous ridges for several miles and even cross over hills. See Figure 95.

One theory of the formation and origin of eskers is that the sand and gravel were laid down in a subglacial stream course. According to this theory, which has been held in favor by many, the sand and gravel were deposited in a tunnel under the glacier. Upon the melting of the

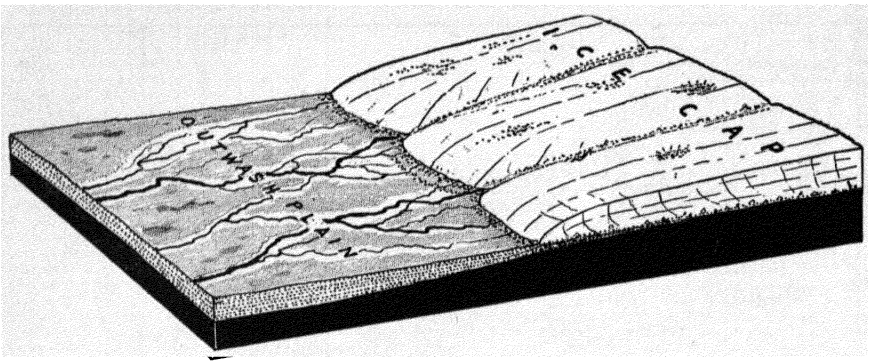


Figure 94 · A diagram to illustrate conditions that obtain while an outwash plain is being developed

ice, these deposits formed a ridge. Some scientists hold that eskers represent deposits of superglacial streams. According to this theory, the sand and gravel were lowered little by little as the ice melted, until they came to rest upon the land surface. Perhaps some of the eskerlike ridges were formed by streams in fissures or in interlobate areas near the margin of a retreating ice sheet.

Kamey areas. The abundance of stratified sand and gravel in hills and short ridges and in small benches or outwash plains has suggested to field workers the term "kamey areas." In such regions it is usually impracticable and probably not worth while to map each of the individual glacial forms accurately, and therefore it is best to group them under an inclusive term such as "kamey area" or "kamey region" or "kame moraine." Such regions undoubtedly result from the varied conditions of deposition at the margin of an ice sheet. The kamey regions of the Central Lowlands are most numerous in southeastern Wisconsin and in Minnesota.

The Driftless Area explained. The area in the upper Mississippi Valley that was never overridden by the ice is shown on the map, Figure 88. The ice that advanced southwestward at various times from the Patrician center was each time diverted in part through the trough of Lake Superior and in part through the trough of Lake Michigan. See Figure 90. With each advance, a small lobe formed on the west

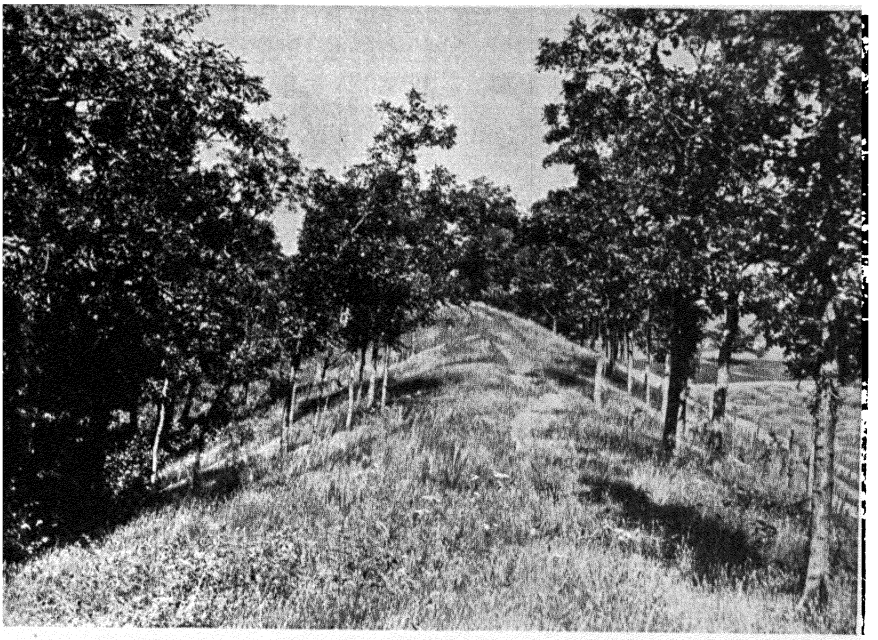


Figure 95 · An esker in the glaciated area of southeastern Wisconsin

flank of the Lake Michigan lobe and occupied the Green Bay depression. Each time three lobes advanced westward and southwestward, but before they had invaded the Driftless Area the climate of North America must have changed so much that the ice fronts began to retreat. From the Keewatin center, west of Hudson Bay, ice moved southward through the territory now included in Minnesota, Iowa, and northern Missouri, and spread eastward and westward; but it never invaded the lands of the Driftless Area. During certain stages the great ice lobes that advanced either from the Patrician center or the Keewatin center occupied the lands south of the Driftless Area, but at no one time did the east and west lobes unite and completely surround the area with ice.

Stages in the Ice Age. As scientists have become better and better acquainted with the drift mantle in the northeastern portion of North America they have recognized at many places that there are two or three layers or sheets of drift that differ in age. The older deposits of glacial drift that are now exposed at the surface are deeply weathered

and somewhat dissected by stream erosion. In these areas there are very few lakes or ponds such as characterize the surface of the most recently deposited mantle of drift. Deep soils, wide valleys, and an absence of lakes in morainic areas imply greater age and help to differentiate the till sheets in different portions of the glaciated area. Thus the moraines in the northern and northeastern portion of Illinois differ notably in topography and drainage from those in the central and southern portions of that state. The moraines in the southwestern portion of Ohio and southern Indiana are much older than the moraines farther north in those states. The rolling prairies of southern Iowa and northern Missouri are much older, from the standpoint of topographic development, than the lands in the central portion of northern Iowa and in the glaciated parts of Minnesota.

In addition to surface features many exposures have been found in the glacial drift along highways and railways in deep wells and in other excavations in which there are buried soils and subsoils. These formations record a long interglacial period when the agents of weathering were at work in the region. In association with the buried soils, certain plant remains have been discovered which indicate that during certain interglacial stages the climate became milder than it has been since the disappearance of the last ice sheet. At a few places other deposits such as river-laid alluvium and lake beds have been found buried beneath one layer of drift and overlying another. These scattered bits of field evidence are of great significance to the geologist in differentiating between the various drift sheets. To the geographer who endeavors to understand the surface features, the contrasts in topography, soils, and drainage are of greatest importance.

The following table presents the order of glacial stages that has been recognized for North America. The oldest drift sheet is placed at the bottom of the column and the others arranged in the order in which they would be found if all were present at any one place. Such a condition, however, is not known to exist. The records of two or three stages are found associated in one section, and in another section the records of two or three other stages may be found. The problem of correlation is exceedingly difficult and has required the attention and services of a number of experts in the science of glaciology.

GLACIAL AND INTERGLACIAL STAGES OF THE ICE AGE

Fourth glacial . .	*Wisconsin* (including much that has been called Iowan). The most recent mantle of drift
Third interglacial .	*Sangamon.* Soils and other interglacial deposits
Third glacial . .	*Illinoian.* A drift sheet widespread in central and southern Illinois, but represented elsewhere south of the Wisconsin till sheet
Second interglacial	*Yarmouth.* Soils and other interglacial deposits
Second glacial . .	*Kansan.* An extensive sheet of drift overlying the Nebraskan in much of Iowa and Missouri
First interglacial .	*Aftonian.* Soils and other interglacial deposits
First glacial . . .	*Nebraskan and Jerseyan.* The oldest known drift sheet

In Figure 88 we have shown the extent and distribution of the older drift sheets where they mantle the surface south of the area invaded by the last or Wisconsin ice sheets. In New Jersey and northeastern Pennsylvania there are thin deposits of moraine that may be as old as any on this continent. These deposits have been called the Jerseyan, but they are generally believed to be of the same age as the Nebraskan till sheet that underlies the Kansan in a section of the Central Lowlands. The Kansan is the next oldest and is especially widespread in Iowa and Missouri; it is the sheet which mantles the surface of northeastern Kansas.

The Illinoian drift, which appears at various places in southern Ohio, southern Indiana, and in central and southern Illinois, as well as farther north in Wisconsin and Minnesota, at the margin of the Driftless Area, is the next youngest sheet of till. Overlying the Illinoian, and also overlying the Kansan and Nebraskan at places, is the Wisconsin drift which gives character to all the recently glaciated portions of the continent. Large areas of this most recently deposited layer of drift are as yet without valleys. Where valleys have been cut in postglacial time they are youthful. The soils also are youthful, and they differ with the several types of glacial and fluvioglacial deposits.

Drainage Changes Resulting from Glaciation

Stream courses shifted and lakes formed. The preglacial drainage patterns in and near the glaciated sections of the Central Lowlands were all more or less altered during the Ice Age. Every stream course was affected in some way by ice erosion or by the deposition of drift, and sometimes by both.

Within the most recently glaciated areas the drainage is yet imperfect. Thousands of small lakes, ponds, and swamps indicate extreme youth from the standpoint of drainage history. Little by little, streams that flow into lakes help to fill the basins with sediments, while the outlet streams, by lowering their channels, drain the waters away to the sea. These conditions exemplify one of R. D. Salisbury's favorite sayings: "Rivers are the mortal enemies of lakes." Efforts have been made to drain many of the lakes and marshes artificially in order to make available for cultivation the fertile alluvium which has accumulated on the lake bottoms. Elsewhere dams have been constructed at the outlets of lakes in order to raise or preserve the level of the water.

In southern New York State, as we have already discovered (p. 136), ice-front lakes formed in the Finger Lakes district and drained for a time into the Susquehanna River. In western Pennsylvania a northward-flowing drainage system was ponded by an advancing ice sheet, and reversed so that in time the drainage turned southward and formed the headwaters of the Ohio River system.

Near Cincinnati the Ohio River was forced out of its former valley to a position farther south. West of Illinois the Mississippi River was crowded out of its former course and forced to cut the narrow valley where Rock Island is now located. The Wisconsin River was pushed westward into the Driftless Area and there so ponded that it formed a large ice-front lake, known as Lake Wisconsin. When the lake receded the stream established a new course in a sandstone formation and carved out the beautiful Dalles of the Wisconsin. See Figure 96.

In preglacial times the Missouri River flowed northeastward from Montana and probably into Hudson Bay. The advance of the great Keewatin ice sheets shifted the stream farther and farther to the south. Waters from the melting ice, added to those brought by the Missouri

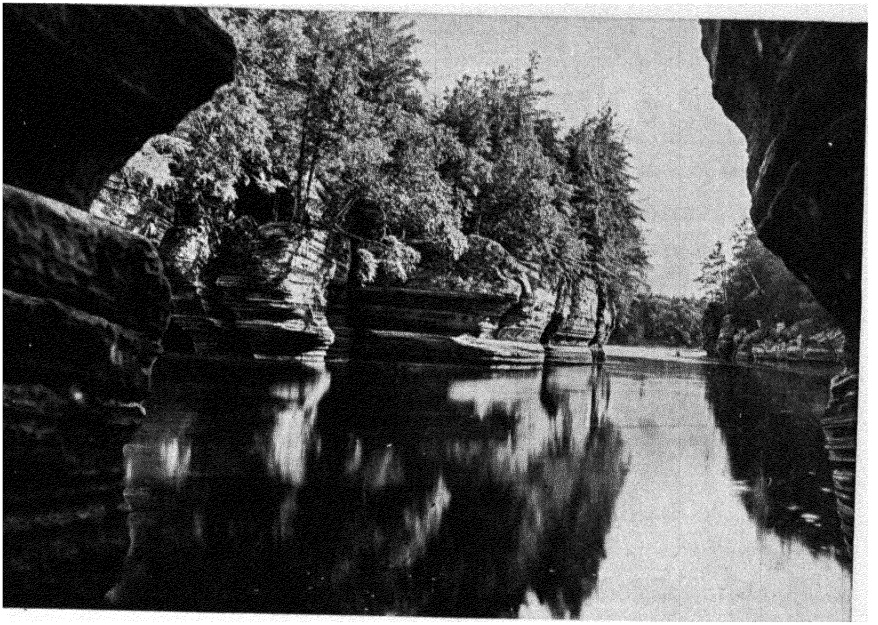


Figure 96 · Steamboat rocks in the Dalles of the Wisconsin River near Kilbourn. Here the river was forced by the ice and morainic deposits to cut a new channel

River from the Rocky Mountain province, followed the margin of the ice southeastward until they joined the Mississippi River.

The ponding of the streams in North Dakota and Minnesota and in southern Manitoba, in front of a Keewatin ice sheet, caused the formation of a very large body of water, which has been called Lake Agassiz. The history of that lake will be presented a little later. During and especially near the close of the Ice Age the Great Lakes were formed and Niagara Falls came into existence.

The history of glacial Lake Agassiz. The dissipation and contraction of the last ice sheet which invaded northern Minnesota and North Dakota fed a large body of water called Lake Agassiz, which existed for about 1000 years. As the ice retreated northward this lake expanded in area, covering the extensive plain drained today by the Red River of the North. At the time of its maximum development the lake was 700 miles long and 250 miles wide. The maximum depth above the present level of Lake Winnipeg was 700 feet. See Figure 97.

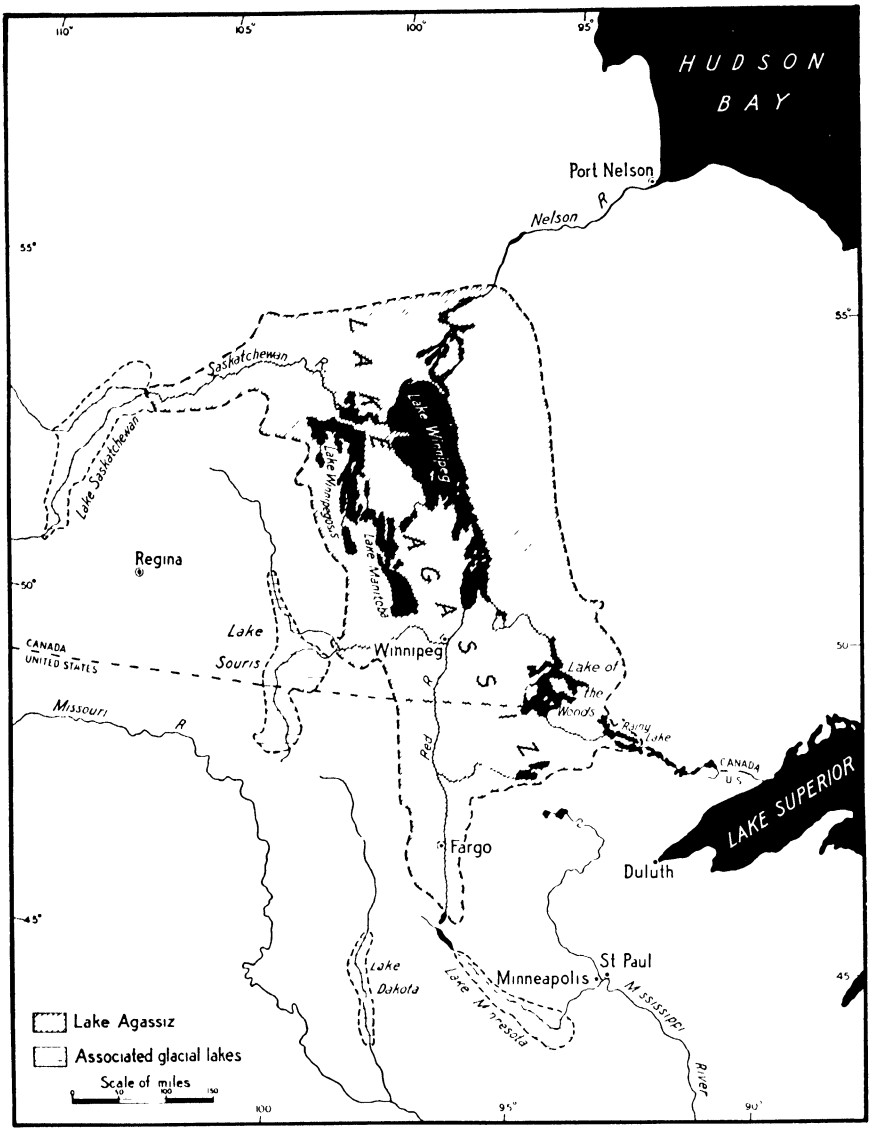


Figure 97 · The area of Lake Agassiz and associated glacial lakes

During the earlier stages in the history of Lake Agassiz its waters drained southward by way of the Warren River, which followed the route of the Minnesota River into the Mississippi drainage system. When the ice had retreated far enough northward, the present drain-

age to the northeast into Hudson Bay was established by way of the Nelson River. After this change in its outlet, Lake Agassiz fell rapidly to about the level of present-day Lake Winnipeg.

Contemporaneous with the retreat of the ice, differential uplift of the land caused the northern portion of the lake basin to be elevated relative to the southern end. This brought into existence the many shore lines which may be seen today at the northern end. Below the outermost shore line (Herman Beach) there are four major beaches which are easily identified in the southern part of the lake area. These are known as the Norcross, Tintah, Campbell, and McCauleyville, all of which are well represented in Minnesota. To the north, the Norcross and Tintah beaches are each double, and the Campbell and McCauleyville beaches are each triple.

While the lake drained southward by the Warren River it passed through seventeen substages, which are marked by successive beach lines. After the northeastern outlet by way of Nelson River was established, fourteen substages followed, each marked today by beach lines which bear the names of places in Manitoba where they are particularly well developed. The divide from the headwaters of the Red River to the Minnesota is very low and, at high-water stages, swampy.

Glacial Lake Agassiz has bequeathed to present-day agriculture an extensive lacustrine plain with fertile soil. It is the North American region par excellence in the production of spring wheat. Other crops, such as oats, barley, rye, and flax, are also grown.

The history of the Great Lakes. More remarkable than the formation of the numerous small lakes, which originated during the dissipation of the last ice sheet, is the history of the Great Lakes. So far as is known, no large lakes existed in this region during preglacial time, but rivers of considerable size had produced wide and deep valleys.[1] Rivers never cut their valleys below sea level. Therefore the preglacial river channels must have been above the level of the ocean, and in this part of the continent they probably were 400 to 600 feet above that level. Since the bottoms of four of the basins, those of lakes Superior,

[1] G. M Stanley, "The Submerged Valley through Mackinac Straits," *Journal of Geology*, Vol. XLVI (1938), pp. 966–974.

Michigan, Huron, and Ontario, are now 200 to 300 feet below the level of the sea some explanation for the great deepening of these troughs must be found. Crustal warping or possibly faulting has been suggested, but there is very little evidence to support such theories. The most reasonable hypothesis is that the great deepening of these basins was accomplished by the successive ice sheets that invaded this region. These ice sheets had great thicknesses at this latitude and therefore had tremendous weight. They were rock-shod and they moved forward with an irresistible force.

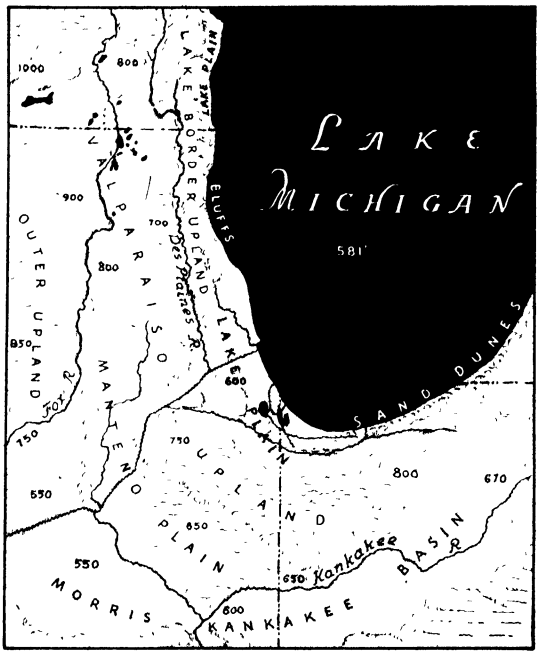


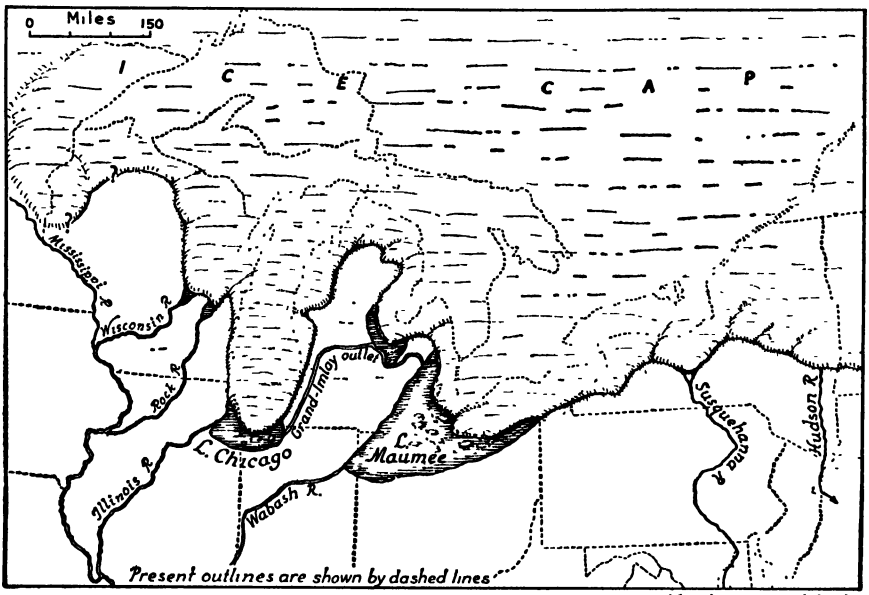
Figure 98 · The physiographic setting of the plain formerly occupied by Lake Chicago

There is abundant evidence of the great erosive work of alpine glaciers in most of the high mountain regions of the world. Many of the canyons in our Western mountains were deepened more than 1000 feet by ice erosion. The depths of the basins occupied by these Great Lakes probably demonstrate the erosive power of the continental ice sheets.[1]

The melting ice furnished vast floods of water, which accumulated as lakes just beyond the great ice lobes. Morainic belts formed the outer boundaries of these ice-front lakes. The waters in the lakes rose, and in time outlets were discovered through low passes in the glacial deposits. The waters from the Western lakes drained by one route or another to the Mississippi River. Thus, in front of the lobe which occupied the basin

[1] F. H. Shepard, "Origin of the Great Lakes Basins," *Journal of Geology*, Vol. XLV (1937), pp. 76–88.

of the present Lake Superior, Lake Duluth came into existence and drained southward by way of the St. Croix River. At the south end of

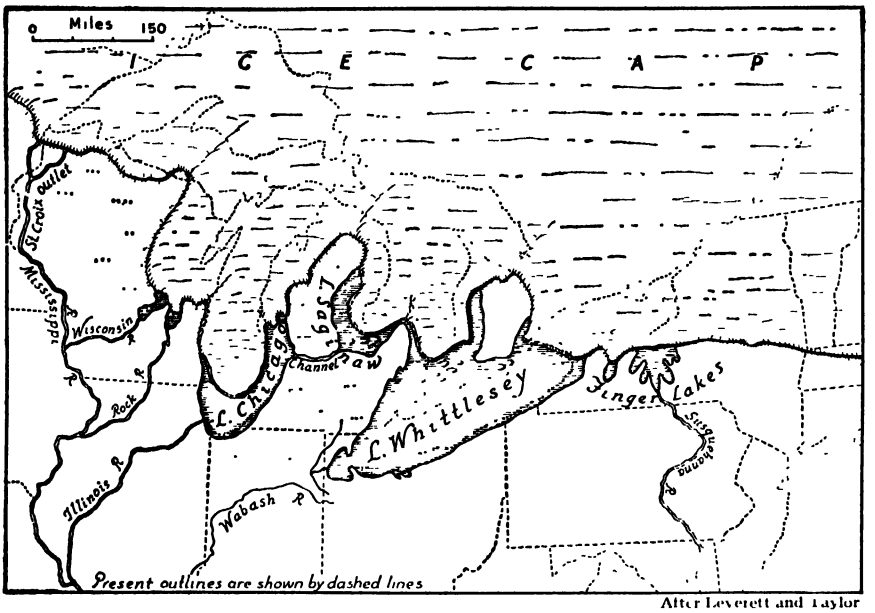


After Leverett and Taylor

Figure 99 · An early stage in the retreat of the late Wisconsin ice sheet, showing the location of Lake Maumee, Lake Chicago, and three other very small ice-front lakes. At this stage the waters from the ice drain by way of the Hudson and Susquehanna rivers in the east and by way of the Wabash, Illinois, Rock, and Wisconsin rivers in the west. All rivers flowing away from the margin of the ice must have been at flood stages

the Lake Michigan lobe was Lake Chicago, which drained into the Des Plaines River and thence to the Illinois River. Lake Maumee was ponded southwest of the Lake Erie lobe and drained by way of the Maumee and the Wabash to the Ohio River. As the ice margin retreated farther and farther north, these lakes became larger. At each stage of their growth special shore-line features were formed. The arrangement and distribution of the ancient lake cliffs, wave-cut terraces, and beach ridges make it possible to trace out the former extent of these lakes at their various stages. Study Figures 99 to 105, which show certain stages in the history of the Great Lakes. See also Figure 98.

When the ice had melted away from most of southern Michigan,

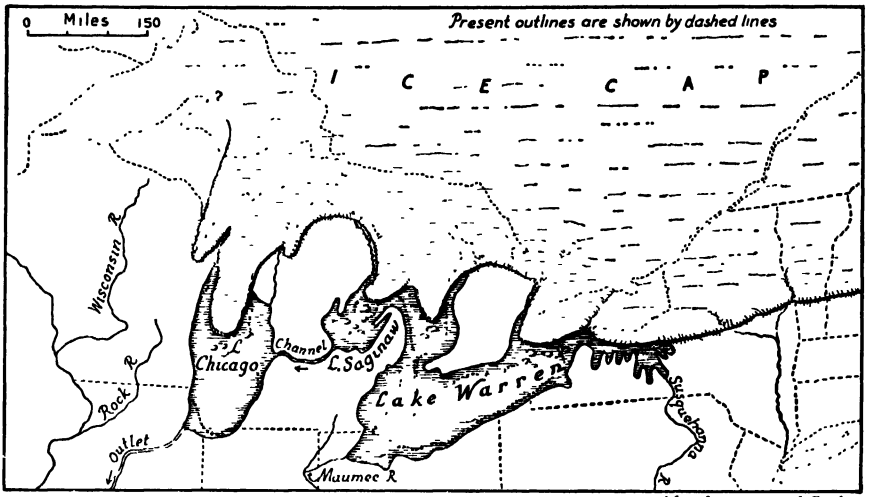


After Leverett and Taylor

Figure 100 · At this stage the Wisconsin ice sheet has retreated so far to the north that the Finger Lakes have come into existence, but they drain southward through the Susquehanna River. Lake Whittlesey occupies the basin of Lake Erie and the surrounding lowlands. The Maumee outlet, by way of the present site of Fort Wayne, to the Wabash has been abandoned. Lake Saginaw has become larger and continues to drain into Lake Chicago. This same outlet serves Lake Whittlesey. Small frontal lakes still exist in Wisconsin at the margin of the Green Bay lobe. At this time the Chicago outlet by way of the Des Plaines River to the Illinois must have been occupied by a very large stream

there remained a lobe in Saginaw Bay; and at the margin of that lobe a small body of water formed, which is known as Lake Saginaw. At one stage the waters from Lake Maumee found a low passage northward near the margin of the ice into Lake Saginaw, and thence westward and southward by way of the Grand River into Lake Chicago. The outlet of Lake Maumee, past the present site of Fort Wayne, into the Wabash was then abandoned.

The expansion of Lake Maumee eastward and northeastward, as it kept up with the retreating ice margin, brought into existence glacial Lake Whittlesey. See Figure 100. This lake drained northward into Lake Saginaw and thence westward into Lake Chicago. At about this



After Leverett and Taylor

Figure 101 · The ice front at this stage has retreated so far to the northward that Lake Chicago occupies the southern half of the Lake Michigan basin and some adjoining territory. The waters in front of the Huron and Ontario lobes are united and form Lake Warren. These waters have united near the front of the ice with the Finger Lakes to the east and Lake Saginaw to the west. Their drainage is westward across the southern peninsula of Michigan by way of the present valley of the Grand River

stage the Finger Lakes in New York formed in valleys from which the ice had disappeared, and their waters flowed for a time into the headwaters of the Susquehanna River.

Little by little, as the ice edge continued to retreat, the shore lines of these ancestors of the Great Lakes shifted. By the mingling of the waters of Lake Saginaw and Lake Whittlesey, glacial Lake Warren was formed. Lake Warren also appears to have been continuous with the waters in the Finger Lake region, but it did not stand at so great an elevation as did Lake Whittlesey. Its waters flowed westward across the southern peninsula of Michigan into Lake Chicago and thence to the Mississippi River instead of southward over the divide in southern New York into the Susquehanna. See Figure 101.

A little later, when the ice had retreated still farther northward, glacial Lake Lundy was formed. It extended westward into the region of Lake Saginaw and eastward into the basin of Lake Huron, and even farther into the region about Kirkfield, north of Lake Ontario. The

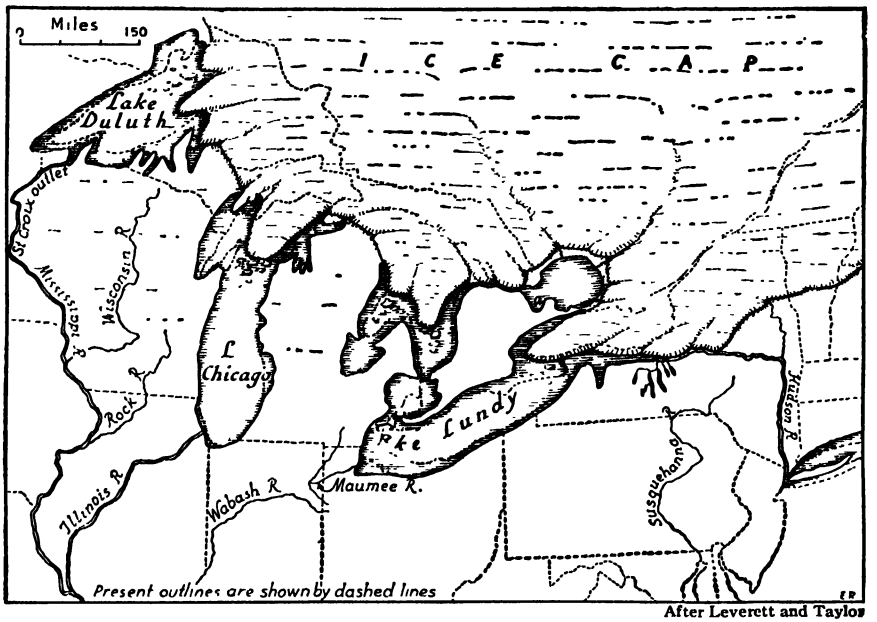


Figure 102 · At this stage the shore lines of the lakes have changed again. Lake Duluth, which undoubtedly appeared at earlier stages although not represented on our diagrams, drains southward by way of the St. Croix River to the Mississippi. Lake Chicago is now nearly as large as the present Lake Michigan. The Grand-Imlay outlet across the state of Michigan has been abandoned. The waters that occupy parts of Lake Huron and all of Lake Erie are known as Lake Lundy. At this time the Mohawk outlet becomes available, and drainage of Lake Lundy is eastward to the Hudson and thence to the Atlantic Ocean

larger portion of Lake Lundy, however, was made up of the basin of Lake Erie. At this time the waters in the vicinity of Lake Erie stood at a slightly lower level because of their discovery of an outlet by way of the Mohawk River. See Figure 102. Thus the waters of Lake Lundy followed the new outlet eastward into the Hudson and thence to the ocean. By the time this stage had been reached, the outlet across the southern peninsula of Michigan by way of the Grand River had been abandoned. Lake Chicago was nearly as large as the present Lake Michigan, and glacial Lake Duluth occupied the western half of the Lake Superior basin. The St. Croix and Chicago outlets were still in use. After the ice disappeared from the lake basins but still occupied



After Leverett and Taylor

Figure 103 · At this stage the ice cap has retreated from the basins occupied by the Great Lakes. The waters of the three upper lakes are united in Lake Algonquin. The drainage from that lake is across Canada and directly into the Champlain Sea. The St. Clair outlet from the north is temporarily abandoned. Ocean waters have advanced into the St. Lawrence valley, flooding all the neighboring lowlands and spreading into the basin of Lake Ontario. The sea waters extended southward into the Lake Champlain basin and may have continued as an estuary to the present site of New York City. The Mohawk Valley also was probably occupied by water

the valley of the St. Lawrence River, the lands adjacent to the Great Lakes were nearer sea level than they are today and the lake waters spread slightly beyond their present outlines. A northern extension of Lake Superior formed Lake Nipigon. Georgian Bay was much larger than it is today; and after a time the waters from the three upper Great Lakes—Superior, Michigan, and Huron—merged into what has been called glacial Lake Algonquin. The waters from this lake drained partly into Lake Erie, partly southeastward from the Georgian Bay region into Lake Iroquois, the ancestor of Lake Ontario, and partly eastward by way of the Ottawa River. The Mohawk outlet was still in use, and so was the Chicago outlet. The Lake Iroquois stage is not shown in the accompanying maps. It precedes the stage shown in Figure 103.



After Leverett and Taylor

Figure 104 · As seen at this stage, the upper Great Lakes are somewhat larger than they are today, and the waters of Georgian Bay are more extensive. Both the Ottawa River and the St. Clair River outlets are in use, but the Champlain Sea has shrunken notably, due to uplift of the American continent, and the Mohawk outlet has been abandoned. Lakes Erie and Ontario appear about as they do today

At this stage a very important incident occurred. As the ice melted away from the valley of the St. Lawrence, the sea waters came in, forming a great inland body of water known as the Champlain Sea. This sea advanced far into the Lake Ontario basin, spread over all the lowlands bordering the valley of the St. Lawrence, and occupied the Champlain–Hudson Valley trough. During this period the New England–Acadian province was an island surrounded by brackish water. See Figure 103. The ancient shore lines of that inland sea, marked by shore terraces carrying, at places, marine shells, stand at present about 600 feet above the St. Lawrence in the vicinity of Montreal.

Finally, with the disappearance of the continental ice sheets and the consequent removal of a great load, the continent of North America rose at the north so that the sea waters withdrew from the upper St. Lawrence and the Hudson–Champlain Lowland. The Ottawa River outlet was abandoned, as were the Trent outlet near Kirkfield and the

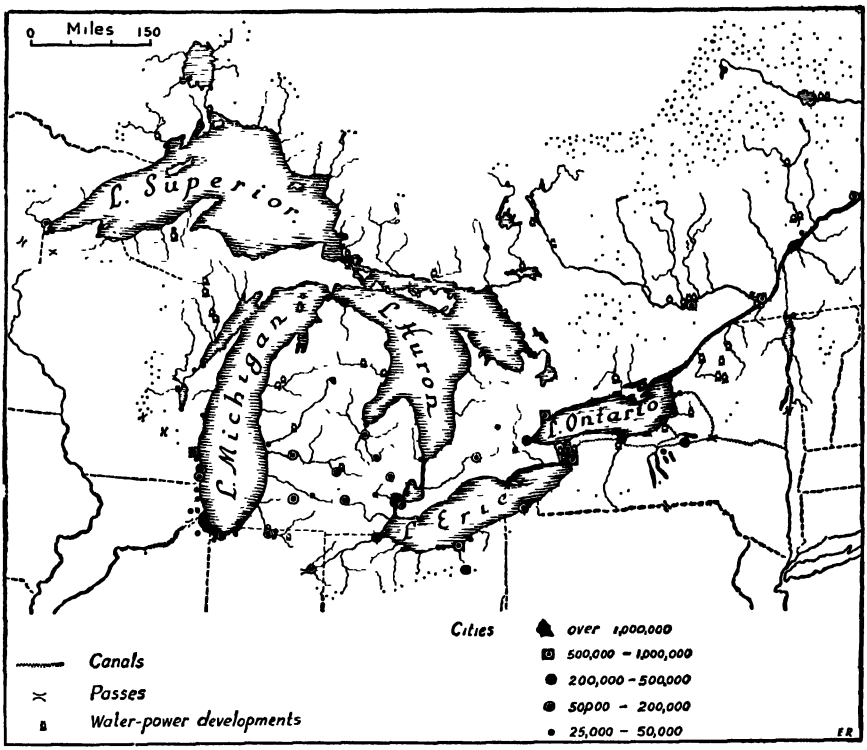
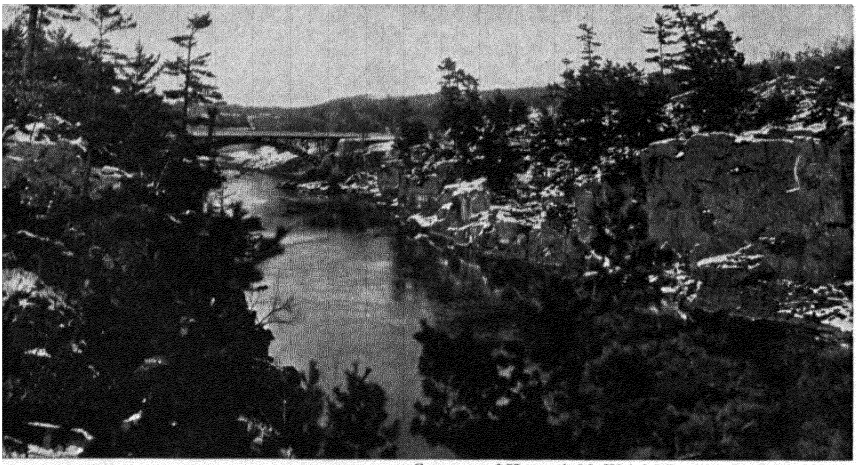


Figure 105 · The changes from the last drainage pattern to this the present-day pattern include the disappearance of the Champlain Sea, the abandonment of the Ottawa outlet, the shrinkage of some of the lakes, and the establishment of the drainage lines of today. This map also shows the strategic locations of many of the large cities in the region of the Great Lakes, some of the water-power-development sites, and certain canal routes. The economic development of this entire area has been profoundly influenced by its drainage pattern and the ancestral outlets of the Great Lakes. Certain of the low passes formerly used as outlets are now occupied by canals, railways, and automobile highways. Many of these routes are also emphasized by notable densities in population and the location of many industrial centers

Chicago and Mohawk outlets. Each of the Great Lakes decreased in size, and the present drainage of the three upper ones became established by way of the St. Clair River into Lake Erie and thence by way of the Niagara River into Lake Ontario and the St. Lawrence. Thus the present St. Lawrence drainage system was established. See Figures 104 and 105.



Courtesy of Kenneth M. Wright Studios, St. Paul, Minn.

Figure 106 · The Dalles of the St. Croix River near Taylors Falls, Minnesota. This gorge was occupied by the waters flowing from Lake Duluth to the Mississippi River. The rocks are ancient lava flows in the Pre-Cambrian complex, located near the margin of the Laurentian Upland

The history of Niagara Falls. Niagara Falls came into existence in the midst of the history of the Great Lakes. When the waters from the basin of Lake Erie first flowed northward, the surface of the ancestral waters of Lake Ontario was 150 feet higher than the surface of the present lake, and the Niagara River was without falls. When the Mohawk outlet became available, the waters in the Ontario basin were withdrawn to a lower level. At that time they built the beach ridge on which the present Ridge Road from Lewiston to Rochester is located. When the waters fell below the top of the Niagara escarpment, which is just south of Lewiston, the falls came into existence. See Figure 107.

The Niagara limestone, which is underlain by soft shales and sandstone, is responsible for the escarpment. See Figure 108. Undercutting at the base of the falls, such as is going on today, has caused block after block of the limestone to give way. As a result, the falls have retreated upstream for a distance of nearly seven miles, leaving a vertically walled gorge downstream from the falls. The depth and width of that gorge represent the dimensions of the falls at various stages in their retreat. The narrow part of the gorge, spanned now by bridges, is probably the record of a period when there was less water than at present flowing

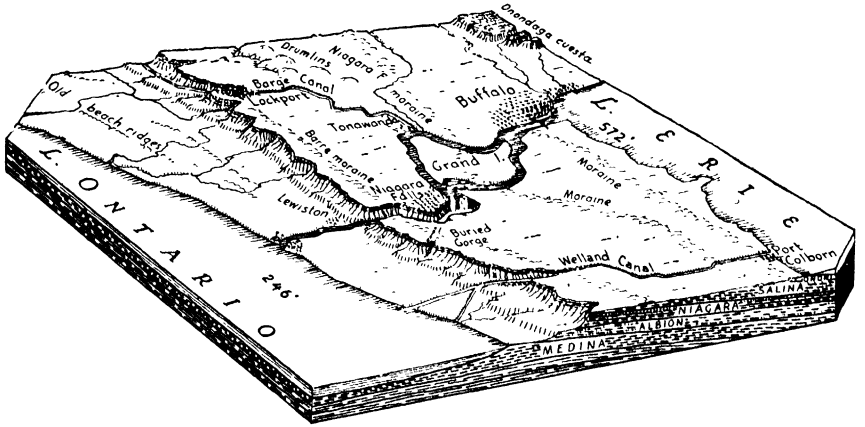
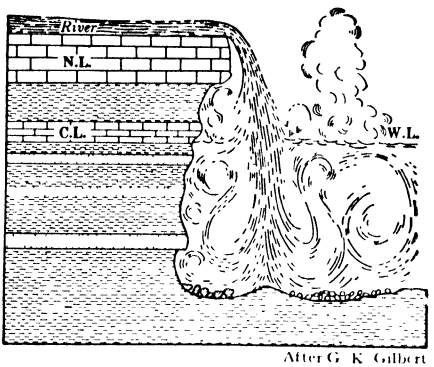


Figure 107 · A diagram to illustrate the structural and physiographic conditions in the vicinity of Niagara Falls. The length of the gorge from the present location of the falls to the escarpment at Lewiston is about seven miles. The moraines on the upland were left by the Lake Ontario lobe of the great ice sheet, and the beach ridges on the lowland plain were developed at stages when the waters in the Lake Ontario basin stood at higher levels

through this route. At the Whirlpool Rapids the stream found soft glacial debris in an ancient valley, and the gorge was cut unusually wide in this unresisting material. A large round basin was excavated at one side of the main gorge, and today the river waters flow in a circular eddy in this basin before moving farther downstream.

The retreat of the falls is now most rapid in the Canadian, or Horseshoe, Falls, where it amounts to about four feet a year. Estimates based on historical records indicate that the time consumed in the retreat from Lewiston to the present site may have been as short as 10,000 years or as great as 25,000 years. Since the surface of the Niagara limestone



After G. K. Gilbert

Figure 108 · Structure section at Niagara Falls, showing the position of the Niagara limestone and the underlying less resistant layers of limestone and shale. "W.L." refers to water level in the pool



Fairchild Aerial Surveys, Inc.

Figure 109 · Niagara Falls from the air

declines to the southward about 35 feet per mile, the falls are certain to have less height as they move upstream. They are now about 160 feet high, but by the time they have migrated two miles farther up the valley they will be less than 100 feet in height. At that place they will be entirely in the Niagara limestone. Undercutting will cease, and the falls will change slowly into rapids. In time the rapids will disappear.

The falls in the Niagara River are among the great scenic features of the continent. Though the vertical descent is not very great, the lateral spread of the combined falls is almost 4000 feet, and the volume of water is greater than that of any other waterfall in North America. See Figure 109.

Shore-Line Features

The margins of the present Great Lakes exemplify almost every type of shore-line feature. Waves have undercut steep cliffs, worn terraces in the rock and glacial drift, and built terraces of loose worked-over materials on the beach. See Figure 110. Undertow and shore-line currents have deposited and redeposited sands in the shape of sand bars,



Figure 110 · Lake cliffs north of Chicago developed in glacial debris. Piers have been constructed to force the accumulation of sands on the beach



Figure 111 · Among the sand dunes at the south end of Lake Michigan. Many of the trees were formerly buried by the sand and thus choked to death

spits, hooks, and barrier beaches. These are illustrated in the map exercises which accompany this book. See Figures 112 and 113.

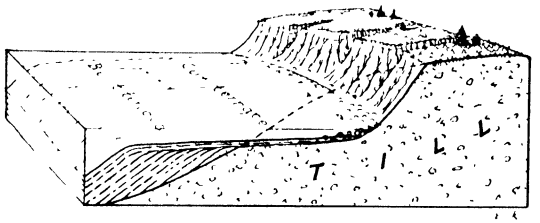


Figure 112 · A diagram to illustrate the development of lake cliffs and wave-cut and wave-built terraces commonly found about the shores of the Great Lakes and many of the smaller glacial lakes in North America

Some of the vast quantities of sand from the glacial material, later modified by wave action, have been redeposited by the winds in large sand dunes, especially on the southern and eastern shores of Lake Michigan. See Figure 111. There the dunes usually migrate inland as the winds from the lake carry the sand from the beach to the leeward side of the hills. Slowly but persistently the dunes march on over forests, swamps, and lowland plains. A typical sand-dune topography with small hills, short ridges, and many undrained depressions has been developed about the southern end of Lake Michigan. Most of the sand hills rise from 40 to 50 feet above the level of the lake, but a few are about 100 feet in height. Northward from Michigan City, along the southeast margin of the lake, there are dunes 300 feet in height and one that is nearly 400 feet high.

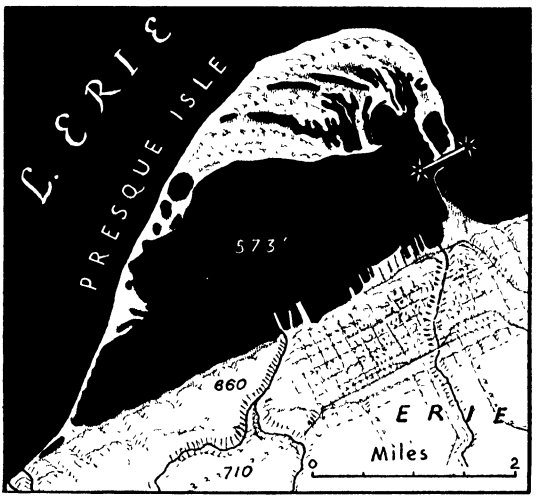


Figure 113 · The sand-and-gravel hook on the south shore of Lake Erie that provides a harbor for Erie, Pennsylvania

Above the present shore lines of the Great Lakes can be traced the ancient beaches which bounded the ancestral lakes in the St. Lawrence system. Cliffs, terraces, sand bars, hooks, and spits of glacial lakes

Chicago, Duluth, Maumee, Whittlesey, Warren, and Iroquois border the margins of the Lake Plains. They furnish unmistakable evidence to support the explanation given here of the evolution of the lakes in this region.

The Mohawk Lowlands

Between the Appalachian Plateau in eastern New York State and the Adirondack Mountains, the Mohawk River follows a lowland trough which, as we have already learned, has played an important part in the drainage history of the Great Lakes. This low pass through the eastern highlands of the United States has played a very important part also in the economic development of New York State and of the whole country.

The Mohawk belt is not by any means a broad and continuous flat land. The topography is very rough at places. Near Little Falls, where the preglacial divide was probably located, faulting has brought to the surface very ancient rocks such as appear in the Adirondack Mountains. These resistant formations have there caused a series of falls and rapids in the stream course.

Since the Schooley Peneplain is recognized in the Appalachians to the south and on the slopes of the Adirondack Mountains to the north it is reasonable to assume that it crossed this belt and has since been in large part removed. The summit of Tug Hill, a long cuesta west of Black River, may be a remnant of that peneplain. The lower surfaces in the Mohawk trough are certainly of much later origin, and the details in topography are due in large measure to the effects of glaciation and lake drainage.

For a time when the Adirondack Mountains divided the great Labrador ice sheet and caused one lobe to move on the east of the mountains through the Lake Champlain trough into the Hudson River Valley and another around the west margin of the mountains and up the valley now occupied by Black River, the lobes appear to have met south of the Adirondack Mountains at about the present location of Little Falls. The lobe that moved westward up the present course of the Mohawk has been called the Mohawk lobe. Since ice came for a

time from two directions into this trough, and undoubtedly shifted its position several times, the waters from the surrounding highlands must have been ponded at different places for longer or shorter periods. This would account for many of the fluvioglacial deposits in the trough and for some of the roughness in topography. When the drainage was established eastward through the Mohawk Valley a large delta was built at the eastern end of the Mohawk trough in Lake Albany.

An Approach to the Human Drama

Within a few years after the establishment of the independence of the United States of America the frontier of settlement moved westward through the Appalachian Highlands into the interior plains of the continent. The advance was always uneven, for the immigrants were guided by the easiest routes of travel, which were the water courses. At each stage the frontier zone of settlements had fingerlike projections and deep re-entrants. Gradually the settlements increased and the bare spaces between the main routes of migration were occupied. The frontier zone moved steadily westward until it reached the western margin of the Central Lowlands, where, because of increasing aridity, there was a distinct halt. See Figure 114.

Those who took part in the great human drama within the Central Lowlands were first guided by the distribution of the better farm lands. They naturally tried to select the best land available from the vast stretches of public domain. As the groups of settlers in any one district became sufficiently large, local forms of government were set up and schools and churches were built. With the development of the farming communities came the need of roads and of railroads; for provision had to be made for the exchange of goods among the individual groups within the Central Lowlands and between the people in that region and those east of the Appalachian Mountains. The age of railroad construction came, very fortunately, at the right time to help in the settlement and economic development of the continent.

The extensive mixed hardwood and softwood forests at the eastern margin of the Central Lowlands and the softwood forests in the north-



Official Photograph, U. S Army Air Corps

Figure 114 · Corn and wheat fields in the midst of the prairies. This picture was taken near Belleville, Illinois

ern sections provided an abundance of construction timber as well as wood for the making of furniture, vehicles, and farm implements. The discovery of coal, oil, and natural gas within the province gave a tremendous impetus to the establishment of manufacturing industries. Iron and copper were known to exist in the neighboring region to the north in the vicinity of Lake Superior. Lead and zinc were discovered in northwestern Illinois and southwestern Wisconsin. There was an abundance of building stone, cement rock, glass sand, and materials used in making concrete. Great salt beds were found in the southern peninsula of Michigan. A vast amount of water power was available. With such natural resources at hand, it is not surprising that the region developed not only as one of the great farming sections of the continent but also as a great manufacturing district. It is doubtful whether there is anywhere in the world a land area equal in size to the Central Lowlands of North America in which the basic environmental factors, such as topography, climate, soil, water supply, water power, waterways, and mineral resources, especially fuels, provide more favorable conditions for economic development.

The prosperity of the farming communities meant an ever-increasing call for wagons and farm implements, sewing machines, furniture, and, in time, for telephones, automobiles, tractors, radio sets, and virtually all that the city dwellers enjoy in the way of electrical equipment and household furnishings. The great wagon-manufacturing firms became producers of automobiles. Numerous small factories scattered about in the towns and villages took up the manufacturing of accessories for the new vehicles of transportation. Certain cities, particularly in Ohio, concentrated on the manufacture of automobile tires. At South Bend, Indiana, at Chicago, Moline, and Deering, Illinois, and at Racine, Wisconsin, great factories were built for the construction of farm implements to meet an ever-increasing demand for labor-saving devices.

Never in the history of the world were so many remarkable farm machines invented and manufactured as in the period of farm expansion in the Central Lowlands of the United States. American farm machinery and tools are now used in most of the great farming lands of the world. In the Central Lowlands also the first airplane was built,

and here are manufactured today many of the most successful of the modern airplanes which are used in the transportation of mail, express, and passengers. Through the perfection of many farm implements and the construction of various types of automobiles and airplanes American inventive genius, at work during a period of great cultural development in this part of the United States, has made many notable contributions to the world.

The combination of fertile farm lands, where the climate was favorable for crop production, and a great wealth of mineral resources, together with remarkably good waterways and sources of water power, brought about a very rapid development not only in the economic phases of the human drama in the Central Lowlands, but also in the cultural phases. The public-school system expanded rapidly, and magnificent school buildings were erected and maintained at public expense. Literally hundreds of colleges and universities were founded. Each state established and developed a state university on a magnificent scale, and, either in connection with that university or as a separate institution, an agricultural college. Technical schools, teacher-training institutions, art museums and art schools, and institutions for business training sprang up. Great public libraries and public parks were established and developed in all the more progressive communities. State parks, sanctuaries for the preservation of bird life and plant life, and state forests were established. Today we find in this central portion of the continent a many-sided human drama moving rapidly forward, and a group of communities which is making a notable contribution to the growth of the nation.

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SELECTED LIST OF TOPOGRAPHIC MAPS FOR THE CENTRAL LOWLANDS

Grimsby, Ontario[1]
Hamilton, Ontario[1]
Niagara, Ontario[1]
Peterborough, Ontario[1]
St. Thomas, Ontario[1]
Dufferin, Manitoba[1]
Brandon, Manitoba[1]

Rochester, New York

Erie, Pennsylvania

Ashtabula, Ohio
Berea, Ohio
Cleveland, Ohio
East Columbus, Ohio
Napoleon, Ohio
Ottawa, Ohio
West Columbus, Ohio
East Cincinnati, Ohio–Kentucky
West Cincinnati, Ohio–Kentucky
Conneaut, Ohio–Pennsylvania

Ann Arbor, Michigan
Bay City, Michigan
Chesaning, Michigan
Elsie, Michigan
Fennville, Michigan
Holland, Michigan
Kalamazoo, Michigan
Milford, Michigan
St. Clemens, Michigan
Stockbridge, Michigan

Horse Cave, Kentucky
Mammoth Cave, Kentucky

[1]Published by Department of Mines and Resources, Ottawa, Canada

Hermitage, Tennessee
Nashville, Tennessee
White Bluff, Tennessee

Muscle Shoals, Alabama
Tuscumbia, Alabama

Bloomington, Indiana

Barrington, Illinois
Blue Island, Illinois
Carlinville, Illinois
Decatur, Illinois
Dunlap, Illinois
Elgin, Illinois
Equality, Illinois
Greenfield, Illinois
Metamora, Illinois
Palos Park, Illinois
Sag Bridge, Illinois
Waterloo, Illinois
Calumet Lake, Illinois–Indiana
Alton, Illinois–Missouri
Pearl, Illinois–Missouri

Chillicothe, Missouri
Elmer, Missouri
Kimmswick, Missouri–Illinois
St. Charles, Missouri–Illinois
Dearborn, Missouri–Kansas
St. Joseph, Missouri–Kansas

Baraboo, Wisconsin
Briggsville, Wisconsin
Chippewa Falls, Wisconsin
Denzer, Wisconsin
Elk Mound, Wisconsin
Fond du Lac, Wisconsin
Kendall, Wisconsin
Neenah, Wisconsin
Sun Prairie, Wisconsin
Surficial Deposits of Southeastern Wisconsin[1]
The Dells, Wisconsin
Winona, Wisconsin–Minnesota

Albia, Iowa
Lehigh, Iowa
Oelwein, Iowa
Elkader, Iowa–Wisconsin

Aitkin, Minnesota
Battle Lake, Minnesota
Cuyuna, Minnesota
Deerwood, Minnesota
Minneapolis, Minnesota
Perham, Minnesota
Plainview, Minnesota
St. Paul, Minnesota
Underwood, Minnesota
Vergas, Minnesota
Wealthwood, Minnesota
Beardsley, Minnesota–South Dakota
Cochrane, Minnesota–Wisconsin

Edgeley, North Dakota
Emerado, North Dakota
Grand Forks, North Dakota
Larimore, North Dakota
Minot, North Dakota
Oberon, North Dakota
Sawyer, North Dakota
Tokio, North Dakota

Peever, South Dakota–Minnesota
White Rock, South Dakota–Minnesota–North Dakota
New Effington, South Dakota–North Dakota

Ardmore, Oklahoma
Claremore, Oklahoma
Kiefer, Oklahoma
Pryor, Oklahoma
Skedee, Oklahoma
Yale, Oklahoma

Abilene, Texas
Pickwick, Texas
Sweetwater, Texas

[1] Plate III, *Professional Paper No. 106*, United States Geological Survey.

VII

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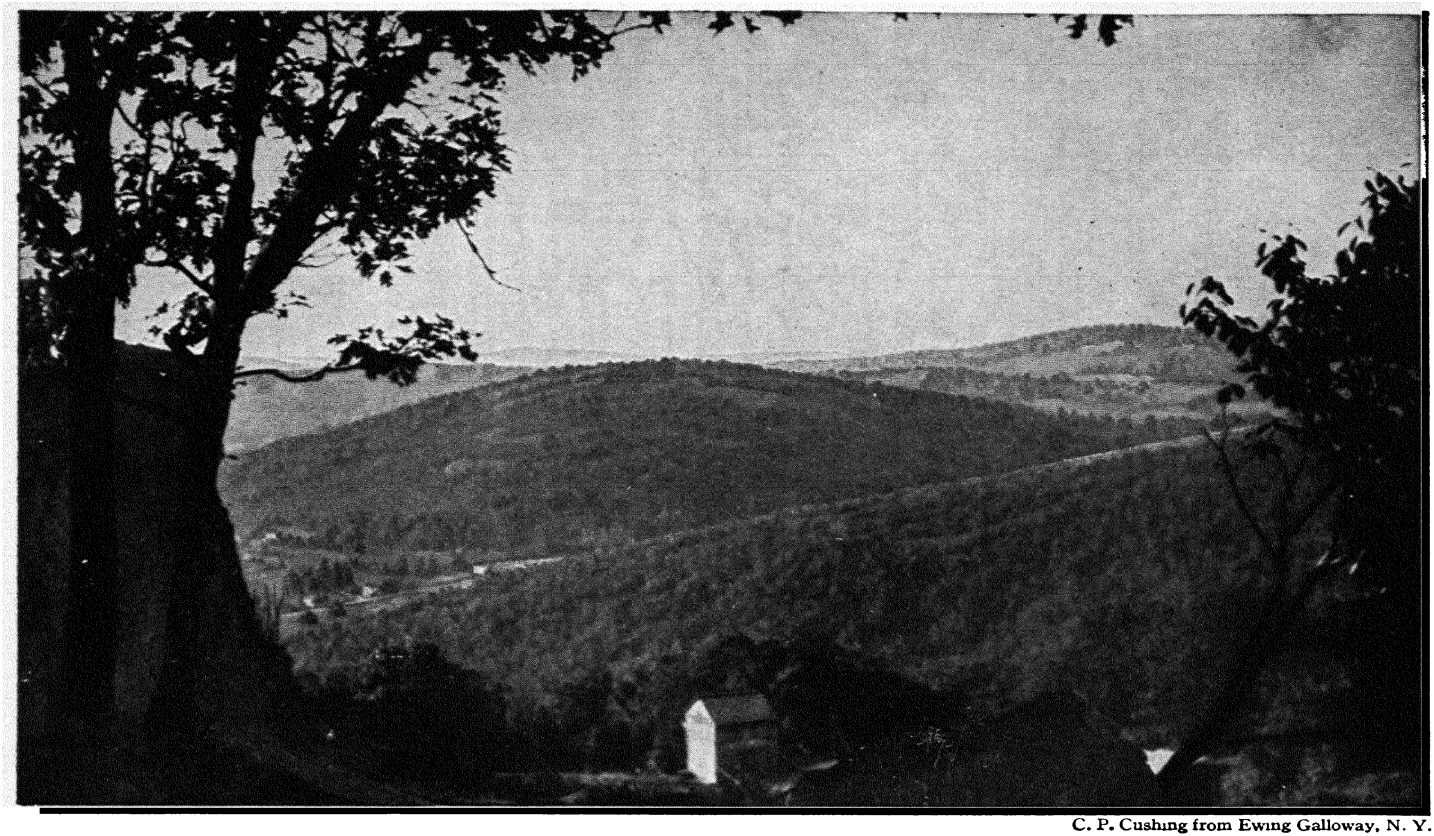
THE INTERIOR HIGHLANDS



C. P. Cushing from Ewing Galloway, N. Y.

Figure 115 · The Ozark Hills in Iron County, Missouri

A General Description

Location. West of the Mississippi Valley Lowland and south of the Missouri River are the Interior Highlands. This province includes the lands that are generally known as the St. François Mountains, the Ozark Plateau, the Boston Mountains, the Arkansas Valley Lowland, and the Ouachita Mountains. Two small outliers west of the Ouachita Mountains, known as the Arbuckle and the Wichita Mountains, are structurally more closely associated with this region than with any other physiographic province. They will be described in this chapter although they rise in the midst of the Osage Plains that are a part of the Central Lowlands. See Figure 115 and the map at the end of this book.

The landscape from the air. Southwestward from St. Louis the surface of the land rises from about 400 feet to elevations that range from 1100 to 1300 feet above the sea. If we were to follow this course in the air we could detect, on a clear day, in southeastern Missouri a group of ancient mountains, the St. François, that appear to have been buried and are now being uncovered as the sedimentary rocks that surround them are worn away. Directly below would be the rolling surface of the Salem Plateau, which for the most part is forested but is dotted with thousands of funnel-like pits where the surface material has been washed into underground caverns, and steep-sided sinkholes where the roofs of caverns have collapsed. This is evidently a land where a large amount of an underlying limestone has been dissolved by ground waters. In some of the pits, or coves, in this landscape good soils have accumulated and farming is carried on. Most of the area is, however, a desolate wilderness with a sparse population.

Approaching the valley of the White River the surface of the land declines and is deeply dissected. Farther south the north face of the Boston Mountains appears as a bold escarpment due to very resistant layers that form the surface of that mountain area. These mountains resemble in some respects the Catskills, for they are carved out of a plateaulike belt and are heavily forested. The settlements in this section

SOUTH

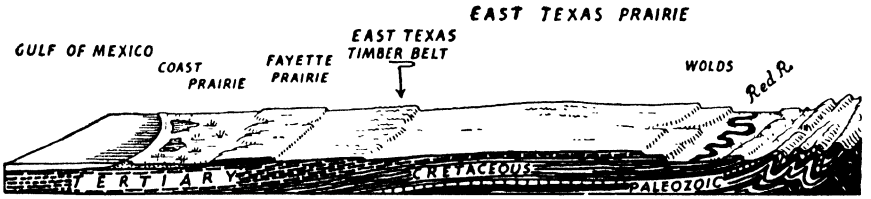
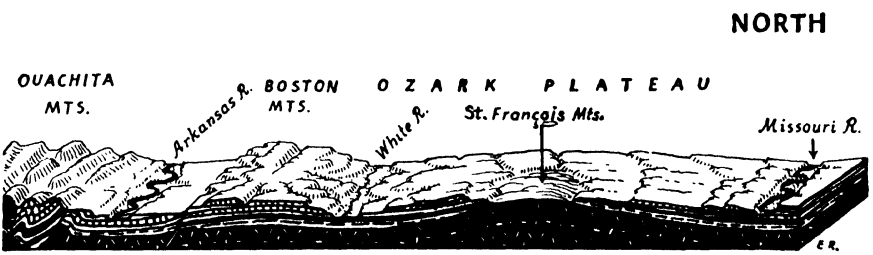


Figure 116 · Diagrammatic structure section from the Missouri River southward to Highlands and the

are limited to the valley bottoms. A little farther south we should be flying over a broad valley of good agricultural lands with Little Rock near its eastern margin. Then we should pass over a belt of mountain ridges that would remind us of the Newer Appalachian Mountains. Here the population is sparse; there are no large settlements, but there are scattered farms and ranches. In time we should come to the inner margin of the Gulf Coastal Plain, which is also the southern limit of the Interior Highlands.

Materials and structure. The diagram reproduced in Figure 116 presents in simple form the generalized structure southward from the Missouri River through the domal structure centering in the St. François Mountains to the White River trough and thence through the Boston Mountains, the valley of the Arkansas River, and the Ouachita ranges to the Gulf Coastal Plain. This structure section reflects a close relationship between the topographic features of the Interior Highlands and the underlying rock structures.

The St. François Mountains consist of Pre-Cambrian granites, porphyries, and metamorphic rocks. Those formations are comparable in age to the rock formations which have been encountered in the Older Appalachian Mountains, the Piedmont, and the Laurentian Upland. They are a part of the fundamental complex exposed at many places in the continent and must underlie the entire province. They were uplifted in the center of this large, low dome at the close of the Paleozoic era, when many physical changes took place in the crustal portion of the earth. See Figure 117.



the Gulf of Mexico, with associated relief features. This section crosses the Interior Gulf Coastal Plain

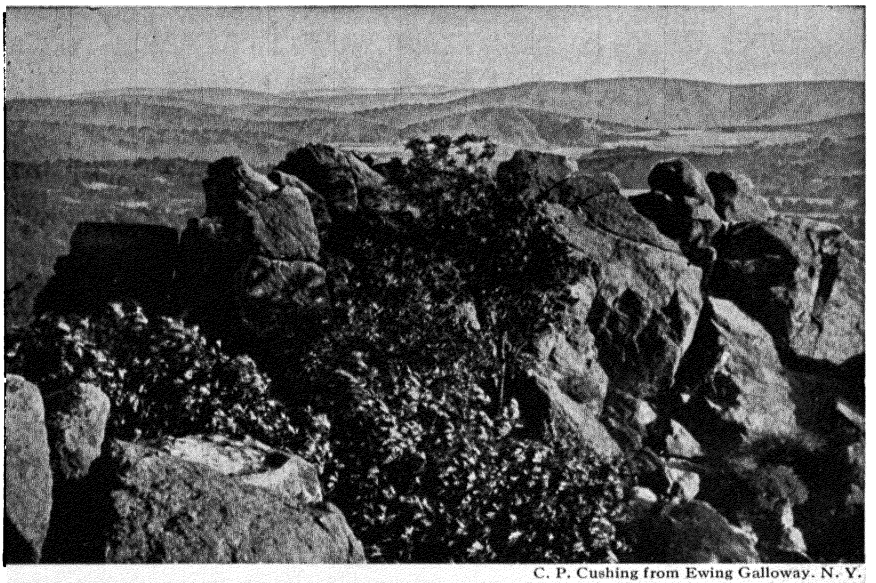
The Ozark Dome is composed of gently inclined strata of Paleozoic sediments. The dip is greatest on the east side and extends across the Mississippi Valley into southern Illinois where the domal structure is represented in the Shawneetown Ridge. On the west side the dip of the strata is so little that in any one outcrop the beds appear to be nearly horizontal.

The Boston Mountains are composed entirely of Paleozoic sedimentary rocks. Here there is a low anticlinal structure at the west end and a monocline farther to the east.

In the portion of the valley of the Arkansas which crosses the Interior Highlands, the underlying rock structure is a complex syncline made up of many small folds. The rock formations are the same layers of sandstone, shale, and limestone that form the Ozark Dome and the Boston Mountains. The terraces and modern flood plain of the Arkansas River are mantled with stream alluvium. This trough is an example of a fair-sized geosyncline.

In the Ouachita Mountains the rock formations are of the same general age as the sedimentary rocks in the more northerly portion of the Interior Highlands as well as in the Newer Appalachian Mountains and the Appalachian Plateau region east of the Mississippi River. They accumulated in inland seas during the Paleozoic era and have since been uplifted and, in the area south of the Arkansas River, tightly folded and much faulted.

The extension of the structure section shown in Figure 116 through the Coastal Plain brings out certain local features in eastern Texas and helps to emphasize the relationships of topography to structure.



C. P. Cushing from Ewing Galloway, N. Y.

Figure 117 · Pilot Knob, one of the more prominent features in the midst of the St. François Mountains of Missouri

Evolution of the Present Land Forms

In the Ozark Dome. As weathering and stream erosion attacked the Ozark Dome, the sedimentary cover was slowly removed and the core rocks in the eastern portion of the dome were exposed. The streams continued their work and uncovered a group of hills that must have existed as somewhat prominent features in the Pre-Cambrian landscape. In an area of about 1000 square miles the ancient rocks are exposed at numerous places and in the St. François Mountains the sedimentary cover has been entirely removed. At many places the older rocks appear just at the surface or as low hills surrounded by Cambrian sediments. It is clear therefore that a hilly or mountainous landscape is being resurrected. Iron Mountain (1077 feet) and Pilot Knob (1014 feet) are the most prominent topographic forms in the group. The local relief is from 800 to 900 feet. At another locality about 60 miles southwest of the St. François Mountains the Pre-Cambrian complex of ancient rocks is being uncovered and another group of hills is being resurrected.

As the streams worked upon the blanketlike layers of sedimentary rocks in the Ozark Dome, they must have passed through successive cycles of erosion more or less like those recorded in the Appalachian Highlands. The inclined strata now appear as cuestas on the slope of the dome. Their escarpments face inward toward the St. François Mountains and their longer slopes decline radially to the margins of this special structural feature. On the east the cuesta slopes are so steep that they cannot be used as evidence of old erosion surfaces. Such slopes are due to structure. On the west the slopes of the cuestas are plateau-like and their surfaces truncate several strata. Such conditions mean old-age erosion surfaces.

The Salem Upland, which is a portion of the broad Salem Plateau or platform in the central part of southern Missouri, is probably part of a peneplain that was formerly widespread in this province. The Springfield Plateau near the west margin of Missouri is another cuesta upland, and its surface probably represents the horizon of the same peneplain recognized on the Salem Upland. Other minor cuesta uplands on the slopes of the Ozark Dome probably belong to the same stage in the erosion history of the province, and it has been suggested by several who have worked here that these upland surfaces be considered parts of the Ozark Peneplain. A little later we will consider the correlation of this peneplain with old erosion surfaces in the Boston and Ouachita Mountains and in the eastern part of the United States.

The Ozark Peneplain cycle of erosion was brought to a close by a renewal of uplift, and in this section there appears to have been a slight redoming. During the succeeding cycle of erosion some broad lowland belts were developed by stream work and in certain valleys wide flood-plain areas were excavated. These surfaces are strath terraces and parts of an incipient peneplain.

Then came a distinct uplift that opened a gorge-cutting cycle. Here the streams have entrenched their old-age meandering courses so that today their meanders are in young valleys. This is positive evidence of rejuvenation. The strath terraces of the previous stage are believed to be of late Pliocene age, and that would make the gorges early Quaternary.[1]

[1]O. H. Hershey, "River Valleys of the Ozark Plateau," *American Geologist*, Vol. 16 (1895), p. 350.

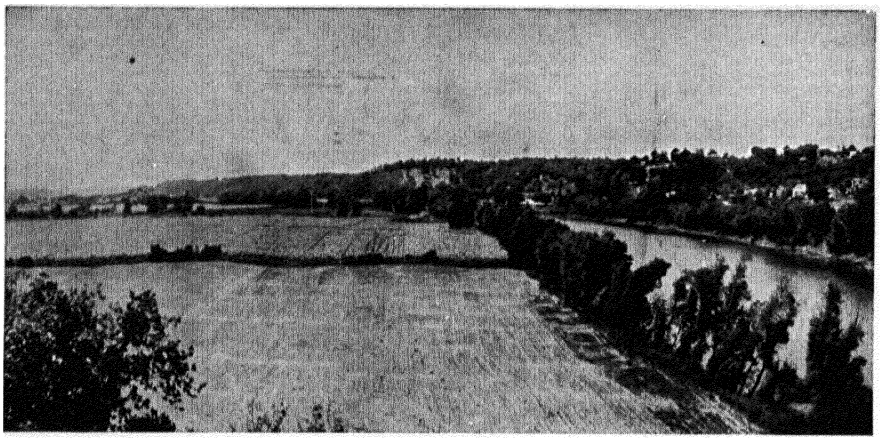


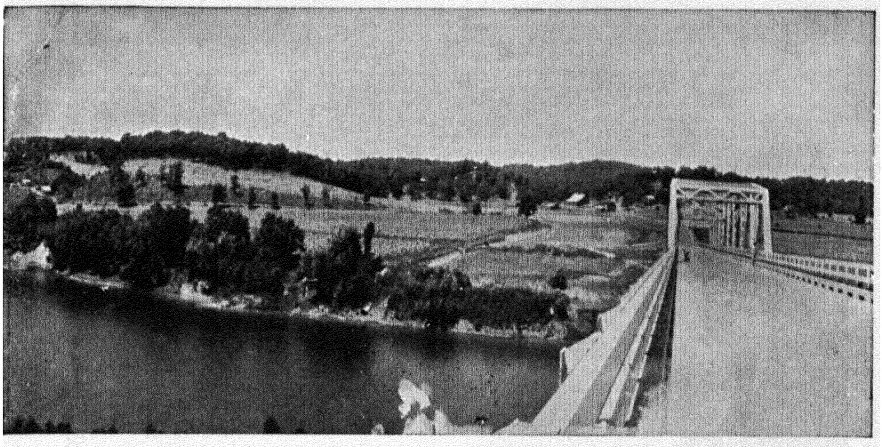
Figure 118 · The valley of the Osage River in Miller County,

In the valley of the White River, at the south margin of the Ozark Dome, several distinct erosion surfaces have been developed. These are clearly shown on the topographic maps of that section. They record many of the details in the physiographic history of this province and invite careful field studies. See Figure 118.

In the Boston Mountains. The Boston Mountains are about 200 miles long and from 30 to 35 miles wide. They rise to an elevation of about 2200 feet, which is 1000 feet above the floor of the valley of the White River. These mountains have been carved out of an uplifted peneplain. Many of their summits are nearly flat and those surfaces truncate inclined strata. The evidence of peneplanation is the same as found in many parts of the Appalachian Plateau, and here as there the summit is called a part of the Schooley Peneplain. See Figure 119.

Following the cycle of erosion when the present summit areas stood near to the base level of erosion, there has been uplift and rejuvenation of the streams. The valleys have been deepened through one, two, and possibly three interrupted cycles of erosion. Many of the valleys are now gorgelike and do not retain clear evidence of the different stages in their history.

In the Arkansas Valley. The Arkansas River flows eastward from the Osage Plains, which are part of the Central Lowlands, through a

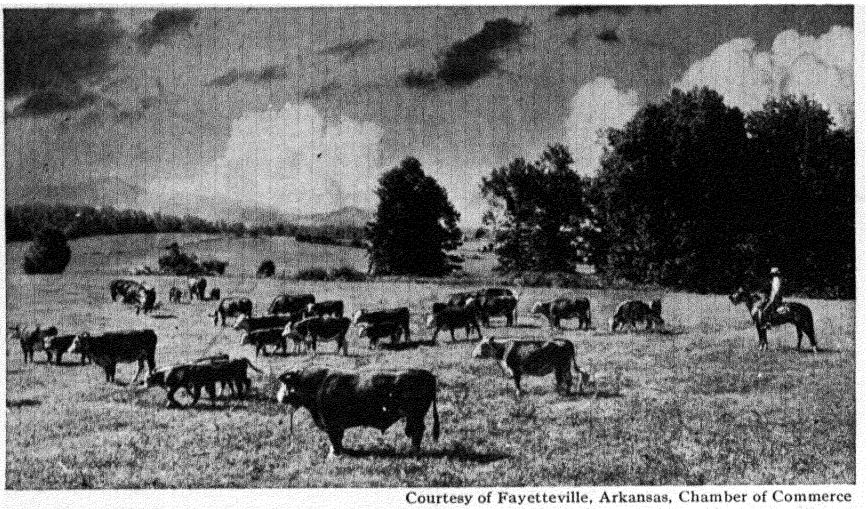


Missouri. The main valley has reached early old age

lowland belt bordered on the north by the Boston Mountains and on the south by the Ouachita Mountains. At Little Rock the river enters the Mississippi embayment area, which is included in the Gulf Coastal Plain province.

The structure beneath the Arkansas Valley belt consists of a series of folds which taken together form a synclinorium; and the Ouachita Mountains to the south, taken as a whole, consist of a series of folds that together form a great anticlinorium. Where the lowland is located the structure is that of a geosyncline, while the highlands have resulted from the dissection of a geoanticline.

In the western portion of the lowland belt, occupied by the Arkansas River, there are low cuesta ridges with east-facing escarpments similar to those in the Osage Plains. Farther east and north of the Arkansas River, and at a few places near the south bank, there are broad alluvial terraces which record the work of streams and imply several recent uplifts which have allowed the streams to lower their channels. In this section of the lowland the underlying hard rocks are buried. South of the river the underlying layers of the great synclinal trough appear as somewhat prominent features, and they are known locally as mountains. Many of them are parts of dissected synclines, and yet they appear today as mesas or tablelands; at other places where the strata are upturned erosion has produced distinct ridges. They are not nearly so bold as are the mountains farther south.



Courtesy of Fayetteville, Arkansas, Chamber of Commerce

Figure 119 · A ranch in northwestern Arkansas, near the base of the Boston Mountains

In the Ouachita Mountains. The Ouachita Mountains are similar in materials and structure to the Newer Appalachians and probably are a part of the same mountain system. The break between Alabama and Arkansas is due to crustal sinking. Approximately 30,000 feet of sedimentary strata of Paleozoic age are tightly folded and most complexly faulted in this belt of mountains. The first uplift occurred at the close of the Paleozoic era, and at that time the intense deformation of the strata took place. As erosion history has proceeded, the more resistant layers in the upturned structure have come to form ridges; and since the folds have pitching axes here, just as in the Newer Appalachian Mountains, a single layer has, at places, formed a series of zigzag ridges. Some of the ridges are curved enough to be hooklike and others are like the ends of canoes. Where faulting has repeated the outcrop of a resistant layer, a series of parallel ridges has been developed.

At the summit of these mountains there is a strong suggestion of an old-age erosion surface. Nearly 20,000 feet of rock material that was above the present ridge tops has been removed, but the surface produced at that time was not so remarkable a plain as the one developed in the belt of the Newer Appalachian Mountains. Here there were numerous knobs or low monadnocks on the ridges, and considerable differences

in the summit elevations in the different portions of the range. Some of the present differences may be due to later elevation. There appears to have been much greater uplift in the central portion of the range than at the north or south or at the east or west. At present the greatest elevations are about 2600 feet above the sea, while at the east the summits are about 500 feet and at the west about 750 feet above sea level. The summit erosion surface truncates various formations, and it has been generally recognized to be a peneplain; the name Ouachita Peneplain has been suggested for this surface. Below the summit level there are numerous broad basinlike areas at about 1100 feet in elevation which have been interpreted as parts of another and younger erosion surface, for which the name Hot Springs Peneplain has been proposed. Following the development of the Hot Springs Peneplain, uplift occurred and the streams were all rejuvenated. In time a series of lower erosion surfaces, that have been called the Tertiary or Late Tertiary Peneplain, were developed. This surface has been dissected by streams, which means a still later uplift and rejuvenation. Thus four cycles of erosion are recorded in this mountain province. During the two older cycles the stream work had advanced far toward the peneplain stage. During the third cycle an incipient peneplain was developed; and during the fourth, youthful valleys were excavated.

The Age and Correlation of Erosion Surfaces

Thus far, local names have been applied to the principal erosion surfaces that have been recognized in the Interior Highlands, and the use of those names without any commitment as to age or correlation may be satisfactory to many students of geomorphology. However, the problem of correlation should be recognized and presented.

In the Ouachita Mountains two well-defined old erosion surfaces cannot be questioned. Farther south, underlying the sediments of the Gulf Coastal Plain, there is an old stream-cut surface, and if that surface were projected northward it would correspond approximately to the summit of the Ouachita Peneplain. Some have suggested, therefore, that these surfaces are of the same age. That would mean they were

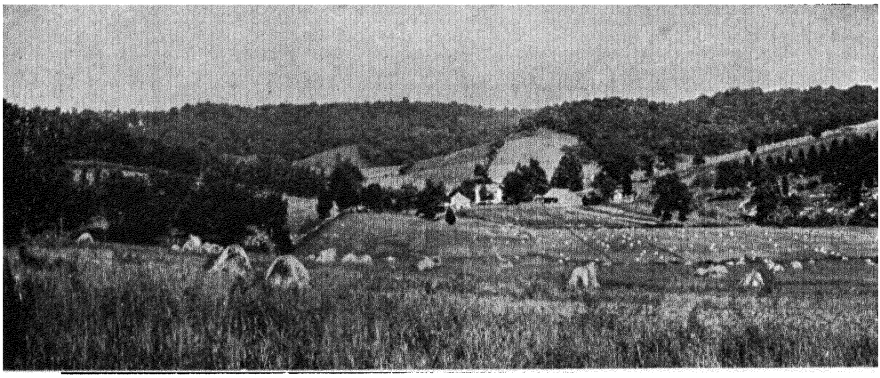
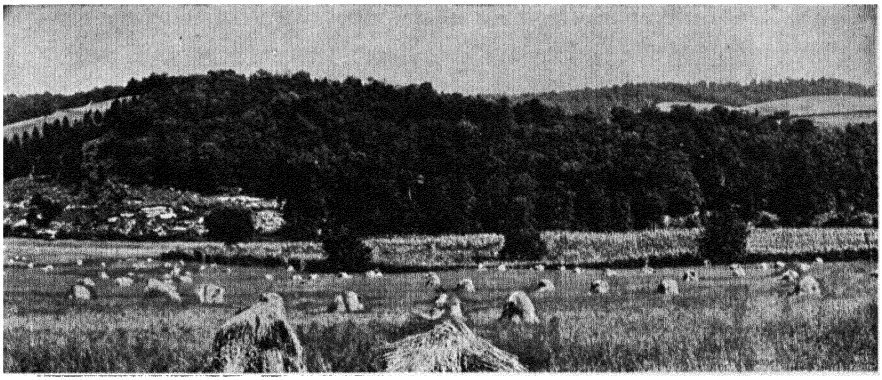


Figure 120 · A typical Ozark landscape in Jefferson County, Missouri.

developed before or during early Cretaceous time. Since the entire province has been subjected to erosion since the great physical revolution at the close of the Paleozoic era, a period of time which has been estimated to be at least 300 million years, some hold that here as well as in the Appalachian Highlands the summit peneplain must be much younger than the surface beneath the Coastal Plain sediments. In the east, where the term Schooley is attached to the summit peneplain, the age is thought to be early or mid-Tertiary (p. 124), and it seems reasonable to infer that the Ouachita Peneplain is younger than the erosion surface buried beneath the Coastal Plain sediments and probably a part of the Schooley Peneplain. If this correlation is correct the surface developed during the Hot Springs cycle is probably comparable in age to the Harrisburg surfaces in the Appalachian Highlands. See Figure 120.

In the Arkansas Valley the oldest peneplain has been entirely removed, but the Hot Springs Peneplain is represented by a few ridge tops and mesas where a synclinal structure is truncated. A much younger stage, called by Hershey[1] the Lafayette Peneplain, has been developed in the Arkansas Valley lowland, and into that surface youthful valleys have been cut. In the Boston Mountains the summit peneplain appears to be of about the same age as the oldest erosion surface in the mountains to the south and it is tentatively correlated with the

[1]O. H. Hershey, "Peneplains of the Ozark Highlands," *American Geologist*, Vol. 27 (1901), pp. 32 ff



This shows late maturity in the present cycle of topographic development

Schooley surface. Here the uplift at the close of the summit erosion cycle was not so much as in the Ouachita range, and subsequent cycles are not clearly recorded.

Still farther north in the region of the Ozark Dome, uplift at the close of the first great cycle of erosion appears to have been but slight, and the correlation of the Ozark Peneplain is very difficult. If two peneplains were ever developed here they were not far separated, and if the present surface has been modified at all during the second cycle it is appropriate to refer to it as comparable to the Hot Springs Peneplain, and, therefore, to the Harrisburg stage in the Appalachian Highlands. This correlation would check with the Lancaster Peneplain in the Driftless Area and the Lexington plain in the blue-grass country of eastern Kentucky.

The Arbuckle and Wichita Mountains

In Oklahoma, west of the Ouachita Mountains, there are two groups of islandlike mountains and hills that rise to a maximum height of about 500 feet above the broad, level plains. The eastern group is known as the Arbuckle Mountains and the western group as the Wichita Mountains. Both groups are within the southwestern division of the Central Lowlands and far south of the glaciated portion of that province. In structures and relationships they appear to be outliers of the Ouachita Mountains.

In each of these archipelagolike areas a series of Paleozoic sediments has been upfolded and faulted, and considerable masses of igneous rocks are associated with the sedimentary strata. The igneous rocks consist chiefly of granites, porphyries, diabase, and gabbro. They resist erosion very differently from the upturned layers of sediments, and they produce isolated steep-sided knobs, or buttes, which, although but 400 to 500 feet in height, are difficult of ascent.

The geologic structure in these two outlying groups of mountains indicates that the folding took place toward the close of the Paleozoic era. A long period of erosion followed, during which the first generation of mountains was nearly destroyed. By the middle of Cretaceous times a peneplain had been developed which may correspond in age to the erosion surfaces beneath the Coastal Plain sediments, or it may be younger. When the upper-Cretaceous sea invaded the interior of the continent, the lands where these mountains are located were submerged and sediments began to accumulate, which in time covered or buried both of these old, worn-down groups of mountains.

During a later (post-Cretaceous) uplift this portion of the continent again became a land area, and on the new land surface rivers established new courses. As the streams proceeded with their downward cutting, they stripped off most of the Cretaceous mantle. They may at this time have developed the erosion surface referred to in the previous paragraph. Later the streams cut deep valleys into the underlying older rock formations. The Washita, Blue, and many smaller creeks appear to have been superimposed upon the mountains in the western group, and Otter Creek and Medicine Bluff Creek appear to have been imposed upon the resurrected Arbuckle Mountains.

As the uncovering continued, the more resistant rocks came to stand out as monadnocks. For a considerable length of time the streams worked to a new base plain at which they succeeded in developing extensive areas of gently rolling topography which may possibly be correlated with the Harrisburg erosion surfaces. Today the streams are working toward a still lower base plain of erosion. At some places they have succeeded in cutting their modern channels to depths of about 200 feet. It appears therefore that three or four cycles of stream erosion are recorded in these mountain areas.

An Approach to the Human Drama

For many decades during the westward advance of the American frontier the Interior Highlands province was an island of sparse population. It was less accessible than the Central Lowlands, and the topography of the higher land was less attractive to settlers than were the gently rolling prairies farther north. Even today a population map of the United States shows that the Interior Highlands are less densely settled than the surrounding lands.

When the pressure of population upon the lands in the interior of the continent became greater, more and more settlers worked their way into the Ozark region of Missouri and into the belt of the Boston Mountains and the valley of the Arkansas River farther south. In the valleys they found many areas that were suitable for farming. The forest resources were attractive, and in the St. François Mountains rich deposits of iron ore were discovered. As exploration continued, indications of lead and zinc deposits were found about the margin of the Ozark Dome, and coal was discovered in the valley of the Arkansas. In the sparsely settled Ouachita Mountains section, south of the Arkansas River, some general farming and some ranching were carried on. Today the farm lands, forests, metal ores, coal, and recreation are playing an important part in the growth in population and in the economic development within this province.

Except for St. Louis and Little Rock, the urban communities in or near the Interior Highlands are not very large. St. Louis, with a population of 857,000, is easily the leading metropolis. This city is at the eastern margin of the Interior Highlands, however, and owes its development to the settlement and economic growth of a much larger area than that included in the province. Its development has, of course, been aided by the resources available in the Interior Highlands and by the markets provided by the inhabitants of that region, but it has not been chiefly dependent upon those resources and markets. St. Louis is the commercial, financial, educational, and industrial center for a large territory which includes, in addition to much of Missouri, portions of all adjoining states. Several of the industries of St. Louis have established markets throughout the nation and in many foreign lands.

Little Rock, with a population of about 102,000, is also at the eastern margin of the province. This city is the financial and trading center for a large farming community which extends into the valley of the Arkansas and the lowlands of the Mississippi.

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SELECTED LIST OF TOPOGRAPHIC MAPS FOR THE INTERIOR HIGHLANDS

Bland, Missouri
Cardareva, Missouri
Coldwater, Missouri
Des Arc, Missouri
Eldon, Missouri
Gainesville, Missouri
Gravois Mills, Missouri
Greenville, Missouri
Halltown, Missouri
Higdon, Missouri
Macks Creek, Missouri
Neosho, Missouri
Piedmont, Missouri
Poplar Bluff, Missouri
Shell Knob, Missouri
Waynesville, Missouri
Williamsville, Missouri

Dardanelle, Arkansas
Hot Springs and Vicinity, Arkansas
Ozone, Arkansas
Morrillton, Arkansas
Harrison, Arkansas–Missouri
De Queen, Arkansas–Oklahoma

Tuskahoma, Oklahoma
Winding Stair, Oklahoma
Wyandotte, Oklahoma–Missouri–Kansas

VIII

o

THE GREAT PLAINS

A General Description

Size. Between the Central Lowlands and the Rocky Mountains, and extending south from the delta of the Mackenzie River to the Rio Grande, a distance of about 4600 miles, there is a land area of very slight relief known as the Great Plains. For thousands of square miles within this province the surface is so monotonously flat that it suggests to a student of physiography the bottom of an ancient sea. Leveling instruments will prove, however, that the surface of the Great Plains declines gently eastward from an elevation of about 5500 feet at the eastern base of the Rocky Mountains to about 1500 feet at the western margin of the Central Lowlands. The width of this province is about 400 miles, which means that the average eastward slope is about 10 feet per mile.

The boundaries. At few places on this continent and, in fact, at very few places in the world is there so great a change in topography within such a short distance as at the western margin of the Great Plains. There the level or gently rolling surface of the plains meets the bold, rugged escarpments of the mountain wall that rises from 2000 to 8000 feet into the air. The change in relief is emphasized by changes in geologic structure, climate, soil, vegetation, and human response.

The eastern margin of this province is less well defined by topographic contrasts than are most of the physiographic boundary lines in North America. In many places it should be thought of as a zone, or transition belt. At the far north the Great Plains extend eastward from the base of the Rocky Mountains to the margin of the Laurentian Upland. There the landscape does not change suddenly, for the entire area is mantled with morainic debris. The topography of the Laurentian Upland is somewhat more varied and has slightly more relief than the adjoining Great Plains.

In southern Canada and in North Dakota the Missouri Coteau, a cuesta form, carries a thick mantle of ice-borne material, which somewhat increases its elevation above the plains to the east. The eastern margin of this higher land is a reasonably good boundary line of this

section of the province. In Nebraska the line swings just east of a very large sand-dune region; and in Kansas, Oklahoma, and Texas there are low escarpments that help to define the eastern margin of the Great Plains and to distinguish them from the Central Lowlands.

Another important feature which helps to distinguish the Great Plains from the Central Lowlands is afforded by the striking contrast in the vegetation of the two provinces. Throughout the United States and southern Canada, the Great Plains are essentially a region of short grasses, whereas the Central Lowlands are characterized by long grasses and woodlands.

The eastern boundary zone of the Great Plains includes much of the 20-inch rainfall line. East of that line the rainfall is in excess of 20 inches, and to the west it is less than that amount. In the lands between the Central Lowlands and the Rocky Mountains the climate is semiarid.

A still more critical examination of this boundary zone in the United States and southern Canada will disclose that it corresponds approximately to a most significant contrast in soils. To the east are the pedalfers, commonly dark brown in color, in which the ferrous minerals are present; to the west are the black pedocals, in which there is a limy layer beneath the surface.

East and west of this boundary zone the contrasts in the number and size of settlements and in the density of population are also conspicuous, for the Great Plains are but sparsely populated, whereas the Central Lowlands furnish opportunities for profitable enterprises for large numbers of people.

In central Alberta there is a transition zone from a land of short grass at the south to a forested belt at the north. The forest continues into the Northwest Territories of Canada, where it fades away, or blends through another transition zone with stunted tree forms, into the tundra of the subarctic lands of the continent.

At the far north the Great Plains extend to the Mackenzie River delta. At the south they border the valley of the Rio Grande where the Balcones Escarpment, which is due to faulting, furnishes an excellent boundary for the province. Just west of Austin, Texas, this escarpment rises about 300 feet above the lower lands to the east. Here, and for



From Ewing Galloway

Figure 121 · Farming in the Great Plains of eastern Colorado. The tractor is pulling a number of drills which are planting spring wheat

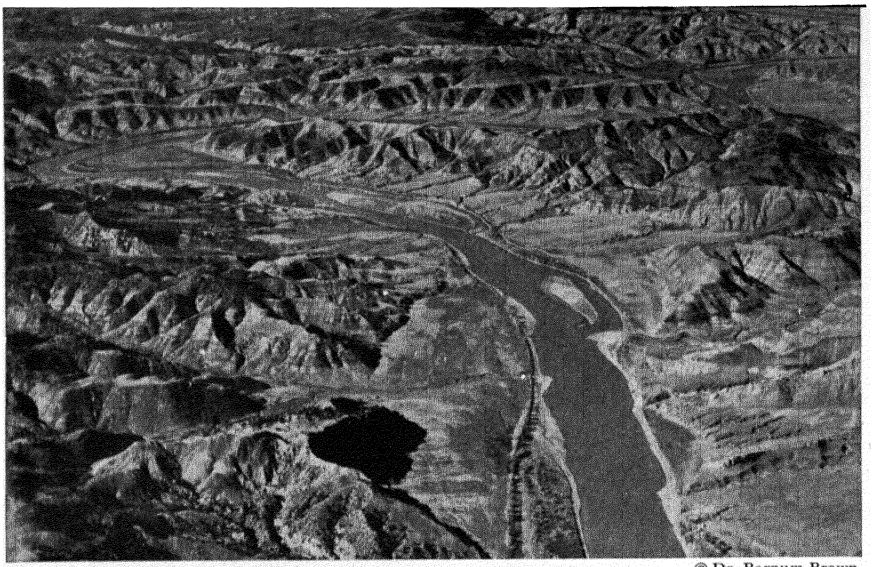
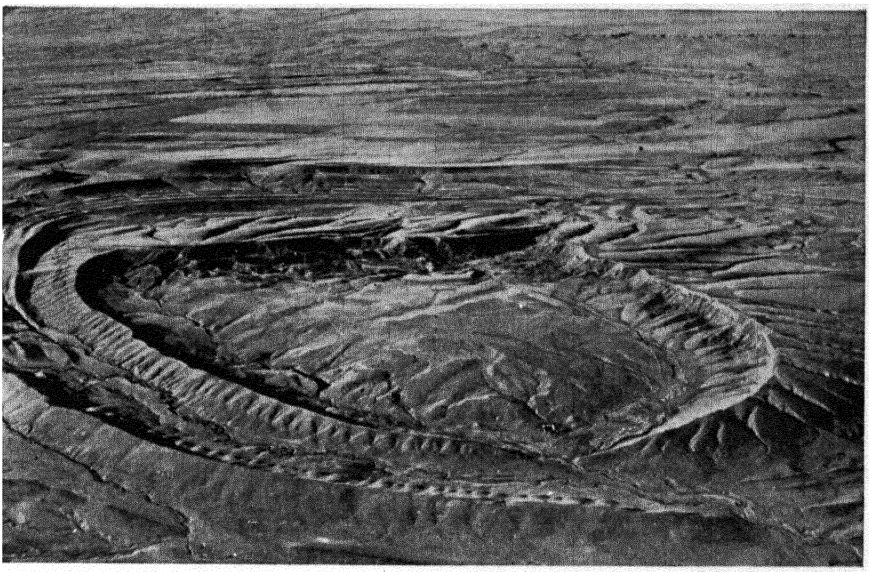


Figure 122 · Stream dissection near the western margin of the Great Plains in Montana. Here the streams are working in comparatively soft and somewhat homogeneous materials in a very dry section

several miles to the south, the margin of the higher block has been so much dissected that it appears as a belt of hills. At Del Rio, on the Rio Grande, the escarpment rises about 1000 feet above the lower lands.

A bird's-eye view. A pilot flying northward from the Rio Grande over this province might be bored for some time by the monotony of the landscape. As he moved northward over the Edwards Plateau and the Llano Estacado he would see a few scattered ranch homes and a few small villages, but most of the time he would see nothing but a broad expanse of nearly level land clothed with wild grasses. See Figure 121. Such an expanse should give him a feeling of comfort, for almost any place within this area would serve as a good emergency landing field. As he moved northward over Texas he might detect thousands of sheep and cattle grazing beneath him.

In northwestern Nebraska he would see, with the help of field glasses, that the surface has been roughened by the development of sand dunes and that the topography is not suitable for a landing place



© Dr. Barnum Brown

Figure 123 · The partial dissection of Middle Dome, twelve miles southeast of Harlowton, Montana. Here the more resistant upturned strata have produced concentric cuestas, a radial drainage pattern has been modified by stream piracy, and wind gaps and water gaps are clearly shown

for a plane. In parts of eastern Wyoming and South Dakota he would see extensive badland areas where the surface is so rough and fantastic that landing with an airplane would be exceedingly dangerous.

As he approached the northern boundary of the United States, he would find the topography becoming gently rolling and would see many undrained depressions containing lakes or swamps. There he would be flying over a surface produced by glaciation.

Still farther north, the change in vegetation from grasses to forests would be the most conspicuous feature of the landscape. This change is due chiefly to the fact that evaporation is less in these northern latitudes than it is farther south, and that the rainfall, though light, is sufficient for tree growth. Before he reached the delta of the Mackenzie, he would enter a region where the growing season is extremely short, where the temperatures are very low except for a short period during the summer, where the trees except along the river banks are stunted, and where the ground is covered with a soft, mushy tundra carpet.

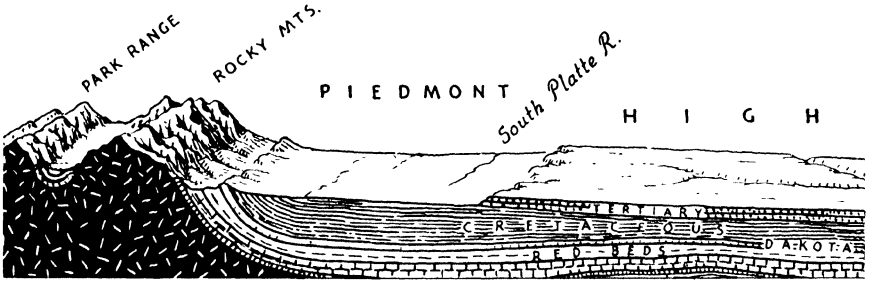
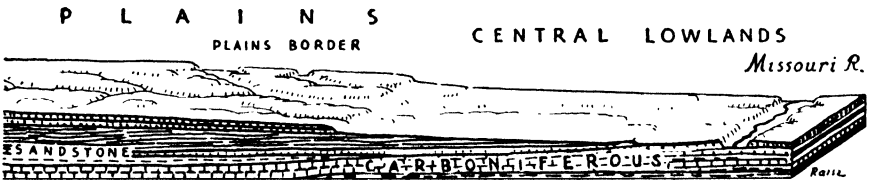


Figure 124 · A diagrammatic structure section from the Missouri River westward

The mountain outliers. Within the area of the Great Plains, and rising somewhat conspicuously above the general surface, are a few isolated mountain regions. The Black Hills of South Dakota and eastern Wyoming are the largest of these mountain outliers; but in Montana, just east of the main ranges of the Rocky Mountains, are the Highwoods, the Little Rockies, the Bear Paw Mountains, the Big Snowy Mountains, and several other small mountain ranges. While these mountain areas give considerable relief to the monotony of the Great Plains and add an element of special interest to a visitor to this province, they are physiographically parts of the Rocky Mountains. See Figures 122 and 123 and the map at the end of this book.

Materials and structure. Beneath the surface of the Great Plains province and throughout the area from north to south the formations rest in a nearly horizontal position. See Figure 124. They consist of extensive layers of sandstone, limestone, shale, lignite, and conglomerates. Many of these blanketlike layers of sediments accumulated in marine waters that swept north from the Gulf of Mexico to the Arctic Ocean. Some formed in inland seas, where the water was brackish; the lignitic material probably formed in boggy or marshy places.

The High Plains, which form a large portion of the Great Plains within the United States, are mantled for the most part with sand, gravel, and silt which were deposited upon this area by eastward-flowing streams. These deposits have been spread out in the form of gigantic torrential fans as the rivers from the mountains, crossing this area of low stream gradients, have been forced to deposit whatever they were



to the Front Ranges of the Rocky Mountains, with associated relief features

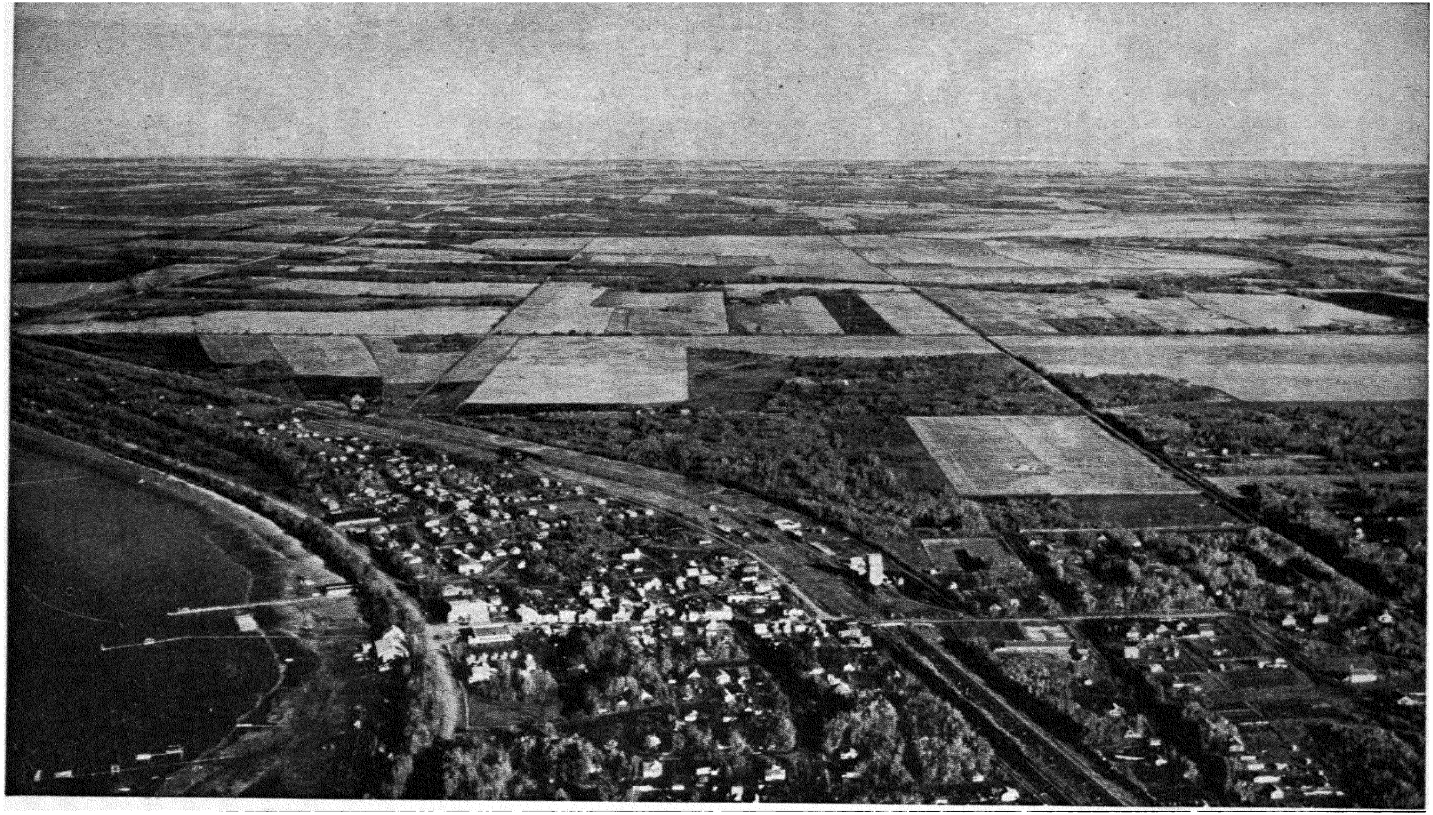
transporting. This fluviatile material extends for hundreds of miles east of the mountains. It is commonly conglomerate, and over considerable areas it is so firmly cemented by lime that it has been called the "Mortar Beds."

Near the northern margin of the United States, in Montana and North Dakota, and throughout the Canadian portion of the Great Plains, where the surface material is of glacial origin, the deposits have the characteristic physical and lithological heterogeneity common to all material left as the continental ice sheets melted away. Topographically the surface varies from gently rolling ground moraines to rough, hilly belts formed near the margin of the ice as frontal moraines. See Figure 125.

No detailed studies have been made of the glacial deposits in the far northern portion of the continent. North of the transcontinental railways of Canada the territory is a wilderness. Travel in that section is chiefly in canoes or other boats that follow the main drainage lines. Passage on foot through the forested area is possible, but very difficult.

At the east margin of the Great Plains, where the change in topography is slight, there is little or no change in the underlying rock structure. The rock layers are essentially horizontal throughout the transition zone from this province to the Central Lowlands. See Figure 124. At the west margin of the Great Plains the sedimentary series turns upward and at places stands in a vertical position. Faulting has occurred and many igneous extrusions have taken place near this margin.

The Dakota Sandstone forms the most conspicuous hogback ridges in the foothill belts about the margins of the different ranges in the Rocky Mountains. See Figures 124 and 144.



Canadian Airways, Ltd., Montreal

Figure 125 · The wheat lands near Sylvan Lake, Alberta

Stages in Topographic Development

We have already learned of the great physical changes that took place throughout the eastern half of the continent at the close of the Paleozoic era. A similar physical revolution occurred in the history of the western part of the continent at the close of the Mesozoic era. At this time the Cretaceous sea, which had spread from the Gulf of Mexico to the Arctic Ocean, gradually withdrew. The Great Plains were uplifted without much deformation, and huge mountain ranges were formed in the adjoining lands to the west. These changes opened the physiographic chapter in the history of the province.

The first cycle of erosion. As the sea bottom in the region of the Great Plains became a land area and a lofty mountain region came into existence farther west, weathering and stream erosion started in both these provinces. The rains that fell soon developed systems of consequent drainage lines on the new land surfaces. A long period of erosion followed, during which the Great Plains were reduced to gently rolling surfaces which were not far above the base plain of erosion. Some portions of the Great Plains south of the limit of glaciation and not included in the area of the High Plains may be parts of this old erosion surface. There is reason to believe that this cycle of erosional work was completed during early Tertiary time and probably before the close of the Eocene period.

A second cycle of erosion. Renewal of uplift in the region of the Great Plains and in the lands immediately to the west brought to a close the first cycle of erosion and inaugurated a second cycle. Stream work was invigorated, and the valleys were being deepened when large quantities of sand, gravel, and silt began to come from the mountains. This material was being carried eastward across the Great Plains by the rivers; but, either because of the too slight gradient or because of the large amount of evaporation resulting from the aridity of the climate, the carrying power of the streams was reduced, and most, if not all, of that great load of debris was deposited as a mantle on the old-age erosion surface developed in the previous cycle. This material forms the gigantic tor-

rential fans that spread eastward several hundred miles from the base of the mountains. The fan materials are known to geologists as the Arikaree (Miocene) and the Ogalalla (Pliocene) formations. They are partially cemented and today constitute the mantle of much of the High Plains section of the Great Plains. Over large areas this fluvial material is as yet undissected. From the standpoint of erosional history and an area where a consequent drainage is being developed it represents extreme youth. It is in the High Plains that the landscape is so monotonously level that a covered wagon, a cabin, an automobile, or even a horse appears conspicuous.

The mantling of a large portion of the Great Plains with vast quantities of torrential wash meant a corresponding reduction in the mountain area to the west. Later we shall endeavor to correlate an old erosion surface in the Rocky Mountains, produced during this period of degradation, with the mantling of the Great Plains resulting from aggradation. In the one region erosion dominated; in the other deposition characterized the work of the streams.

The third and later cycles. The closing of the second great cycle in the physiographic history of the Great Plains was the result of another period of uplift and another period of orographic movements in the mountain area. Throughout the area of the Great Plains the streams were rejuvenated. Where deposition had been the rule, erosion began to take place; and the cutting of the modern valleys, which have become from one to twenty miles in width, was begun. The lowering of these valleys in the area of the High Plains has produced relief of 100 to 300 feet near the valleys of the Missouri, the North and South Platte, and the Arkansas. See Figure 126. Farther south in the drainage basin of the Canadian River, the master stream has developed a valley from five to twenty miles in width, with walls rising as high as 1500 feet above the valley floor.

The north boundary of the High Plains is now marked by a bold escarpment near the Nebraska–South Dakota boundary line. That margin is known as Pine Ridge Escarpment. It stands nearly 1000 feet above the valley lands at its base and is subject to vigorous wind action and to rapid stream erosion during each cloudburst. This escarpment has un-

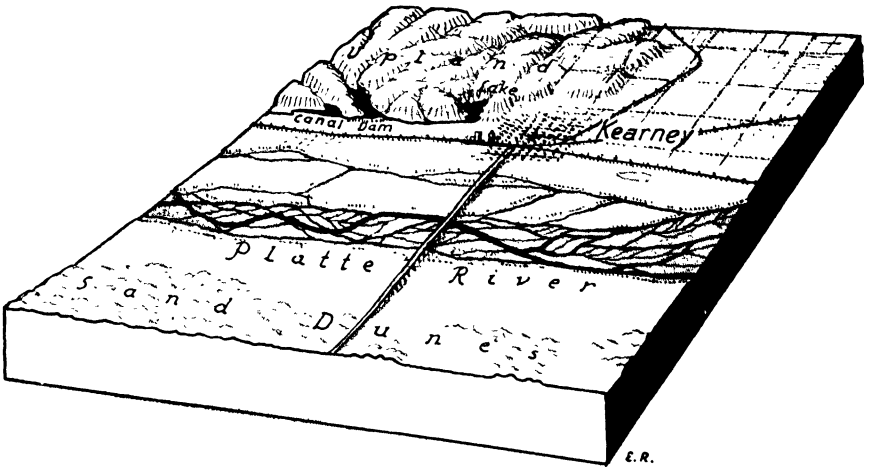
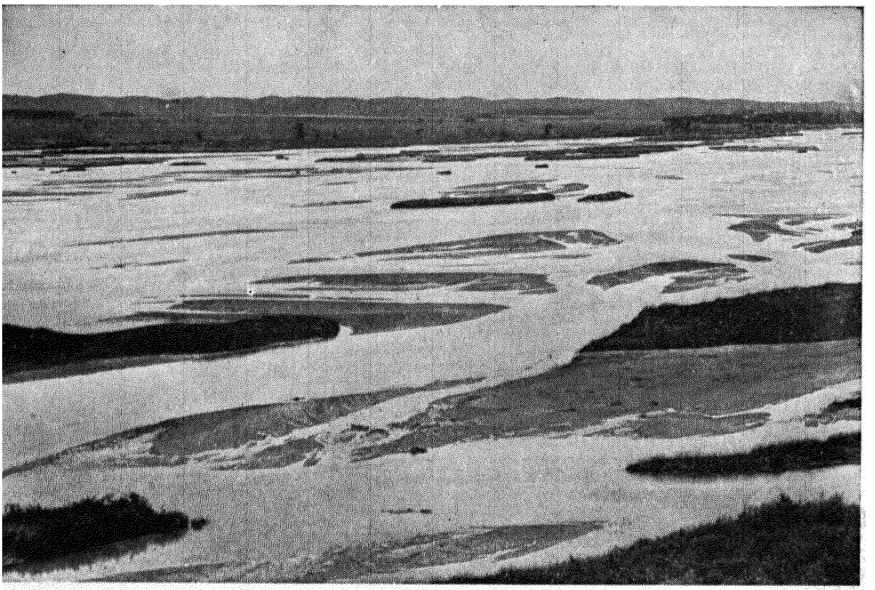


Figure 126 · A sketch map of the braided channel of the Platte River in the vicinity of Kearney, Nebraska. Stream terraces, a section of the upland area, and a belt of sand dunes are also shown

doubtedly migrated southward many miles as the fluviatile mantle has been undermined. At the south the High Plains blend into the Llano Estacado of Texas and finally into the Edwards Plateau.

Changes in climate during the cycles of erosion. Each uplift of the mountain barrier was followed by climatic changes. Whenever the mountain ranges stood at high elevations, the Great Plains were forced to be in a rain-shadow area, as they are today, and thus to have a semi-arid climate. The streams lost in volume because of evaporation, and their power for cutting and carrying was reduced. Whenever the rainfall increased, the power of the streams was augmented.

Climatic changes have undoubtedly played a considerable part in the development of topography in this region. Today the North and South Platte and the Arkansas rivers are probably not down to the base plain of erosion, but their waters have been subdivided over and over again until they flow among sand bars and islands in a complicated braided network of channels. See Figure 127. These streams have been forced to deposit large quantities of material on their beds. The light rainfall is reflected in the short grass of the upland surface and in the development of badlands and sand dunes within this province.



Photograph by G. E. Condra

Figure 127 · The braided channel of the North Platte River between Oshkosh and Bridgeport, Nebraska

Special Physical Features

Stripped plains. The Edwards Plateau and the Llano Estacado of Texas are but little etched. If they were ever covered with an alluvial mantle, that loose material has been removed, and we have examples of stripped plains, or plains resulting from a very resistant stratum from which most fragmental material has been washed away. Such plains are sometimes referred to as *stratum plains.*

A Piedmont lowland. In the Piedmont belt of Colorado just east of the mountains, where the sod may have been thin, the mantle of alluvial waste that must have covered this area at one time has been removed and the streams have lowered the surface below the level of the High Plains to the east. See Figure 124. This accounts for the physical setting of Denver and Colorado Springs and of a number of smaller settlements near the west margin of the Great Plains.

Sand dunes. In northern Nebraska the formation of sand dunes has taken place during the later stages of physiographic evolution. Much of the sand of this hilly belt presumably came from the braided channels of neighboring streams. During periods of very low water the sand becomes dry, and the winds pick it up and carry it to the bordering uplands.

Devils Tower. West of the Black Hills of South Dakota there are a number of conspicuous features that are due to the intrusion of molten rock material into a series of sedimentary strata. The molten material lifted the layers of sedimentary rock and formed small domes. Erosion has completely removed the covering of one of these domes and the core of the intruded mass now stands out as a large column. This mass is known as Devils Tower. Near this tower there are several other partially uncovered masses of the igneous rock. See Figures 128 and 129.

Badlands. Fantastic forms of erosion have resulted from the removal of the sod in portions of Wyoming and South Dakota, especially between the Cheyenne and White rivers of the latter state, and excellent examples of badlands are found here. See Figures 130 and 131.

Stream terraces. In the major stream channels several terraces have been formed. These terraces converge eastward, which strongly suggests that the erosion period which followed the first two cycles already described was punctuated, or subdivided, by slight uplifts to the west in the neighborhood of the mountain barriers. This would have led to the greater separation of the terraces at the west margin of the plains and to the convergence of the terraces to the east. The gravel mantles of these terraces have been carefully studied and mapped in certain localities.[1]

Mesas and small canyons. Near the west margin of the Great Plains, in the vicinity of Trinidad, Colorado, and southward to Raton, New Mexico, vast quantities of basaltic magma rose from the interior of the earth and spread over a considerable area of the province. Upon cooling, this basaltic material became a very resistant rock formation, and it con-

[1] W. C. Alden, "Physiography and Glacial Geology of Eastern Montana and Adjacent Area," *U. S. Geological Survey, Professional Paper*, No. 174 (1932), 133 pages.

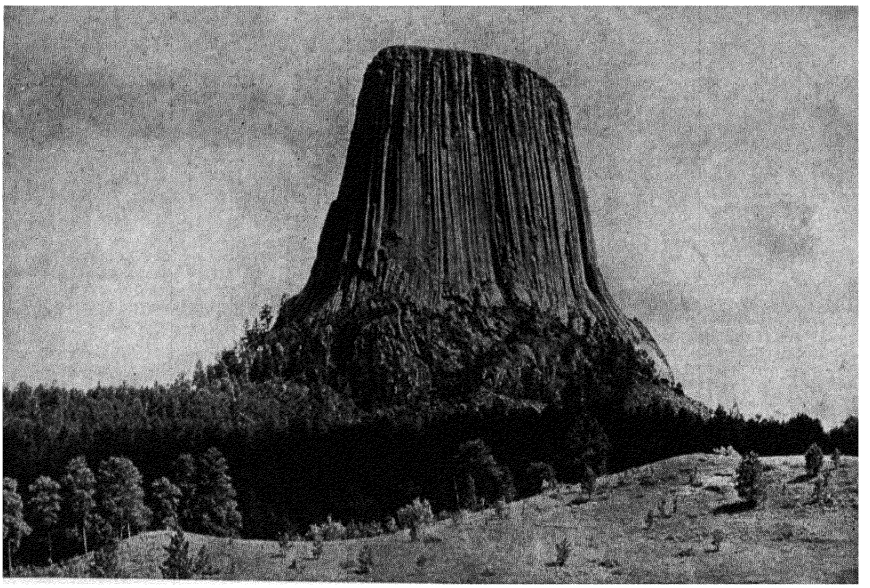


Figure 128 · A close-up of Devils Tower. It is the core of a laccolith and rises 1200 feet above its surroundings. The columnar structure is due to contraction and cracking during the cooling of the lava

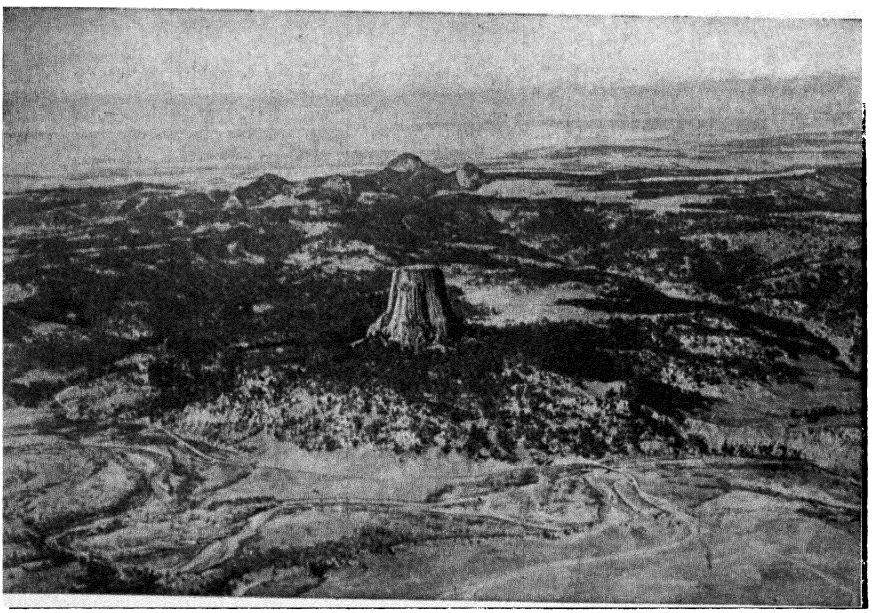


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Figure 129 · An airplane view with Devils Tower in the middle ground and four partially uncovered laccoliths in the distance

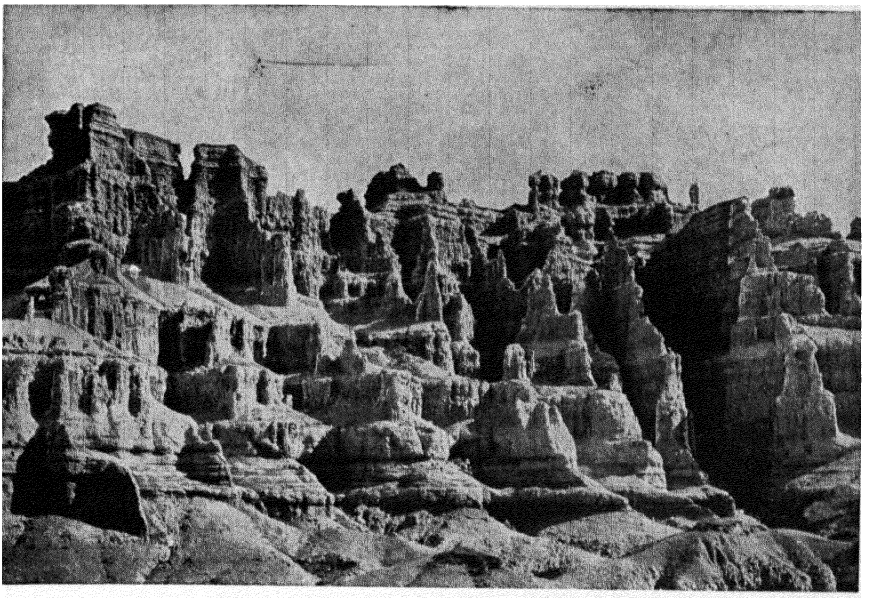

Figure 130 · In the Badlands of South Dakota. The upland surface is nearly destroyed, and erosion is carving the soft materials into fantastic features



Figure 131 · An airplane view of the Badlands, east of the Black Hills, South Dakota. Here the torrential downpours from cloudbursts and intermittent streams are sculpturing a comparatively soft, or poorly cemented, formation

tinues to serve as a capstone on several of the mesas in that part of the country. Mesa de Maya is capped with a portion of this lava, and so is Raton Mesa. Bold canyon walls and rugged rock pillars, which owe their existence to this very resistant black lava, add variety and picturesqueness to this section.

In the Pecos district of New Mexico, mesas, canyons, and bold escarpments have been cut out of the old land surface. In this section, a few miles south of Roswell, are the Carlsbad Caverns, which have been set aside as a national park. They are famous for the beautiful and fantastic crystalline forms that they contain. See Figure 132.

Sinkholes. At several localities within the area of the Great Plains, notably in the Llano Estacado of Texas and the High Plains of Colorado, there are shallow saucerlike depressions that vary up to about a mile in length. They are the result of the work of underground waters which, as the ages have passed, have dissolved a portion of the lime content in the underlying rock formation and have caused the surface to settle. Such depressions are typical sinkholes. Some of them contain lakes, and in some the waters have been ponded so that they might serve as irrigation reservoirs.

Wind-blown depressions. In the more arid portions of the Great Plains, winds are very effective eroding agents. They have carried away loose materials from certain localities and actually have produced some of the saucerlike depressions in this province.

Buffalo wallows. Many small, shallow depressions in the surface of the Great Plains are called buffalo wallows. In the beginning, many of these low places may have been due to irregular settling and to solution. Certain of them, however, were probably lowered in part by the stamping and wallowing of buffaloes, which carried away mud on their bodies. When these depressions dried, the winds also may have deepened them by erosional work.

Glacial features. The glacial ice which affected the Great Plains province came from the Keewatin center west of Hudson Bay and spread

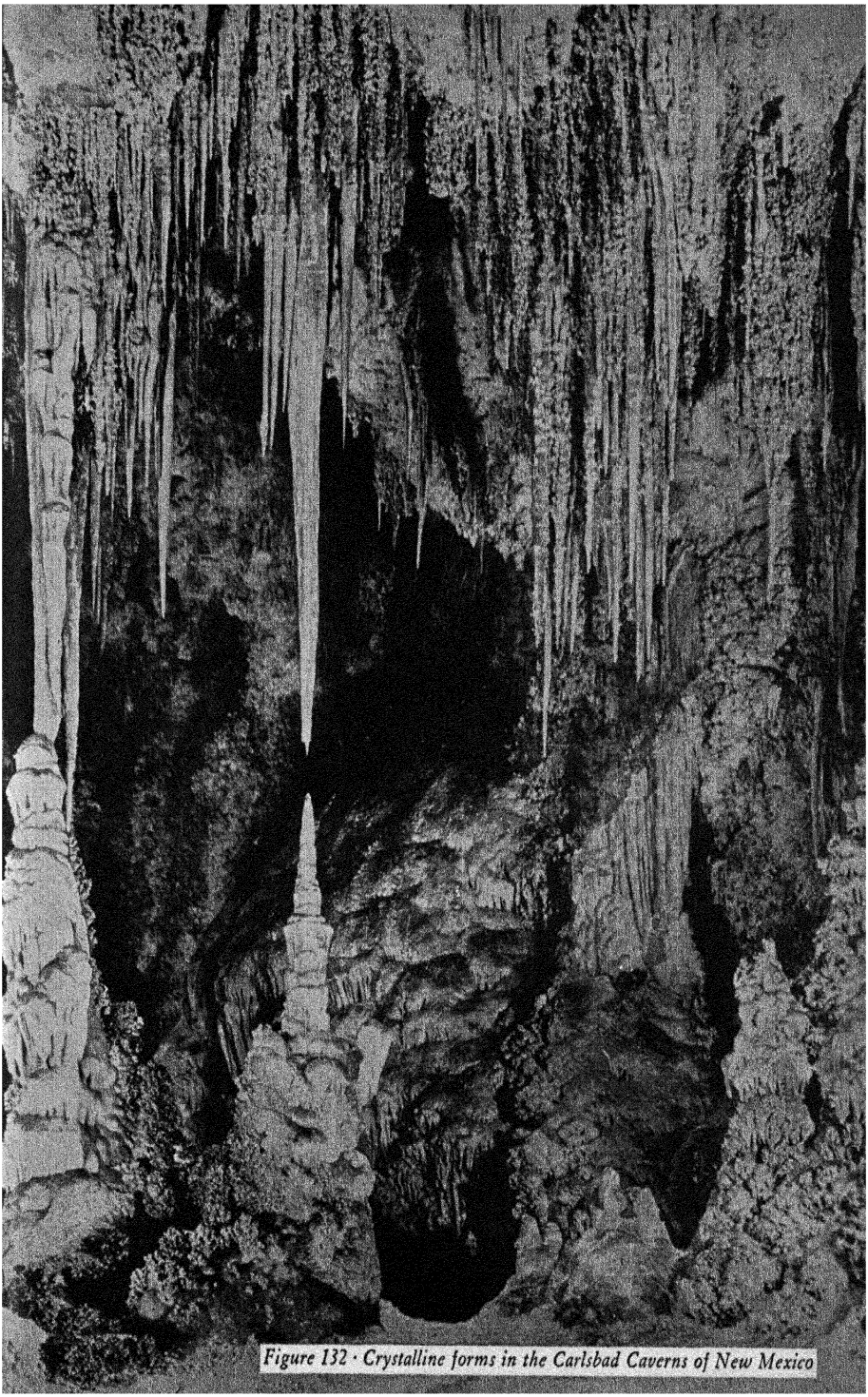

Figure 132 · Crystalline forms in the Carlsbad Caverns of New Mexico



© Dr. Barnum Brown

Figure 133 · The largest known glacial erratic in North America. It is on the Great Plains five miles west of Okotoks and near Sheep Creek, Alberta. The boulder is of quartzite and was transported by the ice for at least forty miles. It is 80 feet long, 40 feet wide, and 30 feet high, and is buried about five feet

westward until it reached the base of the Rocky Mountains in Canada, and southward until it invaded territory now within the United States. See Figure 133. The southern or southwestern boundary of this great ice sheet is shown approximately in Figure 88 on pages 198–199.

The topography of the glaciated portion of the Great Plains is similar to that of the Central Lowland, described in Chapter VI, where ground moraines and frontal moraines give character to the surface features. In the midst of this morainic mantle there are thousands of small lakes and some lakes of considerable size. Lake Athabaska, Great Slave Lake, and Great Bear Lake are at the eastern margin of the Great Plains in northern Canada. They appear to be in line with preglacial valleys which were presumably deepened and broadened by ice erosion. Deposition of morainic material, as in the case of the Great Lakes, may have ponded the drainage and built up the walls of these lake basins. Lake Winnipeg is a remnant of ancient Lake Agassiz.

The loess plains. Bordering the margin of the morainic belt, especially in eastern Nebraska and northeastern Kansas, there are areas where vast quantities of fine, flourlike silt, containing the fossil forms of land life, have accumulated and mantled the landscape. This powdery material is loess. It has the peculiar ability of retaining moisture and of standing, although an uncemented formation, in vertical and even overhanging walls.

Some of the loess may have been deposited by streams, but in this part of the country most of it was undoubtedly brought by winds to its present resting place. The winds may have gathered this material from dry channels of stream courses or from the surface of a recently uncovered morainic deposit where vegetation had not yet anchored the material.

The stream-made topography of the loess plains is beautifully symmetrical. The uniformity of the composition of this soft material gives smoothness to the contours and symmetry to the valley forms. Abrupt walls or cliffs of loess are found bordering the major stream courses where recent undercutting has taken place, or in road cuttings where steam shovels have partly removed the hills.

A Brief Review of the Physical History of the Great Plains

At the close of the Mesozoic era the portion of the continent that is now the Great Plains became dry land. Since then there have been several cycles of erosion and other periods when sediments have accumulated in lakes or valley bottom lands or as great alluvial fans on the upland surfaces. Glaciation has affected the northern portion of the province, and volcanic action and the work of winds are well illustrated locally.

An analysis of the physiographic development within this area illustrates how varied and complex the history of a plains province may be. It illustrates also how intimately the physiographic history of one province is tied up with the history of the adjoining provinces. The mountain barrier to the west has had an important influence upon the

geomorphic changes within the Great Plains, and the development of the great ice sheets in the adjoining province to the northeast has played an important part in shaping the physical features throughout a large section of the plains province. Winds, rains, underground water, and volcanism have made their contributions, and their work must be understood if the evolution of land forms within this province is to be appreciated. See Figure 134.

Nowhere else in the world are there more remarkable examples of extensive alluvial fans that have blended and formed a vast alluvial plain at the base of a mountain region. Nowhere else can more symmetrical examples of consequent drainage be found than in the region of the High Plains, especially in the Llano Estacado and Edwards Plateau sections at the south. In few places on this planet are there such large areas of grotesque physical features as in the badlands of this province.

An Approach to the Human Drama

The settlement and economic development of the Great Plains offer another fascinating field for study. This semiarid belt served as a barrier during the middle period of American history, when the frontier was moving westward. It halted and then delayed for a long time the migration of settlements beyond the meridian of about 100°, the approximate western limit of the 20-inch rainfall zone. Today the Great Plains are a marginal zone where uncertainty in the production of crops and of good grasses for livestock has caused economic uncertainty in the lives of those who have chosen to settle in it. See Figures 135 and 136.

The population of the Great Plains never has been and never should be so dense as is that of the Central Lowlands to the east. This province is a natural grassland, and certainly most of it should be used as pasture. For many decades the short-grass lands of the United States and Canada were devoted to the grazing of livestock, and today grazing is very important in the region; but great irrigation projects, modern methods of dry farming, and the planting of spring wheat have led to the cultivation of more and more of the land within this area. During years when the rainfall is a little above the average the farmers are prosperous; but

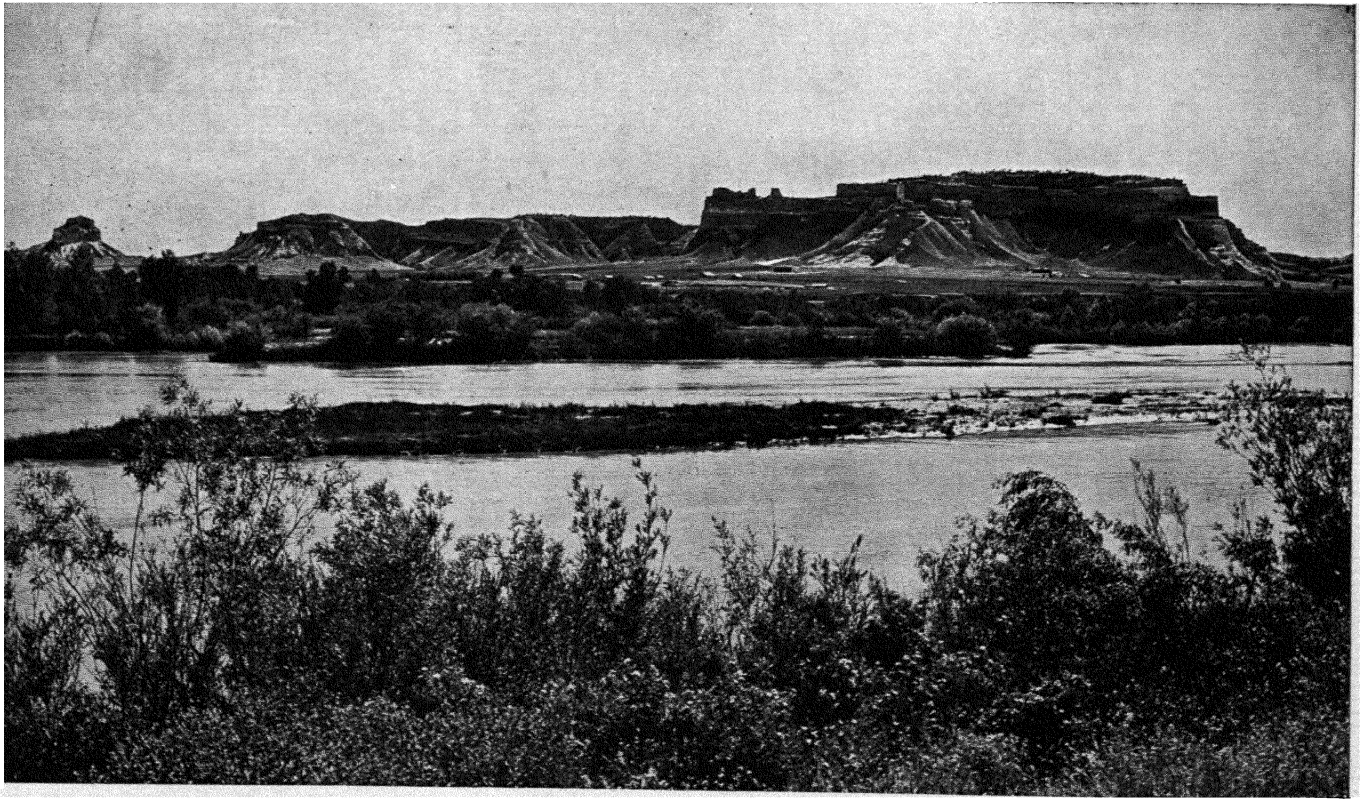

Figure 134 · Scotts Bluff as seen from the North Platte River in Nebraska. This is one of the more striking and picturesque erosional features in this portion of the Great Plains

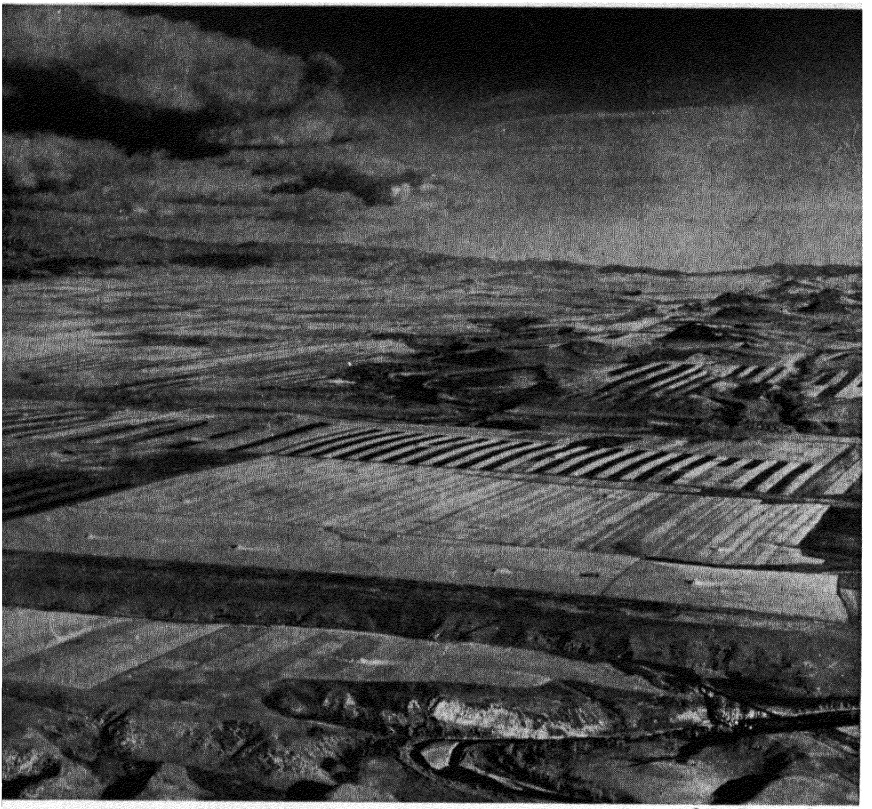

Figure 135 · Strip farming in the Great Plains, near Cowley, Alberta

when there is a series of unusually dry years, disaster follows. In portions of the Great Plains there now exists what has been called the "Dust Bowl." Here, during a period of terrific dust storms, the soils which have taken centuries to form have been blown away in a single day. This could not have happened if it were not for the fact that overgrazing or the removal of the sod for the purpose of cultivating field crops had destroyed the grass cover.

In some parts of the Great Plains beds of lignite have been found. This material is burned locally as fuel, and some day it may be much more widely used. In several localities at the western margin of the province petroleum and natural gas have been discovered and considerable development work has been done. The forests that mantle much



Nelson Edwards from Ewing Galloway, N. Y.

Figure 136 · A large herd of Herefords on a cattle ranch near Brush, Colorado

of the Canadian portion of the province may some day play an important part in the lumber and pulpwood markets.

The Great Plains present many difficult problems in land utilization which demand the co-operation of soil and vegetation specialists, agriculturalists, climatologists, and experienced ranchmen. From the Rio Grande to the Mackenzie River delta the province is a unit from the physiographic standpoint, but it is divisible into several somewhat distinct climatic sections. The Great Plains extend northward from the subtropical belt, through the temperate zone, to the subarctic regions.

Whether the study of the Great Plains is approached from the standpoint of geology, physiography, climate, vegetation, soils, or human occupation, a rich variety is in store for the investigator. This is the land where the frontier woodsman with his ax gave way to the cowboy. Here the six-shooter, more convenient to carry in a saddle, replaced the long rifle of the pioneer. During the middle period of our history this was a land of adventure, cordial hospitality, and romance. Today it is a problem area.

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SELECTED LIST OF TOPOGRAPHIC MAPS FOR THE GREAT PLAINS

Lethbridge, Alberta[1]
Maple Creek, Saskatchewan[1]

Blackfoot, Montana
Brockton, Montana
Cherry Ridge, Montana
Cut Bank, Montana
Fort Custer, Montana
Lake Frances, Montana
Nashua, Montana
Porcupine Valley, Montana
Saypo, Montana
Valier, Montana
Zurich, Montana

Devils Tower, Wyoming
Laramie, Wyoming
Sherman Wyoming
Aladdin, Wyoming–South Dakota–Montana

Bismarck, North Dakota

Oahe, South Dakota
Pierre, South Dakota
Rapid, South Dakota
Spearfish, South Dakota
Sturgis, South Dakota
Edgemont, South Dakota–Nebraska
Oelrichs, South Dakota–Nebraska

Camp Clarke, Nebraska
Ogalalla, Nebraska
Paxton, Nebraska
Scotts Bluff, Nebraska
Utica, Nebraska

Ellsworth, Kansas
Kinsley, Kansas
Salina, Kansas

Arroyo, Colorado
Fort Collins, Colorado
Loveland, Colorado
Mesa de Maya, Colorado
Mt. Carrizo, Colorado
Sanborn, Colorado
Spanish Peaks, Colorado

Tucumcari, New Mexico
Raton, New Mexico–Colorado

Ketchum Mountain, Texas
Sierra Madera, Texas

[1]Published by Surveys and Engineering Branch, Department of Mines and Resources, Ottawa, Canada.

IX

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THE ROCKY MOUNTAINS

A General Description

Extent. All the lands west of the Great Plains and west of the Gulf Coast Lowlands of Mexico are included in the cordilleran portion of North America. At the east margin of this huge highland there is a nearly continuous belt of mountains. Through the center, and extending from southern Mexico to Bering Sea, there is a chain of high plateaus. At the west there is another belt, dominated by young, rugged mountains, with which are associated a few lowlands and a number of deeply depressed areas. See Figures 137 and 138.

The term Rocky Mountains has long been used in describing those portions of the eastern belt of the Cordilleras which lie within the United States and Canada, but for convenience the entire belt stretching from the northernmost part of Alaska to southern Mexico will be referred to here as the Rocky Mountains. In the far north there is a slight break between the Brooks Range, formerly called the Endicott Range, of Alaska and the Rocky Mountains in the Yukon Territory of Canada. In Wyoming there is a large plateau or basinlike area in the midst of the mountain belt. In the southern parts of New Mexico, in southwestern Texas, and in the northern part of Mexico, the Rocky Mountains are represented by a number of low ranges.

The boundaries of the province. From southern Mexico to northwestern Alaska the Rocky Mountain belt is bordered on the east and north by a region of plains. The change from one physiographic type of landscape to the other produces one of the most notable topographic contrasts in the continent. The mountains rise boldly from 2000 to 8000 feet above the adjoining plains. Associated with this conspicuous contrast in relief there are just as conspicuous changes in geologic structure, vegetation, types of settlement, and the occupations of the inhabitants.

On the west the mountains give way to plateau surfaces. The plateaus are high, and therefore the change in elevation is not so great as it is on the eastern margin. Nevertheless, the contrasts in topography

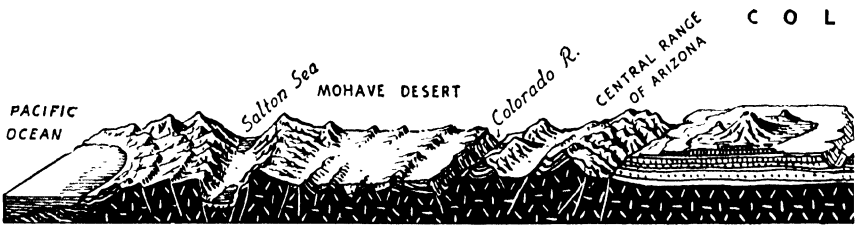


Figure 137 · A generalized structure section through the cordilleran portion of North fornia, with associated relief

are somewhat notable. The western margin, like the eastern, is marked by distinct changes in geologic structure and is emphasized by changes in vegetation and in human occupancy. The shores of Bering Strait form the northern boundary of the Rocky Mountains, as they are here defined, and the east-west ranges, Sierra del Sud, that mark the northern margin of Middle America form the southern boundary.

An airplane view. Those persons who have not seen portions of this or other high mountain regions from some elevated position will find it difficult to visualize the magnificent topographic features in this province. There is nothing in North America east of the Rocky Mountains that can provide the student with mental images of land forms similar to those now to be described. Here majestic peaks rise from 6000 to 8000 feet above their surroundings. The higher summits are more than 14,000 feet above sea level, and often rise through great cloud banks

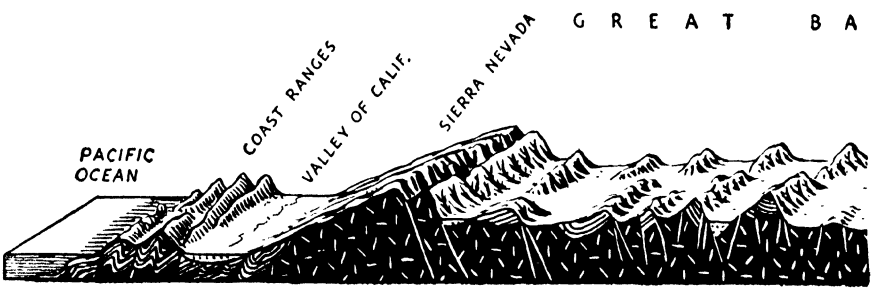
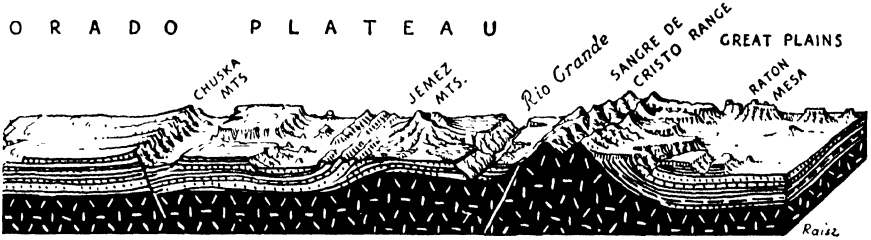


Figure 138 · A generalized east-west structure section through the North American Colorado to the Pacific coast in northern California.

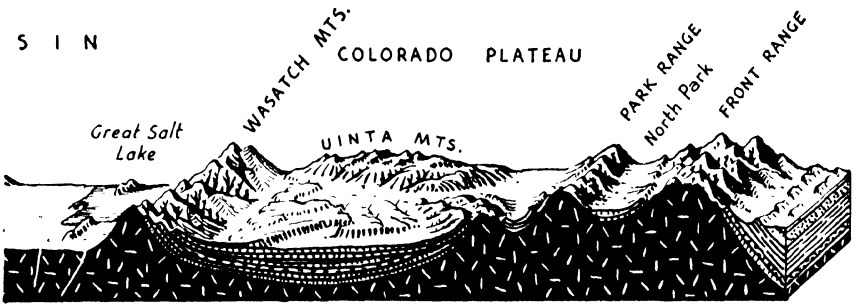


America, from the Great Plains in southern Colorado southwestward to southern Cali- features shown in perspective

into a serene and sunlit atmosphere. Many of the precipitous mountain peaks have defied the efforts of the most daring mountain-climbers. See Figure 139.

The entire belt is predominantly one of bold, rugged features. There are very few places where the topography has been subdued by erosion. Between certain ranges, however, there are basinlike areas, commonly called parks, where the floors are nearly level. Near the summits of most of the high peaks there are snow banks that remain from year to year; and at hundreds of places the perennial snow fields are of such great depth that glacial ice forms and moves slowly down from the huge amphitheatral catchment basins into deep U-shaped canyons.

Groups of magnificent mountain summits present panoramas which are difficult to surpass in boldness, ruggedness, and variety of form and color. In many instances the bare rocks of the mountains have been changed through the processes of weathering or hydrothermal meta-



Cordillera, near the parallel of 40 degrees north latitude, from the Front Range of with associated relief features shown in perspective

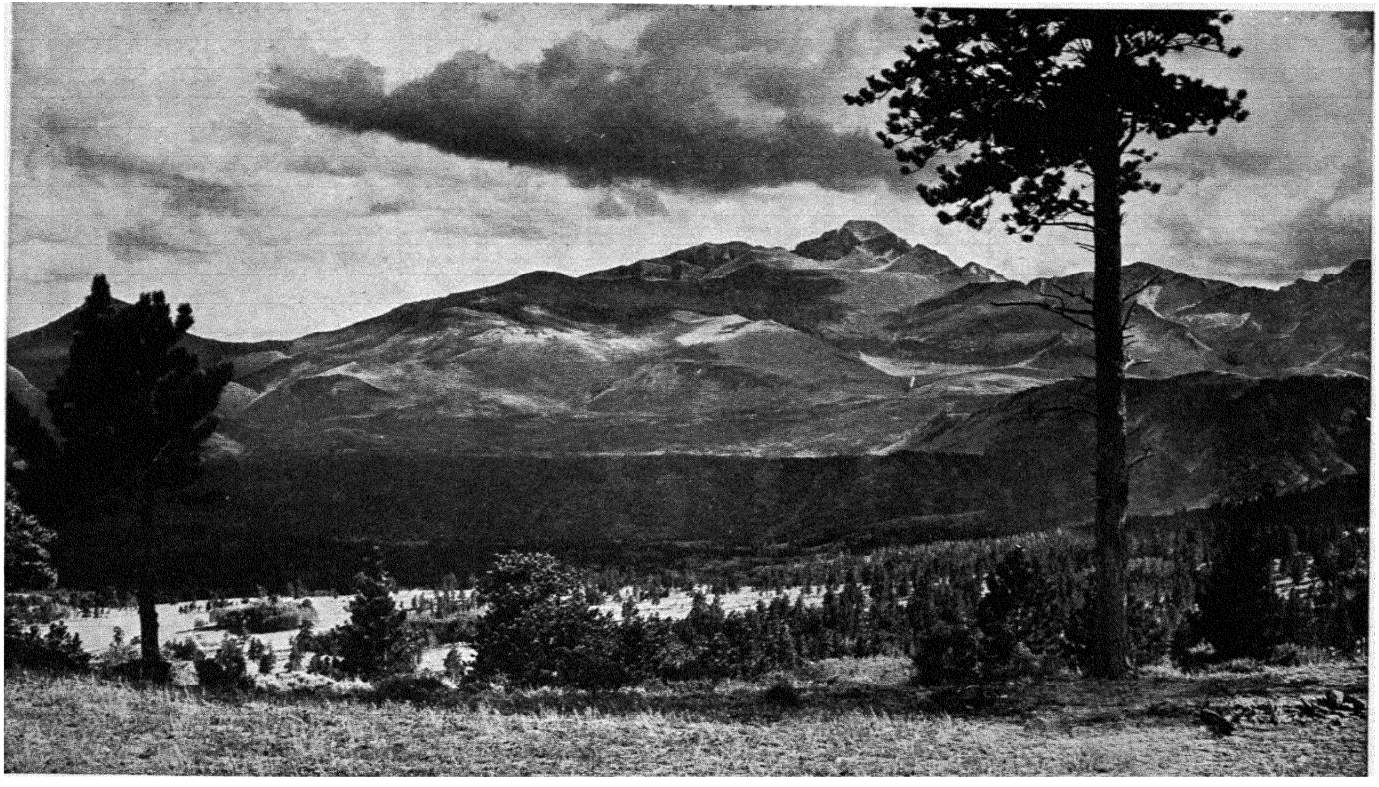


Figure 139 · Longs Peak (14,255 feet), one of the most strikingly scenic features in Rocky Mountain National Park. The dark, even-crested ridge in the middle ground is a lateral moraine of one of the former alpine glaciers of the park



© Hileman, Kalispell, Montana

Figure 140 · Bold escarpments of richly colored rocks, 300 to 400 feet high, in Glacier National Park. The walls have been steepened and each of the canyons has been made U-shaped in form by ice action. The lakes also are due to glaciation

morphism from the darker hues, common to many rocks, to brilliant shades of red, yellow, or brown. These colors, which are comparable in brilliancy to the autumn tints of the Eastern deciduous forests, give character to many of the mountain landscapes. When such masses of color are seen in close association with the pure white mantle of snow or the turquoise shades of glacier ice, they present effects difficult to match anywhere in the world and offer opportunities that challenge the skill of the greatest of all landscape painters. See Figure 140.

In most of the mountain ranges within this belt there are deep canyons with precipitous, rocky walls. Some of the canyons are U-shaped in form with smooth symmetrical contours, but others are V-shaped and exceedingly jagged. Torrential streams, which appear as silver threads when seen from high in the air, flow through these deep gorges, tumbling over rock ledges and attacking all obstructions. They are very vigorous agents of erosion, using boulders as their tools as readily as the streams of the lowlands use grains of sand. During flood periods they hurl the boulders against one another and against all protruding masses with terrific force so that the sound is like that of the rumbling of distant cannon. The streams add to the landscape a dynamic element that is fascinating.

Millions of years have passed while running water has been at work in this part of the continent. It is running water that has done the major work of excavating the huge canyons which radiate from the high summit regions or descend from the divides to the foothills. Through centuries of persistent effort the streams have removed millions of tons of rock material. The pyramids of Egypt and of Mexico, the great temples of Guatemala and of Cusco in Peru, the huge earth dams built by the engineers of later days, the gigantic cement work built by modern engineers, and two or three metropolitan areas all put together would fill but a tiny portion of one of the mighty canyons excavated by the mountain torrents. In addition to their work of excavation, the streams have carried away a mantle of rock thousands of feet thick that once overlay the summits of the present mountain ranges. See Figure 141.

The distribution of forests and lakes adds much of beauty and color to this landscape as viewed from the air. Many of the lakes are in the catchment basins of glaciers that have disappeared; others are distrib-

uted as chains of blue or blue-green gems in the bottoms of the canyons or at the base of cliffs in basins formed by huge landslides or heavy morainic deposits.



Figure 141 · The ancient core rocks are here exposed in the mountains and the younger sedimentary strata underlie the plains to the east. Millions of years of stream work were required to remove the westward extension of the sediments that formerly covered the mountain area

A "close-up." If we climb on foot or on horseback to the summit of one of the ranges of the Rocky Mountains in the United States, giving at-

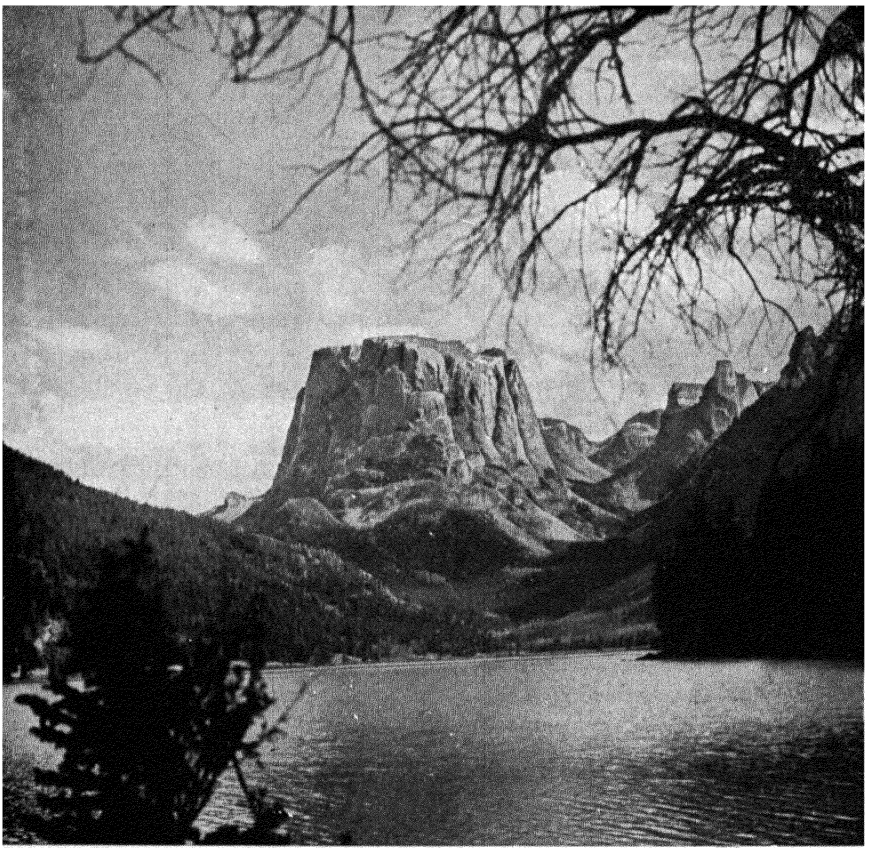


Figure 142 · A view from a camp in the forest zone at the margin of the Wind River Range, near the headwaters of Green River. We see the forest fading out near the base of Square Top Mountain, and above the tree line some of the bare rock surfaces that characterize the summit area of the range

tention chiefly to the native vegetation and wild life, we shall find ourselves passing through one zone after another. Each habitat is limited in altitude by certain climatic conditions or by local conditions of exposure, soil, or rock formations.

In the lowlands bordering the range, we find ourselves in the midst of greasewood and sagebrush, and the wild life, if any, will consist chiefly of coyotes, jack rabbits, sage hens, and prairie dogs. As we come to the foothills we see dwarfed cedars and piñons. They do not form a dense forest growth, but appear as scattered clumps or groves of trees. This

lowest habitat has a semiarid climate. It is a seared, brown, dry, and dusty area, with few permanent homes for white people.

Coming to the immediate base of the range where mountain streams are issuing through the canyons, we find ranch homes where cattle, horses, and sheep are cared for and where the ranchmen have fields of alfalfa, timothy, or peas which produce fodder for the livestock during the winter season. Above the zone of ranch homes we enter the forested belts on the mountain slopes. There pines and aspens, and a little higher spruces and firs, predominate. Among these forest trees many of the ranchmen's cattle and horses graze. If our eyes are alert we may see deer, antelope, bear, foxes, wildcats, elk, moose, and beaver. There also are many forest birds. See Figure 142.

Climbing still higher on the mountain slope, we run into a belt of dwarfed trees that include junipers and cedars. In this belt there are many low flowering plants and shrubs. In time we pass above the tree line into the zone of grasses, mosses, low flowering plants, and large areas of bare rock. Among these high-altitude plants we look for the ptarmigan, the snow bunting, and the marmot. The whistling marmots in the high mountain regions usually announce their presence boldly, but by remaining motionless they endeavor to avoid discovery. Grasses occupy all the high alpine benchlands and basins wherever there is sufficient soil. They are exceedingly luxuriant and provide summer pasture for hundreds of thousands of sheep and goats. The alpine flora includes an abundance of blossoming plants, and large areas of the mountainsides resemble flower gardens. All plant forms are stunted. The growing season is short; so there is very little time for producing long stems.

Still higher, above the grassy fields, we find on the bare rock surfaces a great variety of lichens of different colors and textures, and those of us who look closely may find tiny algae even on the snow near the mountain summits. Overhead, eagles float back and forth searching for game, which they will take to their little ones in a nest on the top of some rocky pinnacle. See Figure 143.

Elements in the landscape. When we attempt to analyze the landscape we find numerous small ranges of mountains, each with its foot-

hills, canyons, cascades, and peaks. Along the stream courses there are summer cottages and pleasure resorts, and on the shores of lakes tourists' camps and fishermen's tents break the monotony of the forest. In some of the ranges near the places where valuable ores have been discovered, mining towns, from which rise the great chimneys of crushing mills and concentrating plants, suggest a tie-up with the outside world. There little communities of workmen have their homes and find their occupations. They are producing something needed in the great industrial centers of the continent. Electric power plants and power lines are now conspicuous features in the mountain landscape at many places. But the high, rugged sections of the country are not the places for crowded populations. Such regions form parts of a choice wilderness which should long remain an inspiration to all who love the out-of-doors where nature has not been modified by man.

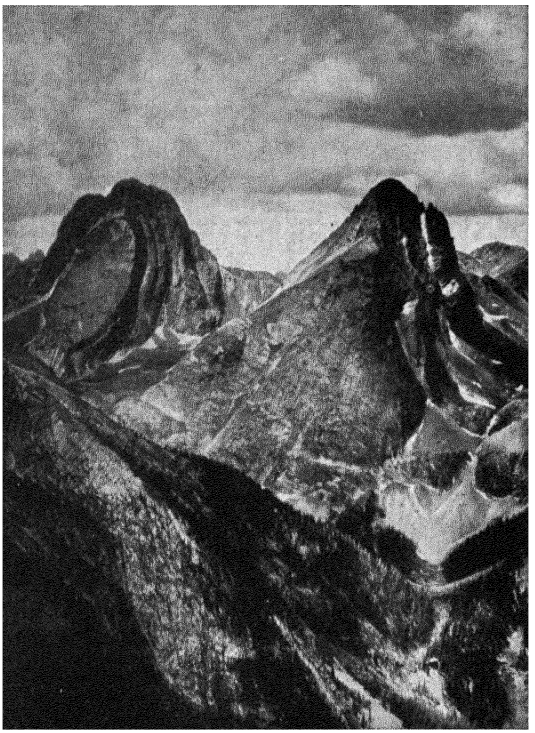


Figure 143 · Two of the conspicuously bare rocky peaks among the Needle Mountains in the core of the San Juan range of southwestern Colorado. They are monadnocks today, and they have been monadnocks in earlier periods of erosion

Each individual range in this great mountain system presents a series of problems in physiography that might well engage the attention of expert field workers throughout a number of seasons. Many investigators have spent from three to five field seasons in the study of the physical history of a single range. The author of this book spent fifteen

field seasons in a study of the physical history of one of the great domes in the Rocky Mountains of Colorado. Travel in these high rugged areas is chiefly in the saddle, and camp is moved by a pack train of mules.

Between or among the mountains there are broad, open basins or parks that occupy a large portion of the total area of the province. In these areas ranchmen have built their houses and small villages have been established. The larger communities in the mountain zone are near the foothills, where there are level lands suitable for building sites and where the soils permit some agriculture to be carried on.

Materials and Structure

The most frequently repeated geologic structure in this province is that of a great anticlinal arch; the Uinta and Big Horn ranges illustrate admirably this type. Some of the anticlines are so short that they might well be described as domes. The San Juan Mountains and the Black Hills are good examples of domal structures. See Figures 144 and 145.

A few of the distinct mountain ranges owe their origin primarily to the breaking of the crustal portion of the earth and to the movement of huge blocks of rock along certain fault planes. The Wasatch Range and the Tetons are excellent examples of such uplifted blocks. Faulting is still going on at the margins of these ranges.

The mountain face directly east of the city of Butte, Montana, is a fault-line scarp, and the west face of the Jefferson Range, southeast of Butte, shows distinct evidence of faulting. The south face of the Beaverhead Range is a fault-line scarp. The east face of the Bitterroot Mountains, which form a part of the boundary between Montana and Idaho, is a remarkable fault scarp. See Figure 146. This very steep mountain face is now cut into a series of huge triangular facets by streams that descend from the crest line, or divide. Where these streams issue through the fault scarp they have very sharp V-shaped notches. The bold western margin of Glacier National Park, which is also the eastern wall of the Flathead Valley, or Flathead trench, is the result of normal faulting. The Lewis and Clark ranges of Glacier National Park have been cut out of a huge thrust block. Chief Mountain is an isolated remnant of



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Figure 144 · Looking south at Sheep Mountain, Wyoming. This view, taken from the air, illustrates remarkably well the influence of geologic structure upon topography as a plunging anticline is being eroded. Notice the cigar-shaped core of the plunging anticline and the many hogback ridges

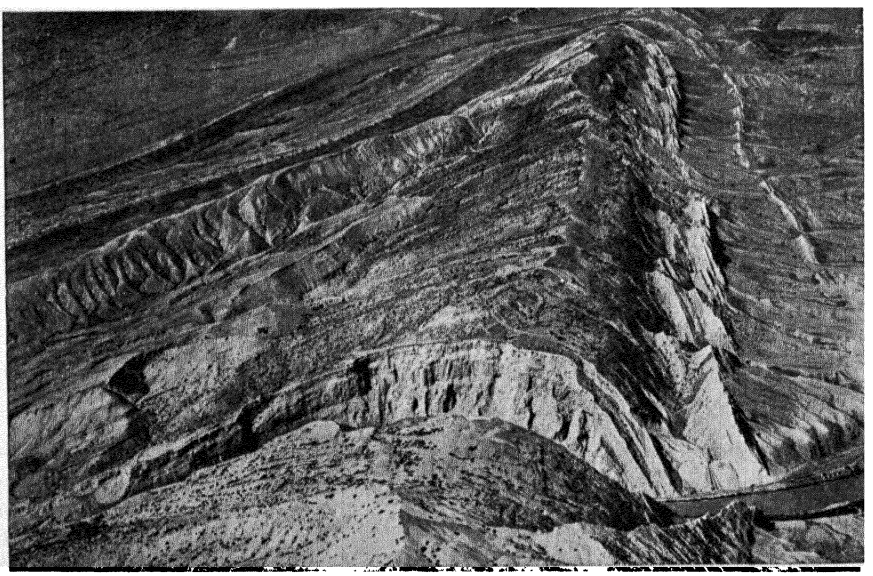

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Figure 145 · Looking north at Sheep Mountain, Wyoming. When this view was taken the plane was over the central portion of the anticline where the Big Horn River bisects the mountain

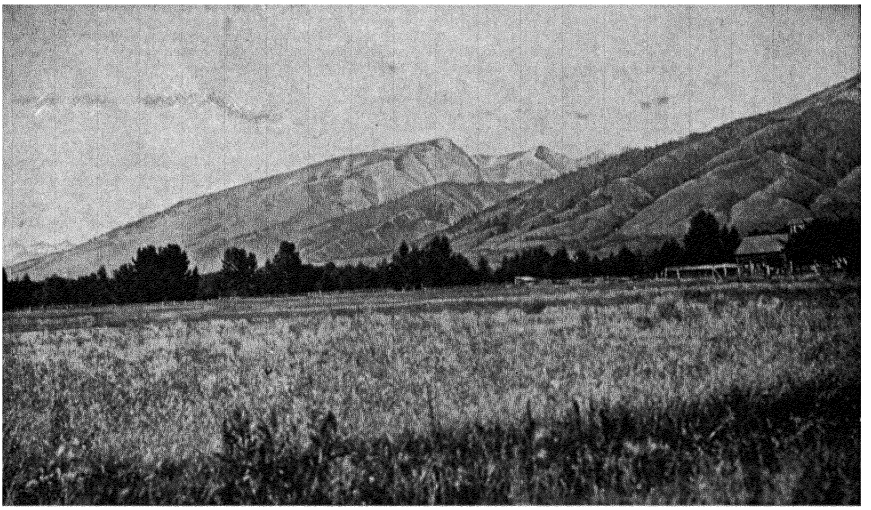


Figure 146 · The steep east slope of the Bitterroot Range near Hamilton, Montana, is a fault face. As streams have dissected the range they have left large triangular, flat-iron-shaped remnants of the fault scarp between the canyons. The foreground is stream alluvium

that great overthrust rock mass and indicates by its location east of the main body of the range that the thrust block extended at least that far over the Great Plains. See Figure 147. At many other localities there is evidence of breaking and slipping.

In the huge anticlinal folds we now commonly find a complex of Pre-Cambrian rocks exposed along the axes with upturned sedimentary layers of Paleozoic and Mesozoic ages on the flanks. These conditions are well illustrated in the Front Range, in the Sawatch and Park ranges of Colorado, in the Black Hills of South Dakota, and in the Wind River Range of Wyoming. In the Big Horn Mountains, erosion has not proceeded far enough to remove all the sediments from the axis of the range, but sufficient work has been done to expose the ancient core rocks at many places. See Figures 148 and 151.

In certain ranges of the Rocky Mountains a huge amount of lava has been poured out, and vast quantities of fragmental materials have been thrown into the air from volcanic vents and have then settled to the earth. In the San Juans, in the Absarokas, and at several other lo-

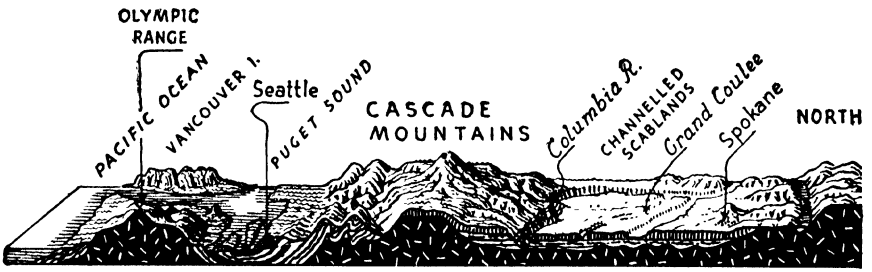


Figure 147 · A simplified diagrammatic structure section near the northern margin of features shown in perspective. The geosyncline of the Puget Sound Lowland and the the east margin of the Rocky Mountain Trench and the Lewis Overthrust

calities, volcanism has played a large and important role. Individual volcanoes, such as the Spanish Peaks of Colorado, form conspicuous features in the modern landscape. See Figure 149.

Evidences of faulting, folding, intrusion of igneous masses, extrusion of lavas, and the accumulation of ejectamenta are associated in the structural features of these mountains. The most ancient core rocks commonly include granites, granodiorites, gneisses, schists, slates, and quartzites. The sedimentary layers which appear on the flanks of the ranges and which accumulated in an inland sea or on land are sandstones, shales, limestones, or conglomerates. The extrusive lavas are chiefly basalts, rhyolites, and latites. The fragmental volcanic materials now form tuffs or breccias, but where mingled with water-worn stones the final product is called a volcanic agglomerate. In the basins there are alluvial sediments thousands of feet thick that were deposited chiefly by streams from the mountain ranges; some may have been laid down in lakes. See Figure 150.

Evolution of the Mountain Topography in the United States

Any attempt to follow through the development of topography in the Rocky Mountain region must necessarily be based upon the studies that have been made within the ranges in the United States. Detailed physiographic studies have not been carried out as yet in the ranges



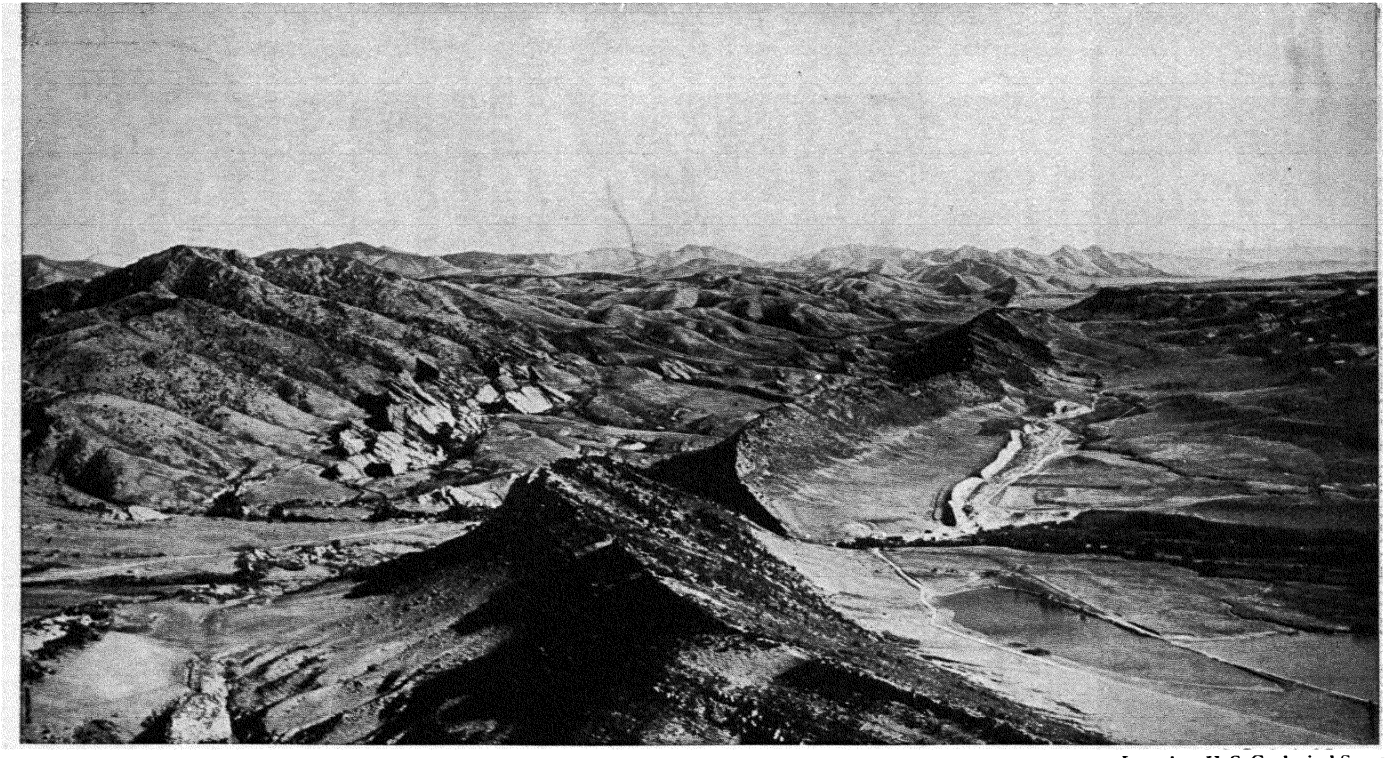
the United States, from the Pacific Ocean to the Great Plains, with adjoining relief lava-capped plateau near the Columbia River are at the left. The normal faulting at fault illustrate the structural relations in that portion of the Rocky Mountains

farther south or farther north. A general structural study has been made near the southern boundary line of Canada, and the Brooks Range of Alaska has been visited by a few scientific parties sent out by the United States government.

The outline now to be presented should be considered as a working hypothesis based upon present knowledge. It is subject to correction as additional information becomes available. It may prove to be applicable to much of this mountain belt, for probably the physiographic history of the province has been punctuated by the same major physical changes.

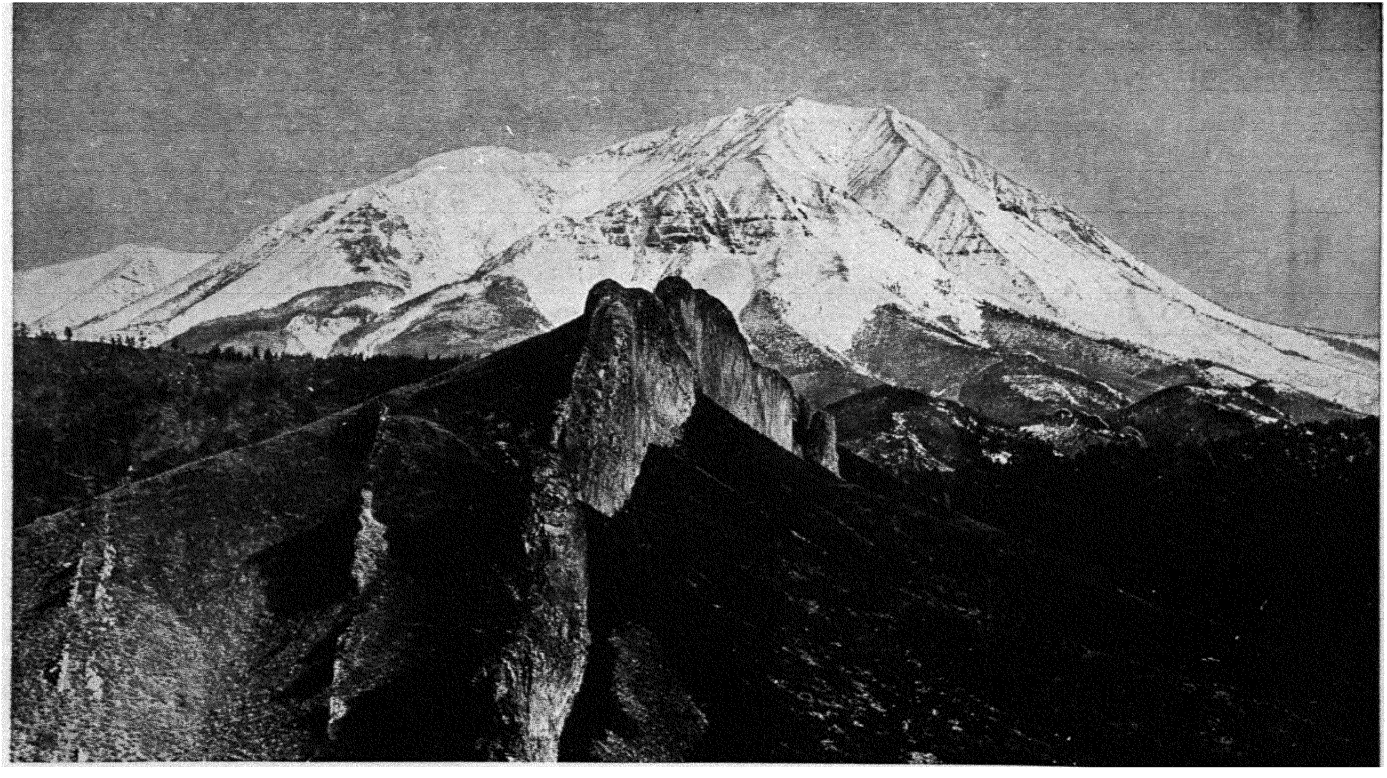
Origin of the ranges. Near the close of the Mesozoic era such tremendous forces developed in the crustal portion of the earth that huge masses of the continent began to move. We have already discovered that the Appalachian Highlands were uplifted relative to sea level and that the ocean waters were forced to withdraw from the Atlantic and Gulf Coastal Plain and from the Great Plains. Never since then have the sea waters spread over much of the continent. In the Rocky Mountain province one of the greatest physical revolutions in the history of the earth was inaugurated. Among geologists this physical change is referred to as the Laramide revolution. See the chart on page 20.

At the close of the Mesozoic era all the ranges in the Rocky Mountains of the United States were formed, and, so far as we know, the Rocky Mountains of Canada, the Brooks Range of Alaska, and the Sierra Madre Oriental of Mexico were uplifted. In certain of the ranges sediments with a combined thickness of at least 20,000 feet were in-



Lovering, U. S. Geological Survey

Figure 148 · The foothill belt at the east base of the Front Range in Colorado, near Lookout Mountain. The upturned strata appear in the hogbacks. The ancient crystalline core, formerly covered by the sedimentary rocks, is at the left. In the middle ground there is a bench that is capped with gravel washed eastward from the range during an earlier cycle of erosion



R. C. Hills, U. S. Geological Survey

Figure 149 · West Spanish Peak is a bold volcanic mountain near the east margin of the Rockies in southern Colorado. The ridge in the middle foreground is one of the many dikes radiating from this volcanic center. Others appear at the left

volved in this great orographic movement. At some places the huge, heavy rock formations were unable to bend and yield. They broke, and slipping occurred along the fault zones. At other places the strata were flexible and bent into very close folds with considerable contortion. See Figures 147 and 151.

The formation of the domes and the great arches undoubtedly went on very slowly. The movements may have amounted to only a few feet in a century, and they may have been characterized by many sudden jerks, which undoubtedly caused earthquakes. Earthquakes are frequent today among all growing mountains. Perhaps there is as much movement going on during the present century as there was during any equal period in the past. Mountain growth is not rapid or spectacular except in centers of volcanic activity.

The early Eocene landscape. Little by little as Tertiary time advanced, the mountain masses rose above their surroundings. It is inappropriate to replace, in imagination, over each of the mountain regions the entire thickness of sedimentary beds involved in the folding. If they were so replaced, they would form gigantic domes and arches and, where faulting occurred, many high escarpments. It is more appropriate to think that weathering and stream erosion began as soon as the uplifted areas rose above the ancient sea in which the sediments were deposited, and that as the uplifting continued, the tearing down was also in progress. However, it is certain that the uplifting movements proved to be far superior to the processes of erosion, and that in early Tertiary time there were magnificent mountain forms in this part of the continent.

In the mountains of the early Tertiary, or Eocene, landscape alpine glaciers formed. The deposits of those glaciers have been found at several localities, and the discovery of other Eocene glacial deposits should be anticipated. The discovery area is in the vicinity of Ridgway, Colorado, and therefore the glacial deposits of that age have been called the Ridgway Tillite.[1] Later, other deposits of the same age were discovered near Gunnison, Colorado,[2] and at several places in Wyoming.

[1] W. W. Atwood, "Eocene Glacial Deposits in Southwestern Colorado," *U. S. Geological Survey, Professional Paper*, No. 95-B (1915), pp. 13–26.

[2] W. W. Atwood and W. W. Atwood, Jr., "Gunnison Tillite of Eocene Age, Colorado," *Journal of Geology*, Vol. 34 (1926), pp. 612–622.

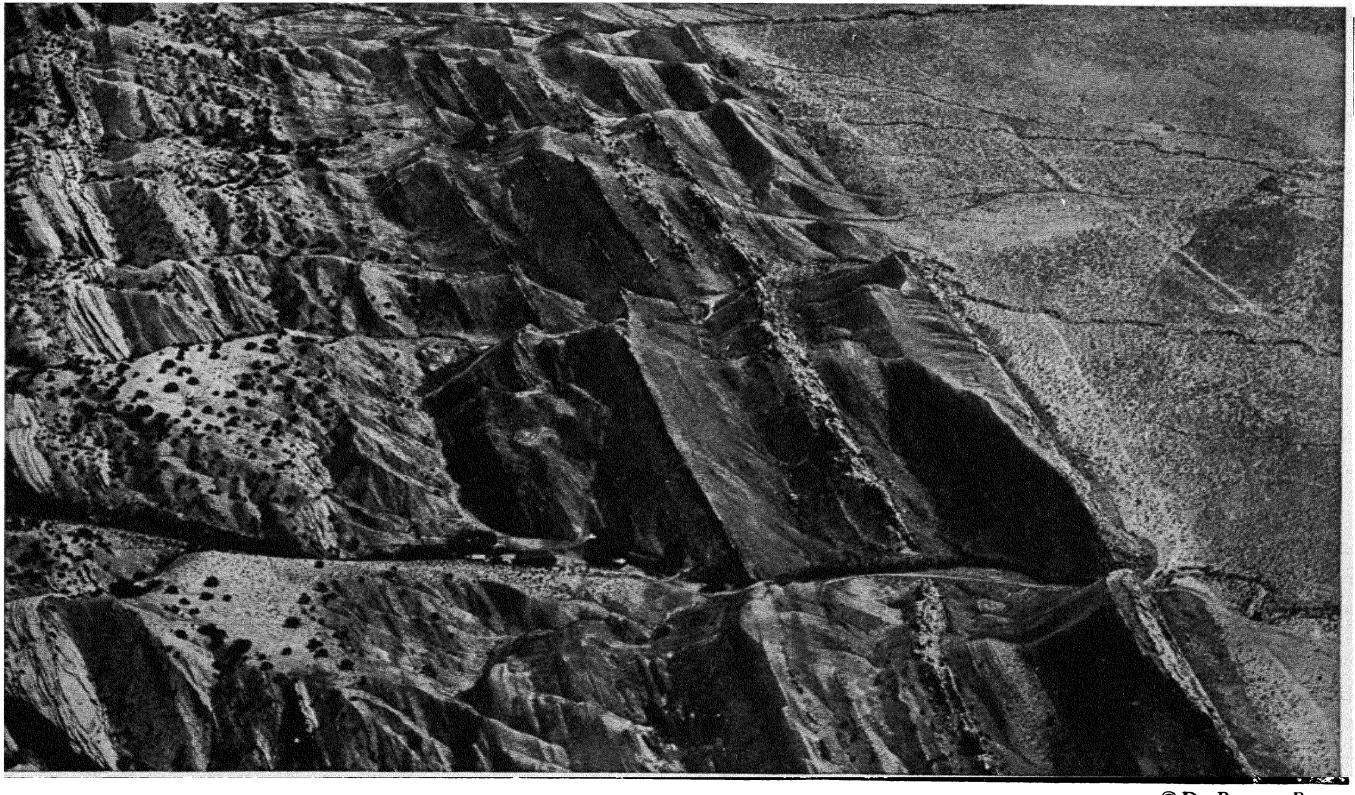


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Figure 150 · Erosion of upturned strata in the Dinosaur National Monument six miles north of Jensen, Utah, and near the western margin of the Rocky Mountain province

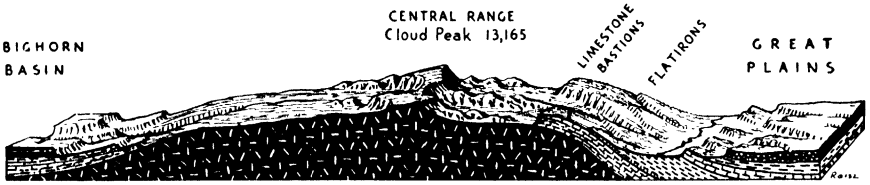


Figure 151 · An east-west diagrammatic structure section through the Big Horn Mountains, with a bit of the relief in the range shown in perspective

No one could expect the record of this early Tertiary period of glaciation to be found in many localities, but it is reasonable to believe that if alpine glaciers existed in southern Colorado and in Wyoming they were present also in many other portions of the Rocky Mountain region. Every bouldery deposit that is associated with the Eocene deposits and overlain by Oligocene or Miocene sediments, or is so situated as to indicate that it was formerly buried beneath sediments of Oligocene or Miocene age, should be carefully examined in order to fill out the record of that ancient ice age. Geologists at work in the Rocky Mountain region should be constantly on the lookout for glacial deposits of early Tertiary age.

Ralph Chaney, in his recent studies of the march of the redwoods and other forest trees southward from the arctic region into the United States since early Tertiary time, has shown that there must have been a mild climate in North America during the Eocene period—certainly a much milder climate than we have today. This conclusion justifies our belief that during the Eocene period, when alpine glaciers formed in Colorado, there were mountains 12,000 to 15,000 feet high in that section and that there must have been an abundance of magnificent mountain scenery. It is safe to imagine that this landscape, with its alpine glaciers, was as picturesque and bold as any that has existed in the western part of the continent during any later time.

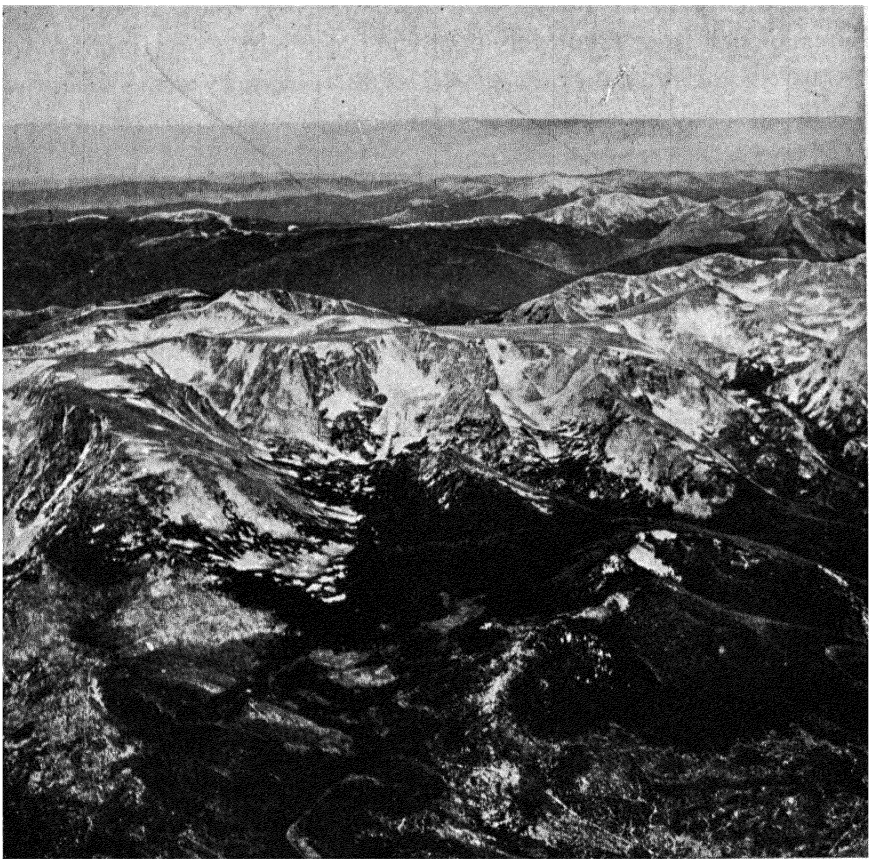
The late Eocene landscape. As the centuries passed, the mountain forms of early Tertiary time became more and more subdued. There is evidence that there was a very long period when the work of streams predominated. In the San Juan region, below the mid-Tertiary volcanics, there is an erosion surface which appears to have but slight

relief. It has been referred to as a peneplain (page 305). In the Front Range of Colorado certain very high, flat surfaces have been interpreted tentatively as remnants of a peneplain of early Tertiary age. This is the so-called Flattop Peneplain.[1] See Figure 152. These old-age surfaces are not very extensive. In the Absarokas and extending eastward into the Beartooth Range there is an early Tertiary erosion surface much of which is buried beneath mid-Tertiary volcanics. Here the old erosion surface has considerable relief and certainly should not be called a peneplain. It may appropriately be referred to as a surface in maturity. The Granite Mountains, which appear today as a disconnected, partially resurrected range, indicate that there was a very rough topography in the central portion of the Wyoming Basin during early Tertiary time. In the South Park area of Colorado the relief indicates that the surface upon which mid-Tertiary sediments accumulated was rough rather than smooth.

While the agents of erosion were continuing their task of subduing the mountain forms, vast quantities of sediments were accumulating in the lower areas among the mountains. These areas may be thought of as basins, although they were not completely closed at all times. Geologists have interpreted some of the Eocene deposits to be of lacustrine origin; others are certainly of fluviatile origin. East of the Rocky Mountains in the area of the Great Plains and bordering the Black Hills, which are but an outlying range of the Rocky Mountains, vast quantities of Eocene deposits accumulated. In the Wyoming Basin the sediments of Eocene age are widespread and are several thousand feet thick. In the Uinta Basin, south of the range of the same name, there are extensive and thick deposits of Eocene age.

By the close of the Eocene period of geologic time the Rocky Mountain province had passed through a period during which mountains were of great magnitude and had become a region in which considerable areas were softened or subdued. There was a relief of from 2000 to 3000 feet in many places, and the conspicuous features in the landscape all rose as monadnocks above the base plains of erosion then existing. The monadnocks were yielding waste material to the streams

[1] W. T. Lee, "Peneplains of the Front Range and Rocky Mountain National Park, Colorado," *U. S. Geological Survey Bulletin*, No. 730 (1922), pp. 1–17.



U. S. Geological Survey

Figure 152 · The summit of Flattop Mountain, near the middle of this view, has been interpreted as a remnant of an early Tertiary peneplain. This picture was taken from the air about five miles southwest of Estes Park at an elevation of 14,200 feet. We are looking westward

as the processes of destruction went on, and the lowlands were being covered to greater and greater depths. It is impossible to assert that there was a widespread peneplain at that time. The cycle of erosion during which the mountains were being dissected and the lowlands were being mantled with alluvial waste had not been completed. There were large areas of rugged mountain country, some areas in the old-age stage of erosion, other places that were maturely dissected, and widespread areas of alluviation. There was considerable variety in the landscape.

Renewal of mountain growth. Somewhere near the close of the Eocene period the Rocky Mountain region as a whole was subjected to another period of mountain growth. This was also a major event in the physical history of the region. The movement was undoubtedly slow, and, as stream erosion proceeded, the uplift continued. The unloading of one area and the loading of another may well have been one cause of differential movements. As the basins received sediments and became heavier, they sank and the mountain areas that were losing material rose. The old structural lines were re-emphasized and in time, as erosion continued, another generation of mountains came into existence. The arches, the great domes, and the fault blocks were lifted several thousand feet above the position which they had held near the close of Eocene time.

In addition to the re-emphasis of the folds and fault blocks, a large amount of volcanic activity occurred at several places in the Rocky Mountains during the mid-Tertiary period. In the San Juan region a huge volcanic plateau was built up. Here the lavas, tuffs, breccias, and agglomerates accumulated to a thickness of at least 7000 feet. These outpourings from volcanic centers or great fissure vents spread over the eastern portion of the range, completely burying the younger rock formations in that section. They spread northward over the entire area where the Black Canyon of the Gunnison River has been excavated. Still farther north, in the Crested Butte and Anthracite region and in the area of the Grand Mesa, volcanoes were particularly active. In the Spanish Peak region and in the Trinidad and Raton area there was a vast amount of volcanism. Between North and Middle parks in Colorado, in the region of the Rabbit's Ear Range, is found another center of great volcanic activity. Still farther north, in Yellowstone Park and in the Absaroka Range, are found the most widespread and remarkable of all the mid-Tertiary volcanic records. It was at about this time also that the lava flows which cover thousands of square miles in the plateau areas associated with the Snake and Columbia rivers poured forth.

As the mountains grew and as volcanism progressed, stream erosion continued in the uplifted areas and deposition went on in the basins and on the bordering plains and plateaus. This was a remarkable period of alluviation in the region of the Great Plains.

Contemporaneous denudation of the mountains and filling of the basins. The mid-Tertiary period of erosion and basin-filling must be thought of as another significant chapter in the physical history of the Rocky Mountain province. During this period thousands of feet of sediments, brought from the mountains, accumulated in the neighboring lowlands. They constitute today the mid-Tertiary sediments of the Rocky Mountain area as well as those of the same age to the east of the mountains on the surface of the Great Plains, and to the west of the mountains on the surface of the high plateaus.

The remnants of those mid-Tertiary deposits are exceedingly widespread today; but the outliers, in their present distribution and topographic locations, indicate that the deposits were formerly much more widespread than they are now. They consist of sand, clay, gravel, and volcanic ash. Some have been interpreted as being of lacustrine origin, but most of them are thought to be of alluvial origin. They represent, for the most part, the material brought by the streams from the mountain areas and spread out on the neighboring lowlands or in the intermontane basins. They include some deposits which have been classified as of Oligocene age, some of Miocene age, and some of Pliocene age.

The last, or youngest, in the series of these formations is, in many areas, a heavy bouldery deposit, commonly referred to as a high-level boulder conglomerate. Such deposits cap mesas in the Wyoming Basin, rest high on the slopes of the Big Horn Range, and are particularly widespread on both the north and south slopes of the Uinta Range. Heavy bouldery beds found on the outskirts of the San Juan Mountains are probably of about this same age.

The Arikaree and Ogalalla formations, which mantle the High Plains east of the Rocky Mountains, represent a late stage in this period of alluviation and basin-filling. Ogalalla beds are commonly thought to be of Pliocene age.

The north-south troughs of western Montana are partially filled with mid-Tertiary deposits that have been called the Bozeman beds. They consist of silts washed from the neighboring mountains, volcanic ash that has settled in the basins, and some lacustrine sediments. Since they were deposited in structural troughs, in valleys, and in passes high among the mountain ranges—localities all below remnants of a summit

peneplain of that section—they must be younger than that peneplain. The Bozeman beds are well preserved in two of the passes in the Beaverhead Mountains north of Idaho Falls, Idaho, and southwest of Butte, Montana. One is the pass in which the town of Monida, Montana, is located, and the other is Bannock Pass. Since these sediments are of mid-Tertiary age, the old erosion surface on the summits of the ranges near by must have been developed early in Tertiary time.[1] If a correlation is attempted, it should be with the Flattop Peneplain described in the Front Range of Colorado (page 301).

The Bozeman sediments have been slightly tilted, which indicates that they were deposited previous to the last mountain-making movements in this province.

The Rocky Mountain Peneplain. The mid-Tertiary period of denudation and basin-filling was very long, and during this time portions of the mountain ranges were reduced to slight relief and became parts of a remarkable peneplain. Many persons who have studied the Front Range of Colorado have called the remnants of this old-age erosion surface in that section the Rocky Mountain Peneplain.[2] A remnant in the San Juan Mountains in southwestern Colorado has been called the San Juan Peneplain.[3] The name Green Ridge Peneplain has been given to the remnant in the Green Ridge, north of Rocky Mountain National Park. Medicine Bow Peneplain,[4] Sherman Peneplain,[5] Gilbert Peak surface,[6] Wind River Peneplain,[7] and many other local names have been applied to remnants in the Medicine Bow Range, in the Park Range west of North Park, in the Laramie Range and its northern extension,

[1] W. W. Atwood, "The Physiographic Conditions at Butte, Montana, and Bingham Canyon, Utah, When the Copper Ores in These Districts Were Enriched," *Economic Geology*, Vol. 11 (1916), pp. 697–740.

[2] W. T. Lee, "Peneplains of the Front Range and Rocky Mountain National Park, Colorado," *U. S. Geological Survey Bulletin*, No. 730 (1922), pp. 1–17.

[3] W. W. Atwood and K. F. Mather, "Physiography and Quaternary Geology of the San Juan Mountains of Colorado," *U. S. Geological Survey, Professional Paper*, No. 166 (1932), 176 pages.

[4] W. W. Atwood, Jr., "Records of Pleistocene Glaciers in the Medicine Bow and Park Ranges," *Journal of Geology*, Vol. 45 (1937), pp. 113–140.

[5] E. Blackwelder, "Cenozoic History of the Laramie Region, Wyoming," *Journal of Geology*, Vol. 17 (1909), pp. 429–444.

[6] W. H. Bradley, "Geomorphology of the North Flank of the Uinta Mountains," *U. S. Geological Survey, Professional Paper*, No. 185-I (1936), pp. 163–204.

[7] L. G. Westgate and E. B. Branson, "The Later Cenozoic History of the Wind River Mountains, Wyoming," *Journal of Geology*, Vol. 21 (1913), pp. 142–159.

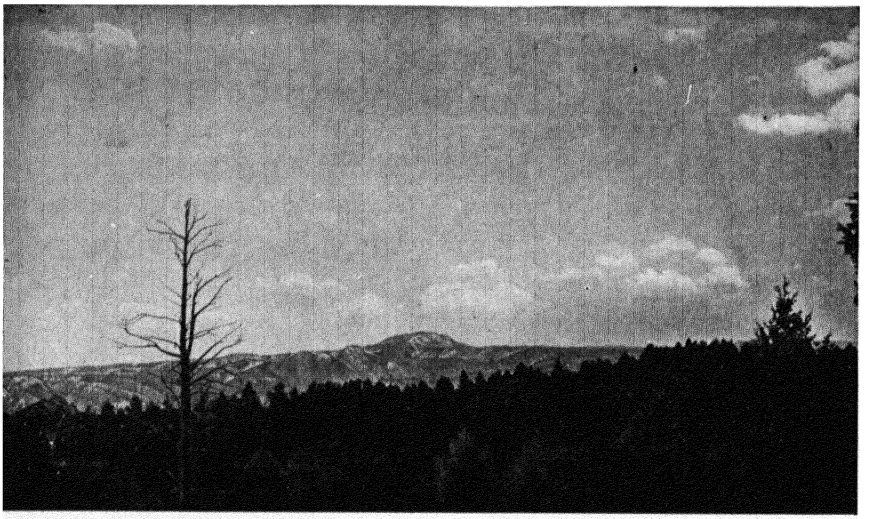


Figure 153 · The sky line is a part of the summit peneplain of the Rampart or Front Range in Colorado. Little Scraggly is the conspicuous monadnock that rises above the general level of the peneplain

commonly referred to as the Casper Range, in the Wind River Range, and in the Uintas, the Big Horns, and the Owl Creek Range. There are undoubtedly other remnants of this peneplain in the Rocky Mountains. See Figures 153, 154, and 155.

Since these peneplain remnants are so widespread in this physiographic province and are of approximately the same age, and since there is no other equally widespread peneplain recorded in the present landscape within this mountainous region, they will all be referred to as parts of the Rocky Mountain Peneplain. As thus identified, this peneplain is indeed a remarkable surface. It is also a very important key to the interpretation of the history of each range where it has been recognized. Its recognition is not based solely upon uniformity of level in the different subsummit areas. Truncated geologic structures, and at places stream gravels which represent the work of the old-age streams that wandered about during the very late stages in a cycle of erosion, have been found.

At several localities the margins of the peneplain remnants are found mantled with Pliocene sediments, which help to determine the age of the surfaces involved. See Figures 156, 157, and 158. At many places



Figure 154 · A portion of the summit area in the San Juan Mountains of southwestern Colorado. Here the rocks are all mid-Tertiary volcanics. Remnants of the late Tertiary peneplain appear in the foreground, and in the distance there are several conspicuous monadnocks. Uncompahgre (14,300 feet), the highest peak in the range, is at the right. It is composed of nearly horizontal layers of lava. The canyons were excavated, for the most part, during the Pleistocene. They have been severely glaciated

rock pediments were formed about the margins of the ranges. They commonly carry a thin veneer of alluvial waste. On both the north and south flanks of the Uinta Range the formation known as the Bishop Conglomerate (see page 310) mantles the peneplain surface and the pediments.

No two widely separated portions of a single peneplain are ever of exactly the same age. As a peneplain is developing, the downstream portions of a drainage basin reach the post-mature and old-age stages long before the middle portion of the basin has reached that stage, and still longer before the areas drained by the headwaters of that river system have been reduced to old age. During a given cycle of erosion a peneplain may be present in the lower portion of a drainage basin, while the middle portion may be in maturity and the headwater regions may be in a youthful stage.

Since the peneplain remnants in the Rocky Mountain province be-

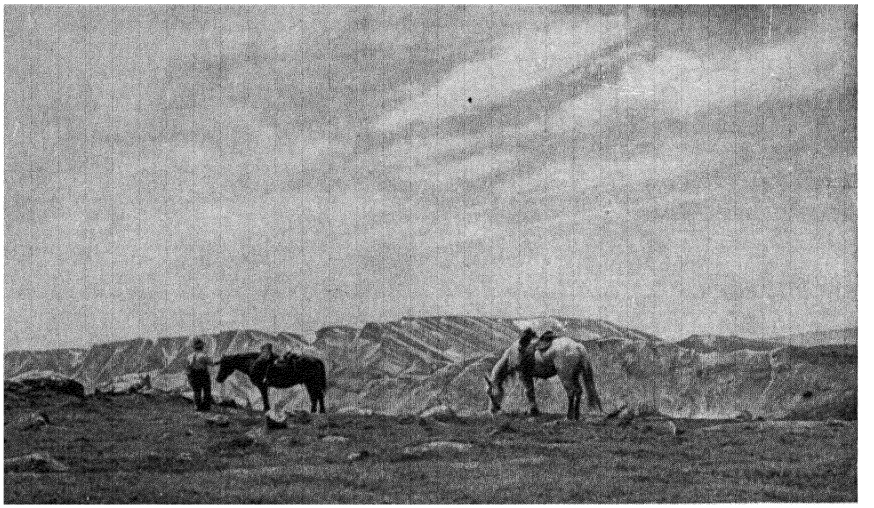


Figure 155 · Here, as at many places in the western part of the Wind River Range, the summit peneplain truncates a series of upturned sedimentary strata and continues eastward over a complex mass of crystalline and metamorphic rocks

long, as a rule, to distinct drainage systems, since some of these drainage lines lead to the Gulf of Mexico and others to the Pacific Ocean, and since some of the streams have much longer routes of travel than others to the ultimate base-leveling body of water, the work of erosion is never advancing at exactly the same rate in any two distinct mountain ranges. All that it is safe to say is that these peneplain surfaces are about the same age. Their development in so many portions of the region is positive evidence that there was a long period of relative stability during mid-Tertiary time. That period was so long that the streams in many of the mountain portions of the province reduced considerable areas of their drainage basins to the peneplain stage.

The late Tertiary landscape. Above the widespread Rocky Mountain Peneplain of late Tertiary age there remained considerable areas with bold and picturesque relief. The San Juan Mountains were not completely subdued. In the Needle Mountain area of that range there are conspicuous monadnock forms that rise above the subsummit peneplain. In Colorado, Pikes Peak, Longs Peak, Mount Evans, and all the beautiful crest-line features in Rocky Mountain National Park were monadnocks.

In the Sawatch Range there were magnificent monadnock peaks. The crest-line features of the Wind River Range, including Gannett and Fremont peaks, and the higher summits of the Gore Range, the Sangre de Cristo Mountains, and the Big Horns are all monadnocks; and to the present day they continue to be monadnocks that rise above the Rocky Mountain Peneplain. The Snowy Range, in the midst of the Medicine Bow Mountain area, rises distinctly above the great peneplain.

The alluviation which was proceeding as the Rocky Mountain Peneplain was developed resulted in the accumulation of sediments in the Wyoming Basin, South and North parks, and in the Big Horn and Uinta basins, and east of the Rocky Mountains in the area of the Great Plains. Some mountainous areas were actually buried beneath these slowly accumulating sediments, and others were partially buried. Thus, in the Wyoming Basin, in North Park, and in the Big Horn Basin, the complex mountain structures that are beginning to appear again today were completely masked by alluvial deposits before the close of the mid-Tertiary period of filling; the Granite Range of central Wyoming was almost entirely buried; and portions of the Big Horn, Owl Creek, and Uinta ranges were buried, as, undoubtedly, were portions of the Beartooth and Absaroka ranges. The west end of the Wind River Range and probably all the Gros Ventre Range were mantled, and the mantling continued westward into the Jackson Hole region of today. Similar deposits must have covered a part, at least, of the Laramie Range and parts of the Medicine Bow Range as well as the Yampa Plateau and parts of the Front Range of Colorado. During this same period mid-Tertiary volcanism had buried portions of the Rocky Mountain area, and lava flows had spread over portions of the Great Plains. See Figures 154 and 161.

A cycle-end-surface was being developed in which the old mountain areas retained some rugged features, but were in large part subdued to the peneplain stage. The intermontane basins were nearly or completely filled with sediments, and those sediments were actually mantling portions of the mountain ranges as a thin veneer. The filling brought the surfaces of the basins to about the same elevation as that of the peneplains. The late Tertiary landscape in the Rocky Mountain province consisted of extensive tracts of nearly level lands above which rose, along

the axes of the major ranges, a few low mountains. In a few areas volcanic activity increased the relief and undoubtedly added considerable variety to the physical features of the landscape.

During this long period of filling there were many minor physical changes which account for the numerous unconformities that have been found in the mid-Tertiary series of sediments. These details in each of the great chapters in this history are being omitted from this volume.

The high-level boulder conglomerates. Near the close of this long period of sedimentation a vast amount of gravel and boulders was spread out about the margins of many of the ranges. Captain King, in his studies near the fortieth parallel, discovered large areas in eastern Utah capped with what he called the Wyoming conglomerate.[1] Later observers have adopted the name "Bishop conglomerate" for this same formation, and they have found it to be even more widespread north and south of the Uinta Mountains than was reported by King. Near this range it contains well-rounded masses of quartzite three to four feet in diameter. Farther from the mountains the material is smaller, grading into boulders one to two feet in diameter, then to cobblestones, and, at distances of 20 to 30 miles from the mountains, to fine gravel. See Figure 156.

The Bishop conglomerate is evidently a stream wash made up of numerous alluvial fans which are more or less blended on the pediments and in the relatively flat lands that border the remnants of the Uinta Mountains. The author of this book has mapped and described extensive areas about the margins of the San Juan Mountains that are capped with a bouldery formation similar to the Bishop conglomerate and of about the same age.[2] In southwestern Colorado the mantle of wash material from the mountains has been traced outward for 50 miles from the base of the San Juans. Many other field workers have described high-level boulder cappings near the ranges in the Rocky Mountain province.

From the physiographer's point of view, however, the Bishop and

[1] C. King, "Geological Exploration of the Fortieth Parallel," *U. S. War Dept., Chief Eng., Annual Report* 1871 (U. S. 42d Congress, Second Session, H. Ex. Doc. 1, Pt. 2, Vol. 2), App. Z. (1871), pp. 1027–1030.

[2] W. W. Atwood and K. F. Mather, "Physiography and Quaternary Geology of the San Juan Mountains of Colorado," *U. S. Geological Survey, Professional Paper*, No. 166 (1932), 176 pages.

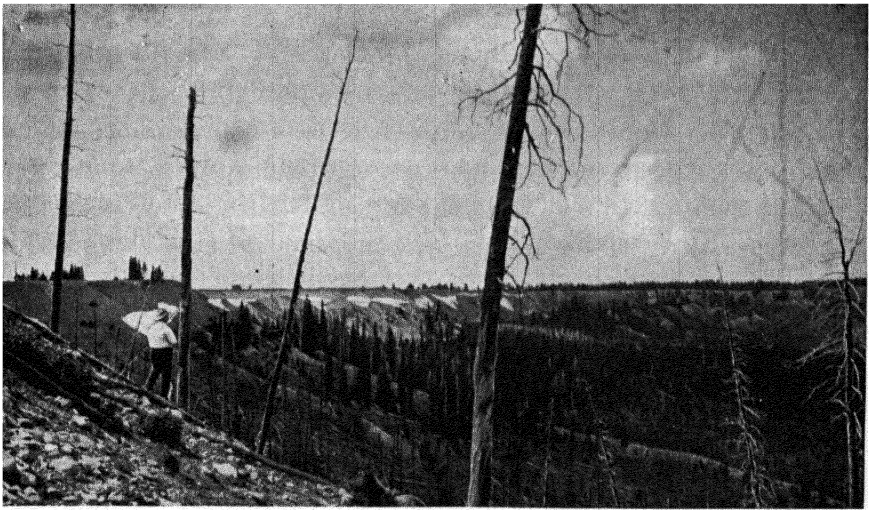


Figure 156 · The Bishop conglomerate shown in the immediate foreground and in the long escarpment at the left mantles a large portion of the north slope of the Uinta Mountains and formerly spread over thousands of square miles in the southern portion of the Wyoming Basin. This conglomerate accumulated in mid-Tertiary times as the Uinta Mountains were being reduced by stream erosion

similar conglomerates do not alone represent the closing of the long period of alluviation or sedimentation. They may mean the rejuvenation of streams in their headwaters and thus mark the beginning of a new cycle of erosion in the neighboring highlands. When a renewal of mountain growth occurs and each range is somewhat re-emphasized, the headwaters of the drainage systems are at once rejuvenated. In the middle courses of those major streams there may be no quickening of the current or deepening of the channel. The deepening in that section must await the headward erosion from the mouth, or from far downstream where uplift caused the rejuvenation. Throughout the major portion of each drainage basin, rejuvenation moves as a wave up the main stream and, in time, up each tributary stream. At any moment in the process there will normally be a series of interrupted profiles in the stream gradients. In time the deepening of the valley will reach the base of the mountains and continue still farther into the valleys of the headwater tributaries. While that slow process of headward erosion is proceeding, the headwater streams that have been rejuvenated because

of greater uplift along the mountain axes will be carrying vast quantities of waste material as far as they can. That will normally be to the base of each range; and there, because of loss in gradients, deposition will take place and alluvial fans will be constructed.

Thus the Bishop and other associated and similarly placed conglomerates suggest to the physiographer a new cycle of erosion in the mountain areas at the same time that they furnished an additional mantle for the lowlands. Certainly a new cycle soon followed, for the Bishop conglomerate and the underlying sediments were soon dissected by stream erosion.

The suggestion has been made by Bradley[1] that the Bishop conglomerate may record an increase in aridity. If we assume that increased aridity accounts for this conglomerate, we must rely on cloudbursts and occasional floods. We should find other supporting evidence to explain the increase in aridity which came just shortly before the opening of the Pleistocene ice age.

In the San Juan region the high-level boulder conglomerate extends for many miles into New Mexico, Arizona, and Utah. It was traced eastward into the San Luis Valley and southward into the valley of the Rio Grande. This boulder conglomerate rests in the mountains upon the subsummit peneplain which is known to be of late Tertiary age. At some places it rests upon a surface which truncates the underlying sedimentary formations upturned about the margin of a mountain area, and at other localities it rests upon mid-Tertiary volcanics. Eastward this conglomerate declines below the present floor of the San Luis Park and is buried under recent lava flows, which, in turn, are buried by Quaternary alluvium. The San Luis Park is a down-faulted block. The break is at the east margin of the park near the Sangre de Cristo Range. In this park the Rio Grande has cut through the Quaternary alluvium, through the great lava flows which cap the boulder conglomerate that rests upon the San Juan Peneplain, and through that conglomerate into the underlying erosion surface.

Bradley[1] has mapped with great care the extent of the Bishop conglomerate on the north side of the Uintas. One of the most remarkable

[1] W. H. Bradley, "Geomorphology of the North Flank of the Uinta Mountains," *U. S. Geological Survey, Professional Paper*, No. 185-I (1936), pp. 163–204.

remnants of this boulder bed is on the south side of the range, where it caps Diamond Mountain, northeast of Vernal, Utah. There a thick mantle of the conglomerate rests upon a surface that truncates the series of Paleozoic and Mesozoic sediments and some beds of the mid-Tertiary sediments. This surface corresponds topographically and physiographically to the summit of the Yampa Plateau.

On the north side of the Uinta Mountains there are several large areas capped with Bishop conglomerate. Near the east end of the range, on an outlying cuestalike form named Queen Hornet Mountain on the King map, this conglomerate rests on a surface which truncates the older sediments. Also, in the region north of Gilbert Peak and Tokawana Peak, there is a large area where the conglomerate remains almost untouched by subsequent erosion. See Figure 156. In Mount Elizabeth the conglomerate is remarkably well exposed and forms the capping of the divide between the Hayden Fork of Bear River and Black's Fork of Green River. At this locality the conglomerate contains large contributions from the formations exposed in the core of the Uinta Range. Many of the boulders are from two to three feet in diameter, and the mantle is from 50 to 100 feet thick.

The age of the Bishop conglomerate has been determined as Miocene or Pliocene. It has been correlated in age with the basal portion of the Browns Park formation, which is believed to be of late Tertiary age. It precedes slightly the opening of Pleistocene time in the Rocky Mountains, and therefore, on the basis of physiographic evidence, a Pliocene age is favored for this conglomerate. It is certain that the Bishop conglomerate rests upon a peneplain and blends into a pediment on the mountain slope called the Gilbert Peak surface by Bradley, and thought by him to be of late Tertiary age. Nowhere in the Rocky Mountain region have the physiographic relationships been found so clearly defined as near the Uinta Mountains. The lands bordering that range to the north and south are today in regions of semiarid climate, which may account for the fact that the larger remnants of the conglomerate are left in this part of the Rocky Mountain province. See Figure 157.

The closing of the mid-Tertiary period of denudation and filling. By the close of the mid-Tertiary period of erosion in the mountains and

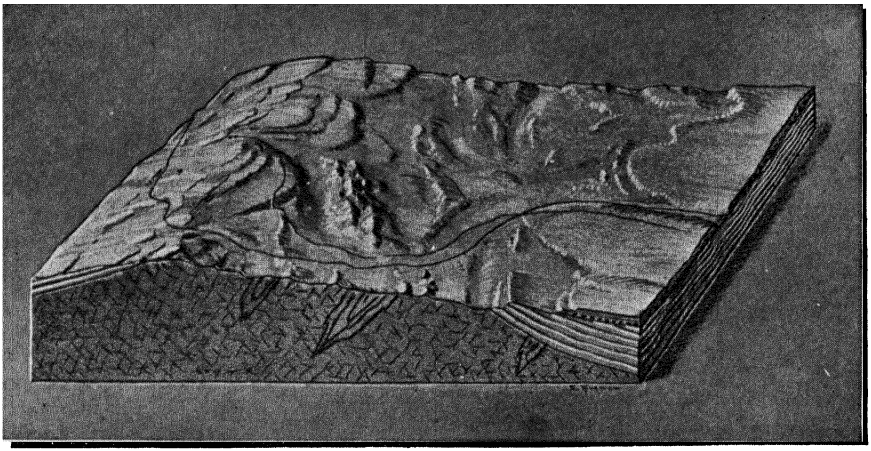


Figure 157 · The Laramie Range in the vicinity of the Sherman Mountains. The structure and surface at the western margin of the Great Plains appear at the right. Here the late Tertiary alluvial deposits mantle the plains. A compound cuesta is shown at the left, and in the central portion an extensive peneplain has been somewhat dissected. At the close of the mid-Tertiary period of filling, this range was nearly covered with alluvial deposits

deposition on the lowlands, the cycle-end-surface already referred to had been developed. Recall that in that landscape there were crest-line peaks in each of the major mountain ranges that stood out as conspicuous features in the landscape. Adjoining many of the crest-line areas there were somewhat extensive peneplains in which the old-age erosion surfaces truncated formations that ranged in age from Pre-Cambrian to Tertiary. Adjoining the peneplained areas, and at places lapping upon them, there were vast expanses of nearly horizontal sediments for the most part unconsolidated or but poorly cemented. They were youthful sediments which had just accumulated in the basins among the mountains and in the lands bordering the mountain region to the east, west, and south. A new term is needed to describe such a composite cycle-end-surface, for such a landscape cannot be called a peneplain. Possibly the word *endsurf* may prove acceptable.

Imagine in that landscape a drainage pattern which had evolved during the long period of degradation and alluviation. The streams were working on very low gradients and presumably meandering through most of their courses in soft, loose, alluvial material. They

were still aggrading their flood plains, and so their channels were undoubtedly shifting from time to time because of the very low gradients and occasional overloading. Braided channels, such as at present characterize the North and South Platte rivers in their routes across the Great Plains, should be added to the picture. It was an exceedingly peaceful time, when rivers were lazily wandering across a subdued and monotonous landscape. But it was a time just preceding an event of remarkable significance and the opening of an era when the streams of the Rocky Mountain region were about to experience a series of difficult and thrilling adventures.

Renewal of mountain growth. Late in Tertiary time, after the mountain ranges had been subdued, after thousands of feet of mid-Tertiary sediments had accumulated, after the great volcanic flows of Colorado, Wyoming, and Idaho had been poured forth, after the vast quantities of ejectamenta had settled and accumulated as breccias, tuffs, and ash beds, and just before the opening of the Pleistocene period, there occurred throughout the Rocky Mountain region within the United States another physical revolution which is of major significance in the physical history of that part of the continent. The movement this time was very widespread; it was epeirogenic more than orogenic. The mountain ranges were somewhat emphasized, but the most significant feature was the widespread general uplift. It is believed that the entire Rocky Mountain region was affected during this period of uplift, and that the neighboring physiographic provinces, including the Great Plains to the east and the High Plateaus to the west, were uplifted. Probably the entire cordilleran section of North America was involved in the movement.

Rejuvenation of streams. Accompanying the uplift there was a quickening of the work of running waters. We have already referred to the influence which the upward movement had upon the headwater streams that were at work in the monadnock areas and the consequent deposition of the boulder conglomerates bordering many of the mountain ranges. Thousands, perhaps millions, of years passed before the rejuvenated Colorado, working headward through the great plateau section, cut the Grand Canyon in Arizona and finally affected the work

of its tributaries in the southwestern portion of the mountain province; and before the quickening of the Arkansas, South Platte, North Platte, Laramie, Sweetwater, Missouri, Yellowstone, Clark Fork, or Snake affected the development of valleys within the Rocky Mountain province. The process of headward erosion is not rapid. It must be recognized that this work proceeds very slowly, along with most other changes taking place in the evolution of a landscape. Alluviation continued about the margins of the monadnock areas, and the crest-line peaks continued to crumble away.

When the quickening influence of stream work reached the mountain area and downward cutting began in the immediate province under consideration, the lazy old-age streams took on the characteristics of youth and began to lower their courses. It was then that the incidents occurred which have produced many of the most magnificent scenic features in the several ranges of this province.

Superposition of the main drainage lines. At the close of the mid-Tertiary period of erosion and alluviation, virtually all the main streams of the Rocky Mountain region were flowing at places over buried mountain ranges. As they lowered their channels they encountered hard rocks with complex mountain structures, which they found it necessary to attack. In virtually every instance the streams that have had the experience of attacking those ancient rock formations have cut magnificent gorges or water gaps which today are among the most striking physiographic features in the mountain area.

There are at least twenty-five notable canyons or water gaps in the middle and southern portions of the Rocky Mountains in the United States that are the result of the superposition of streams. In the course of the North Platte there are at least four such gorges and in the valley of the South Platte there are at least two. The Black Canyon of the Gunnison, the three water gaps of the Colorado River where it crosses the Gore and Sawatch ranges, the Flaming Gorge of the Green River where it enters the Uinta Mountains, Ladore Canyon where the Green River crosses the Yampa Plateau district, the striking water gap near Thermopolis where the Wind River crosses the Owl Creek Range, the gorge of the Shoshone just west of Cody, the two canyons of the Big

Horn where that river cuts through a doubly plunging anticline west of the main range of the Big Horns and then after a few miles of peaceful meandering enters a deep gorge near the north end of the Big Horns, and the canyon of the Snake through the southern extension of the Teton Range are all examples of canyons or water gaps which have been cut as these superimposed streams have lowered their courses into the underlying mountain masses. See Figures 158–162.

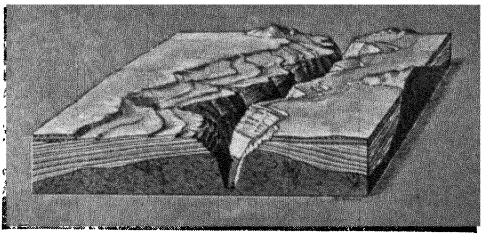


Figure 158 · The structural and topographic relationships of the North Platte at the canyon near Alcova, Wyoming. The Tertiary sediments formerly covered the area where the canyon has been cut. The stream has lowered its course through the Tertiary strata, through Mesozoic and Paleozoic beds, and into the Pre-Cambrian complex. This is a clear case of superposition

If the major valleys in the Rocky Mountains had been developed through the normal work of headward erosion into the late Tertiary cycle-end-surface, the drainage pattern would be very different from what we find today. As headward erosion advanced, each stream would have avoided the hard rocks of the mountain areas. Each of the main valleys would be found in the areas of weaker sediments. In time tributary streams would have worked headward into the mountains; but the master streams, in their headward erosion, would not have cut through mountain ranges when there was easy going in soft materials only a few miles to one side or the other.

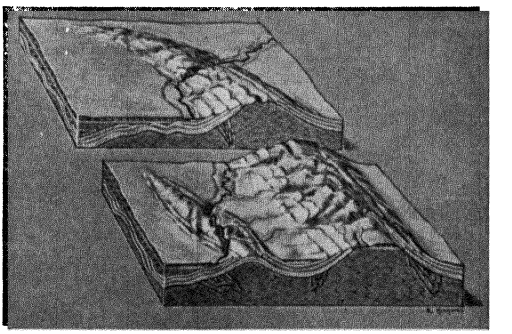


Figure 159 · The canyons of the Big Horn River where that stream crosses Sheep Mountain at the left and the Big Horn Mountains at the right. Superposition of drainage is the only possible explanation of these relationships. See also Figures 144 and 145 of Sheep Mountain

Today there is not a single major river leaving the Rocky

Mountain region in the United States that does not plunge through a mountain range. Several of them plunge through mountain ranges at a number of places. In central Wyoming, Muddy Creek has cut such a notch through the Green Mountains, and Whiskey Gap, in the Ferris Mountains, is a water gap. Devil's Gate, cut by the Sweetwater, near the famous Independence Rock, is another example of a river's doing what seems today an inane thing; for a few hundred yards away it could have located a course in relatively loose, soft material and have avoided the difficult task of cutting the gateway in very resistant granite. Many of the minor streams (more than will be mentioned) have cut water gaps in their courses. All these streams were superimposed. They found themselves located over buried mountain ranges and had no choice in the matter but to deepen their channels in those hard rocks as rapidly as possible.

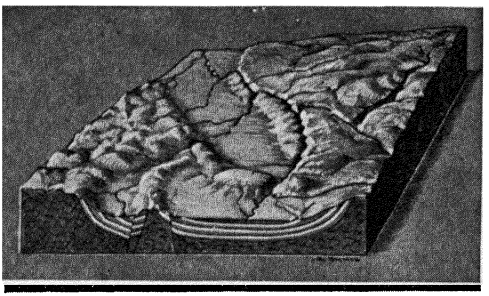


Figure 160 · Structural and topographic relationships at the west margin of the Medicine Bow Range. Here the North Platte leaves a lowland trough, plunges into a canyon which it has cut in granite, follows that canyon for 30 miles, and then returns to a valley lowland. This is another clear case of superposition

With the development of the modern valleys and their many tributaries, a large part of the mid-Tertiary filling of the Rocky Mountain region has been removed. As the alluvial material was carried away, the ranges have come to be more and more prominent relief features. The Rocky Mountains of today

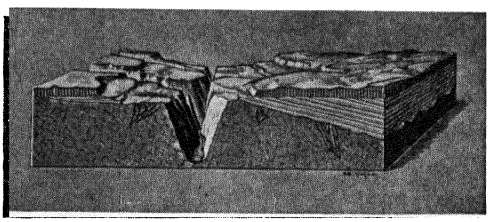


Figure 161 · The structural and topographic relationships at the Black Canyon of the Gunnison. Here Tertiary lavas formerly covered the area where the canyon has been cut. The river was located on the surface of the lavas, and as the land has been uplifted the stream has lowered its course through the lavas and found it necessary to cut into a complex mass of hard Pre-Cambrian rocks. This is a case of superposition

are not the result solely of the orographic movements that occurred at the close of the Mesozoic era. The early Tertiary generation of moun-

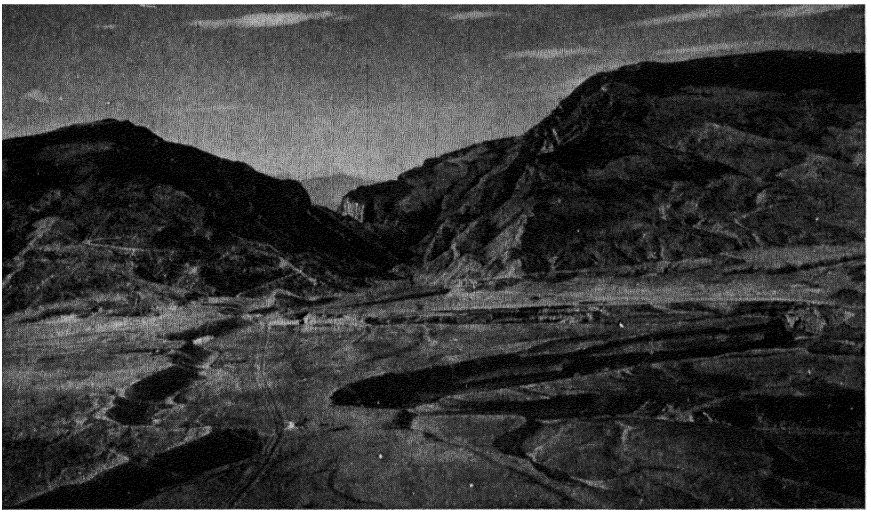


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Figure 162 · Looking westward from a position in the air over Cody, Wyoming. In the foreground the meandering course of the inner gorge of the Shoshone River is shown, and at the left there is a well-defined stream terrace. The great notch in the mountain range was due to stream superposition. The Shoshone River has lowered its channel as the mountain mass has been uncovered or resurrected

tains was removed, and another generation of mid-Tertiary mountain forms was in large part obliterated. A remarkable cycle-end-surface was produced. Then came the great period of removal, during which many streams were superimposed, mountains were resurrected, great gorges or water gaps were cut, and the present landscape was produced. See Figure 162.

From a geologic point of view the ranges are all young mountains. Since they stand so high above the remnants of Tertiary filling, they have been redissected and many of the peneplain remnants, even of late Tertiary age, have been in large part destroyed. The peaks have been sharpened and deep canyons have been cut. The mountains have become more and more prominent as the work of uncovering has advanced.

The work of erosion has dominated since the last widespread uplift, but that work has not been accomplished by streams alone. Valley gla-

ciers formed again and again in each of the high mountain areas, and the work of ice accounts for many of the topographic features in the present landscape.

Piracy of the Missouri. The Continental Divide swings far to the west in Montana in a great bend which follows the crest line of mountain ranges for many miles but crosses several of the valleys that contain Bozeman beds (p. 304) in such a manner as to suggest that piracy has occurred at these localities. Sometime after the mid-Tertiary period of valley-filling, the Missouri River appears to have worked headward from the present location of Great Falls, captured most of the area in the big bend, and shifted the Continental Divide from a position on or near the Front Range far into the midst of the mountains. A large portion of the Rocky Mountain area in western Montana that formerly drained westward into tributaries of the Snake River has been taken over by the eastward-flowing river so that it now drains into the Gulf of Mexico. There are many wind gaps through the present Continental Divide which were formerly occupied by running water. The principal drainage changes in this section are described and fully explained in an article published in 1916.[1]

The Great Ice Age in the Rocky Mountains

The work of the glaciers. During the period when the continental ice sheets formed on the Laurentian Upland and in the Cordilleran province of British Columbia, snows accumulated in all the high mountain areas on the continent. Ice formed near the upper ends of the major canyons, at the bottom of deep snow fields. In time that ice began to move, carrying with it loose material that was frozen into it near the base or had come to rest upon its surface. Little by little the rock-shod ice deepened and widened the catchment basins and made them amphitheatral in form. See Figure 163.

As more and more ice formed at the heads of the valleys, the glaciers moved farther and farther downstream. They became vigorous agents

[1]W. W. Atwood, "The Physiographic Conditions at Butte, Montana, and Bingham Canyon, Utah, When the Copper Ores in These Districts Were Enriched," *Economic Geology*, Vol. 11 (1916), pp. 697–740.

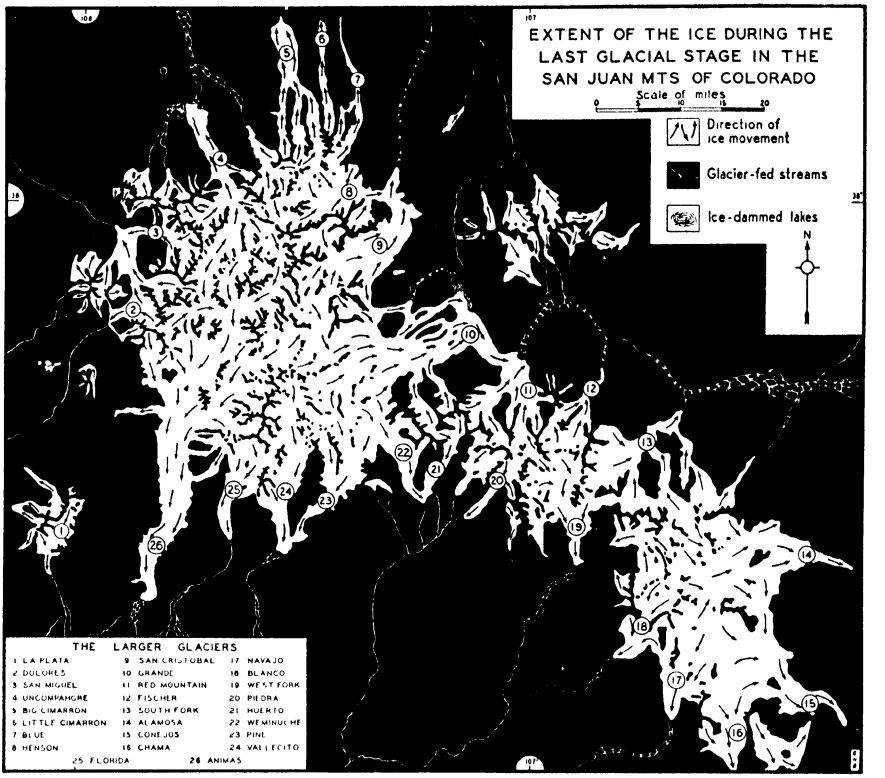
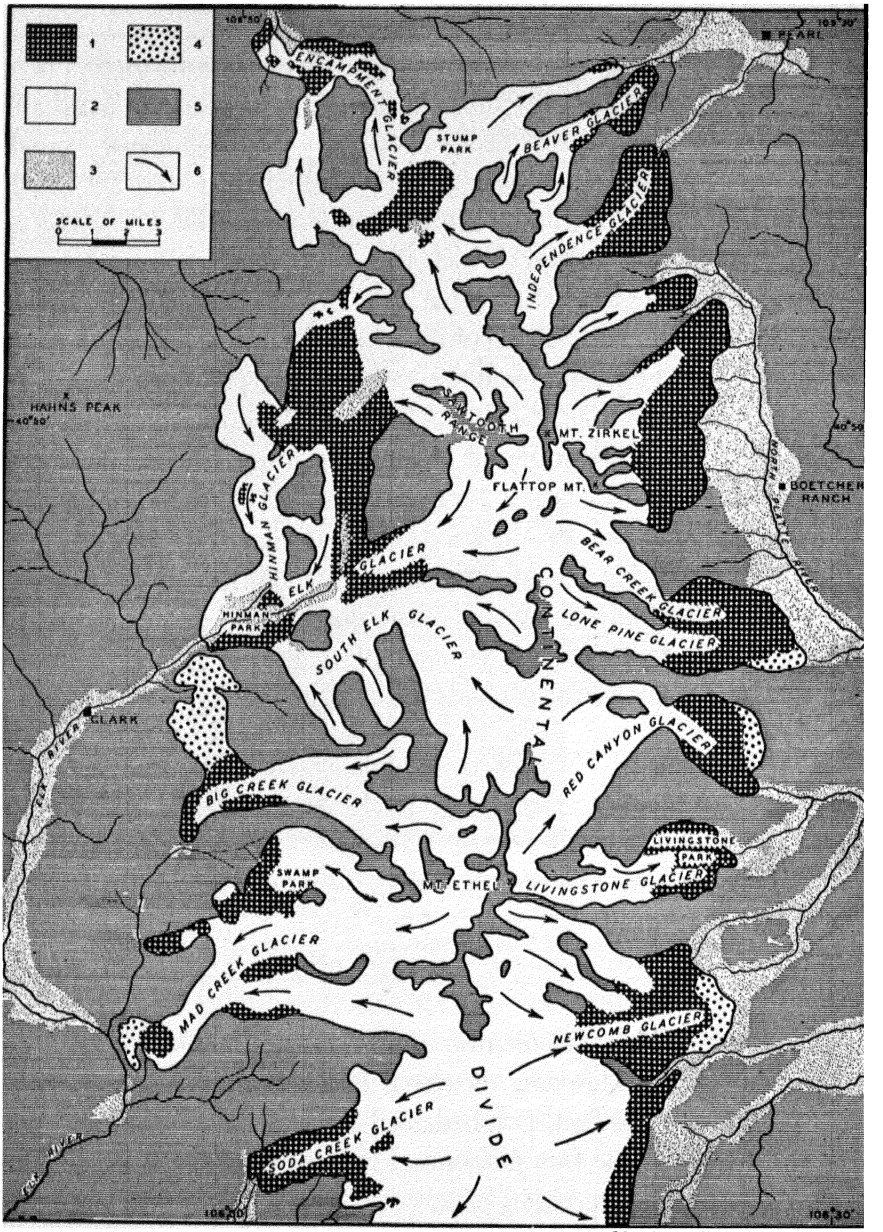


Figure 163 · Very little of the summit area of the San Juan Mountains rose above the ice, and even less rose above the snows of the Pleistocene Period. The glaciers moved, in general, radially in the mountain canyons from the great centers of snow accumulation. They descended in most instances to the margin of the range

of erosion, deepening the preglacial valleys and changing them from V-shaped to U-shaped forms. At places they gouged out basins in the solid rock and smoothed, polished, and striated rock surfaces on the floors and walls of the troughs through which they moved.

At the maximum position of advance they left terminal moraines, and at recessional stages they built up other frontal moraines that now cross the valleys as hilly belts. Upon the melting of the glaciers, lateral and medial moraines that first formed on the surface of the ice came to rest at the sides or in the midst of the canyons. Beyond the terminal moraines and beyond many of the recessional moraines outwash deposits of sand and gravel accumulated as valley trains. See Figure 164.



Map by Wallace W. Atwood, Jr.

1. Heavy Wisconsin moraine
2. Areas once covered by Wisconsin glaciers
3. Wisconsin outwash deposits
4. Pre-Wisconsin moraine
5. Areas unglaciated during Wisconsin time
6. Direction of ice movement

Figure 164 · Glacial features of the Park Range in northern Colorado. Here the last two stages of Pleistocene glaciation are recorded

With the melting away of the alpine glaciers, lakes formed in many of the valleys upstream from morainic obstructions or in the rock basins carved by the ice. Bordering the catchment basins there are usually precipitous rock walls, and on the floors of the basins there are usually one or more lakes. The amphitheatral areas where the ice formed are called *cirques*, and the lakes which they contain are *cirque lakes*.

Glacial features are illustrated at so many places in the high mountains of the cordilleran portion of the continent that one hesitates to call attention to any particular mountain range. Every possible variety is represented in the San Juan, Sawatch, Uinta, and Wind River ranges. The Teton Mountains exhibit glacial phenomena admirably, and in Glacier National Park and in Jasper National Park, which is 200 miles north of the Canadian boundary, the effects of alpine glaciation are beautifully illustrated. In each of these parks a number of small glaciers remain. They are the shrunken remnants of the glaciers that existed during the great Ice Age. Farther north there are more glaciers among the mountains. The Brooks Range is nearly covered with ice.

Glacial deposits. The earliest, or oldest, glacial deposits of Pleistocene age thus far discovered in the Rocky Mountain region are in the San Juan region of southwestern Colorado. They were first reported in 1884 by Hills as mantling a surface west of Tongue Mesa at the northwest margin of the range.[1] More extensive deposits of this age were later described under the name of Cerro till.[2] Other moraines of about the same age have been described as Buffalo till.[3] They are found in the Jackson Hole region near Grand Teton National Park[4] and farther north in Yellowstone National Park. Bradley has recently reported moraines of this age on the north slope of the Uinta Range and called them the Little Dry moraines.[5] During the last few years other

[1]R. C. Hills, "Extinct Glaciers of the San Juan Mountains, Colorado," *American Journal of Science*, Vol. 27 (1884), pp. 391–396.

[2]W. W. Atwood and K. F. Mather, "The Evidence of Three Distinct Glacial Epochs in the Pleistocene History of the San Juan Mountains, Colorado," *Journal of Geology*, Vol. 20 (1912), pp. 385–409.

[3]E. Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *Journal of Geology*, Vol. 23 (1915), pp. 97–117, 193–217, 307–340.

[4]F. M. Fryxell, *Glacial Features of Jackson Hole, Wyoming*, Rock Island, Illinois, 1930.

[5]W. H. Bradley, "Geomorphology of the North Flank of the Uinta Mountains," *U. S. Geological Survey, Professional Paper*, No. 185-I (1936), pp. 163–204.

glacial deposits of about the same age have been found in several localities. Some of these have been briefly described in a paper on the Butte region.[1] There are glacial deposits in several localities near Pikes Peak and one near Bailey, Colorado. There are other deposits in Colorado southwest of the Florissant Basin, some in South Park, near Nederland, and in the Home Quadrangle on the high divides neighboring the canyon of Cache la Poudre.[2]

We are certain that the Cerro and Buffalo till deposits, the Little Dry moraines near the Uinta Mountains, and the moraines at the other localities mentioned are of much greater age than the glacial deposits commonly reported by field workers in the Rocky Mountains. Those seen by virtually everybody who visits the mountain area in order to study the glacial deposits are recognized as of Wisconsin age or a little older. The Cerro-Buffalo moraines are far distant from the present crest lines of the mountains. They are not related to the mountain valleys of today; so it is impossible at any place to call them distinct lateral or terminal or recessional moraines. They have in many instances lost their morainic topography. They are greatly weathered, and at some exposures huge crystalline rocks three or four feet in diameter are so disintegrated that they may be crumbled in the hand. It is often exceedingly difficult to find striated stones in these very old glacial deposits.

During the Cerro-Buffalo stage of glaciation in the Rocky Mountains, the ice is believed to have been of the alpine type, although at places it must have come from miniature ice sheets that covered considerable areas of the neighboring mountain region. That ice was certainly much more extensive than any ice that has since formed in the mountain region. The glaciers of the two later stages were but miniature tongues of ice in comparison with those that deposited the Cerro-Buffalo group of moraines.

Furthermore, these very early Pleistocene deposits are not in any of the modern valleys or canyons of the mountain region. In each instance they are found on high places—on the divides or intercanyon ridges—

[1]W. W. Atwood, "The Physiographic Conditions at Butte, Montana, and Bingham Canyon, Utah, When the Copper Ores in These Districts Were Enriched," *Economic Geology*, Vol. 11 (1916), pp. 697–740.

[2]W. W. Atwood and W. W. Atwood, Jr., "The Opening of the Pleistocene Period in the Rocky Mountains of United States," *Journal of Geology*, Vol. 46 (1938), pp. 239–247.



Figure 165 · The low crescentic ridges on the valley floor beyond the village are frontal moraines left by the ice that occupied the valley of the Animas River during the Wisconsin stage of glaciation. They are a few miles upstream from the city of Durango in Colorado and in the San Juan Mountains

or are far away from the modern canyons. The younger deposits, which are so clearly evident in the mountain region, are all definitely related to the modern canyons. The older moraines antedate the cutting of these canyons. They must therefore represent very early Pleistocene time.

The earlier of the two late series of moraines were called the Durango moraines in the San Juan region, the Bull Lake moraines in the Wind River and Teton regions, and the pre-Wisconsin moraines in the Wasatch and Uinta areas and in many other areas among the mountains. The terminal moraines of this stage are generally from three to ten miles farther down the canyons than are those of the Wisconsin stage in the mountain area. See Figure 165.

Perhaps the Cerro-Buffalo moraines and the Little Dry moraines, representing the earliest and most extensive Pleistocene ice thus far known to have formed in the mountain area, should be correlated with the Kansas stage of glaciation in the continental interior. The Durango-Bull Lake moraines may be of about the same age as the Illinois moraines in the upper Mississippi Valley.

The Late Stages in Erosion

Since the widespread uplift in late Tertiary time which rejuvenated all streams in the Rocky Mountains and opened a new cycle of erosion, there have been several minor uplifts. Each of these has affected the work of the streams and caused considerable variety in the topographic features that have developed as the cycle-end-surface has been dissected.

As the streams proceeded with their work they developed broad valleys in the weaker rocks and excavated many parklike areas that are high above the modern canyons. These topographic forms represent the valley-and-park stage, or cycle, of erosion, during which the outer valleys, now appearing as high benches above the modern canyons, were developed. See Figure 166.

Then came a very distinct canyon-cutting cycle, when the modern canyons were excavated. On the walls of several of these canyons there

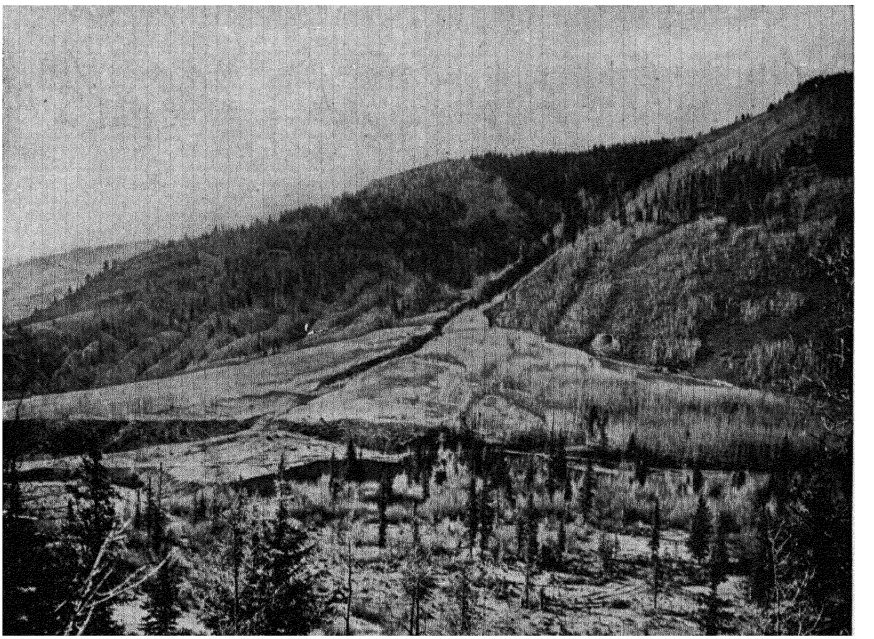


Figure 166 · A modern alluvial fan in one of the valleys of the San Juan Mountains of Colorado. Dissection has resulted in the development of a secondary fan

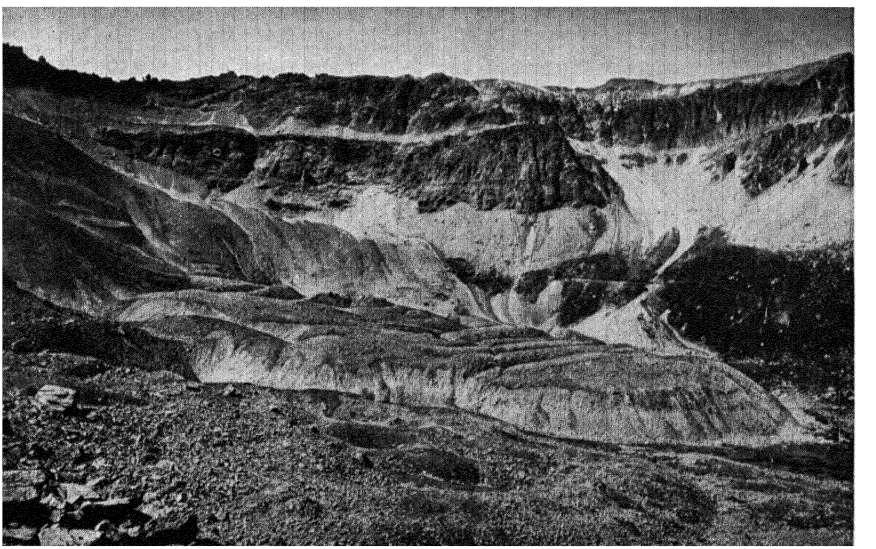


Figure 167 · This rock stream is located in Silver Basin high among the San Juan Mountains of Colorado. It is a huge mass of angular rock fragments with more or less ice and frozen mud. In form and motion it suggests the term "rock glacier." The rock streams have formed since the glacier ice disappeared

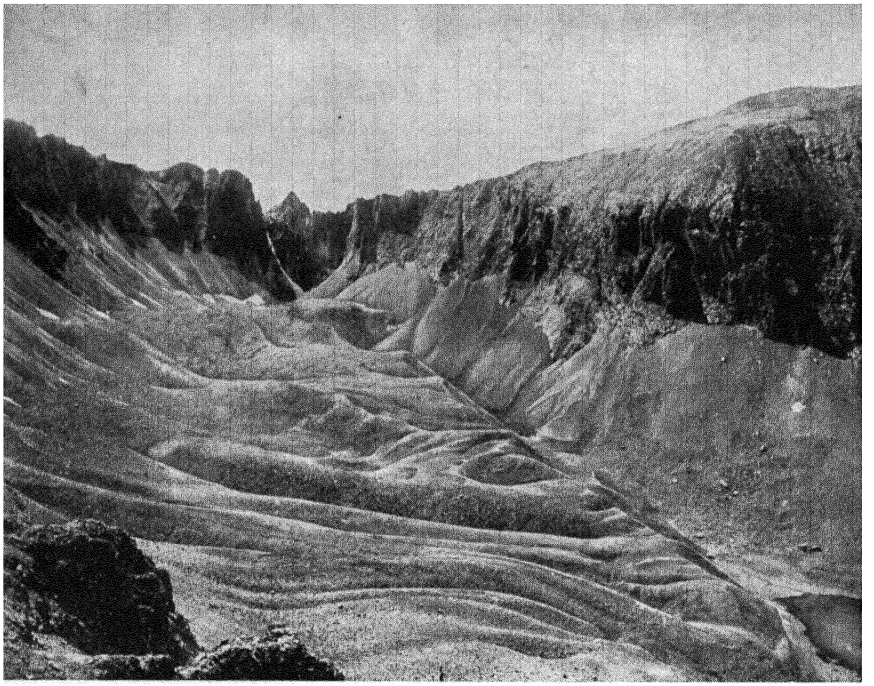


Figure 168 · One of many rock streams high among the San Juan Mountains of Colorado. Here angular talus blocks that have accumulated in a great cirque have become a coarse-grained mud. The mass at times is soaked with water, and it has moved slowly over the floor of the basin

are spurs and benches; and it appears, in many cases at least, that the canyon-cutting stage should be subdivided into at least two parts. See Figures 167 and 168.

In the excavation of the intermontane basins and in the dissection of the Great Plains and of the plateau region west of the mountains, several stages have been recognized by various field workers. These are recorded in many instances by broad benches or terraces or by mesalike remnants. They are of local importance in explaining the details of topography, but they must not be so much emphasized in the presentation of this broad analysis of the physical history of the ranges that they overshadow the major events which punctuate that history. They are, after all, of minor significance, although they do explain certain of the lower features in the landscape.

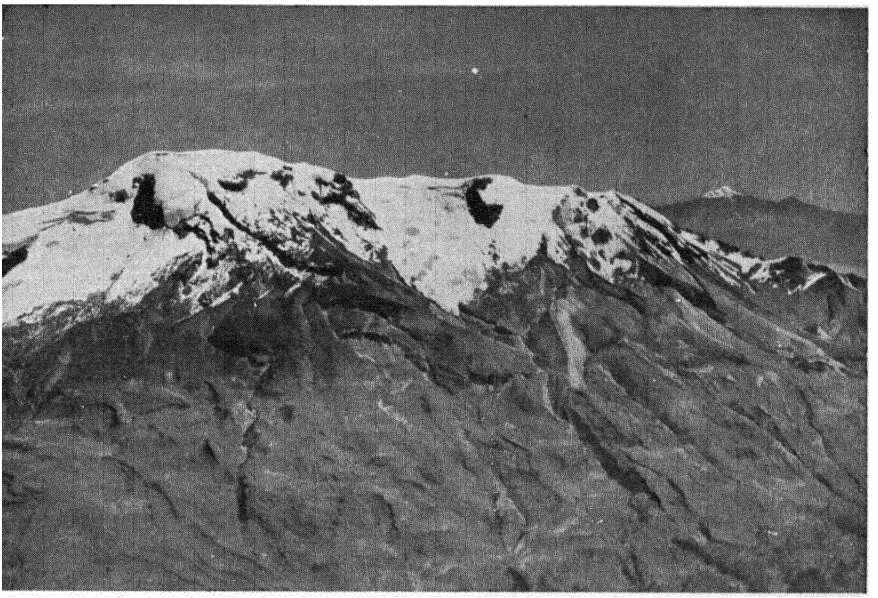


Figure 169 · Mount Ixtaccihuatl (17,343 feet). This dormant volcanic peak is one of the striking scenic features that may be seen on a clear day from the city of Mexico. The summit rises about 10,000 feet above the floor of the ancient lake basin in which the one great metropolis of Mexico is now located

The Sierra Madre Oriental of Mexico

The boundaries. At the east margin of the Mexican Plateau and immediately west of the coastal plain bordering the Gulf of Mexico, there is a poorly defined belt of mountains known as the Sierra Madre Oriental, or the Eastern Sierra Madre. In some places the ruggedness of this belt may be ascribed to dissection of the eastern margin of the plateau rather than to true mountain structures. At other places these mountains are bold and rugged and rise abruptly above the plateau surface to the west.

The eastern boundary of this belt coincides with the line separating the undeformed sediments of the Coastal Plain from the folded strata of the mountains. The western boundary is a ragged or irregular line at the east margin of the broad expanse of the central plateau area of Mexico. See Figures 169 and 170.



Figure 170 · Mount Popocatepetl (17,876 feet). This active volcanic peak, also a beautiful scenic feature, adjoins Mount Ixtaccihuatl on the eastern rim of the Valle de Mexico. In legend this mountain is the warrior prince who vowed that he would keep a perpetual fire in honor of his sweetheart who lies on the summit of the other mountain covered with a white shroud

Structural trend. The Sierra Madre Oriental extend south to the volcanic area that crosses Mexico just south of the central plateau province. These mountains are among the southernmost features displaying the general north-south alignment that characterizes the North American mountain belts. Farther south the structural trend is east-west, and the mountains belong physiographically to Middle America.

Certain of the north-south-trending ridges west of the Rio Pecos in Texas and New Mexico, and the Sierra del Carmen and Sierra del Burro, just south of the Rio Grande, form conspicuous though disconnected links between the Rocky Mountains of Colorado and northern New Mexico and the higher Sierra Madre Oriental farther south. The northern group of ridges rises but 2000 to 3000 feet above the sea; but to the south, in the magnificent peaks of Hidalgo and Querétaro, the summits reach elevations of 10,000 feet and a little more. Asteca Canyon, near Monterrey, is one of the striking scenic features of the range.

Physiographic development. When the highland, or cordilleran, portion of Mexico rose above the sea at the close of the Mesozoic era, mountain ranges were defined at the east and west margins of the central plateau. Those early Tertiary ranges were largely or completely removed in a succeeding cycle of erosion when, according to Hill,[1] a widespread erosion surface was developed which he has called the Cordilleran Peneplain. Later in Tertiary time there was a renewal of uplift, a re-emphasis of the mountains, and a consequent rejuvenation of all erosional processes. During the succeeding cycle or cycles of erosion the dissection of the ranges has continued. Many beautiful forms have been carved out, deep canyons have been excavated, and torrential fans of loose material have been constructed at places about the bases of the ranges. The details in this last chapter in the physiographic evolution of the Sierra Madre Oriental have not been worked out.

The Canadian Rocky Mountains

The ranges and trenches near the international boundary. In northern Montana and southern Canada there is a northwest-southeast trend to most of the mountain axes, and between certain of the ranges there are distinct troughs or trenches which are primarily the result of structural features. In the eastern part of the belt, in the portion which is commonly referred to as the Rocky Mountains in Canada, there is a huge mountain mass which moved eastward with the mountain ranges of Glacier National Park over a great fault plane. South of the international boundary this fault is known as the Lewis Overthrust, and there both the Lewis and Clark ranges have been moved eastward fully fifteen miles. The mountains of southern Canada presumably moved as far eastward as did those in Montana and advanced over the western margin of the Great Plains. Since then, erosion has forced the mountain front to retreat westward. Crow's Nest Mountain, which stands out as an isolated peak east of the main front of the Rocky Mountains in southern Canada, is a remnant of the fault block which formerly

[1] R. T. Hill, "Growth and Decay of the Mexican Plateau," *Engineering and Mining Journal*, Vol. 85 (1908), pp. 681–688.

extended at least that far to the east. The history of this mountain is similar to that of Chief Mountain in Montana.

West of the front range in Canada, and crossing the international boundary line, is the Rocky Mountain trench. This extends 900 miles northwestward from Flathead Lake in Montana to the Liard River in British Columbia. Portions of this lowland trough are occupied by the Flathead, Kootenay, Columbia, and Fraser rivers, and several others. West of this trench is the Purcell Range, which crosses the international boundary line. On the west side of that range is the Purcell trench, which begins in Idaho near Bonners Ferry and continues northward until it joins the Rocky Mountain trench in Canada. It is about 200 miles long and is occupied in part by rivers and in part by the long and strikingly beautiful Kootenay Lake.

Still farther to the westward is the Selkirk Range and then the Selkirk trench. The latter begins near the international boundary line and continues northward until it joins the Rocky Mountain trench. West of the Selkirk trench is the Columbia Range, and beyond that is the eastern margin of the Interior Plateau of British Columbia.

Materials and structure. Field studies pursued near the southern margin of Canada in the Cordilleran province indicate that in the Rocky Mountains proper there are gentle folds of Pre-Cambrian and Cambrian sedimentary layers.[1] In many of the individual mountain masses these great layers of very ancient sediments appear to be in a nearly horizontal position much as the rock strata in Glacier National Park. The eastern part rests upon the fault plane which has been described (page 293). A little farther west in the Purcell Range there is a large amount of faulting, and the formations are all upturned and in vertical or nearly vertical positions. Most of the rocks are Pre-Cambrian in age and consist of schists, phyllites, quartzites, and many intrusive masses. The upturned edges of the several rock formations have been truncated so that they appear as north-south bands in the mountain range. Still farther west, in the Selkirk system, the rock formations are upturned and stand nearly on edge. They consist chiefly of Pre-Cambrian and

[1] R. A. Daly, "Geology of the North American Cordillera at the Forty-ninth Parallel," *Geological Survey of Canada Memoirs*, No. 38 (1912), pp. 17–43, 567–642.

early Cambrian sediments that are tightly folded. In this area there are large intrusions of granite. Here again there is evidence of a vast amount of erosion. West of the Selkirk comes the Columbia system of mountains, and here there are vast quantities of metamorphics, chiefly schists, also large quantities of intrusive igneous rocks and volcanics.

Evolution of the topography. There is a vast amount of difference in the details associated with the histories of individual ranges in the Rocky Mountain province, but in the main outlines of the physiographic evolution of the Northern Rockies there is probably simplicity similar to that in the physiographic evolution already presented on pages 294 to 328. The great events which punctuate the physical history of these northern ranges are probably closely associated with the physical revolutions that punctuated the history of the ranges farther south.

These northern ranges were uplifted at the time of the Laramide revolution, which marks the close of the Mesozoic era and the opening of Cenozoic time. Then followed a long period of erosion, during which old-age erosion surfaces were developed in portions of the area. In the intermontane lowlands sediments accumulated during Eocene time, and since then have been somewhat uplifted and deformed. That means another period of mountain growth, during which time much of the faulting may have occurred. Erosion and sedimentation continued through the millions of years that followed, and by the close of Tertiary time another great surface of erosion must have been developed. The mid-Tertiary sediments and the mountain ranges were all uplifted late in Tertiary time, and before the opening of the great Ice Age deep valleys had been excavated in this uplifted mass.

When climatic conditions made continental glaciation possible in North America and when alpine glaciers formed in all the high mountain areas of the continent, many of the ranges of the Canadian Rockies were severely modified by ice action. At the east base of the Rocky Mountains the ice of the valley glaciers met the advancing front of the great Keewatin ice sheet. On the west, in Canada, the alpine ice tongues descended to the margin of the Cordilleran ice sheet.

Remnants of many glaciers remain in these mountains. There are hundreds of small bodies of ice in the Front Range within the areas



Canadian Airways Ltd., Montreal

Figure 171 · Mount Strong Glacier, in British Columbia. In the higher portions of the Rocky Mountains of Canada there are vast areas of perpetual snow and many long valley glaciers. Medial moraines are well shown on the surface of this glacier

set aside as national parks both to the south and to the north of the boundary line between Canada and the United States. Northward the evidence of glaciation grows more and more conspicuous. In Jasper National Park, which is 200 miles north of the boundary line in a very beautiful section of the Rocky Mountains, there are hundreds of glaciers and numerous cirques where glaciers formerly existed. Virtually all the valleys in these high mountain areas are U-shaped in form because of the deepening and widening effect of mountain glaciation. Thousands of little lakes are present in the mountains. Some of them are in the cirques, and some are on the valley floors where the water has been ponded by terminal or recessional moraines. The national parks of this section are places of superb beauty. There the peaks have been sharpened by the work of ice near the summits, and the cirques are bordered by vertical walls which extend far down into the canyons below. The drainage has been much disturbed by glaciation. See Figure 171.

The far-northern portion of the Rocky Mountains in Canada has been but little visited, and there is no detailed information available regarding its physiographic history.

The Brooks Range of Alaska

At the north margin of the Yukon Plateau in Alaska and extending eastward into Canada there is a mountain range the summits of which vary from 5000 to 6000 feet above sea level. This range, recognized as part of the Rocky Mountain system, was long known as the Endicott Mountains. Later the name was changed to the Brooks Range in recognition of the long and very efficient services of Alfred H. Brooks as chief of the Alaskan division of the United States Geological Survey.

Brooks Range has been crossed at a few places by exploring parties. One expedition crossed it at the international boundary line between Alaska and Canada, and another crossed it much farther west. Those persons who have seen the central portion of the range and the flanks to the south and north report that it is a very sharply defined mountain mass, rising conspicuously above the Yukon Plateau at the south and above the narrow marginal Anaktuvuk Plateau on the north. The lower lands to the north of the Brooks Range blend into the Arctic Coastal Plain and correspond in position to the Great Plains in the United States and Canada.

There is a remarkable uniformity in the summit elevations in the Brooks Range, and this fact has suggested an ancient peneplain to expert observers on the exploring expeditions. The range is covered for the most part with perennial snow fields and contains a number of glaciers. The erosional features are described as distinctly youthful, and presumably very little has been accomplished here since the close of the great Ice Age. In fact, this is another region where the Ice Age has really not been closed. The glaciers have shrunk, but have not disappeared.

The Brooks Range is a wilderness area with no permanent homes. A few hardy prospectors visit the range during the summer seasons in the hope of "striking it rich," but they leave for lands with more daylight as the winters set in.

Places of Special Scenic Interest

The Royal Gorge. West of Canon City, Colorado, the Arkansas River issues from a sharp V-shaped canyon that the stream has cut into the Pre-Cambrian granitic core in the Front Range of the Rocky Mountains. This gorge is about 2000 feet deep, and at some places the base is so narrow that there is scarcely room for the stream. The running water, pounding away at all obstructions in the channel, is actively at work in lowering its bed. Perhaps the mountains are rising and thus forcing the stream to continue its downward cutting. This would help to account for the narrowness of the gorge and its nearly vertical walls.

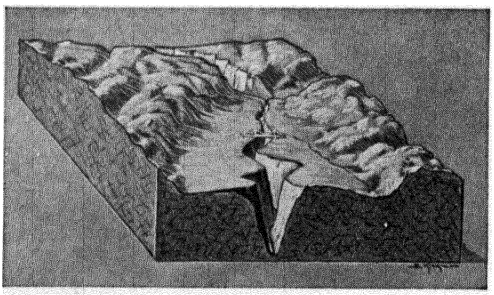


Figure 172 · The structural and topographic relations at the Royal Gorge of the Arkansas. Here the distant summit is a part of the Rocky Mountain Peneplain, and two later stages of erosion are shown. It is clear that the stream, which here crosses a mountain range, was located before the peneplain surface was uplifted. This is a case of antecedent drainage. The stream has held its own as the range has risen. The modern gorge represents the work which the stream was forced to do during the most recent period of mountain growth

The upland surface into which the Royal Gorge has been cut is now several hundred feet higher than the pass, a little to the north, which is used by an automobile highway. See Figure 172. It is evident that the stream must have been located before the pass was excavated. Probably the Arkansas River helped in the development of the Rocky Mountain Peneplain and has held its old course, cutting downward as the mountain range has risen.

Lake San Cristobal. This is a beautifully situated body of water in the canyon of the Lake Fork of the Gunnison River and near the north margin of the San Juan Mountains. The lake is about three miles long and is bordered by the heavily forested slopes of the canyon walls.

At the downstream end of this lake is the lower portion of the Slum-

gullion Mud Flow. This huge mass of disintegrated volcanic material came from a large basin between four and five miles to the east and moved down a tributary valley as a mass of mud ranging from one-quarter to one-half mile in width. It pushed across the canyon of Lake

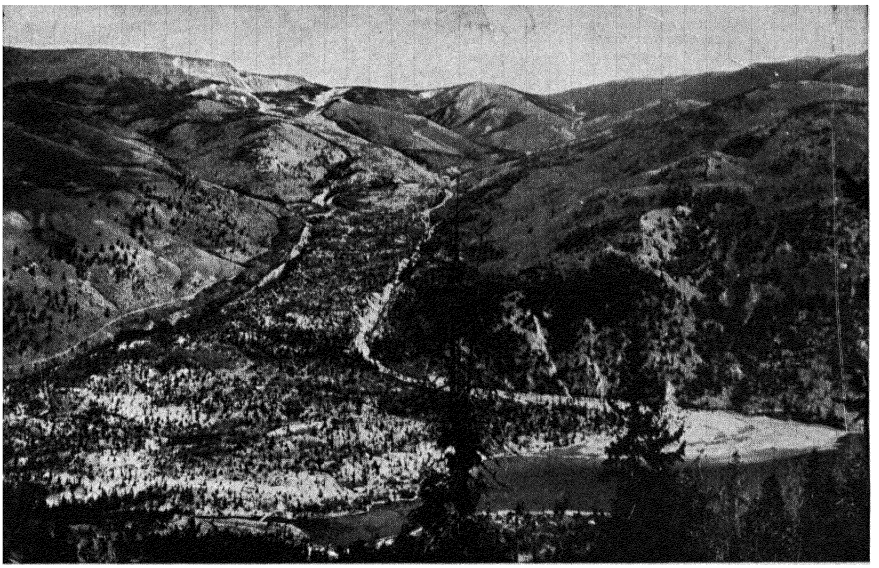


Figure 173 · Looking eastward across the lower end of Lake San Cristobal and at the Slumgullion Mud Flow. An immense volume of disintegrated volcanic debris, soaked with water, broke forth from a basin shown near the sky line, moved four to five miles down a mountain valley, and crossed the canyon of Lake Fork. In detail the topography of this mud flow is very rough. There are ponds on its surface, and at places there is evidence of movement since the forest was established

Fork and completely blocked the stream. In time a narrow outlet for the lake was established at the west, or far, side of the canyon at the margin of the great mud flow. See Figure 173.

The Needle Mountains and the Grenadier Range. Rising conspicuously above the summit peneplain in the heart of the San Juan region are the Needle Mountains and the Grenadier Range. They are composed of granitic and metamorphic rocks that are a part of the fundamental Pre-Cambrian complex underlying all parts of the continent.

They are very old mountain forms that stood as monadnocks on a Pre-Cambrian erosion surface. They were buried beneath Paleozoic and

Mesozoic sediments, resurrected during a cycle of erosion that followed the Laramide revolution, reburied by lavas and volcanic tuffs during mid-Tertiary time, and again excavated. During later cycles of erosion they have come to stand out again as monadnocks and have developed into sharp, pinnacle-like features. The slopes of many of them defy the boldest of mountain-climbers. See Figure 143.

The Garden of the Gods. West of Colorado Springs and near Manitou the upturned red beds at the east base of the Rocky Mountains have been weathered and eroded into a number of fantastic forms. His satanic majesty is usually credited with the hoodoo forms and many of the striking features in a landscape such as this, but here another idea prevailed and the name Garden of the Gods was adopted. In this foothill belt vertical walls of upturned red sandstone, with narrow gateways through them, rise to a height of from 50 to 60 feet. As the winds, the rains, and the changes in temperature have helped forward fragments of the rock material to the neighboring stream beds, holes have been worn out of the upturned strata, huge masses have been left as balanced rocks, mushrooms or toadstool-like forms have been weathered out where the layers offered a difference in resistance, and many sharp pinnacles have been left standing. The "official" guides in the Garden of the Gods point out formations said to resemble statesmen, seals, bears, and camels. The red sandstone formations that appear in the Garden of the Gods produce striking scenic features at many other places.

Mountain of the Holy Cross. In the heart of the Sawatch Range in central Colorado, not far from Redcliff, there is an impressive peak hidden from view except at a few favorable outlook points. This peak rises to an elevation of 13,966 feet. It is composed of the granitic rock which forms a part of the core in the Sawatch Range.

On the northeast side of this peak the joint planes and fissures are so arranged that the snow which becomes lodged there forms a great white cross hundreds of feet in length, from which the peak takes its name. A trail is being built to high points on the range from which excellent views of the mountain may be secured. An automobile road has been completed to the lower end of the trail. See Figure 174.

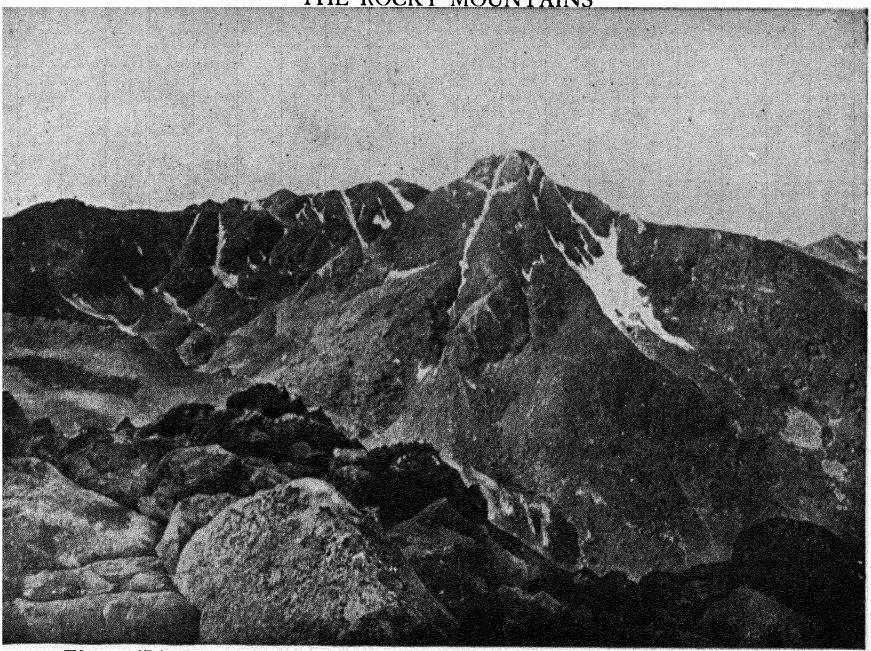


Figure 174 · Mountain of the Holy Cross (13,966 feet) in Colorado. This photograph, taken in 1873 by Mr. Jackson, is one of the best shots ever made at this impressive peak

Rocky Mountain National Park. In Colorado, about 50 miles in a straight line northwest from Denver, a little more than 400 square miles of the most picturesque portion of the Front Range in that state have been set aside as a national park. This area includes a portion of the Continental Divide and the mountain slopes to the east and west. Among the crestline peaks there are several that rise over 12,000 feet above sea level; Longs Peak, the highest in the park, is 14,255 feet in height. See Figure 175.

In this park there are a few tiny remnants of glaciers, many large catchment basins that formerly contained ice, a large number of beautiful lakes, long U-shaped troughs which were deepened and widened during the Ice Age by the alpine glaciers, and a full assortment of moraines. It is an excellent locality in which to study the sculpturing of a complex mass of Pre-Cambrian core rocks in the midst of a mountain range as well as the effects of ice work in a mountain area. The stages in physiographic evolution outlined in this chapter are here well shown.

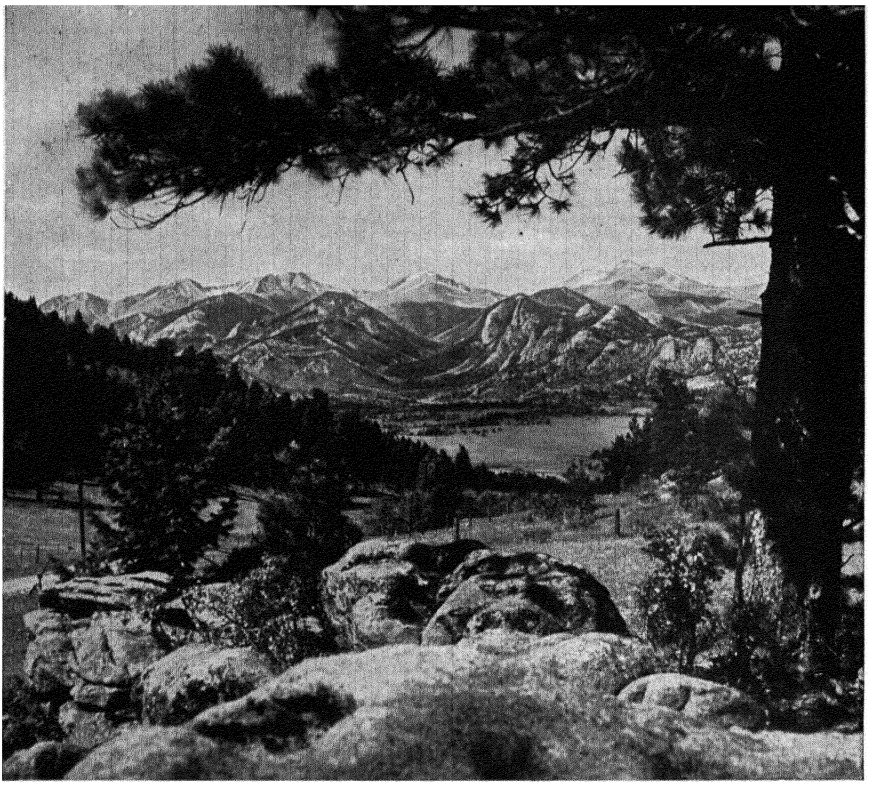


Photo courtesy of the Colorado Association

Figure 175 · Looking westward to the crestline peaks in Rocky Mountain National Park

Yellowstone National Park. Yellowstone Park, most of which is located in northwestern Wyoming, is characterized by an extensive lava plateau, several volcanic peaks, a beautiful display of hot-spring terraces, a remarkable group of geysers and geyser cones, and, surpassing all in scenic attractiveness and beauty of coloring, the canyon of the Yellowstone River. To the east of the park is the Absaroka Range of lofty summits, and to the northwest is the Gallatin Range. See Figure 176.

The lava flows and volcanic fragmental debris in the park are at least 1000 feet thick, and they bury a rough underlying topography. In one section the volcanic ash buried a forest of gigantic trees which, while covered, slowly changed to stone. They have been uncovered by erosion and today stand as rock pillars. The surface of the plateau was cov-

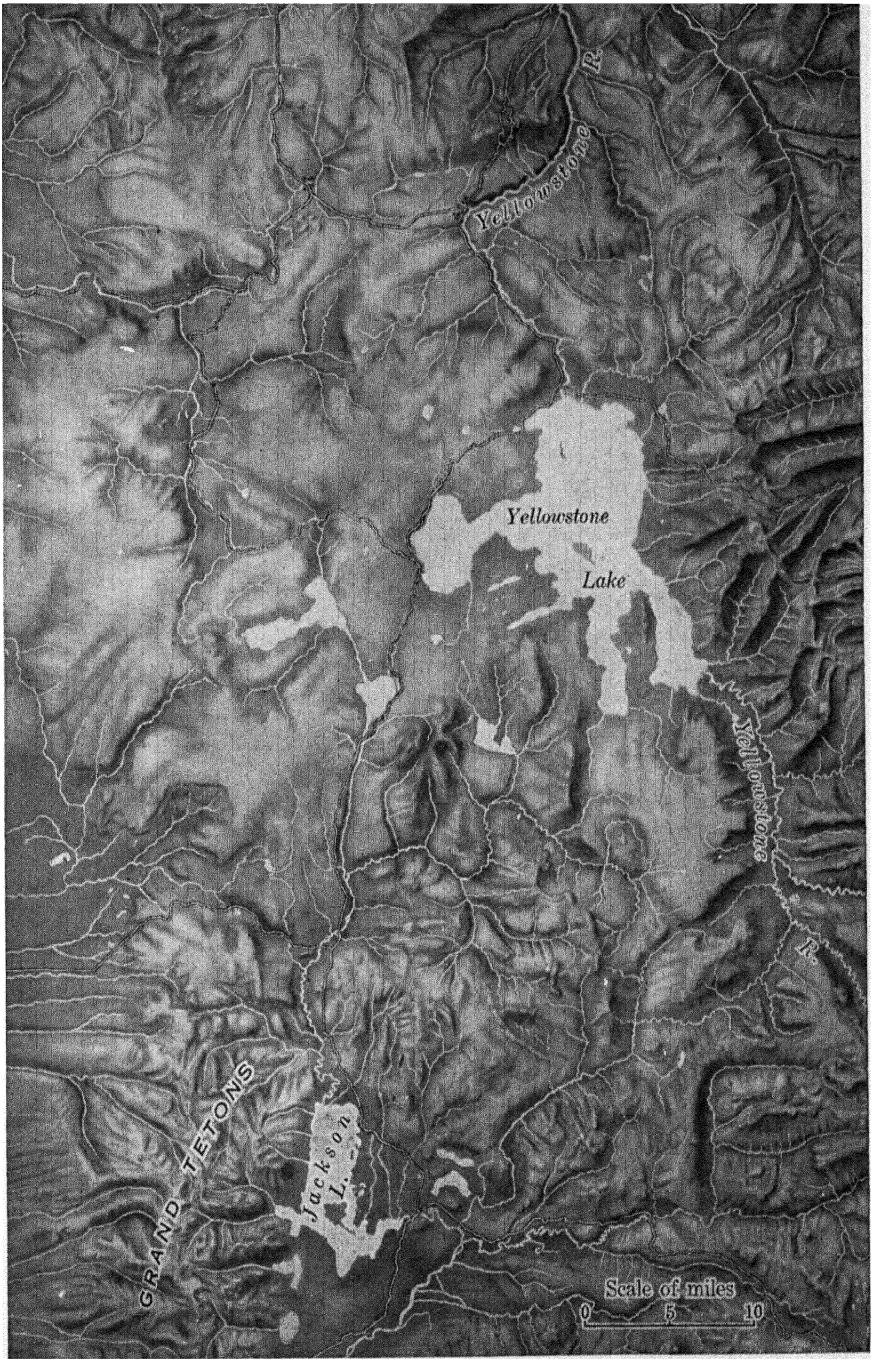
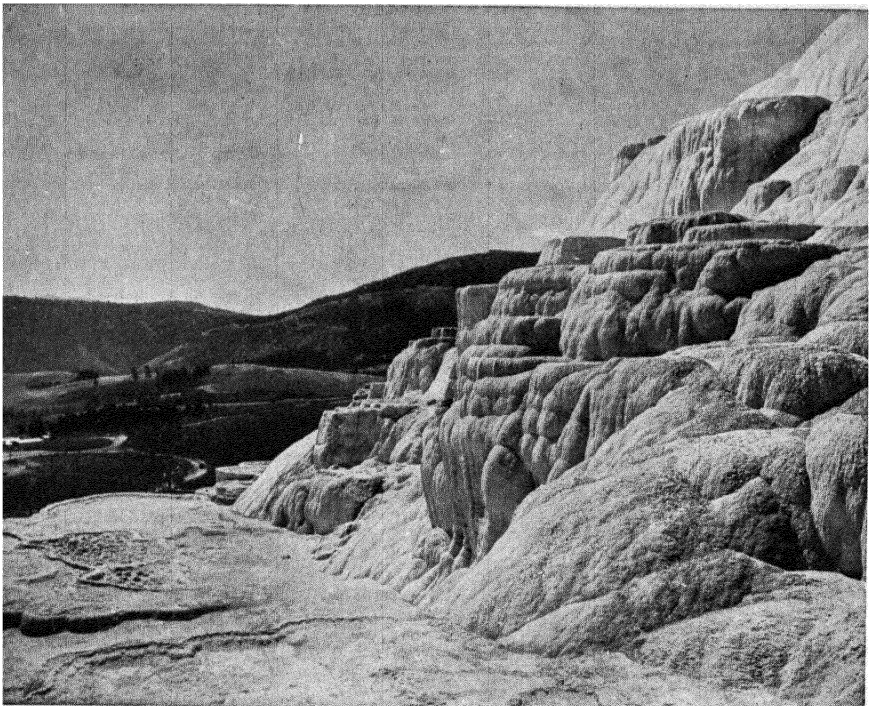


Figure 176 · The land forms and drainage pattern in the Yellowstone and Grand Teton national parks



Courtesy of Chicago, Milwaukee, St. Paul and Pacific R. R.

Figure 177 · Pulpit Terrace in Yellowstone National Park. Here the hot springs bring to the surface vast quantities of lime in solution, and as the waters pour down the hillside evaporation takes place and lime is precipitated. These terraces are at places beautifully colored by the presence of algae living in the warm waters

ered in large part by ice that descended from the bordering ranges of mountains during the great Ice Age. Morainic deposits are found at many localities.

The hot-spring terraces are composed of lime that is being brought from deep in the earth. As the spring waters flow down the hillsides and cool, the lime is precipitated. See Figure 177. In the warm waters that remain in pools on the terraces, or slowly overflow from one bench to another, live tiny algae which by their colors of yellow, brown, and pink add much to the beauty of the hot-spring deposits. When the waters leave one portion or another of the formation which they are making, the algae die in that section and the pure white of the limestone appears in the picture. At these springs the heated waters flow freely to

the surface. At other places they come into basins of fine earth material and there form pools of boiling mud and small mud volcanoes.

At several localities in the park the ground waters erupt intermittently, forming beautiful fountains, and are true geysers. There are geysers at a few other places on the earth, but the Yellowstone assortment of more than a score is unsurpassed. These geysers have very different periods of eruption, and the height to which their waters rise during these periods varies greatly. Old Faithful, which erupts regularly summer and winter, year in and year out, throws its waters about 120 feet into the air for four to five minutes at intervals of about sixty-five minutes. Giant Geyser erupts at irregular intervals and throws its water 250 feet into the air. See Figure 178.

The geysers build up curious and fantastic cones at the surface. The heated waters of the springs that supply Old Faithful, as well as of the springs supplying the other geysers of this type, bring silica to the surface in solution. As they flow away they are cooled, and the material in solution is precipitated. Little by little, a crater is formed about each spring opening and a cone is built up. When the waters from the geyser fountains are blown against the trees, they cause a white crust of silica, or quartz, material to form on the leaves and branches.

The intermittent eruptions of geysers are explained by constrictions in the fissures or vents through which the waters rise. Wherever the heated ground waters move freely to the surface, we have ordinary hot springs. When the movement is delayed near the source of heat, the ground waters become superheated even to temperatures far above the usual boiling point. This is possible because of the weight of the column of water above. In time, however, the waters explode, forming steam which forces the waters above the steam into the air. As the weight in the water column is reduced, more and more of the superheated waters change into steam, and thus the fountain continues to play for several minutes.

In the central portion of this park, at an elevation of 7740 feet above the sea, is Yellowstone Lake, a body of fresh water 300 feet deep that covers 140 square miles. This is the highest large lake in North America. According to several investigators the outlet of this lake was formerly by way of Outlet Channel at the southwest, into the headwaters of the



Courtesy of Chicago, Milwaukee, St. Paul and Pacific R. R.

Figure 178 · Grand Geyser in Yellowstone National Park

Snake River. At that time it may have been an ice-front lake with its surface higher than it is today. According to Goode a small stream working headward from the north in post-glacial time captured the lake waters and diverted them northward. Perhaps the capture of the lake outlet was due entirely to normal headward erosion, but it may have been helped by the overflow of the lake at a time of unusually high water. The pass to the southwest was abandoned, and the headwaters of the Snake River were diverted into the drainage that led to the Gulf

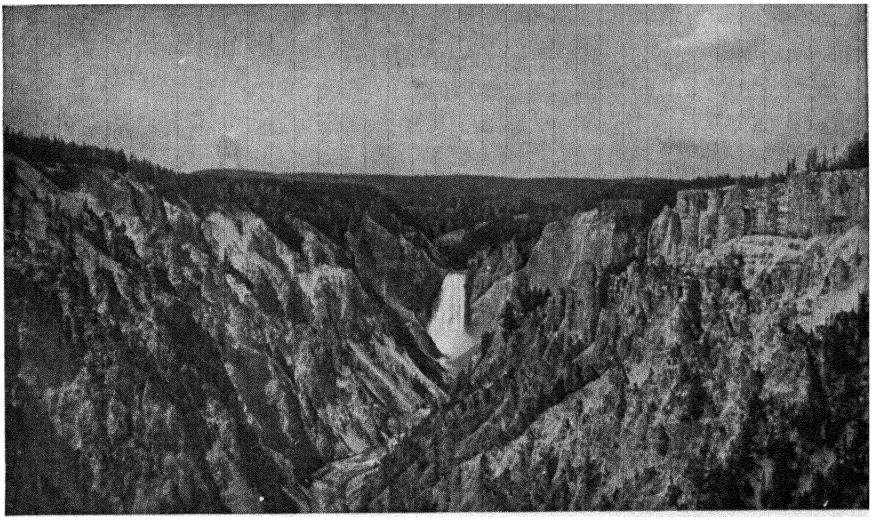


Figure 179 · Here the Yellowstone River drops about 310 feet and plunges into a magnificent canyon about 1200 feet deep. The canyon has been cut into volcanic debris and lava flows where hydrothermal metamorphism has produced brilliant shades of brown, yellow, and red

of Mexico. In this way the Continental Divide was shifted from the east side of Yellowstone Lake to the west side.[1]

The canyon which the Yellowstone River has cut in the lava plateau of the park is from 1000 to 1200 feet deep. That is not a great depth for canyons in the cordilleran portion of the continent. However, the walls of this gorge are so steep, so varied by fantastic pillars and rugged spurs, and so gorgeously colored, that to many people they present the most beautiful of spectacles. The coloring of the walls is due to the oxidation and hydration of the slowly disintegrating lavas.

In this canyon are the Upper and Lower Falls of the Yellowstone. The falls occur where the more resistant parts of the lavas are delaying the work of the stream. At the Upper Falls the drop is about 110 feet, and at the Lower Falls about 310 feet. See Figure 179. In the bottom of this gorge near the stream there are active hot springs.

[1]J. Paul Goode, "Piracy of the Yellowstone," *Journal of Geology*, Vol. VII (1899), pp. 261–271. Recently the interpretation made by Goode has been questioned by A. D. Howard in "History of the Grand Canyon of the Yellowstone," *Geological Society of America, Special Paper No. 6*, November, 1937, pp. 118–124.

Waterton-Glacier International Peace Park. In Alberta and Montana, to the north and south of the international boundary line between Canada and the United States, a magnificent mountain area of about 2000 square miles has been reserved for park purposes. In 1931, by action of the Congress of the United States and the Canadian Parliament, this area was established as the Waterton-Glacier International Peace Park. In this park there are more than 75 glaciers, more than 250 beautiful mountain lakes, and a wonderfully sculptured mountain mass with huge amphitheatral cirques, sharp pyramidal peaks, and deep U-shaped canyons. Much of the reservation is an unharmed wilderness and a paradise for lovers of the out-of-doors. This area is the portion of the Rocky Mountain Front Range where the remarkable thrust faulting referred to on page 293 occurred. On both sides of the international boundary line the effects of alpine glaciation are admirably shown. See Figure 180.

Jasper National Park. The largest of the Canadian parks is Jasper National Park. It contains 4200 square miles of rugged mountain country on the east slope of the Rocky Mountains in northern Alberta. This park is a wilderness area and a wild-life sanctuary. The Athabaska River flows through it. Yellowhead Pass is the western entrance.

In the park are glaciers, huge perennial snow fields, hundreds of jewel-like lakes of wonderful coloring, deep canyons, a number of hot springs, and many unclimbed peaks. Maligne Lake is a strikingly beautiful body of water. Another center of special interest is Fiddle Creek Canyon, through which flows a roaring stream 200 feet below its rim. At places the walls of this canyon are only 20 feet apart.

Banff, Yoho, Glacier, and Kootenay parks. Among the many other Canadian national parks these four, all of which are in the Rocky Mountain province, have been established because of their special scenic and scientific values. Banff Park is in western Alberta on the east slope of the Rockies. It includes 2585 square miles of beautiful mountain landscape and the celebrated Lake Louise section. Yoho, Glacier, and Kootenay parks are in southeastern British Columbia. Each contains between 500 and 600 square miles of rugged mountain scenery, where numerous glaciers, snow fields, waterfalls, and mountain lakes may be seen. In the



Figure 180 · Land forms and drainage features in Glacier National Park, Montana

Yoho valley one of the waterfalls is over 1200 feet high. The waters of Emerald Lake, which is also in this park, are famous for their various shades of green.

In each of these parks the rock formations are so well exposed and the topographic features are modeled on such a gigantic scale that students of geology and physiography are naturally attracted to these areas. They are equally interesting to lovers of alpine flora or of the animal life of a mountain region. They have become very popular as both summer and winter resorts.

An Approach to the Human Drama

During the early days of exploration in the Far West the Rocky Mountains were a great barrier. Many exploring parties, hoping to reach the Pacific coast, swung south of the ranges and followed what came to be known as the Santa Fe Trail. Those who held their course near the North Platte River discovered that they could swing north of the Laramie Range and enter the Wyoming Basin, where travel was fairly easy up the valley of the Sweetwater. From there they proceeded around the south end of the Wind River Range and into the valley of the Snake River in the Plateau section farther west. That route was known as the Oregon Trail. The Lewis and Clark route westward followed the Missouri River to the base of the Rocky Mountains, then swung southward, following valley routes that presented less difficulty than the mountain ranges, and, after crossing the Bitterroot Mountains, emerged on the Columbia Plateau.

The members of these early exploring parties were not particularly interested in settling within the mountain area. They were looking for the easiest routes through the highland belt to Far Western goals. This was true also of those parties which started west during the great stampede to the gold fields about the middle of the last century.

As the frontier of more or less permanent settlements moved westward, some of the pioneers paused at the foot of the mountains and there established settlements. That pronounced physiographic line has served for a long time as a very definite break in transportation. If the pioneers wished to go farther, they found it necessary to abandon their

wheeled vehicles and proceed on foot, leading or driving their pack animals into the mountain areas. The chain of cities now located at the east base of the mountains represents the effect of this break in transportation conditions. These cities include Trinidad, Pueblo, Canon City, Colorado Springs, Denver, and Boulder in Colorado, Cheyenne and Sheridan in Wyoming, and Calgary in Alberta. Their prosperity has resulted in large measure from the fact that they are at the margin of two strikingly different physiographic provinces.

Among the first to examine the mountain ranges seriously were prospectors in search of valuable ore deposits. As they made discoveries, mining camps were established, and many of these camps grew rapidly to be mining towns. Several of these towns became centers of great excitement as vast wealth was discovered in the mountains. Cities having such names as Leadville, Silverton, Gold Hill, and Telluride suggest at once the mineral wealth that was causing the concentration of population at certain places.

As transportation facilities improved, and especially as railroads were constructed into the mountains at many places and in time through the mountain belt to the Far West, more mining properties were developed and more crushing mills, concentrating plants, and smelters were built. Gold, silver, copper, lead, iron, zinc, and coal have been found at many localities. The history of mining within this mountain region, if fully presented, would fill a large volume and would be replete with thrilling stories of wonderful successes and pitiful failures.

At hundreds of places the hillsides were opened up by hopeful workmen who, with picks and shovels, followed mineral veins or shear zones, or tunneled far into the mountains in the hope of uncovering a bonanza deposit. Most of that work was done in vain; but, as the gophering process continued, some truly rich deposits were discovered. As a result, some of the prospectors were well repaid and great companies were established which in time produced vast fortunes. From a single hill at Butte, Montana, more than eight hundred million dollars' worth of ore has been removed, and many of the mining properties have commanded millions of dollars from those who wished to purchase them for development.

In time the ores in several mining areas became exhausted, and the mining towns, which for a period were the centers of great prosperity,

virtually passed out of existence as centers of activity and population. Little by little the inhabitants who could leave have drifted away. Sometimes a few unfortunates remain as watchmen; or individual workers remain who are hopeful that some day they may discover some neglected treasure, or that the price of the metals may rise and ore which formerly could not be mined at a profit will become sufficiently valuable to justify a renewal of activity.

As the mining industry developed, there was a demand for timber for use in the mines and for the construction of mills, concentration plants, and homes. There was a demand also for food. Thus opportunities for lumbering and farming attracted another group of settlers. The farming was concentrated in the valleys or in the parklike areas among the mountains. Ranchmen also settled in the mountain area, using the grass in the forests and high above the tree line as pastures. These ranchmen commonly found it necessary to provide winter pastures in the lower lands bordering the mountains for their cattle and sheep. Irrigation was necessary at many places, for which the mountain streams provided an abundance of water.

As engineering and science advanced, the use of water power became more and more significant in the mountain region. There were many waterfalls, and most of the streams had such high gradients that it was possible for mining companies and towns and cities to have independent hydroelectric plants. Today power lines cross many of the ranges and follow through the great mountain canyons to provide electricity for lighting both the underground developments in the mines and the homes and cities at the surface. This form of power is also used in the mills and crushing plants.

As population has increased and wealth has accumulated, more and more people have come into the mountains for their vacation periods. The great scenic features of the region, the features of interest to scientists, and the delightful summer climate will not disappear, but will remain for all time as assets to the nation. Hundreds of thousands of people now visit the national parks in the Rocky Mountains of the United States and Canada. Many of these visitors come for only a few days, but others spend weeks or months in the region. Other hundreds of thousands seek camp sites in the national forests of the mountain area.

As soon as the harvesting season in the interior plains is over many of the people turn their faces westward. They seek relief from the heat and monotony of the home region and in modern covered wagons migrate into the mountains. The automobile licenses about the tourist camps here reflect the nomadism of the people. They commonly show that the owners have followed the shortest possible route. Thus, in Colorado the out-of-state license plates most commonly seen are those of Kansas, Oklahoma, and Missouri. A little farther north the license plates indicate that many of the nomads have come from Nebraska, Iowa, and Illinois. Still farther north many people from Minnesota and the Dakotas may be found camping among the mountains, and in the Canadian Rockies the cars of many of the summer nomads have provincial licenses from Alberta and Manitoba.

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SELECTED LIST OF TOPOGRAPHIC MAPS FOR THE ROCKY MOUNTAIN PROVINCE

Northwestern, Alaska

The Selkirk Range, British Columbia[1]
Banff, British Columbia–Alberta[1]
Donald, British Columbia–Alberta[1]

Spokane, Washington–Idaho

Bayhorse, Idaho
Borah Peak, Idaho
Buffalo Hump, Idaho
Custer, Idaho
Rathdrum, Idaho
Irwin, Idaho–Wyoming

Bonner, Montana
Coopers Lake, Montana
Glacier National Park, Montana
Helena, Montana
Libby, Montana
Ovando, Montana
Sapphire, Montana
Hamilton, Montana–Idaho
Missoula, Montana–Idaho

Bald Mountain, Wyoming
Blue Mesa, Wyoming
Cloud Peak, Wyoming
Como Ridge, Wyoming
Dayton, Wyoming
Fremont Peak, Wyoming
Fort McKinney, Wyoming
Grand Teton, Wyoming
Grass Creek, Wyoming
Jackson, Wyoming
Meeteetse, Wyoming
Oregon Basin, Wyoming
Saddleback Hills, Wyoming
Yellowstone National Park, Wyoming

Uinta Mountains, Utah[2]

Axial, Colorado
Canon City, Colorado
Colorado Springs, Colorado
Colorado Springs Folio (No. 203)
Daton Peak, Colorado
Denver Mountain Parks, Colorado
Dillon, Colorado
Glenwood Springs, Colorado
Leadville, Colorado
Minturn, Colorado
Montezuma, Colorado
Monument Butte, Colorado
Pikes Peak, Colorado
Pikes Peak Special Map, Colorado
Pueblo, Colorado
Rocky Mountain National Park, Colorado
San Juan Mountains, Colorado (3 maps)[3]
Home, Colorado–Wyoming

Taos, New Mexico

Monterey, Mexico–United States[4]

[1]Published by Surveys and Engineering Branch, Department of Mines and Resources, Ottawa, Canada.

[2]Plate 4 from Professional Paper No. 61, U. S. Geological Survey.

[3]Plates 1, 2, and 3 from Professional Paper No. 166, U. S. Geological Survey.

[4]Published by American Geographical Society of New York (scale 1:1,000,000).

X

THE CORDILLERAN PLATEAUS

The Subdivisions

We now turn our attention to that great chain of plateaus that occupies a central position in the North American cordillera. The division of this long belt into six subprovinces is somewhat arbitrary, but, nevertheless, convenient. We shall consider first the southern portion, calling it the Mexican Plateau, and shall then move northward through the Colorado Plateau, the Great Basin region, and the Columbia and Snake River Plateau. Later we shall consider the Interior Plateau of British Columbia and the Yukon Plateau of Alaska.

The Mexican Plateau

The boundaries. The Mexican Plateau, which extends from the Sierra Madre del Sur northward into New Mexico and Arizona to the margin of the Colorado Plateau, is bounded on the east by the Sierra Madre Oriental and on the west by the Sierra Madre Occidental. In New Mexico, Arizona, and in all but the southern part of the Mexican portion of this plateau the population is sparse. There are hundreds of square miles without any permanent homes. At the southern end of this plateau is the beautiful basin in which the capital city of Mexico is located. On the southern margin of that basin, near the great chain of volcanic mountains that crosses the country from east to west and marks the beginning of Middle America, are the magnificent snow-capped volcanic peaks of Popocatepetl and Ixtaccihuatl. These peaks stand as sentinels overlooking the center of Mexican industrial, financial, and cultural life. See Figure 181.

An airplane view. When seen from the air, the central portion of Mexico appears as a broad expanse of dry land with numerous isolated mountain blocks that rise 2000 to 3000 feet above the general level of the highland area. Among the mountain ranges there are many shallow, closed basins containing ephemeral lakes. These basins are called *bolsons*, which is a Spanish word meaning "purses." The small lakes

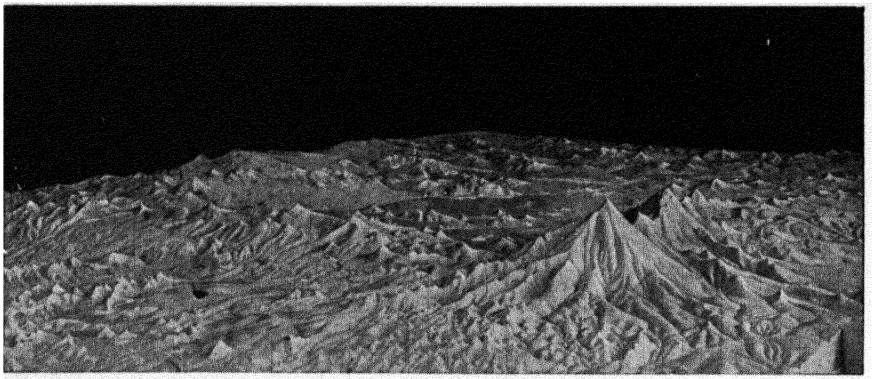


Figure 181 · A relief model of the southern portion of the Mexican Plateau. We are here looking into the basin where the city of Mexico and Xochimilco and many other villages are located. The sharp peak in the foreground is Popocatepetl, and just beyond, at the right, is Ixtaccihuatl

are fed by streams from the neighboring mountains. During a large part of each year the lakes disappear either because the water evaporates or because it sinks into the ground. The lake floors are then exposed as sandy and very dusty plains.

There are extensive belts of sand dunes on the plateau; and in some places fantastic pinnacles and pillars on the mountainsides add picturesque features to the landscape. Forests of stunted palms clothe some of the lower mountain slopes, but most of this vast area carries only a scanty growth of desert brush and cacti. This plateau declines in elevation from 7000 feet at the south to about 4000 feet at the international boundary line, and then rises to the northward to elevations between 5000 and 6000 feet near the southern margin of the Colorado Plateau. Occasionally a small village breaks the monotony of this sparsely populated land. A large proportion of the people in the Mexican part of the plateau are concentrated in San Luis Potosí, the city of Mexico, and neighboring villages. See Figure 182.

The landscape in the United States portion of this province resembles that in the Mexican portion. Here are numerous mountain blocks and closed basins. The climate is arid, and the physiographic changes are chiefly the result of processes of weathering, the torrential wash following occasional cloudbursts, and the work of winds. Below elevations

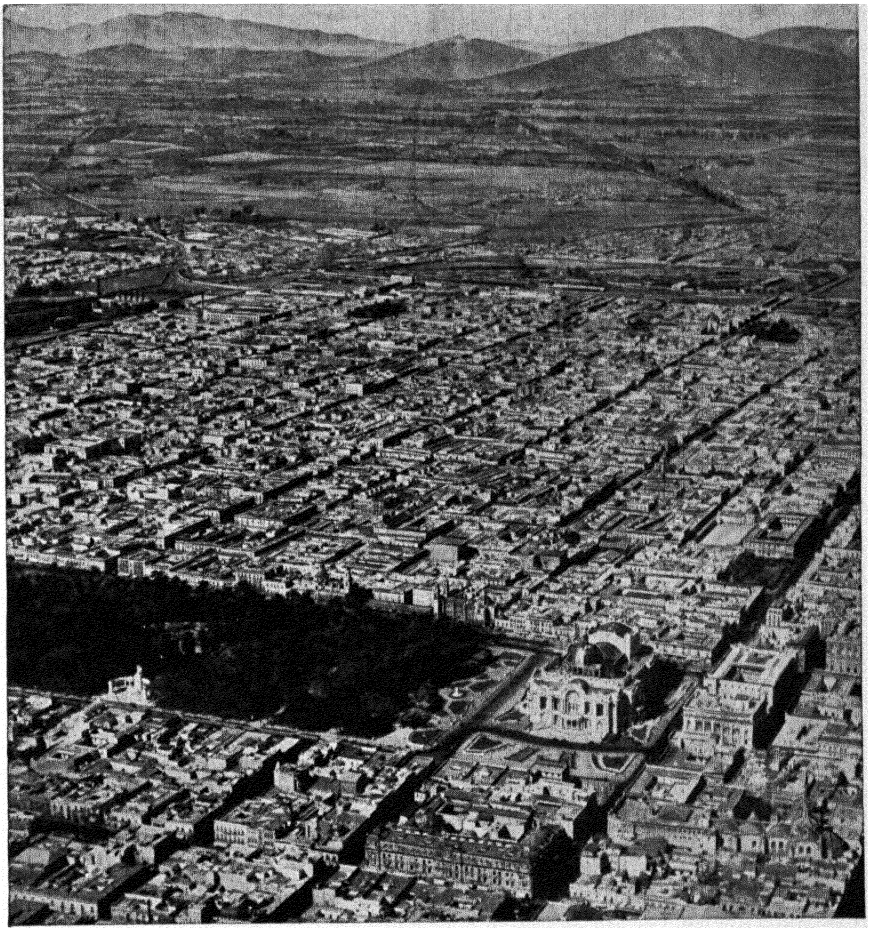


Figure 182 · A section of the city of Mexico from the air

of 3500 feet, the yucca, cactus, and creosote bush are abundant. Above 3500 feet and up to 5000 feet, greasewood and sagebrush predominate. Still higher come the cedars, and above 7000 feet on the mountain slopes there are pines and firs. The chief cities in this part of the plateau are Santa Fe and Albuquerque in the north and El Paso in the south. The other settlements are small.

Materials and structure. In the mountain ranges of this province the rock formations are predominantly sediments of Paleozoic and Meso-

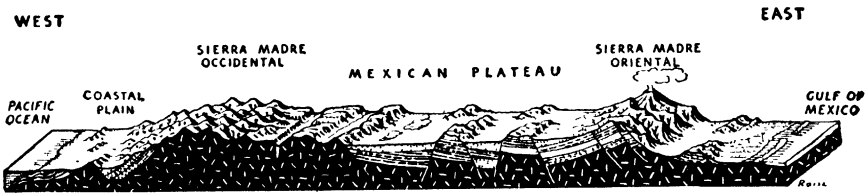


Figure 183 · Diagrammatic east-west structure section through central Mexico, with associated relief shown in perspective

zoic ages. In the Mexican portion most of the sediments in the higher land features are of Mesozoic age, but north of the Rio Grande in New Mexico and Arizona there are Paleozoic sediments associated with the Mesozoic strata in the mountain ranges. At many localities, but conspicuously in the southern portion of the province, there are vast quantities of volcanic extrusives. These rocks consist of lavas and fragmental materials that have been cemented into tuffs or breccias. Near the city of Mexico there are a number of cinder cones.

All the lower lands, which include the intermontane basins and valley floors, are mantled with recent alluvium, so that more than half the area of the Mexican Plateau appears on the geologic map as Quaternary in age.

The geologic structure in the mountain ranges of this province has been worked out in a few places, and there the strata have been found to be complexly folded and faulted. Many of the ranges are block mountains that have been uplifted and tilted in one direction or another. Associated with the breaking or cracking of the plateau surface, lavas have poured forth or volcanoes have broken out. On the basin floors the alluvial waste material rests in a nearly horizontal position, but at the base of each mountain slope torrential fans mantle rock pediments and descend at low angles into the neighboring basins. See Figure 183.

Physiographic development. The physiographic history of the Mexican Plateau has not been worked out in detail, but a broad general outline will here be presented as a working hypothesis. The great rock mass which constitutes this plateau was uplifted near the close of the Mesozoic era or early in the Tertiary period. During that period of uplift the sea was forced to withdraw and the mountain ranges were

formed. Then ensued a long period of erosion, during which much of the area may have been reduced to a peneplain. If desert conditions and closed basins were present during early-Tertiary time, the making of this peneplain differed greatly from the development of such features in humid regions with drainage to the sea. The base plain of erosion could not have been determined by sea level, and the old-age erosion surface could not have been at or near sea level. The hills must have been cut down, and the basins filled to some intermediate level. Extensive pediments must have been formed and huge alluvial fans constructed. In most of the plateau the work was in part degradational and in part aggradational, as it is today. It is not certain, however, that the early Tertiary climate was exceedingly arid. The first peneplain may have been developed in part by streams that reached the sea and were controlled in their downward cutting by sea level.

In mid-Tertiary time, following the first long period of erosion, there was another period of uplift and mountain-building. At this time a series of mountain folds and great fault blocks was formed which had a northwest-southeast trend, in contrast to the earlier mountain structures which have a nearly north-south alignment. Accompanying this physical revolution there was widespread volcanic activity. Extensive lava flows were poured out upon the surface, and great masses of molten rock were forced into cracks and fissures near the surface of the plateau.

Following this period of mountain-building and volcanic activity came another period of erosion, which has continued to the present day. This period, which has lasted millions of years, may have been divided into several cycles. The stream work in the plateau has been interrupted locally on several occasions by a renewal of volcanic activities, for fragmental materials thrown from volcanoes are interbedded with stream gravels at many places. Today there may be seen in the plateau mountain ranges in various stages of dissection, great pediments, large bolsons, huge alluvial fans, sand dunes, and a few canyons.

This long period of erosion presents many interesting problems involving the development of the present topographic features in a semidesert region. Where the streams find an exit to the sea, the development of a peneplain near the level of tidal waters is progressing slowly.

Throughout this semidesert province the mountain streams become

torrents following cloudbursts, and vast quantities of loose material are hurried to the foothills. The debris gathered in the mountains is deposited in the form of torrential fans, and the streams are soon lost by sinking into the ground or by evaporating into the dry air of the desert.

The disruption of rock material, caused by great changes in temperature, is in progress during all periods. The temperature often rises to 120° F. in the daytime and falls to as low as 50° F. during the night, and the resulting expansion and contraction of the rocks soon weaken the surface layers, causing cracking and exfoliation, or scaling. The loose material is drawn down the mountainsides by gravity and, in falling, is broken into smaller particles. In time the particles become so small that the winds pick them up, scatter them over the landscape, pile them up in dunes, or carry them out to sea. The processes of weathering and the work of the winds predominate in many areas. After a time a sort of peneplain may be developed, but it will not be near sea level. It will be at some intermediate horizon where the work of degradation and aggradation meets.

On the modern alluvial plains a few settlers have established homes and small farms. They pick out areas where there is at least a little water for irrigation. At times, however, their water supply disappears, and they are desperate. Today the railroads distribute water to some of the settlements and thus help to sustain life in the drier parts of this plateau.

The Valle de Mexico, which was a bolson containing several shallow lakes at the time of the Aztec settlements and the first visit of Cortez, has now been partly drained by the cutting of a canal that leads the waters which accumulate there into the Rio Tula and thence to the Gulf of Mexico. Most of the present city of Mexico is located on the floor of a former lake. One of the ancient canals of that city is still in use. The "floating gardens" of Xochimilco, a suburb a few miles southeast of the city of Mexico, represent an advanced stage in the occupation of the same bolson lake. Some of these gardens were first established on rafts by farmers who took from the bottom of the lake sufficient mud to form a cultivable soil on the rafts. As the rafts sank, more mud was added to their surfaces. Trees were planted, and their roots helped to anchor the rafts. Today the village is a Venetian type

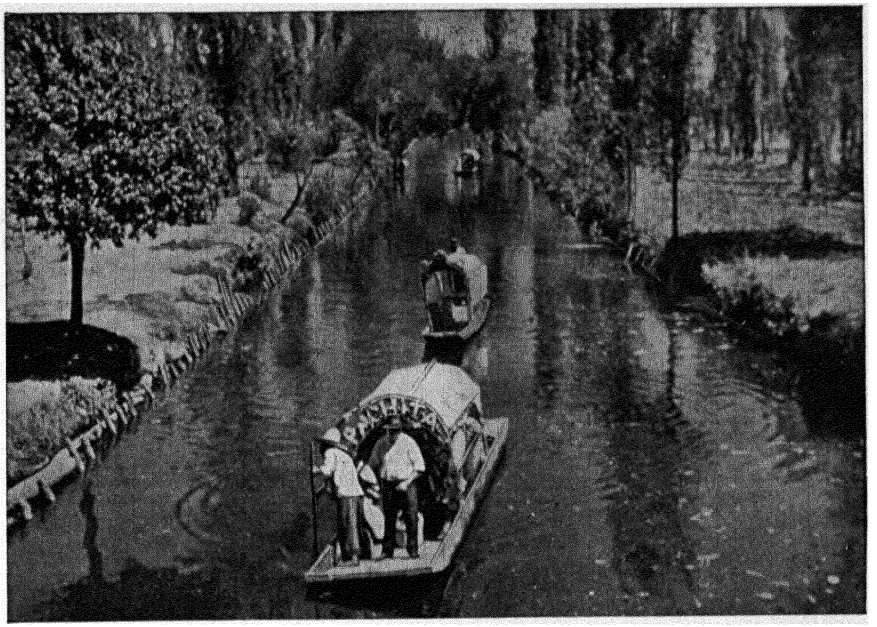


Figure 184 · One of the many canals in Xochimilco. The low, flat lands are used for gardens

of settlement where much of the travel is on canals. Mud is still being taken from the bottom of the canals and added to the lands to fertilize the soil where large quantities of vegetables and flowers are produced for the neighboring markets. See Figure 184.

A large section in northern Mexico, in the states of Chihuahua and Coahuila, does not have exterior drainage. This great bolson is composed of several closed basins among more or less isolated mountain blocks. Here the meager rainfall is gathered into small suicidal streams that lose themselves in the sands of the desert or are evaporated. For a long time the Rio Grande emptied into a large shallow basin in this area southwest of the present city of El Paso. The headward erosion of a small stream later diverted the waters of this basin to the Gulf of Mexico.

Many of the major topographic features of the plateau, such as mountain chains, great troughs, and long mesas, extend northward from Mexico into the United States. The structural alignments are chiefly north and south. In the eastern portion of the plateau section in New

Mexico there are large areas where the strata are nearly horizontal and other places where the beds are faulted and so tilted as to produce a broken plateau.

Farther west in New Mexico and in eastern Arizona, block mountains, bolsons, playas, mesas, volcanic peaks, and volcanic necks, or plugs, characterize the landscape. There are sand dunes, one large area of gypsum dunes, an extensive alkali marsh having an area of over 160 square miles, and long north-south troughs filled with alluvium to depths of at least 300 feet.

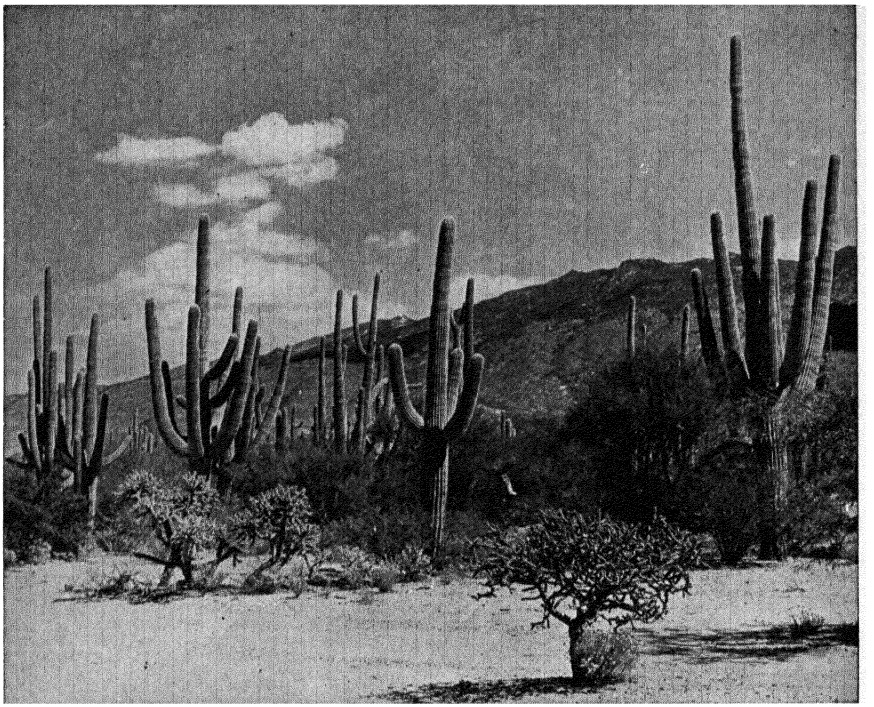
The Rio Grande, which is the chief drainage line of this portion of the Mexican Plateau, rises in the San Juan Mountains, where it obtains most of its water from rains and melting snow. Between Santa Fe and El Paso this river flows through at least eight basins, which formerly may have been bolsons, and through narrow gorges cut in mountain masses that subdivide the surface of the plateau. When the Rio Grande was seeking a route southward from the mountains, it may have been ponded at several places and each time may have been forced to rise until it overflowed from one basin to another. Certainly some of the bolson basins of this plateau have contained lakes, for today there are well-marked shore-line features about their margins.

This is a region of numerous unsolved problems in physiography. Probably the chief topographic features of this province were outlined late in Tertiary time by faulting. Since then there has been volcanic activity at many localities. The streams continue their work of dissecting the uplifted blocks and of filling the basins. Ephemeral lakes come and go, and a large amount of wind work is being accomplished.

The Colorado Plateau

A general view. The Colorado Plateau has an area of about 130,000 square miles and is made of horizontal or nearly horizontal sedimentary strata of brilliant colors, sculptured at many places into the most fantastic of landscape features. In no other part of the world are there so many striking examples of the work of running water and the relationship of structure to the work of erosion. Here may be seen not only the most magnificent of all the canyons on this earth but hundreds of





Grant, National Park Service

Figure 186 · The giant cactus and other forms of vegetation common in the semi-desert sections of the southwestern United States

other canyons that are thousands of feet deep and bordered by nearly vertical walls. Here also may be seen cliffs over 1000 feet in height and hundreds of miles long that are marching slowly northward, deeply dissected mesas, great fault-line scarps thousands of feet high, partially eroded domal mountains, natural bridges on a gigantic scale, tall monuments and spires, and large areas of weird erosional features of the badland type. See Figure 185.

The region is one of intense interest not only to students of geomorphology but to those primarily interested in the more ancient geologic studies and to all students of the distribution of plants or of human occupancy of land areas. See Figure 186.

The boundaries. To the north and northeast this plateau province is bounded by the base of the Rocky Mountains. At the west and north-

west a bold escarpment, largely the result of faulting, extends southward from the Wasatch Range to the Grand Wash Cliff at the western margin of the Grand Canyon region. At the southeast and south the hydrographic boundary is taken for convenience as the limit of this plateau province. This means that the portions of the plateau country which are drained into the Colorado River are included in the region, and that the portions which are drained into the Gila River or into the Rio Grande are excluded.

Materials and structure. In the depths of the Grand Canyon of the Colorado the Pre-Cambrian Archaeozoic complex of crystalline and highly metamorphic rock is exposed. See Figure 187. Resting upon these very ancient rocks there is a series of Pre-Cambrian sedimentary rocks of Proterozoic age that have been uplifted, tilted, and at places folded. Above these and beautifully exposed in the walls of the Grand Canyon there are 4000 feet of nearly horizontal Paleozoic sediments. They consist of sandstones, shales, conglomerates, and limestones. On the plateau surface, but at some distance from the Grand Canyon, there are Mesozoic and Tertiary formations and, at many localities, volcanic mountains, cinder cones, and elevations resulting from laccolithic intrusions. The volcanic formations near or at the surface are of Tertiary or later age.[1] The geologic structures are shown in Figures 187 and 190.

Subdivisions. The Colorado Plateau may be divided into four sections for convenience in study. The Grand Canyon section is at the southwest. To the north are the High Plateaus of Utah. At the northeast is the Uinta Basin. And at the southeast there is a section so dissected by streams that it may well be called the Canyon Lands.

The Grand Canyon Region

A north-south section. The airplane drawing shown in Figure 187 presents some of the most striking features in this part of the Colorado Plateau. At the north are the Pink, White, Vermilion, and Chocolate cliffs, formed, respectively, by Eocene and Cretaceous, Jurassic, and

[1] C. E. Dutton, "Tertiary History of the Grand Canyon District," *U. S. Geological Survey Monograph*, No. 2 (1882), 264 pages.

SOUTH

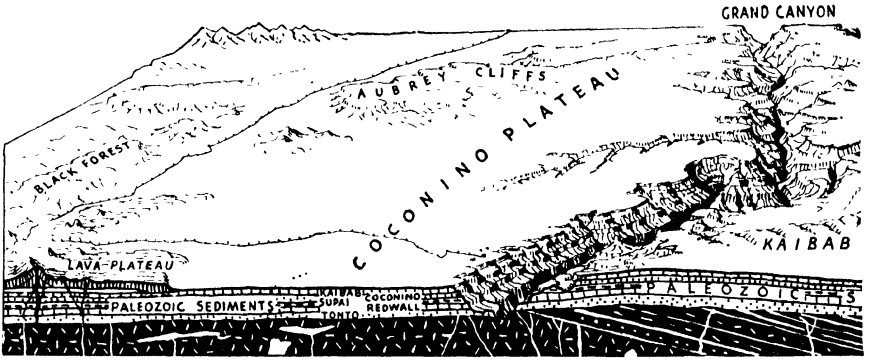
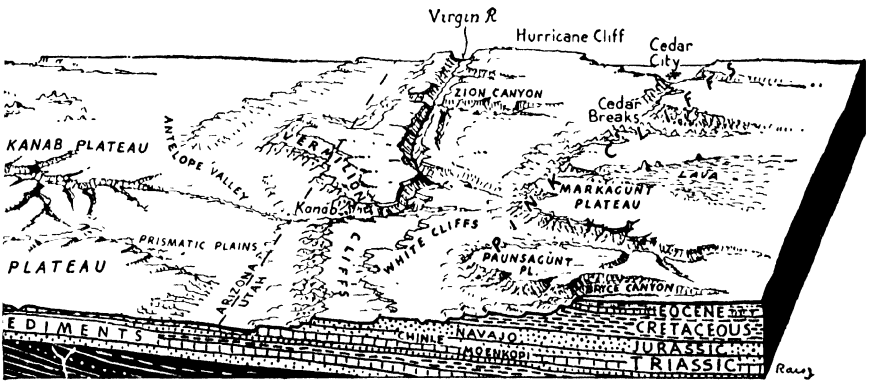


Figure 187 · A north-south diagrammatic structure section through the Grand Canyon

Triassic strata. Both the Vermilion and Chocolate cliffs are carved out of layers of Triassic age in colors that suggest the local names of these escarpments. These are the northward-marching cliffs referred to on page 366 in which weathering and erosion are undermining the resistant surface strata and thus causing sapping and crumbling at the south margin of each gigantic cuesta. See Figure 187.

The Chocolate Cliffs are but a few hundred feet high. They are so broken down at places by weathering and erosion that they are discontinuous. The Vermilion Cliffs rise from 1400 to 2000 feet above the plateau surface at their base, and they extend in a sinuous line for more than 100 miles. They are strangely sculptured and beautifully colored.

The White Cliffs, which rise nearly 1000 feet above the surface bordering them on the south and extend in a general east-west direction, are approximately parallel to the Vermilion Cliffs. The beautiful gorge of Zion Canyon, which has been set aside as a national park, is cut through these white rocks of Jurassic age and into the underlying vermilion strata. See Figure 188. The Pink Cliffs are about 800 feet high. They are composed of less well cemented formations than the cliffs to the south. The material is largely clay and shaley limestone. Here are Bryce Canyon and Cedar Breaks, which have been set aside as national reservations because of their fantastic features and spectacular coloring. See Figure 189.



portion of the Colorado Plateau, with associated relief features shown in perspective

The part of the plateau into which the most magnificent portion of the Grand Canyon has been cut is from 7500 to 9300 feet above sea level. About 70 miles south of the Grand Canyon the San Francisco Mountains rest upon the plateau surface and rise to a height of 12,700 feet above the sea. They are in the midst of 3000 square miles of volcanic features where there are hundreds of cinder cones and many extensive flows of lava. See Figure 211.

An east-west section. The Grand Canyon region is a broken plateau. An east-west structure section on the north side of the Grand Canyon shows a series of giant steps separated by fault-line escarpments. See Figure 190. At the west margin is the Grand Wash escarpment, which varies from 1000 to 4000 feet in height. Here a displacement of at least 7000 feet has taken place, but the present cliff is the result of differential erosion along the gigantic fault.

The division of the plateau surface just east of the Grand Wash is called the Shivwits; and its surface, capped in large part by lava, is about 5000 feet above tidal waters. Farther east there is an escarpment called the Hurricane Ledge, which rises about 1800 feet above the plateau to the west. This ledge is located near another great fault where there has been a displacement of at least 6000 feet. Each of the great escarpments in this plateau is retreating or marching eastward.



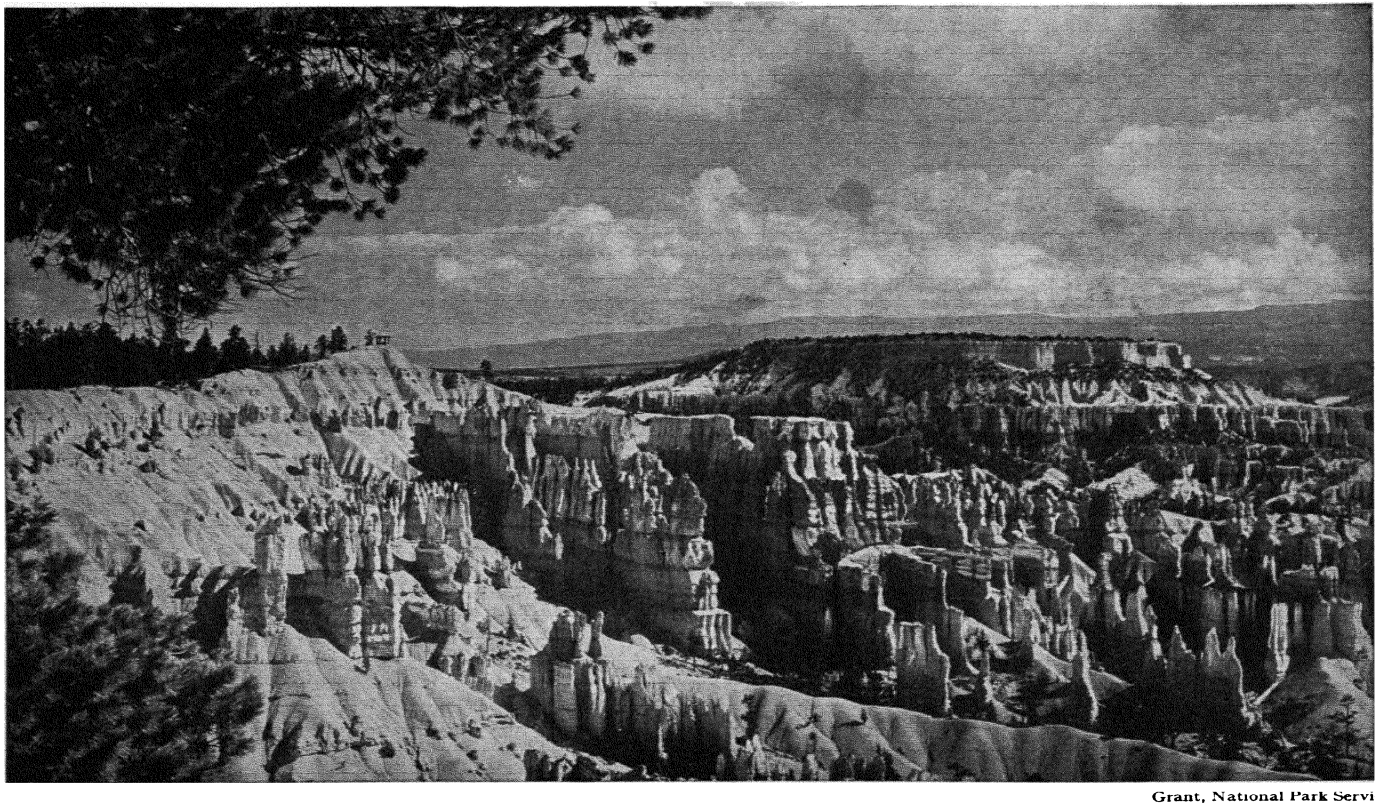
Grant, National Park Service

Figure 188 · Zion Canyon in southern Utah. This gorge has been cut through a white overlying sandstone into a sandstone of deep-red color which farther south forms the Vermilion Cliffs

The plateau above and bordering Hurricane Ledge on the east is known locally as the Uinkaret. Here there are at least 150 volcanic cones that rise 500 to 800 feet above the plateau surface. A little farther east is the Toroweap fault-line escarpment of about 700 feet at the south but less to the north. Then comes the Kanab Plateau, at an elevation of 7000 to 8000 feet above the sea. This plateau is defined at the east by other fault-line escarpments.

The highest of all the giant steps in the Grand Canyon region is the Kaibab Plateau, which rises to an elevation of a little over 9000 feet at its south margin, where it forms the rim of the Grand Canyon. This plateau is about 35 miles wide and declines northward to the base of the Vermilion Cliffs, where it has an elevation of about 7500 feet. The eastern border of the Kaibab is a monoclinal fold, as shown in Figure 190.

East of the Kaibab Plateau, at an elevation of 5000 to 8000 feet, is the Marble Platform, into which a portion of the Grand Canyon of the



Grant, National Park Service

Figure 189 · Looking northward into Bryce Canyon from Sunrise Point. The carving of these fantastic forms is accomplished chiefly by torrential rains from cloudbursts and by winds. They are brilliantly colored

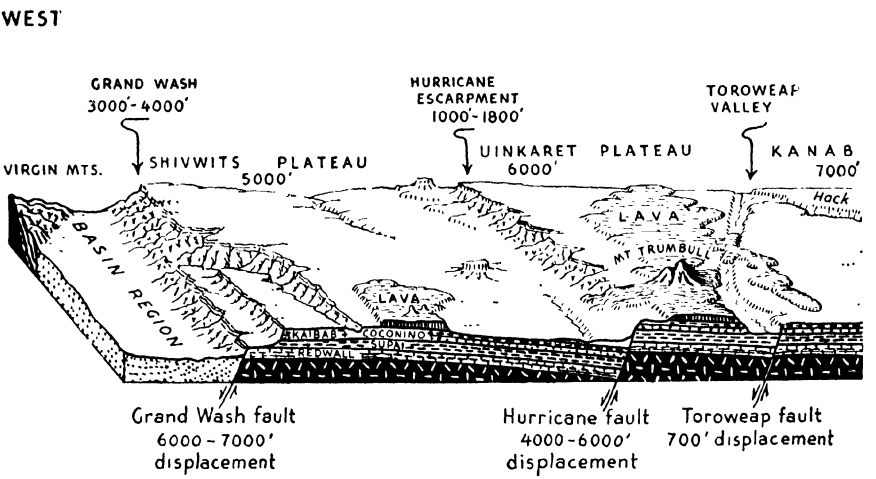
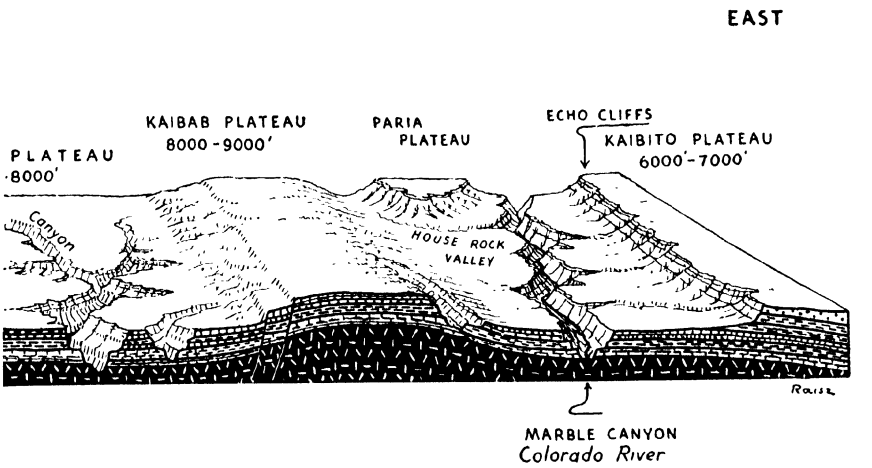


Figure 190 · An east-west structure diagram just north of the Grand

Colorado River has been cut. Still farther east are the Echo Cliffs, which correspond to the Vermilion Cliffs. They face westward and are retreating slowly to the east. See Figure 191.

The Grand Canyon. The Colorado River flows in a canyon for at least 500 miles, but the most majestic portion is in the 200 miles of its course between the junction of the Little Colorado and the Grand Wash escarpment. This portion is commonly referred to as the Grand Canyon of the Colorado. Here the canyon attains its maximum depth, which is about 6000 feet, and a width which varies from 5 miles to more than 15 miles. In its course through the Grand Canyon the stream descends from 2640 feet to 1000 feet above the sea. That means an average fall of about seven feet per mile. The stream is commonly 300 to 400 feet wide and about 40 feet deep, but at many places there are dangerous rapids, where, at low-water stages, the depth is less than 10 feet. During flood periods the river rises 50 to 60 feet above the low-water stages in the narrow inner gorge and becomes a raging torrent. Such large quantities of sand and silt are carried in suspension by this canyon-cutting stream that its color is that of coffee with cream in it. Gravel, cobblestones, and boulders are constantly being rolled along the bottom of the channel.



Canyon of the Colorado, with associated relief shown in perspective

In the cutting of the Grand Canyon through the broken plateau, the combined processes of weathering and stream erosion have produced a series of remarkable architectural features with strong horizontal lines and steplike profiles. See Figure 192. Huge temples and pyramids stand out in relief on the canyon walls, and bold, rocky spurs project far out into the great abyss. Many of these features are so large that they would be called mountains if they rose above some level surface, but here they are mere details on the walls of a gigantic chasm.

Near the rim, in the deepest and most magnificent portion of the Grand Canyon, there are two formations which are certain to catch the eye of an observer. One of these formations is the actual rim rock. It is the Kaibab limestone, a blue-grey fossiliferous stratum 500 feet thick, which accumulated in sea waters. The other is a very light-colored cross-bedded sandstone, called the Coconino formation, which appears as a white or cream-colored ribbon a few hundred feet below the rim rock on each side. This is a very interesting rock formation which has provoked many spirited debates. Perhaps it records an ancient desert where wind-blown sands were widely distributed. These two resistant strata, the Coconino sandstone and the Kaibab limestone, help to hold up the plateau surface and cause steep cliffs of nearly 1000 feet in height on each side of the canyon. These cliffs have added



Figure 191 · A view from the air over the Painted Desert of Arizona. Echo Cliffs are at the right in the foreground. Marble Canyon crosses through the center. In the middle distance are the Vermilion Cliffs and Paria Plateau. See also Figure 190

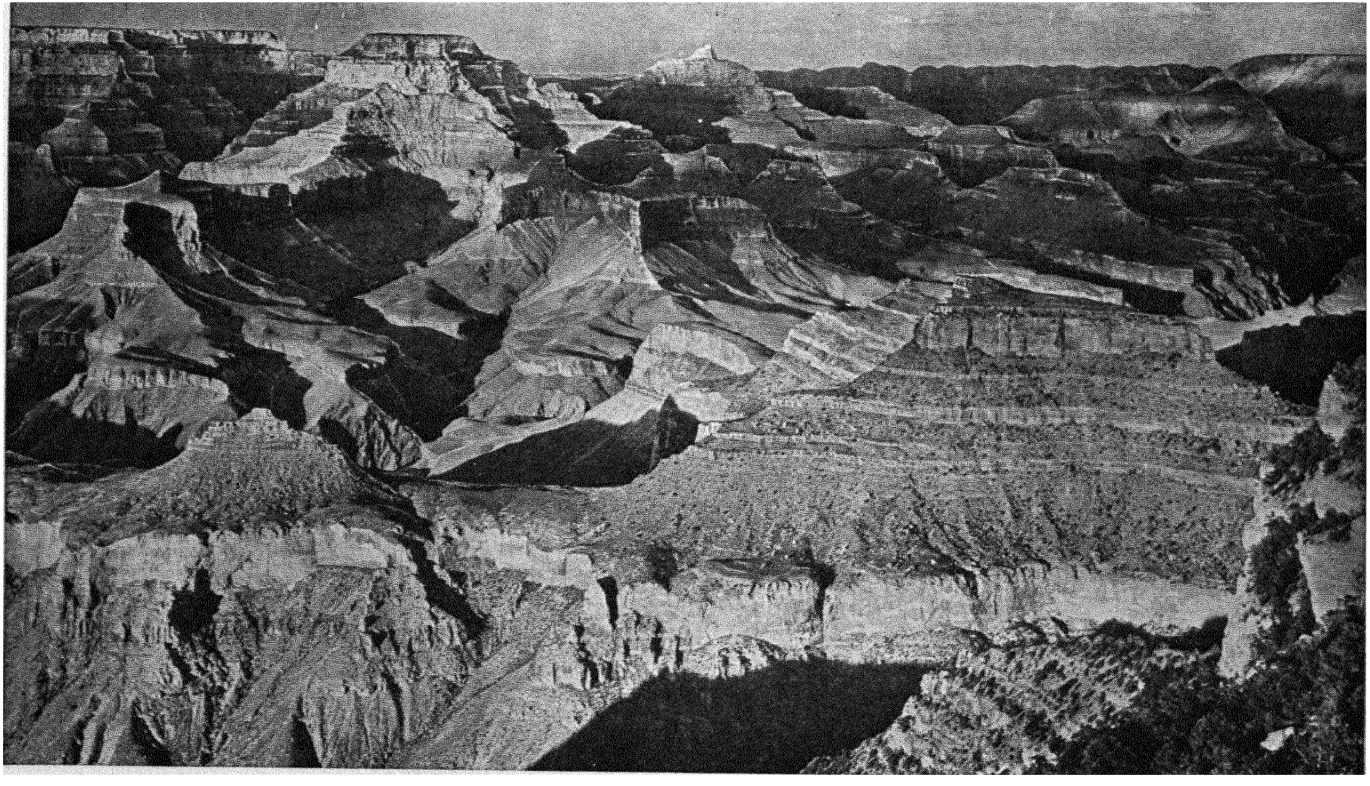


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Figure 192 · The north wall of the Grand Canyon of the Colorado including Cape Royal, Wotan's Throne, and Vishnu Temple. The lower cliff in the foreground and the cliffs midway on the sides of the temples are parts of the famous Red Wall

greatly to the difficulty of finding places where trails could be constructed into the canyon. See Figures 193 and 194.

Part way down on the wall of the canyon there is a formation about 500 feet thick known as the Red Wall. This is really a blue limestone, but it has been stained red by waters dripping over its surface after having passed through or over higher formations of red color. The Red Wall appears as a great ribbon winding in and out about the temples and spurs and into the tributary canyons. It appears on both sides of the great gorge and can be traced as far as the eye can reach.

Below the Red Wall, and extending to the rim of the inner gorge, there is commonly found a broad, gently sloping surface called the Tonto Platform. There certain softer formations, chiefly shale, come to the surface. Below the Tonto Platform, at the rim of the inner gorge, there is a very resistant cliff-making rock called the Tapeats sandstone. The inner gorge in the Kaibab Plateau section is about 1000 feet deep. For several miles it is a sharp V-shaped notch cut into the Pre-Cambrian crystalline rocks. See Figure 187.

No words can adequately describe the beauty and grandeur of this canyon. Scientists, journalists, poets, and thousands of travelers have tried, but their efforts have been unsuccessful. The canyon must be seen to be appreciated. The illustrations used in this section will do more than any words to depict some of the striking features of the chasm.

Crater Mound, or Coon Butte. In the Grand Canyon section of Arizona, a few miles southeast of Canyon Diablo, there is a huge crater three quarters of a mile in diameter and 600 feet deep. See Figure 195. The rim of this crater rises 120 to 160 feet above the surrounding plateau surface. In the rim are exposed the upturned edges of the plateau strata, and on the floor of the crater there is a considerable filling of loose material which has been washed in from the nearly precipitous infacing walls. This formation, which is known as Crater Mound or Coon Butte, is farther removed from the San Francisco Mountains than any of the well-defined volcanic features of that center. There are no volcanic rocks associated with the butte, but on the plateau near the crater many fragments of meteorites have been found.

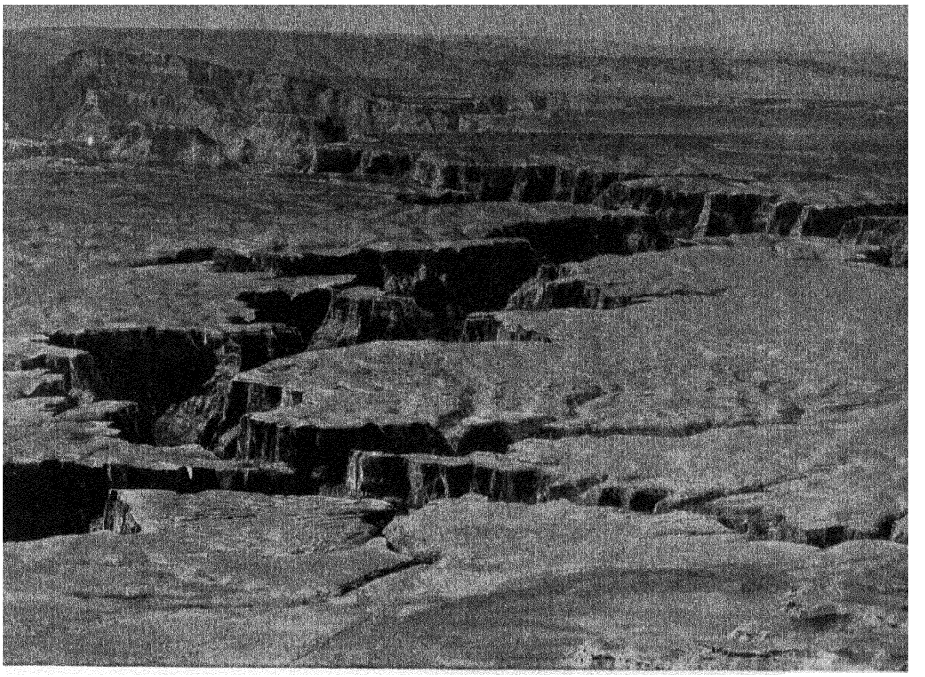

Figure 193 · Canyon of the Little Colorado near its junction with the Colorado River

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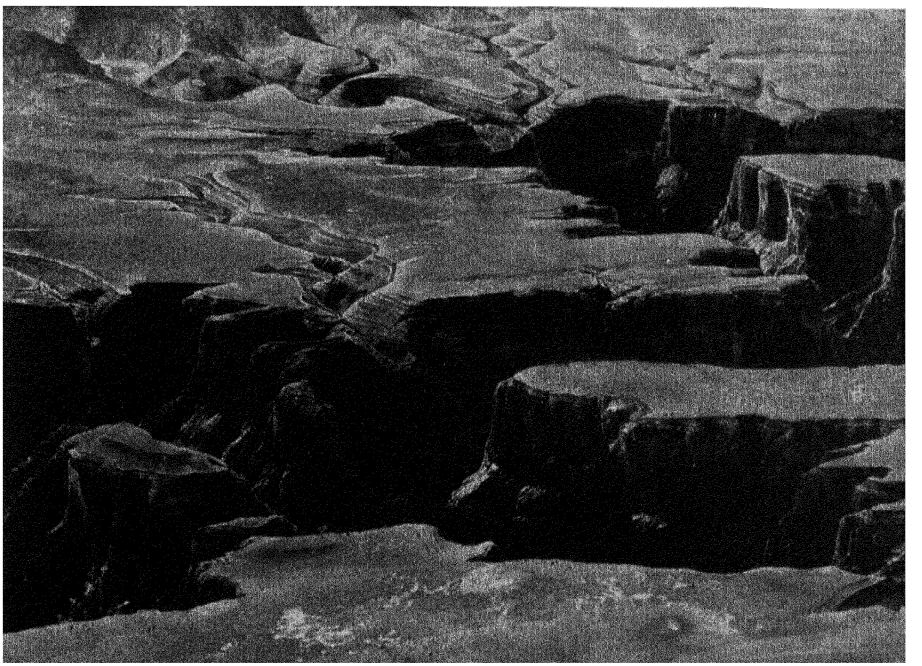
Figure 194 · A close-up of the Canyon of the Little Colorado



A theory favored by many is that this huge crater is the result of the impact of a meteor. To those who favor this hypothesis it resembles some of the lunar craters. Mining men have searched thus far in vain by deep drillings to find the great meteor that is supposed to have caused this crater. Recent geophysical observations suggest that the meteor entered the ground at an oblique angle and broke into several fragments, and that the fragments are embedded in the earth a little south of the crater.

The High Plateaus of Utah

The surface of this the highest section of the Colorado Plateau province rises to more than 11,000 feet above the sea. Here the sedimentary strata, mantled at many places with lavas, are nearly horizontal, but they have been broken along north-south fault zones into three distinct belts, or subplateaus. Between these subplateaus, which for the most part are clothed with forest trees, there are long, grassy valleys.[1]

On the higher portion of this plateau there are glacial moraines, striae, grooves, and rock basins. There are many small lakes present, and they occupy glacially scoured basins or undrained areas in the moraine mantle. It is believed that a small ice cap formed in this section of the plateau province.

The boundaries. The west margin of the High Plateaus of Utah is at the bold escarpment resulting from the Hurricane Fault. The Grand Wash Cliff, so conspicuous farther south, is combined with the Hurricane uplift in this section. Very recent lava flows have spilled over from the surface of the plateau and obscured the Hurricane escarpments for a distance of about 30 miles.

The cuestas with their beautiful south-facing cliffs at the north margin of the Grand Canyon section mark the southern boundary of the High Plateaus of Utah and form there a gigantic flight of steps. See Figure 196. The Pink Cliffs turn northward and for 175 miles mark the eastern margin of this subprovince.

[1]C. E. Dutton, "Report on the Geology of the High Plateaus of Utah," *U. S. Geographical and Geological Survey of the Rocky Mountain Region* (1880), 307 pages.



Fairchild Aerial Surveys, Inc.

Figure 195 · Coon Butte, the meteor crater near Canyon Diablo, Arizona. It is three quarters of a mile in diameter and 600 feet deep

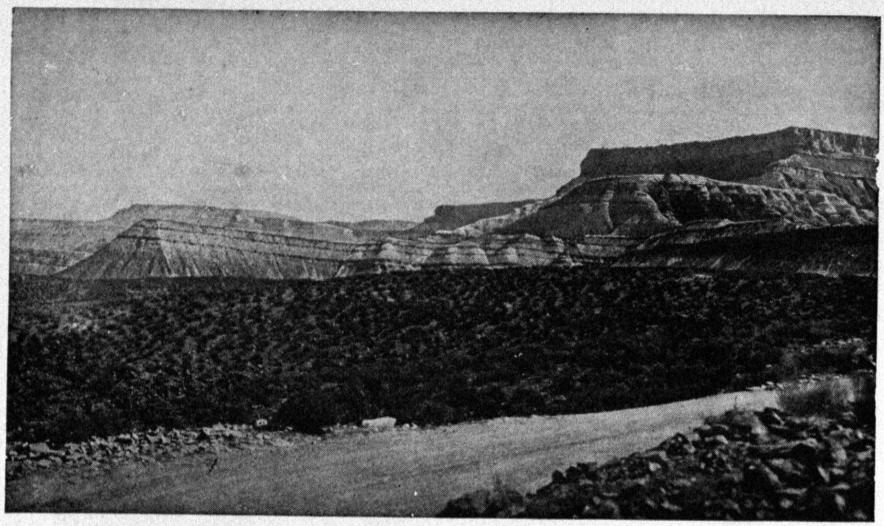


Figure 196 · The Vermilion Cliffs, one of the south-facing escarpments on the Colorado Plateau in southern Utah. See also Figure 187

The Uinta Basin

The structure. South of the Uinta Mountains there is a structural basin known as the Uinta Basin, the surface of which is from 8000 to 9000 feet above sea level. The strata of the plateau province dip northward toward the mountains and then, at the very base of the range, they are bent upward. The northward dip of the strata has resulted in the development of great cuestalike forms with south-facing escarpments. The Pink Cliffs of the plateau section farther west curve eastward and cross this section, where they are known as the Roan Cliffs. A lower cuesta front in this section is called the Book Cliffs. Both the Roan Cliffs and the Pink Cliffs are northward-marching escarpments. Above Roan Cliffs the surface is called the Roan Plateau; and portions of that tableland, isolated by stream-cut canyons near the east margin of the section and bordering the Rocky Mountains, are known as Book Plateau, Grand Mesa, and Battlement Mesa. See Figure 197.

The Green River, which crosses the Uinta Range and the Yampa Plateau in deep, steep-sided gorges, crosses the Uinta Basin section in a gorge about 3000 feet deep, known as Desolation Canyon. There are



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Figure 197 · The sculpturing of nearly horizontal beds of shale in the plateau north of the town of Green River, Utah



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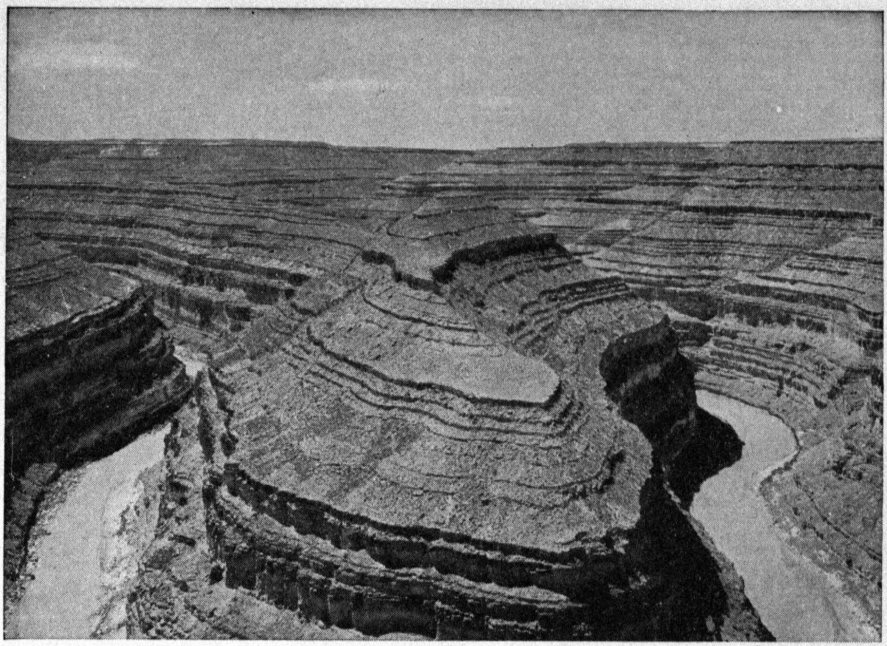
Figure 198 · Canyon del Muerto and Canyon de Chelly north of the Navajo country in northeastern Arizona

many areas within this basin where the surface has been deeply dissected and cut into fantastic features characteristic of badlands. The Colorado River crosses the eastern portion of this section.

The Canyon Lands

A much-dissected landscape. The southeastern portion of the Colorado Plateau province, where the streams from the Rocky Mountains have all developed canyons, is a weirdly dissected landscape. See Figure 198. It is one of the most difficult of regions to explore on foot or



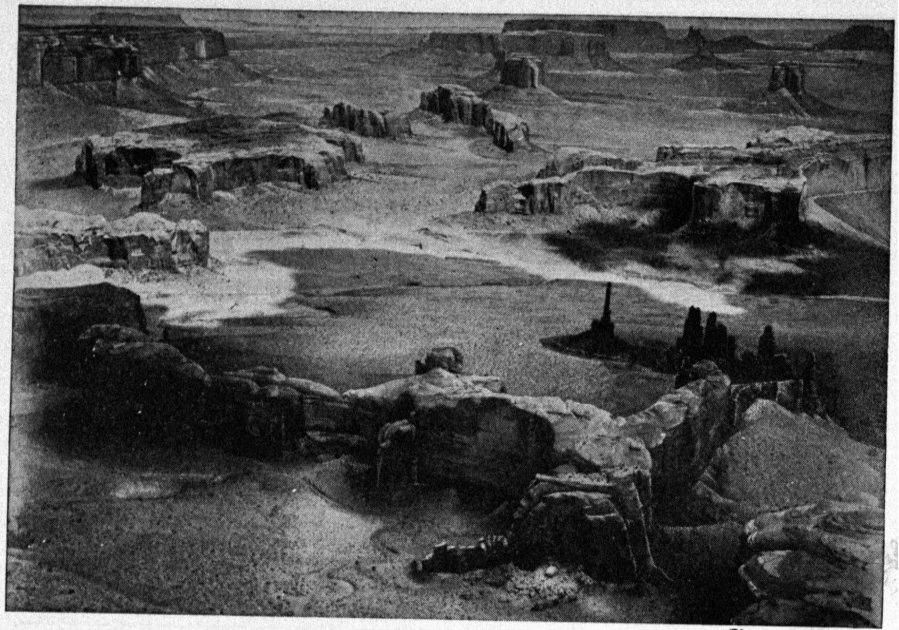
Grant, National Park Service

Figure 199 · Meanders being carved in horizontal strata by the San Juan River as it crosses the plateau to join the Colorado River

on horseback, and those who have followed the stream course in boats report a series of thrilling adventures and many narrow escapes. An airship, which would float slowly over this region at a height of a few hundred feet, would undoubtedly prove to be the most satisfactory means of exploration. See Figure 199.

In northeastern Arizona is Monument Valley, where sharp spires, obelisks, and towerlike masses of rock rise hundreds of feet above their surroundings. See Figure 200. This is the land of the modern Navajos, and it was the home of many prehistoric peoples. At the eastern margin of the canyon lands is the Mesa Verde, a huge cuesta which has been deeply dissected by streams. Here, in great recesses on the walls of the canyons, are found the ruins of ancient cliff dwellings. See Figure 224 on page 426.

East of the Little Colorado is the brilliantly colored area known as the Painted Desert. Here the rocks show gorgeous shades of red, yellow, brown, and green. The strata are gently inclined in a mono-



Photograph by Hall

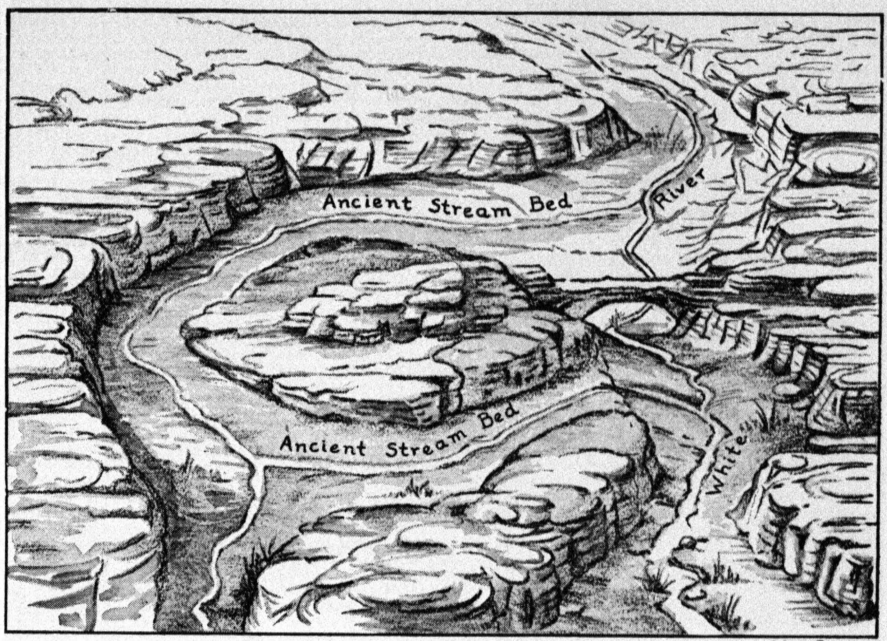
Figure 200 · An air view taken over Monument Valley in northeastern Arizona. This is an excellent example of erosion in a desert region. Most of the work is accomplished by rain from cloudbursts and by winds

clinal fold, and they present a series of cliffs that are slowly migrating as weathering and erosion proceed. The region is another one of fantastic sculpturing.

In the area north of the canyon of the San Juan River there are several plateau surfaces that vary from 6000 to 7000 feet above sea level. There are bold escarpments bordering some of these plateaus, canyons with vertical walls, a group of small mesas called The Tables of the Sun, and several remarkable natural bridges that have been set aside as national monuments. See Figures 207, 208, and 209. Here the landscape is bold and rugged, curves have given way to angles, and there are many fantastic features. There is little or no vegetation, and the deep reds, browns, yellows, and buffs of the rock formations provide color for the landscape.

Gregory[1] has recently published a paper dealing with the geography

[1] H. E. Gregory, "The San Juan Country: a Geographic and Geologic Reconnaissance of Southeastern Utah," *U. S. Geological Survey, Professional Paper, No. 188* (1938), 123 pages.



After Gregory

Figure 201 · A sketch of Sipapu Natural Bridge and the associated canyons, illustrating how the cutting of deep meanders might result in the development of a natural bridge and the diversion of a stream

and geology of this portion of the plateau. His explanation of the natural bridges in this region is presented in Figure 201.

Laccolithic mountains. At several localities in the Canyon Lands section of the Colorado Plateau, huge masses of molten rock rose toward the surface of the earth, spread out between the layers of sedimentary rock, and formed great domes in the overlying strata. See Figure 202. The molten materials which have cooled and formed solid rock are called laccoliths, and the resulting relief features are called laccolithic mountains. If explosions had occurred when the magmas rose toward the surface and lavas had poured forth, true volcanoes would have come into existence. In southeastern Utah, west of Fremont River, a tributary of the Colorado River, a group of these laccoliths, called the Henry Mountains, rise conspicuously above the plateau surface.[1] A little to the

[1]G. K. Gilbert, "Report on the Geology of the Henry Mountains," *U. S. Geographical and Geological Survey of the Rocky Mountain Region* (1877), 160 pages; 2d ed. (1880), 170 pages.

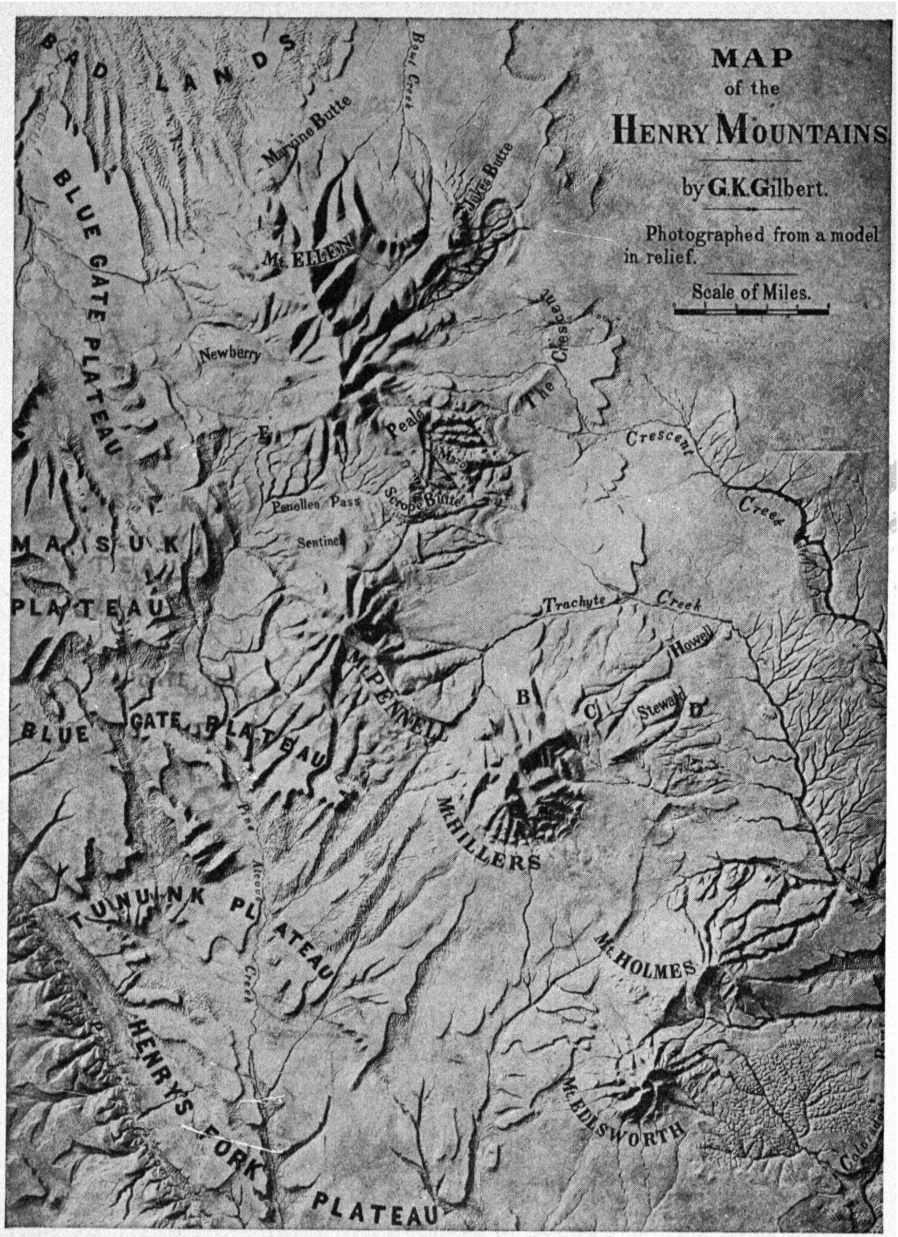


Figure 202 · These mountains of southeastern Utah are maturely dissected laccoliths. Gilbert's report on the region is one of the classics in American literature dealing with geomorphology

north is the San Raphael Swell, a huge elongated dome which has been uncovered, and eroded so deeply that the upturned strata in the flanks now form cuestas that present infacing escarpments. La Sal and Abajo mountains, east of the Colorado River in Utah, are also laccolithic in origin. Ute Peak, a short distance west of the Mesa Verde in the southwest corner of Colorado, and the Carrizo Mountains in northeastern Arizona are of the same origin. Navajo Mountain, on the east side of the Colorado River near the Utah-Arizona boundary line, is the result of the intrusion of a great mass of molten rock. Here the sedimentary cover has not been entirely removed. See Figure 203.

In the Henry Mountains, and in most of the other formations given here as examples, the overlying strata of sedimentary rocks that were uplifted have been so largely removed that the igneous core rock is exposed. In such cases the sediments appear as hogbacks and flatirons about the margins of the mountains, or as cuestas farther away where the inclination of the strata is less. Figures 204 and 205 present airplane views of special features in the southeastern part of the Colorado Plateau.

An Outline of the Physiographic Evolution of the Colorado Plateau

Development of the plateau surface. The inauguration of the period during which the present surface features have been carved out of the rock formations of the Colorado Plateau came at the close of the Mesozoic era. At that time there was a broad uplift of the entire province with some local folding. A cycle of erosion was opened during which vast quantities of rock material were carried away. In the region immediately adjoining the Grand Canyon of the Colorado, at least 6000 feet of rock were removed from an area of hundreds of square miles. Following this widespread erosion and wasting away of the surface of the plateau province, layers of sands, clays, and gravels, which have been referred to as the Eocene beds, were deposited over much of the plateau area. Then came a renewal of erosion and necessarily the development of a consequent drainage pattern on the surface of the Eocene deposits.

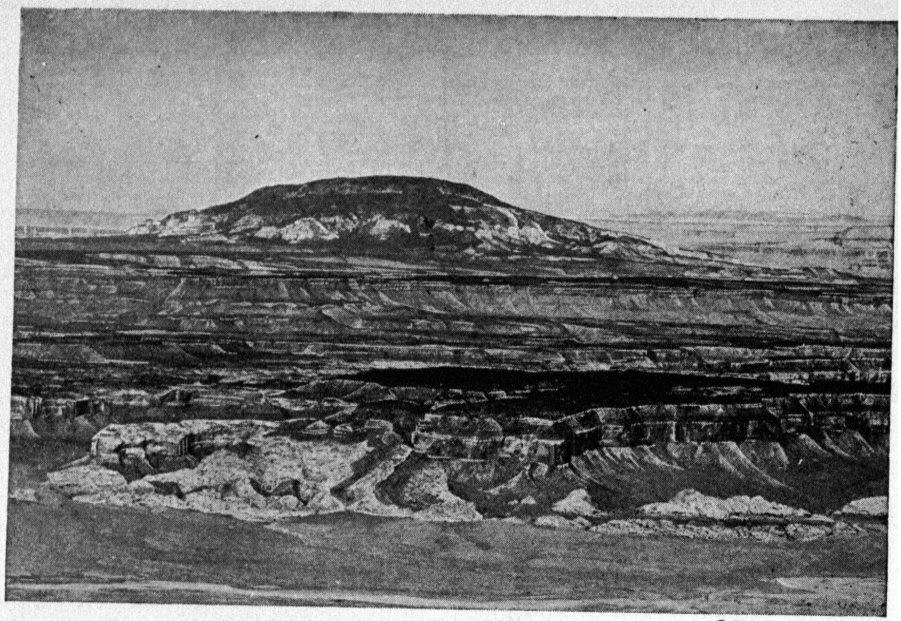


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Figure 203 · Navajo Mountain, a laccolith in northern Arizona near the junction of the San Juan with the Colorado River

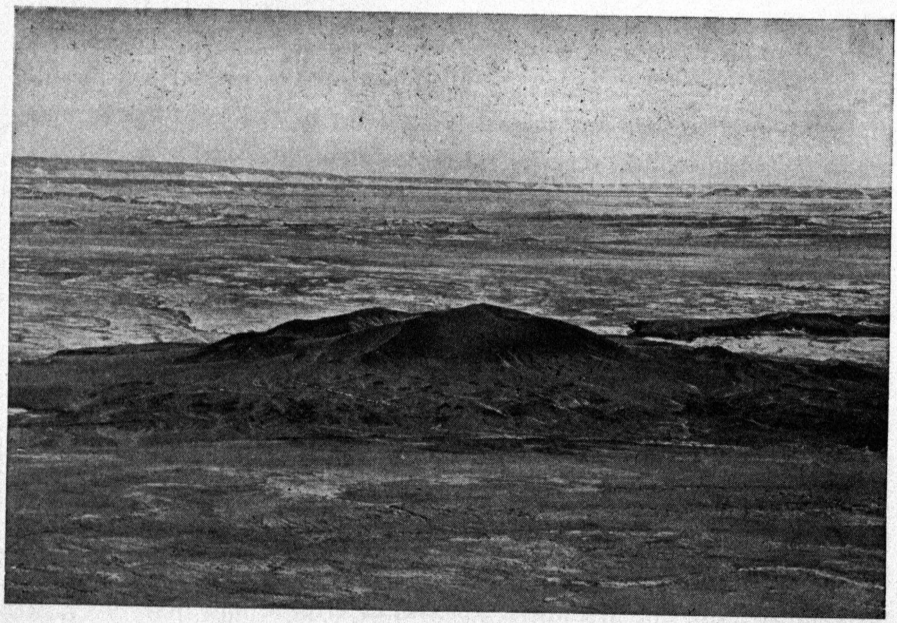

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Figure 204 · Shadow Mountain, or Black Knob, a volcanic cone on the Colorado Plateau a few miles northwest of Cameron, Arizona

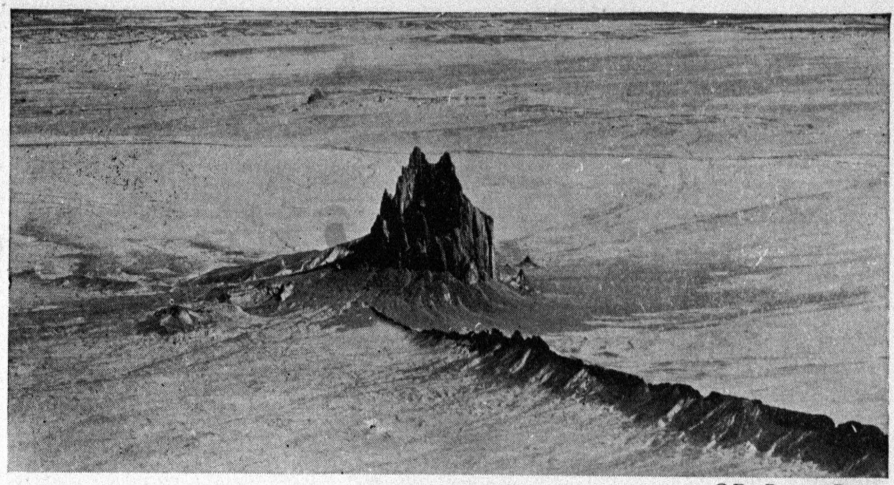

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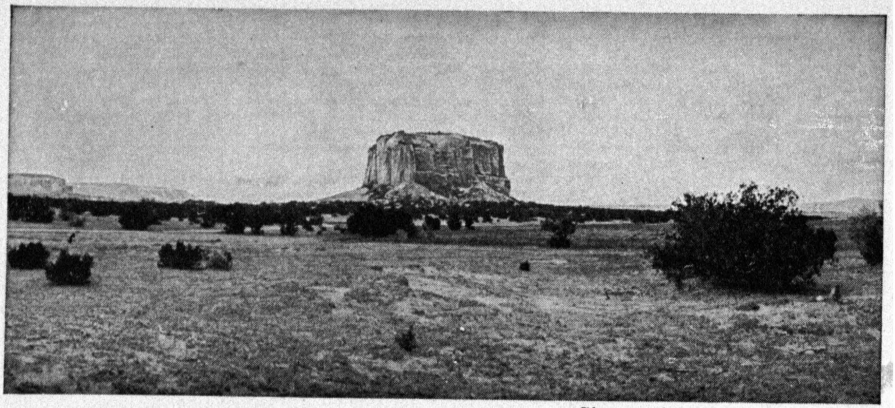
Figure 205 · Shiprock, a conspicuous volcanic core or plug that rises about 500 feet above its surroundings in northwest New Mexico. The black ridge at the right is due to the superior resistance of a nearly vertical dike

It was at this time (Miocene) that the main drainage lines of today were fixed, and it is since then that the major topographic features of the plateau have been carved out of the rock strata of this province. See Figure 206. As valley-deepening went on, the streams were superimposed upon the older underlying rock structures. Erosion continued, and an old-age erosion surface, which now constitutes the greater part of the plateau, was developed. That surface is known as the Plateau Peneplain.

During the uplift which followed the deposition of the Eocene deposits, considerable faulting took place; and yet the escarpments which must have appeared in the landscape as a direct result of that faulting were removed in the base-leveling processes long before certain lavas were poured out and before the canyon cycle was inaugurated. There are lava flows on the plateau surface that cross these fault-line zones where the effects of thousands of feet of throw along the faults had been removed before the lavas were outpoured.

The present escarpments bordering the fault blocks in the broken part of the plateau are fault-line escarpments. They have come to stand out because of later differential erosion and later movements along the fault planes. The shattering of the rocks near the fault-line zones



Photograph by Wallace W. Atwood Jr.

Figure 206 · The Enchanted Mesa near the Indian village of Acoma in New Mexico. This is a sandstone monadnock rising about 400 feet above the plateau surface

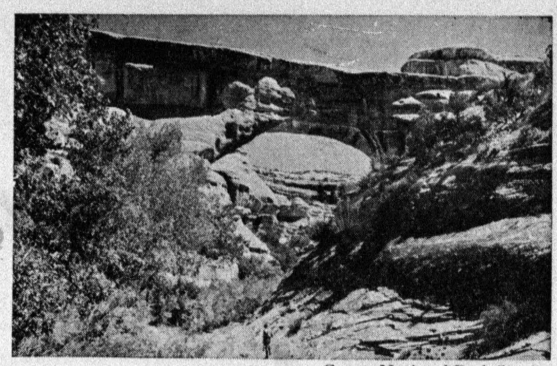
has helped to hasten erosion in those zones, and in each case the formations in the downthrown block have yielded more rapidly than the strata in the higher block.

Development of the subsummit peneplain. At many places in the surface of the plateau there are broad, shallow valleys indicative of late maturity or early old age. They are only a few hundred feet deep, but they seem to indicate a new base plain of erosion to which the streams were working for a considerable length of time before the canyon-cutting cycle was inaugurated. These valleys have suggested to some field workers another cycle of erosion after the Plateau Peneplain was developed and before the modern canyons were cut. The valley floors may be referred to as parts of a subsummit peneplain in the plateau. This erosion surface must be of late Tertiary age. The Plateau Peneplain and the subsummit erosion surface were developed before the cutting of the great canyons and appear to be of about the same age as the Rocky Mountain Peneplain in the province to the east.

The canyon cycle of erosion. Since the development of the subsummit peneplain there has been an uplift of several thousand feet and a continuation of faulting which has helped to produce the new fault scarps along the old fault lines. All streams were rejuvenated following

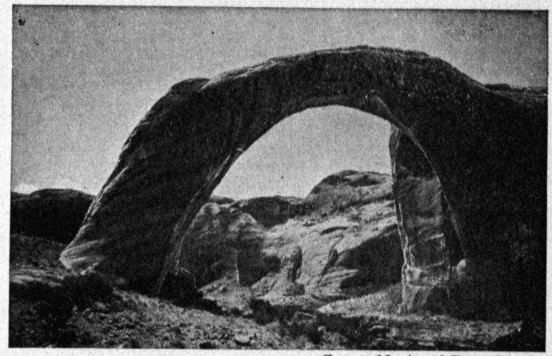
the uplift, and the Colorado River and its tributaries began the task of cutting the modern canyons.

Since the lands rose during late Tertiary time, or at about the beginning of Quaternary time, the canyon-cutting has taken place during and since the last great Ice Age. During these relatively recent millennia the streams have excavated the magnificent gorges that give so much character to this part of the continent. Some have entrenched their meandering courses which were developed during the previous cycle. See Figure 199. The great cliffs, which have been referred to, have continued to retreat during this last cycle of erosion; the mesas have been more and more reduced; and weathering and wind erosion have assisted in the development of natural bridges and the many fantastic features in the plateau region. See Figures 207, 208, and 209.



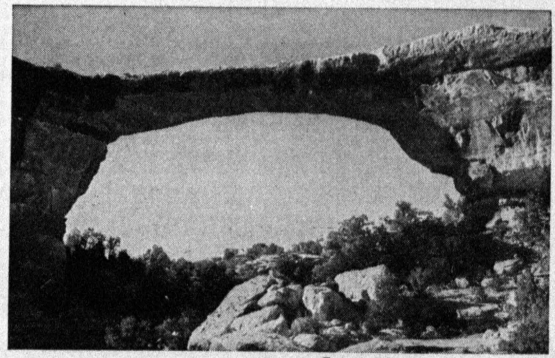
Grant, National Park Service

Figure 207 · Augusta, or Sipapu, Natural Bridge in White Canyon, southeastern Utah



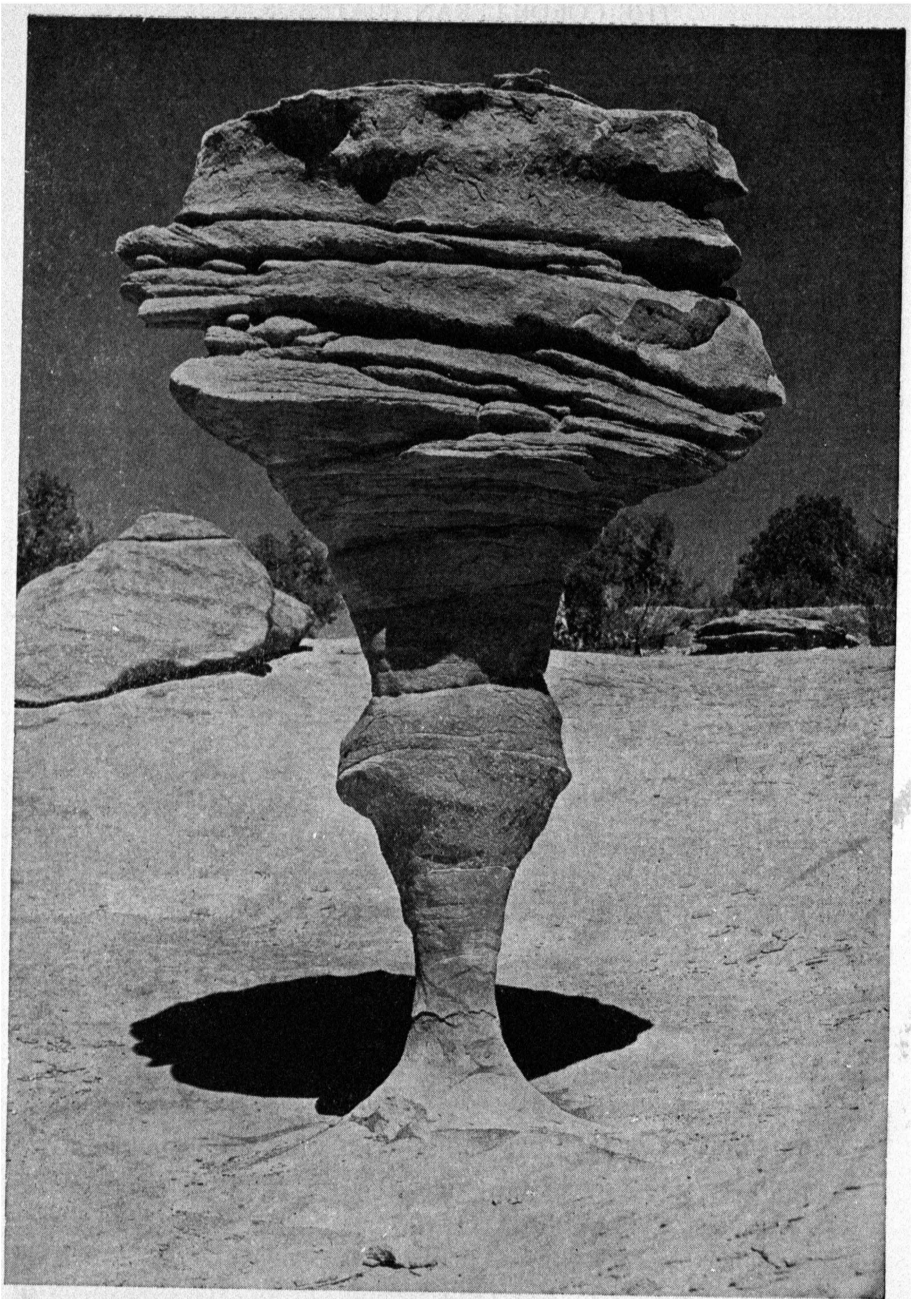
Grant, National Park Service

Figure 208 · Rainbow Bridge, a separate national monument in southeastern Utah



Grant, National Park Service

Figure 209 · Edwin Bridge spans a wide gulch in Armstrong Canyon, southeastern Utah



Grant, National Park Service

Figure 210 · The Goblet, a good example of wind erosion in a sandstone formation. This pillar can be seen by taking a short walk from the road between Blanding, Utah, and the Natural Bridges National Monument

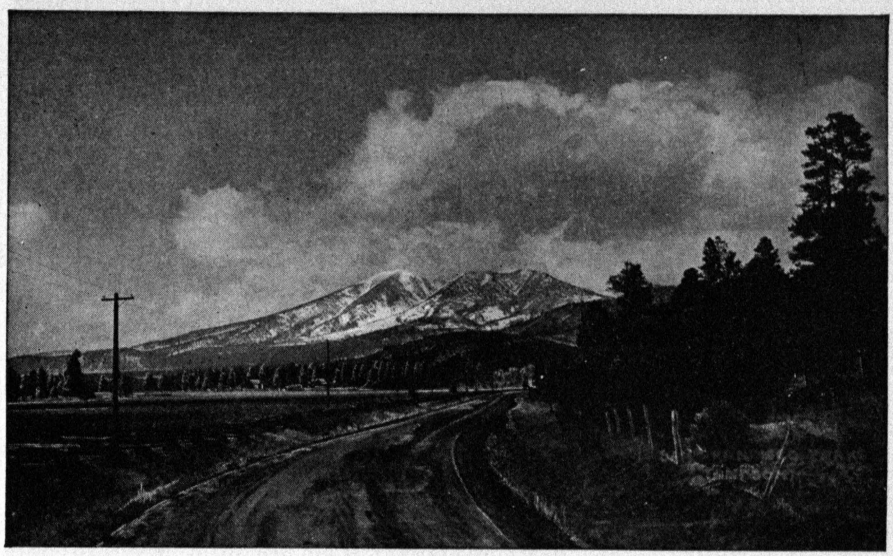


Figure 211 · The San Francisco Mountains. These are volcanic peaks built upon the Colorado Plateau surface near Flagstaff, Arizona. The summits rise more than 12,000 feet above sea level, and about the base of the mountains there are at least three hundred cinder cones. This is a remarkably interesting volcanic center

Aridity has favored the development of the fantastic elements in the landscape. Whenever cloudbursts have occurred the streams have been particularly effective, for there has been little or no vegetation to delay the work of earth sculpture. See Figure 210.

Volcanic activity has been renewed in this very late period. In the vicinity of the San Francisco Mountains there are cinder cones and lava flows so recent that they resemble the modern flows in the Hawaiian Islands. They are without soil and entirely without vegetation. At places there are lavas that have poured over canyon walls, which proves that they came during the last, or present, cycle of erosion. See Figure 211.

The Colorado Plateau region is one in which physiographic changes are taking place so rapidly and on such a gigantic scale that it serves as an excellent laboratory for all students of geomorphology. Here the classic field studies of Powell, Gilbert, and Dutton, referred to in the reading list at the end of this chapter, were carried out. There is no place in the world where the work of running water is illustrated so strikingly as in the Grand Canyon of the Colorado.

The Great Basin

The boundaries. In the midst of the western cordillera, between the Rocky Mountains and the Sierra Nevada on the east and west, the Columbia and Colorado plateaus at the north and southeast, and the Sonoran Desert at the southwest, there is a large area which is commonly referred to as the Great Basin. That name suggests, intentionally, an area of interior drainage, which is an appropriate description of much of the province. It is not a single basin, but an aggregation of hundreds of basins. Furthermore, the boundaries of this physiographic province do not correspond exactly with those of any hydrographic basin. There are some portions of the Great Basin from which there is drainage to the coast. There are considerable areas in the Rocky Mountains and in the Sierra Nevada from which the drainage is into this basin; yet those areas are not included in the basin province; they are more appropriately included in the mountain provinces.

The east boundary of the province is clearly defined by the conspicuous topographic change resulting from faulting at the west base of the Wasatch Range and at the west margin of the Colorado Plateau. The west margin of the province is equally well defined as a result of faulting at the east base of the Sierras. At the north and south the boundaries are not marked by distinct changes in topography. See Figure 138.

Vegetation and rainfall. This physiographic province contains numerous north-south mountain ranges in addition to many small basins. Some of the basins contain lakes, others are grass-covered lowlands, and some are barren desert wastes. For the most part, the mountain ranges are but poorly clothed with vegetation.

The Great Basin is in the rain-shadow area of the Sierra Nevada and is therefore a land of marked aridity. At certain stations an annual rainfall of less than three inches a year has been recorded. About the margin of the region there are oases having prosperous agricultural communities. Small settlements break the monotony along the railroad lines and the main automobile routes. A few ranchmen have located in the basin, and there are a number of active mining camps. On the whole, however, the region is but sparsely populated.

The mountain ranges. The mountain ranges in the Great Basin province, with their north-south axes, are commonly from fifty to seventy-five miles in length and from six to fifteen miles in width. They rise from 3000 to 5000 feet above the basin floors and from 7000 to 10,000 feet above sea level. They have long been referred to as block mountains, and their steeper faces are commonly interpreted to be fault scarps or fault-line scarps. See the map at the end of this book.

There are simple block mountains within the province and some of the best examples are located in the northern portion of the Great Basin. There are numerous other ranges, however, in which the strata are distinctly folded and in which field workers can detect no evidence of faulting.

If mountains are simple fault blocks not yet worn down, the base on the fault side should be a straight line, or as nearly a straight line as a fault may be. Discordance in outline and structure in certain ranges suggests very strongly that there have been at least two periods of mountain growth within this province. During one of those periods folding predominated and gave rise to the mountain ranges; and during the other, faulting characterized the uplift. See Figure 212.

Unquestionably a vast amount of faulting has taken place within this province. At the west base of the Wasatch Mountains and at the east base of the Sierras where huge mountain masses have been uplifted there is evidence of very recent faulting. Alluvial fans and glacial moraines show fault scarps that appear to have been formed only yesterday. In each of these zones earthquakes are common. The Ruby-East Humboldt range is bounded on the east and west by faults and terminated at the north by the union of those faults. At the base of many of the ranges there are triangular facets on the mountain spurs which in many instances may be interpreted as positive evidence of faulting. In the fault zone at the east base of the Sierra Nevada there are many indications of volcanic outbursts. See Figure 230.

Many of the stream profiles in these ranges are convex upward, which is additional evidence of recent and somewhat rapid upward movement of the range into which the stream is cutting. Along the base line of several of the ranges there are hot springs; which supports the hypothesis of faulting. The sharp V-shaped valleys that continue to the very margins

of some of these basin ranges are interpreted as evidence of recent uplift. In these cases rejuvenation is constantly taking place, and the valleys do not become widened.

On the summits of several of the basin ranges there is a monotonous sky line and some broad, gently rolling surfaces. These surfaces truncate the structure in such a way as to suggest that the ranges were once reduced to a peneplain and that the peneplain has been uplifted and broken. This type of evidence strengthens the conviction that many of the ranges are in at least the second cycle of erosion.

The basins. Between the various ranges in this province there are lowland areas many of which are closed basins. In some of the basins lakes exist, the waters of which have become either brackish or exceedingly salty. All lakes without outlets become salty, and those with outlets remain fresh or become fresh even if they were formerly salty.

Great Salt Lake is the most notable example of a saturated brine on the North American continent. Utah Lake, however, has an outlet and is a fresh-water lake; it drains by the Jordan River into Great Salt Lake. Klamath Lake, at the foot of the Cascades in southern Oregon, rises to a sufficient height to overflow and thus is kept fresh. Pyramid Lake in Nevada overflows occasionally and thus tends to keep fresh. Carson Lake, also in Nevada, receives large quantities of fresh water from the Sierra Nevada each spring and is forced to overflow, thus keeping fresh.

Great Salt Lake. The water in Great Salt Lake contains from four to nine times as much salt per unit volume as the ocean. At periods of maximum salinity, when the dissolved material amounts to 27.72 per cent of the weight of the lake water, the salinity of the lake exceeds that of the Dead Sea. The specific gravity of the lake water exceeds that of fresh water by from 10 to 22 per cent, according to the amount of salt dissolved in the water. The human body does not sink in the water of Great Salt Lake.

The level of Great Salt Lake has varied as much as 10 feet since the settlement of the Mormon people in Utah. The lake is very shallow, which means that its area expands and contracts notably. In 1850 the lake covered 1750 square miles. In 1869, after a series of unusually rainy



Photograph by Eugene Kingman

Figure 212 · One of the Basin Ranges in southeastern California, with sand dunes in the foreground

seasons, the area was about the same as today, a little over 2000 square miles. During the years 1901 to 1904, the lake nearly disappeared.

The rivers that flow into Great Salt Lake come from the western portion of the Uinta Mountains and from the Wasatch Mountains. Some of those in the latter group empty first into Utah Lake, which drains northward into Great Salt Lake.

Ancient Lake Bonneville. The ancestor of Great Salt Lake is Lake Bonneville. The waters of this ancient lake were fresh, for it had an outlet to the north through Red Rock Pass into the Snake River; thence to the Columbia River and the Pacific Ocean.[1] See Figure 213.

At its maximum high-water stage the surface of Lake Bonneville was 1000 feet above the present Great Salt Lake. At that elevation on the west face of the Wasatch Range and about the margins of many of the ranges to the west clearly defined shore-line features can be seen.

There were two stages of high water in the history of the lake that occupied the Bonneville basin. During the earlier stage the shore line stood about 910 feet above the present level of Great Salt Lake. This stage can doubtless be correlated with a period of humid climate during which glaciers formed in the neighboring mountains.[2] It was followed by a period of very low water when the lake became salty. This low-water stage occurred during an arid period when the glaciers disappeared and there was so much evaporation that salt was precipitated about the margin of the shrinking lake waters. Then came the second high-water stage during another period of humid climate when glaciers again formed in the mountains and descended into the lake basin. Waters from the melting snows and ice and from the rains that fell directly into the basin caused the lake waters to rise, this time to the maximum height of 1000 feet above the present level of Great Salt Lake. During this stage the lake was nearly 20,000 square miles in extent, or about ten times the area of the present Great Salt Lake. Many of the lesser mountain ranges of today were islands in Lake Bonneville, and others formed prominent peninsulas in that body of water. See Figures 214 and 215.

[1] G. K. Gilbert, "Lake Bonneville," *U. S. Geological Survey Monograph*, No. 1 (1890), 438 pages.

[2] W. W. Atwood, "Glaciation of the Uinta and Wasatch Mountains," U. S. Geological Survey, Professional Paper, No. 61 (1909), 93 pages.

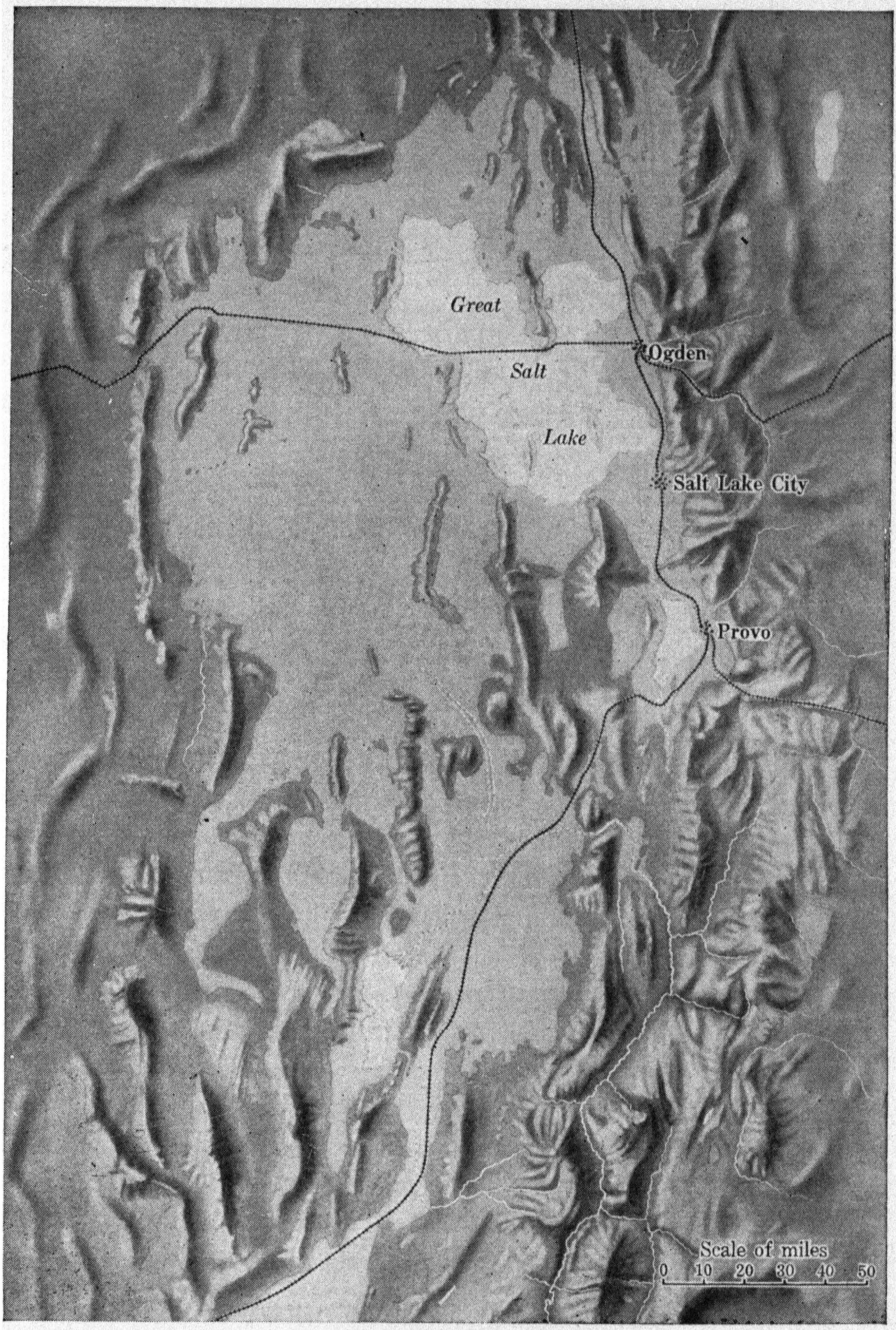
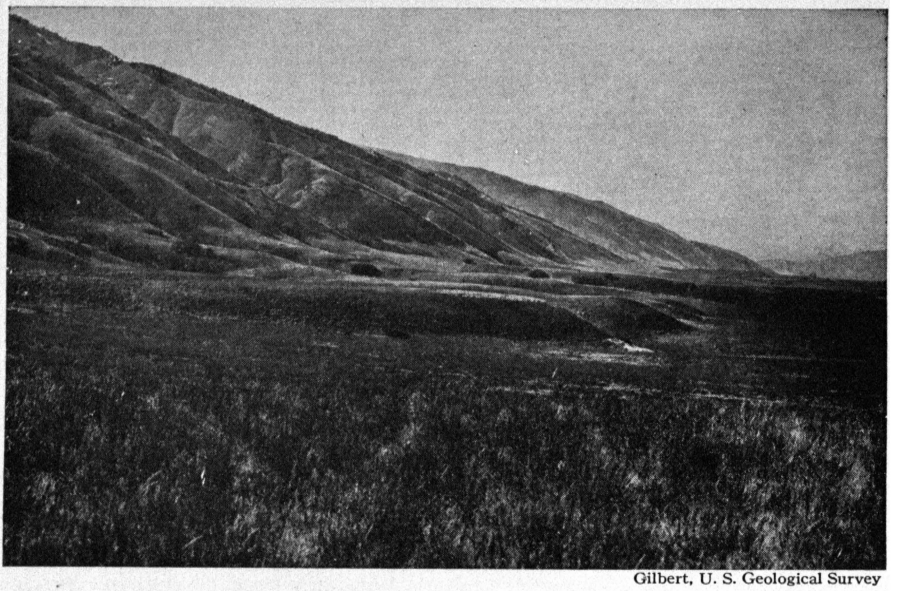


Figure 213 · Ancient Lake Bonneville at the eastern margin of the Great Basin

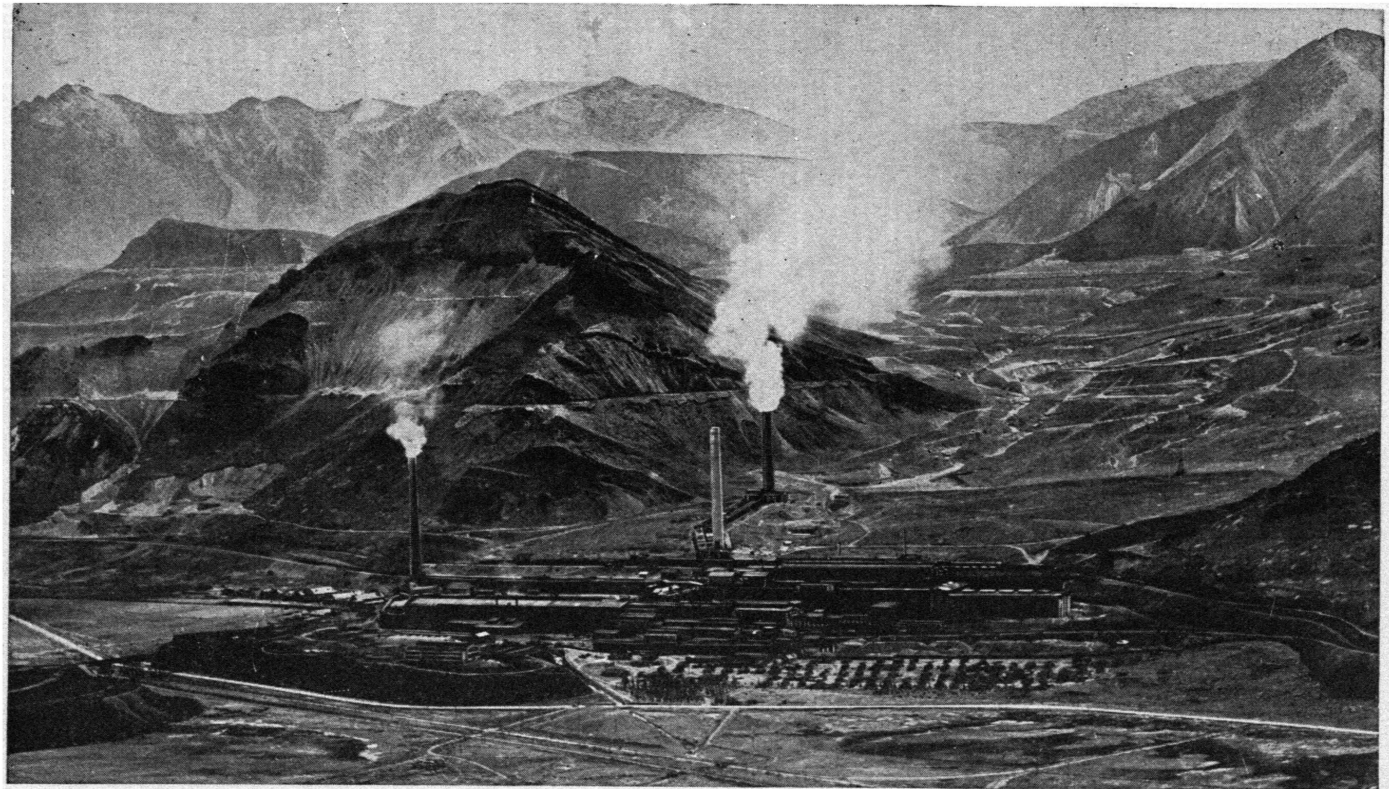


Gilbert, U. S. Geological Survey

Figure 214 · The Bonneville shore line on the east wall of Cache Valley near Logan, Utah. The benches are delta-like deposits formed when the lake water stood several hundred feet above the base of the range

At the maximum, or Bonneville, stage, the outlet to the north through Red Rock Pass was discovered and the outflowing waters began to lower the channel at the pass and thus to lower the level of the lake. The downward cutting for the first 375 feet was somewhat rapid. At that level the waters encountered resistant rock and the draining of the lake was halted. This is known as the Provo stage. Broad terraces were developed about the shores of the lake, and these appear today as the most conspicuous of all shore-line features in this ancient lake basin. Great deltas, lake cliffs, beach ridges, and sand bars were also developed. The shore-line features of this stage are about 625 feet above the present level of Great Salt Lake. Since the Provo stage, evaporation has continued until the lake is a salt brine with an average depth of but 15 feet.

Ancient Lake Lahontan. In western Nevada, at the east base of the Sierra Nevada, another lake formerly existed which had a history similar to that of Lake Bonneville. The shrunken remnants of that lake are Honey, Pyramid, Winnemucca, North Carson, and Walker lakes, and



© Dr. Barnum Brown

Figure 215 · The Garfield smelter, a few miles southwest of Salt Lake City and at the margin of one of the basin ranges. On the mountain slopes the shore lines of ancient Lake Bonneville can be seen

several smaller bodies of water. In the relief drawing, Figure 216, the outline of Lake Lahontan is shown. There was an early high-water stage and a later and still higher stage in the history of this lake, and these stages are correlated with the periods of glaciation and deglaciation in the neighboring mountains.[1] The highest shore lines are 530 feet above the present waters of Pyramid Lake. There are three distinct terraces about the margins of Lake Lahontan, which stand at 110, 320, and 530 feet above the surface of Pyramid Lake.

Death Valley. Near the western margin of the Great Basin, and in California, there is a long north-south trough called Death Valley. Here the bottom of the depression is 276 feet below sea level. That is the lowest land area within the continent of North America. Bordering the valley there are mountain ranges of the Basin Range type. This section exhibits many striking topographic features that characterize desert landscapes. Here there are playas, salinas, pediments, steep-faced shrinking mountains, alluvial fans, and sand dunes. The mountain forms are sharp, rugged, and very picturesque. Here faulting is still in progress. See Figure 217.

Sand dunes. Since the Great Basin is a region of great aridity, we must not be surprised to find that there are considerable areas of sand dunes in the lowlands bordering the ranges. One such area, north of Winnemucca, Nevada, is forty miles long and from eight to ten miles wide. The average thickness of the sand is about 75 feet, and the dunes are slowly migrating eastward. Another area of sand dunes has developed south of Carson Desert. These dunes are marching across the desert landscape along a front from four to five miles in width. The depth of the sand in this area varies from 200 to 300 feet. Sand dunes are among the most common topographic features in most desert areas.

The opening of the physiographic history. In the geologic structure within the Great Basin there is a period of mountain-making recorded in the early post-Jurassic time and another period of mountain growth recorded during early Tertiary time. During this latter period, the physi-

[1] I. C. Russell, "Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada," *U. S. Geological Survey Monograph*, No. 11 (1885), 288 pages.

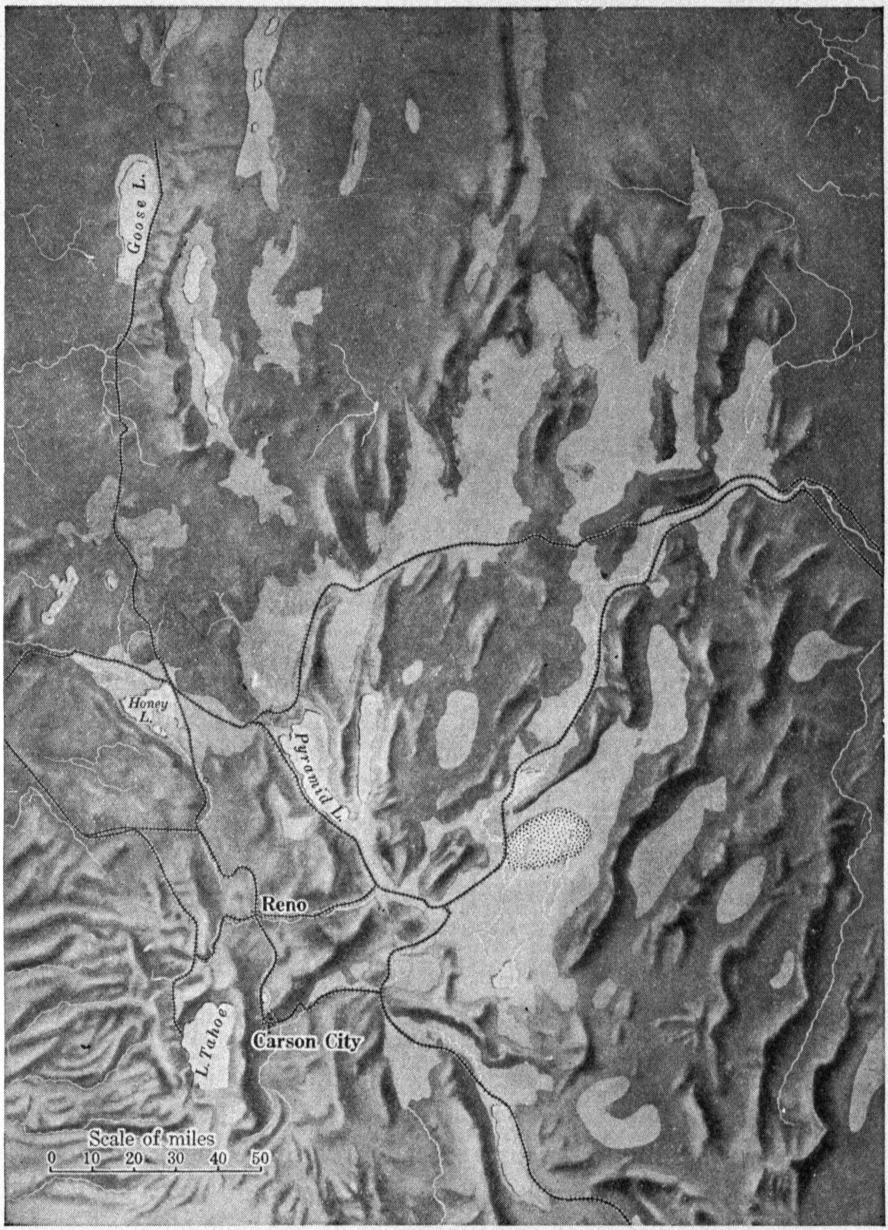


Figure 216 · Ancient Lake Lahontan at the western margin of the Great Basin

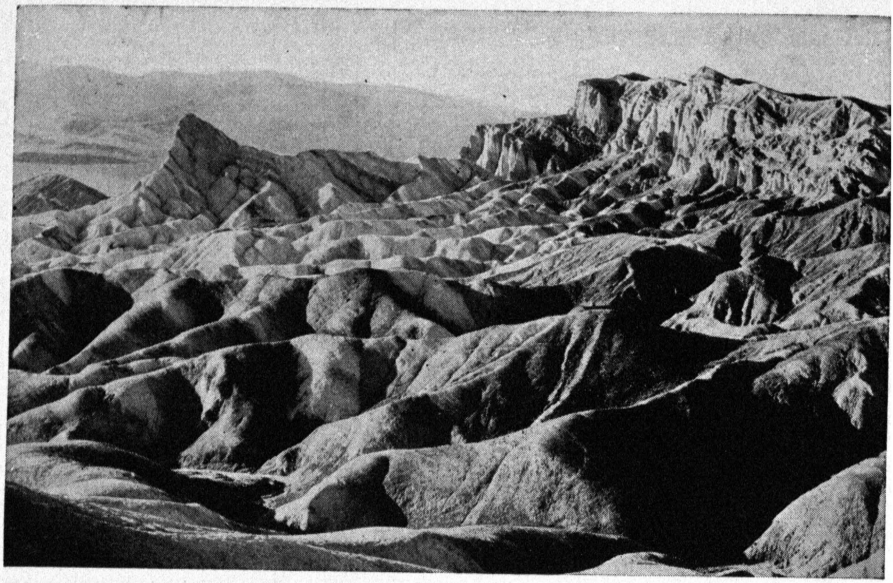


Figure 217 · Erosion of upturned strata in the desert of the Death Valley region

ographic evolution of the ranges which we see today was begun. Both folding and faulting occurred and numerous small north-south ranges were formed. Faulting has continued through Tertiary and Quaternary time, and probably faulting is going on today in this region.

An early Tertiary erosion cycle. A new cycle of erosion always accompanies the growth of mountains. The processes of weathering and stream-cutting begin at once the work of reducing the land to a new base plain of erosion. It appears that a widespread old-age erosion surface may have been developed in the Great Basin during an early Tertiary erosion cycle. The evidence of this is now found in the summit areas of certain ranges where the surfaces truncate inclined strata and have a gently rolling topography. These conditions suggest that they are parts of an old peneplain. The summit areas in this region do not correspond in elevation to one another as do the individual mountain crests of the Appalachian region. They are at various elevations, and some of them are inclined surfaces. They have been uplifted differently and somewhat deformed. We have here a broken peneplain.

A late Tertiary mountain-making. The uplift and breaking of the early Tertiary erosion surface appears to have been in post-Miocene time and it may have occurred late in the Tertiary period. Folding was renewed in some of the ranges; at other places huge masses were uplifted along fault planes; and lavas were poured forth at many localities.

A later cycle of erosion. A renewal of erosion followed the post-Miocene mountain-making. The uplifted mountain masses yielded debris, which was deposited in the intermontane lowlands. As Pleistocene time advanced, ice formed in the high mountains east and west of the Great Basin and in the East Humboldt, Snake, and Ruby ranges within the basin. Rains were heavy during that period; the water from the melting snows of the mountains and from the melting ice caused a quickening of all erosional processes and an increase in deposition on the lowlands. This greater abundance of water explains the presence of the large lakes, Bonneville and Lahontan. For each period of deglaciation there was a corresponding period of low waters.

Recent changes. As the Pleistocene period came to a close and the mountain glaciers melted away, the rainfall became less throughout the province and many of the lakes dried up entirely. Lake Bonneville shrank below the rim of its outlet to the north at Red Rock Pass and became a lake without an outlet. Lake Lahontan shrank until it was represented by a few remnants of standing water in the lower parts of its very irregular basin. Streams have continued their work of dissection in the mountain areas and of deposition of alluvial materials in the lowlands. Recent fault scarps are conspicuous, and the earthquakes commonly reported in this part of the continent reflect the continued growth of mountains through the renewal of faulting.

Playas. Many of the lakes in the western portion of Nevada, east of the Sierras, are intermittent. They may dry up for a portion of each year or, as in the case of Silver Lake in Oregon, they may disappear entirely every few years. The floors of the lakes that dry up occasionally are smooth, clay-covered surfaces, called *playas*, and the lakes which occasionally occupy those basins are referred to as *playa lakes*. The

floor of Silver Lake has been cultivated several times for the production of crops and was last used for that purpose in 1929. All these lakes expand and contract from month to month and from season to season.

Lake precipitates. In the basins where evaporation occurs periodically, the material in solution is left on the floor of the lake. In many cases the material is salt, and therefore the glistening white plains, resembling surfaces covered with fresh snow, are known as *salinas*. In certain basins the evaporation of the lake waters has resulted in the precipitation of potash and, in some cases, of carbonate of soda. Owens Lake, in California, contains concentrated deposits of bicarbonate of soda. On the floor of Death Valley there are rich deposits of borax which were mined for a time. They have now been abandoned for richer deposits in a neighboring basin.

Alluvial fans. The basins between the mountain ranges are areas of accumulation. About their margins great torrential fans have been developed by streams which lose their velocity when they leave the mountain gorges. In many instances the streams disappear entirely and all the material that is being carried in suspension and all that which is transported by rolling along the channel is deposited. In some instances the loose alluvial wash is known to be from 1000 to 2000 feet deep.

Rock pediments. The gentle slopes about the margins of some of the ranges in the Great Basin area appear to be the blending of alluvial fans, but when they are examined closely they are found to be rock pediments thinly veneered with alluvial material. In many instances streams leaving a mountain range retain sufficient power to do some cutting; even if they spread out into a series of distributaries they may erode the lands bordering the base of the range and reduce the rock surface to a gentle slope with about the same angle as that formed in the building of alluvial fans. As the mountain wastes away through weathering and as the streams at the base continue to carry away the loose material, the rock pediment becomes wider and wider at the expense of the mountain range. The range thus shrinks in size, often retaining a somewhat steep mountain front, and in time may disappear entirely.

An excellent research problem. In pursuing further physiographic studies within this province, the possibility must be recognized that certain of the basin ranges are in their first cycle of erosion whereas others are in their second or even third cycle. It must be recognized also that an individual range will vary greatly in its outline as it passes through stages of youth, maturity, and old age in a cycle of erosion. In the early stages fault scarps may appear and triangular facets may be present at the ends of mountain spurs. As erosion continues, such physiographic evidence of faulting will disappear and the mountain mass will become smaller and smaller until but a few monadnocklike forms rise above a mantle of alluvial waste.

The field investigator must be careful in discriminating between rock pediments that are thinly veneered with alluvial waste and torrential or alluvial fans. The origin of some of the basins may be due superficially to the meeting of alluvial fans. The deep-seated origin of the basins, however, is due to orogenic movements. They are structural troughs.

Throughout his study the investigator must recognize that he is not dealing with a single base plain of erosion as he would be if he were studying the physiographic evolution of the Columbia or Colorado plateaus. Much of the Great Basin area is without external drainage, and the floor of each closed basin becomes the local base level of erosion. As the mountains shrink in size, the rock pediments broaden, and in time a gentle surface veneered with alluvium occupies the area where there was once a mountain range.

The influence of changes in climate must be kept constantly in mind, for the various stages of glaciation and the high-water and low-water periods in the lake histories must be correlated with oscillations in climate. Each uplift of the great Sierra block at the west margin of the Great Basin had a profound influence upon the climate throughout the Great Basin region, for each time that the mountains rose they put this region into a rain-shadow area. Changes in temperature are marked, and wind work is almost certain to be an important factor. The problem is complex, and simplicity or uniformity in the history of the ranges or of the basins must not be expected.

The Columbia and Snake River Plateau

Location and extent. West of the Rocky Mountains of Idaho, east of the Cascade Range of Washington and Oregon, and south of the Okanagan Mountains, there is one of the most extensive lava plateaus in the world. It is a land of gently rolling surface with several deep canyons and a few mountains that rise as islands above a sea of lava or as recent volcanic cones. The southern boundary of the Columbia and Snake River Plateau province is placed at the south margin of the great lava flows in this part of the continent. It is not marked by any pronounced break in topography.

This province is in the rain-shadow area of the Cascade Range, where the average annual precipitation is less than 10 inches. Irrigation agriculture has made possible a few prosperous oases here, and dry farming has made portions of the region famous for their wheat-producing possibilities. Large areas of the province are used as pasture lands.

Materials and structure. In the walls of the canyons of the Snake and Columbia rivers, in the Blue Mountains of northern Oregon and southern Washington, which rise in the midst of this plateau area, and in certain other elevated topographic features, the materials that compose the Columbia and Snake River Plateau are well exposed. On the walls of the canyon of the Snake, a few miles above Lewiston, Idaho, and near the Seven Devils Mountains, a number of old mountain forms buried beneath lava flows are disclosed. See Figure 218. At the east base of the Cascade Range there are places where a mature erosion surface is being uncovered as the basaltic lavas are worn away. In these older buried or partially buried features there are granites and ancient metamorphic rocks, including gneisses and schists, and a complex of sedimentary strata. The profile of the old land surface on the canyon walls indicates that the region was one of considerable relief at the time the lava flows began to pour forth. The canyon of the Columbia has been cut thousands of feet into the black basaltic flows of the northern portion of this plateau country.

The Blue Mountains are the most conspicuous mountains that were completely surrounded and partly buried beneath the floods of basalt

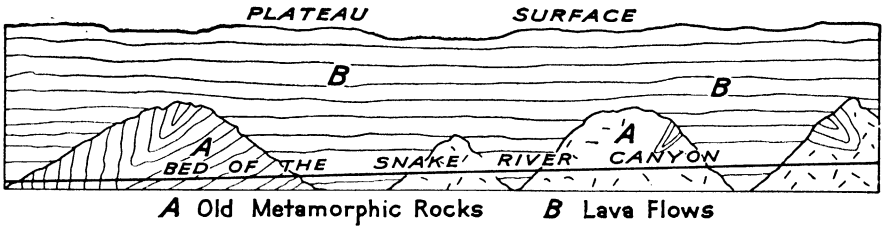


Figure 218 · Diagrammatic structure section of formations exposed on the wall of the Snake River Canyon, a few miles above Lewiston, Idaho, and near Seven Devils

in this province. Their summits rise to elevations between 8000 and 9000 feet above the sea and from 2000 to 3000 feet above the surface of the plateau. These mountains are composed of Paleozoic and early-Mesozoic rocks that have been complexly folded and faulted and affected by the intrusion of various kinds of igneous rocks. They were deeply dissected by streams long before the period of plateau-building. On the flanks of the Blue Mountains the younger lava flows rise to 7000 feet, which is fully 1000 feet above the plateau. These lava flows have been so upturned as to indicate that since the plateau was built there has been a renewal of mountain growth in the region.

East Butte, Idaho, is a volcanic cone that rises about 2000 feet above the present surface of the lava plateau. It is composed of a light-colored lava called rhyolite, and is a representative of an earlier period of outpouring in the Snake River Basin. The later flows are of basaltic lava, which is either black or dark brown.

The outpouring of lava. Since there are Jurassic strata involved in the folds of the partially buried mountains and since most of the plateau lavas are of Miocene or Pliocene age, it is evident that the topography beneath the lavas was developed after Jurassic time and before mid-Tertiary time. When the lavas began to pour forth, the landscape probably resembled that in the Great Basin region to the south, with numerous small mountain ranges and intervening basins. The lavas appear to have issued through fissures, although there were many true volcanic vents. The Craters of the Moon in southern Idaho, which have been set aside as a national monument, are in volcanic cones that rise conspicuously above the surface of the lava plateau about them. These

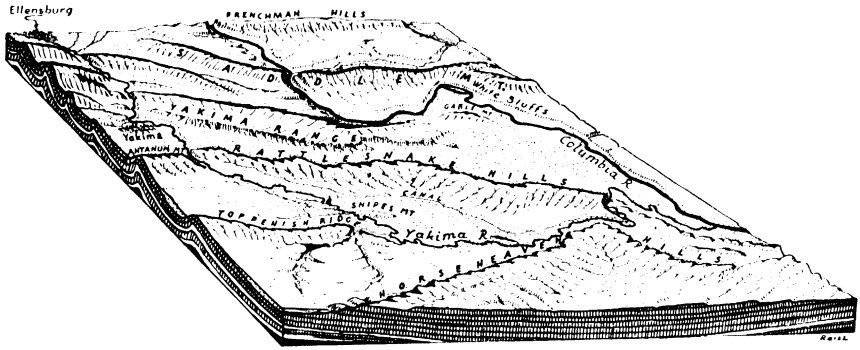


Figure 219 · In the western portion of the Columbia River Plateau the lava flows have been folded into low anticlinal mountains

cones are closely associated with a zone of faulting where rock fracturing made possible a remarkable series of volcanic eruptions.

At least 200,000 square miles in this province were buried beneath lava. The individual flows vary from ten to two hundred feet in thickness, and on the walls of certain of the canyons from twelve to twenty such flows are exposed. The maximum thickness of the lava is at least 5000 feet. The amount of rock material that was transferred from deep in the earth to the surface has been estimated at 100,000 cubic miles. It is not strange that there has been some sinking and deformation since this transfer took place. The surface of the lava varies from 6000 feet above sea level to a few feet below it. At various places, and especially in the Ellensburg section east of the Cascade Range in Washington, low anticlinal folds have been formed. This means that there has been some buckling of the lava flows. See Figure 219.

Between the sheets of lava at a few places there are deposits laid down by rivers and some that accumulated in lake waters. These deposits indicate that during the Miocene and Pliocene times volcanism was interrupted by periods when drainage lines were established and when some of the surface waters were ponded. Near Payette, Idaho, the sediments deposited in lakes during an intervolcanic period measure 1000 feet in thickness. They are of late Tertiary or early Quaternary age, and since they too have been uplifted and deformed, they furnish additional evidence of a very late period of earth movements in this plateau province.

The Cordilleran ice sheet invaded the northern portion of this province and forced the Columbia River to shift its course several times. In this section there are morainic deposits and sand and gravel that were washed outward from the margin of the great ice sheet. Alpine ice from the Cascade Range also reached the canyon of the Columbia River.

Dissection of the plateau. Following the period of widespread lava outpouring, the drainage lines of the Columbia and Snake rivers and their tributaries were established and the work of dissection was begun. Magnificent canyons, comparable in size to the Grand Canyon of the Colorado, were cut into the plateau.

The Snake River rises in Yellowstone National Park, flows southward in a shallow valley near the Teton Range, turns directly to the west, where it has cut a deep gorge through a mountain mass, and enters the land of lava flows at an elevation of about 6000 feet. For many miles the river flows in a shallow valley in the surface of the Black Plateau. At the American Falls, in Idaho, the stream plunges 50 feet; sixty miles farther on at Twin Falls it drops 180 feet, and at Shoshone Falls, two miles beyond, it plunges 210 feet. By this time the river has a canyon about 700 feet deep. The falls in this stream course are all of the Niagara type. They are caused by resistant beds which the falling water undermines, thus forcing the falls to recede upstream and to develop steep-walled gorges.

Still farther on, the canyon of the Snake becomes more than 5000 feet deep and from ten to fifteen miles wide. For forty miles it resembles the Grand Canyon of the Colorado in size, but its somber colors make it much less attractive than the famous Arizona gorge. At the eastern margin of this province and in the adjoining mountains, the canyon of the Salmon River is second in grandeur only to that of the Snake.

The walls of the Columbia River canyon rise 2000 to 3000 feet above the stream course where it crosses the plateau. Southwest of Spokane, in the region of the great bend of the Columbia River, there are nine or ten abandoned rock channels of the canyon type which are known as coulees. The largest, the Grand Coulee, is between 800 and 900 feet deep and from one and a half miles to four and a half miles wide. The walls of this gorge are nearly vertical, and at places in the old stream

channel there are deep holes where lakes now exist. Possibly the deeper places were made upstream from the very resistant rock masses, just as pits are being made today in the present stream channel above the Dalles of the Columbia. Possibly they were made below falls that retreated upstream. See Figure 220.

The favorite explanation for the cutting of the coulees is that the work was done in part by waters issuing from the Cordilleran ice sheet during the glacial period. The position of the frontal moraine of the Okanagan lobe of ice, as shown in Figure 221, would indicate that the presence of the ice and of the moraine must have blocked the Columbia River effectively and forced it to cross the plateau where the Grand Coulee was cut. The varied positions of the ice front at different times may have caused the other rock channels to be cut by waters of the Columbia combined with waters from the melting ice. Large, powerful streams are very effective in dissecting a basaltic lava plateau, for they are able to tear away the huge columns that formed as the lava cooled. Small streams cannot do such work, and they flow in shallow valleys in the surface of a basaltic flow or are lost by sinking into the cracks and fissures in the lava.

The scablands. Associated with these old rock channels there is a network of shallow stream courses crossing the plateau from the northeast, near Spokane, to the southwest. They come to the rim of the Columbia River canyon a few miles above the gorge cut by that river through the Cascade Range. At places these old channels contain considerable deposits of sand and gravel, which are interpreted as glacial outwash. This section of the plateau has been referred to as the "channeled scablands" of Washington.[1] See Figure 221.

An area of interior drainage. In the southwest portion of this land of lava plateaus, and east of the Cascade Mountains of southern Oregon, there is an area without exterior drainage which is known as the Great Sandy Desert. It is about 4000 feet above the sea and contains a large number of small volcanic cones and two fairly large lake basins. Much of the water that falls on this part of the plateau evaporates, sinks into

[1] J. H. Bretz, "The Channeled Scablands of the Columbia Plateau," *Journal of Geology*, Vol. 31 (1923), pp. 617–649.



Reclamation Service

Figure 220 · A portion of the Grand Coulee

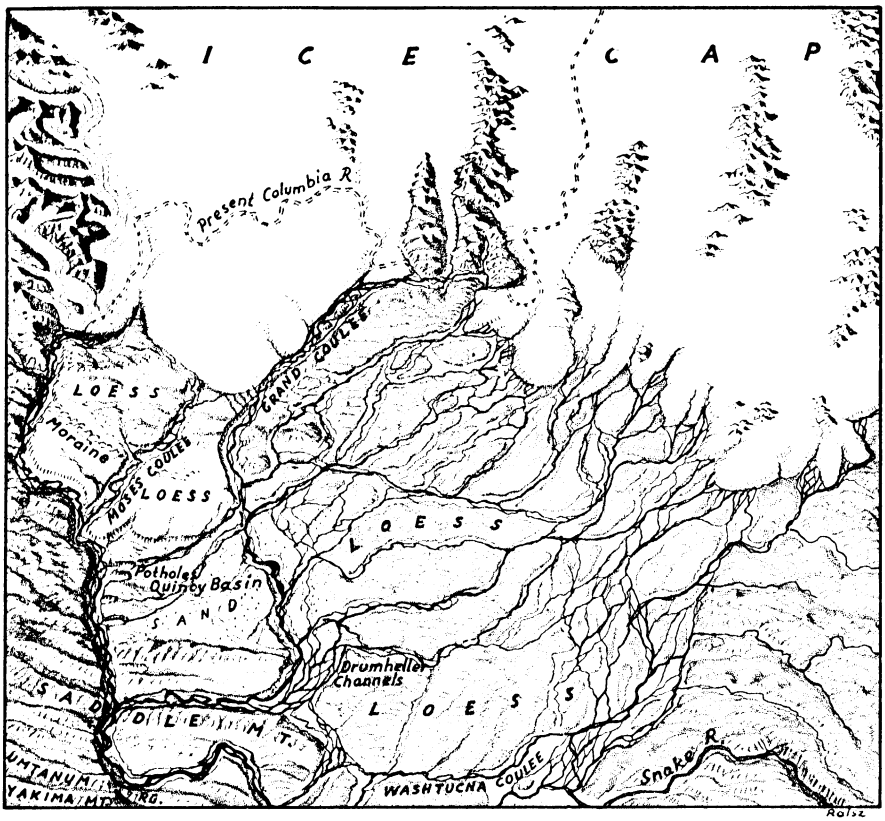


Figure 221 · The northern portion of the Columbia River Plateau during a late stage in the Pleistocene Ice Age. A portion of the present valley of the Columbia is covered by ice, and the waters from the melting ice flow through a network of channels across what are now known as the Scablands. The Grand Coulee and other gorges in the lavas are being excavated

the ground, or collects in the two basins and forms Harney Lake and Malheur Lake. Following a series of heavy rains, Harney Lake overflows into Malheur Lake. This means that the former is fairly fresh, and that the latter lake is becoming more and more saline.

Recent changes in level. There are places about the west margin of the province where the very recent lava flows have been folded, truncated, and later dissected by streams. The Yakima River is evidently an antecedent stream, for it crosses several mountain ridges in this section of

the plateau. However, the surface into which the Yakima River has lowered its channel has been interpreted recently as a rock pediment and reported to be of very local extent.[1] See Figure 219.

Near the junction of the Snake and Columbia rivers, at the western margin of this plateau region, there has been sufficient depression to have allowed the sea waters to enter upon the land. The evidence of this is recorded in marine deposits now 1200 feet above sea level. Their present position is, of course, evidence of uplift, and their age indicates that the uplift took place late in Pleistocene time.

Interior Plateau of British Columbia

Location and extent. Northward for 500 miles from the Okanagan Mountains, which connect the Rocky Mountains with the Cascades near the international boundary line, and between the Rocky Mountains and the Coast Ranges of Canada, there is an extensive plateau which resembles in some respects, though it is much more dissected, the great intermontane plateau area in the western part of the United States. This is the Interior Plateau of British Columbia. It has an average width of about 100 miles and a general summit elevation of about 3500 feet. At the north it is closed in by a series of mountain ranges that are as yet but little known. They fill the area between the Rocky Mountains and the Coast Ranges and extend northward for about 250 miles. Beyond this mountain mass the country again assumes a plateaulike character, but this portion of the continent is a part of the Yukon Plateau.

The plateau ranges. In British Columbia the term Rocky Mountains is commonly limited to what are called the Front Ranges in the United States. Many of the mountains in northern Montana and Idaho, which in the United States may be grouped together as the northern Rockies, extend into Canada and are there known as plateau ranges. They include, among others, the Selkirk, Purcell, Columbia, Cariboo, and Gold ranges, and are separated from the Rocky Mountains by a broad trough which is the northward extension of the Flathead Valley, and from the Coast Ranges by an area which is distinctly a plateau.

[1] A. C. Waters, "Resurrected Erosion Surface in Central Washington," *Bulletin Geological Society of America*, Vol. 50 (1939), pp. 635–660.

Physiographic history. At the close of the Mesozoic era there was a pronounced mountain-making movement in Canada just as there was in the United States. At that time the Interior Plateau of British Columbia was uplifted. During early Tertiary time, stream erosion proceeded vigorously, and, according to Canadian reports, streams developed a widespread old-age erosion surface which is well preserved in the southern half of the Interior Plateau.

Following Eocene time there must have been another period of uplift in this plateau region, for the early Tertiary erosion surface was deeply dissected before the mid-Tertiary sediments and volcanic debris accumulated here. Alluvial material was washed from the neighboring mountain ranges into the plateau area, and lavas were poured forth from a large number of vents within this region. Vast quantities of fragmental material thrown into the air from volcanoes accumulated on the plateau surface.

The mid-Tertiary period appears to have been one of intense volcanism in this part of the continent. There are some evidences of Miocene lakes in British Columbia between the Coast and Gold Ranges. Either one large lake or a series of smaller lakes must have existed in the area. Many of the volcanic vents are at the inner base of the Coast Ranges, where there has been distinct folding, with some faulting, in the geologic structure. The Miocene period, on the whole, was one of accumulation of material and of upbuilding of the plateau.

Toward the close of the Tertiary period there appears to have been still another general uplift of the cordilleran provinces of Canada. As a result the vigor of the streams was renewed and canyons 3000 to 5000 feet deep were developed. The Fraser River and its tributaries established an extensive drainage system, and in some of the valleys gold-bearing gravels were deposited. The mid-Tertiary volcanic accumulations and the old Eocene erosion surface were deeply entrenched before the opening of Pleistocene time.

The Ice Age. Somewhere in the Interior Plateau of British Columbia, and presumably at a considerable distance north of the international boundary line, one of the very large ice sheets of North America was formed. This ice sheet must have resembled the ice sheets of the Kee-

watin and Labrador centers of eastern Canada; but, since the Cordilleran section is bounded by mountain ranges on the east and west, the movement of the ice from the center was chiefly northward and southward. Where the ice of the Cordilleran sheet moved against the Rocky Mountains at the east and against the Coast Ranges at the west, it met valley glaciers descending from the mountain barriers. Other alpine glaciers formed in the Gold Ranges and descended to the plateau surface, where these smaller tongues of ice must have united with the large continental ice sheet.

At many places in the Coast Ranges it appears that ice from the Cordilleran sheet may have passed westward through the mountains to the Pacific border. Certainly in the region of the Fraser River a great ice tongue moved westward into the trough east of Vancouver Island and from there spread to the north and south. This huge ice mass is known to have been at least 3000 feet thick. It must have accomplished a large amount of erosion, and it presumably deepened the trough through which it moved. The mass of ice which moved southward has been called the Strait of Georgia Glacier; the one that moved northward is called the Queen Charlotte Sound Glacier.

In this province there is a widespread mantle of morainic materials, and glacial striae have been discovered on bedrock surfaces at many places. The arrangement of the moraines and the direction of striae furnish considerable evidence as to the location of the center of snow accumulation and the direction of movements in the resulting mass of ice.

It is known that a number of englacial lakes existed here for a time after the ice sheet had shrunk or melted away, for their shore lines are well preserved as terraces in many localities. One such lake appears to have been very large, extending 88 miles from east to west and at least 50 miles from north to south.

Post-glacial work. Upon the final melting of the Cordilleran ice sheet, streams began anew their work of excavation. Since that time most of them have been busily engaged in the removal of the glacial debris which was deposited in their valleys. Some have cut far below the glacial drift into the underlying rock structure. Such streams have sharp inner gorges of striking beauty.

As in other areas of intense glaciation, the lakes which existed for a time at the margin of the ice have disappeared. Even some of the lakes that formed in morainic basins have been drained, while others have been filled with alluvial material and the accumulations resulting from vegetable growth. In many of the deep valleys glacial moraines have ponded waters and formed the most beautifully situated lakes on the continent.

The Yukon Plateau

Location and extent. Between the mountain system which borders the Pacific Ocean in Alaska and the Rocky Mountain system represented in Alaska by the Brooks Range, there is a broad upland surface with a gently rolling topography which has been appropriately called the Yukon Plateau. This physiographic unit extends eastward and southward from Alaska into Canadian territory. It is the continuation of the Interior Plateau of British Columbia, although it is separated from that section of the cordilleran plateau belt by a mountainous area that has been but little surveyed. The Yukon Plateau includes much of the Canadian territory near the headwaters of the Yukon River and extends to the northwest as far as the Great Bend in that river where it reaches within the arctic circle. From the region of the Great Bend the plateau area of Alaska extends to the west and southwest, reaching to Bering Strait in the headlands of the Seward Peninsula and to Bering Sea in certain highland areas near Bristol Bay. See Figures 222 and 252.

Materials and structure. Wherever this plateau section has been carefully examined, it has been found to consist for the most part of a complex of ancient metamorphic rocks which have been tightly folded and compressed and later truncated through a long period of erosion. At a few places, early Tertiary sandstones, shales, conglomerates, and beds of lignite are associated with these very ancient rocks. These younger formations have been upturned and truncated, which means that the erosion surfaces preserved in the summit areas of the plateau are not of great age. They may be mid-Tertiary, but, on the other hand, judging from the physiographic history of other portions of the plateau sections in the cordilleran provinces, they may be of late Tertiary age.



Canadian Airways Ltd., Montreal

Figure 222 · The valley of the Yukon near Dawson. The city is located on one of the lower stream terraces. The upland crests are parts of the Yukon Plateau

The landscape. In the upstream portion of the Yukon Plateau the summit elevations range as high as 6000 feet above the sea. When viewed from a position a little above the general level of the upland surface, they appear to be parts of an extensive tundra-covered landscape with a gently rolling topography. There are many deep valleys cut into this plateau surface, but from most positions of outlook they are hidden from view.

In Alaska the width of the plateau upland is about 200 miles, and summit elevations vary from 2000 feet above sea level to about 4000 feet. The plateau surface is far more continuous in the Canadian section and in the eastern or upstream portion of the Alaskan section than in the Alaskan portion near Bering Sea.

Southwestward from the Great Bend in the Yukon there are several broad lowland areas, and the plateau remnants become fingerlike projections extending in the case of the Seward Peninsula to Bering Strait, and in the case of the Ahklun Mountains to Bering Sea. In this part of Alaska the valley lowlands and the delta lands are very extensive. The Yukon Flats at the Great Bend in the river near Fort Yukon are located farther upstream than any other of the broad lowlands. From Tanana downstream, the modern flood plain of the Yukon becomes very broad and the remnants of the plateau correspondingly less extensive until in the belt between Nulato and Anvik there are only a few isolated monadnocklike remnants of the plateau rising as islands in a vast sea of alluvium. Below Anvik most of the lowland is a great delta in which the Kuskokwim River is assisting the Yukon to fill in a portion of Bering Sea.

Upstream along the Koyukuk River the bordering hills are found to rise to an altitude of about 3000 feet. They continue with a monotonously even summit elevation until they reach the foothill belt of the Brooks Range.

In the Seward Peninsula the upland surface consists of hills and ridges that rise from 800 to 2000 feet above the sea. This upland is broken by many broad valleys with gentle slopes, in some of which there are basin lowlands of considerable extent. A few isolated peaks rise above the general level of the upland, and these undoubtedly should be interpreted as monadnocks. On the seaward slopes of the peninsula there are high marine benches, or terraces, up to a height of about 1500 feet.

A physiographic problem. Anyone who undertakes the analysis of the physiography of the Yukon Plateau province will find that the development of the summit peneplain is the natural beginning in the history of the present land forms. He will find, however, that there must have been a number of distinct stages in the dissection of the plateau.

In the headwaters of the Yukon drainage system at White Horse Pass, Chilkoot Pass, and several other less well-known passes in the mountains there is a strikingly uniform elevation of about 6000 feet. The fact that these broad, open, U-shaped passes are all at about the same elevation is undoubtedly of physiographic significance. Do they represent a stage in the dissection of the lands following a period of widespread uplift during which the mountains and the plateau provinces were all uplifted? Are they true wind gaps from which the streams that formerly flowed directly to the Pacific Ocean have been diverted? The waters falling on the western side of White Horse Pass, which serves today as a divide, reach the sea within a distance of less than 100 miles; while those waters that fall on the inland side of the pass, a few rods away, must flow a distance of about 3000 miles to reach the sea.

In the upper-Yukon region there are a number of high benches and hilltops which correspond in elevation to the levels recorded in the passes through the mountains. Farther downstream the high benches become less extensive; but lower, and therefore younger, bench levels begin to appear. Each new lower series of benches is represented upstream by narrow terraces, but with increasing distance downstream in the valley of the Yukon the benches in each series become broader. They are represented in many of the tributary valleys of the Yukon. Each system of benches, if united by filling in the intervening spaces, would reproduce a broad flood plain which would become more and more extensive with increasing nearness to Bering Sea.

Today the modern flood plain of the Yukon River is but a narrow strip of alluvial material at Dawson. It becomes broader downstream until it is several hundred yards wide at places along the Alaskan boundary. In the Great Bend, the Yukon Flats are ten to twenty miles in width and nearly one hundred miles in length. Downstream from these flats there are places where the stream is bordered by bold, rocky walls. Below the junction of the Yukon with the Tanana River the modern

alluvial lowland becomes a vast meadowland which stretches as far as the eye can reach. It represents, as well as any area in the world, the constructional portion of an extensive cycle-end-surface. This base-level plain is interrupted by monadnocks in the form of hills and short ridges which rise from a few hundred feet to a thousand feet above its surface. A few of these monadnocks border the immediate channel of the Yukon River. From their summits the expanse of the monotonous lowland which is being produced by the river is one of the most thought-provoking vistas in the world.

Here the streams have been at work for millions of years reducing a vast area to a level as low as running water can ever reduce a land mass. The surface stands but a little above the sea level and is occasionally covered by the flood waters of the river. It retains a gentle slope seaward that corresponds to the present gradient of the stream. As the years pass, each monadnock is shrinking in size; if the work now in progress is not interrupted, the entire area and, in fact, the entire drainage basin will be reduced to the base plain of erosion. Here is a peneplain in the making, and while under construction it is receiving a mantle, or veneer, of alluvium. It may later be uplifted; and if so, it will then be dissected; and from the remnants of the plain, which will then be upland surfaces, the work of today may be interpreted by later visitors to this region as a part of an ancient cycle-end-surface.

The details in the physiographic history of the Yukon Plateau province have never been worked out. Those persons who have visited the region have seen certain sections in detail; and a few, with special assignments from the United States Geological Survey, have had the privilege of traveling there somewhat widely. There is general agreement that the summit represents an old erosion surface, which has been called the Yukon Peneplain. The later uplift and dissection of this peneplain opens a history yet to be deciphered. During that period the Yukon River and its tributaries may have shifted their positions on several occasions. The so-called "bench claims" in the uplands may be cited as possible evidences of such shifts. In those localities gold-bearing stream gravels have been discovered where now no streams are present. Each series of benches represents a portion of an ancient stream course, and when put together they may define ancestral drainage lines distinct from the

present drainage arrangement. Detailed physiographic studies of this region may possibly serve as a guide to further prospecting and may prove to be of very great economic value.

A thorough study of the history of erosion in the Yukon drainage basin offers a most fascinating problem for solution. Here is the one great drainage system on the continent where continental ice has not disturbed the orderly sequence of events in the work of streams. During the Ice Age, waters from melting snows in the bordering mountains and heavy falls of rain and snow may have modified the activities of the streams somewhat. Floods from glacial waters presumably overloaded many of the streams tributary to the Yukon and led to the deposition of vast quantities of gravel. The interior of the Yukon Plateau province was not covered by continental ice. Alpine glaciers existed in the mountains that bordered this province, but those tongues of ice did not extend far beyond the foothills of the mountain ranges. The Yukon Plateau must have been, as it is today, a region of comparatively light precipitation. Here is recorded a very long period of work by a mighty river with many large tributaries.

An Approach to the Human Drama

The plateau lands that form the central zone in the great cordilleran section of the continent and extend from the Valley of Mexico to Bering Strait present remarkably varied and fascinating studies in the human phases of geography. We have considered the relief features in considerable detail, but before approaching any study of human responses other environmental factors should also be studied.

Climate. These plateaus extend from south of the tropic of Cancer northward a little beyond the arctic circle. Therefore, mean average temperatures, length of frost-free periods, and length of days and nights differ in the various sections of this long chain of plateaus. In the southern sections the temperatures are such that the normal growing season is from six months to a year in length. In the high plateaus in the western part of the United States the frost-free period varies from three to nine months, but in the far north it is scarcely 60 days.

One generalization about the climate is a fairly safe one, and that is in relation to the rainfall. These plateaus, bordered on the east and west by high mountain barriers, are in a rain-shadow belt and for the most part are semiarid. The rainfall map of the continent opposite page 6 shows that, except in central Mexico, where there is a rainy season, and on certain mountain ranges within the plateaus, the rainfall throughout the high plateau areas of North America is less than 30 inches a year. In several sections it is less than 20 inches a year, and some parts receive annually less than 10 inches of rain.

These climatic conditions have played a conspicuous part in determining the occupations of the people in this region and the types of human culture that have been developed.

Vegetation. In the southern portion of the Mexican Plateau section there are some large trees and during the rainy season grasses and flowering plants flourish, but much of the landscape in the plateau section of Mexico is dominated by a semidesert type of vegetation, including cacti, yucca, greasewood, and various thorny and wiry plants. During the dry season the northern section of the Mexican Plateau is brown and seared. Here dust is abundant and large areas are without any plant life.

In the United States the intermontane plateaus are, for the most part, a land of sagebrush, greasewood, yucca, piñon pine, cedars, and cacti. A few of the valleys are clothed with grass; the high mountain areas within the plateaus and the very high plateaus north of the Grand Canyon of the Colorado are forest-covered. In these higher portions there are large areas of primeval pine forests. See Figure 223.

The Interior Plateau of British Columbia is so much farther north than the high plateaus of the United States and Mexico that it is cooler and therefore evaporation is less and a more widespread growth of forest trees is possible. Still farther north, toward the Yukon country, the growing season is so short that the plateau is in the tundra belt. The forests in the Yukon portion of Alaska are limited to the stream margins; the upland surface is clothed with mosses and dwarfed shrubs. The flowering plants that grow to be fair-sized bushes in the United States are here but a few inches tall, and one must bend over to touch the topmost branches of full-grown oak trees bearing acorns.

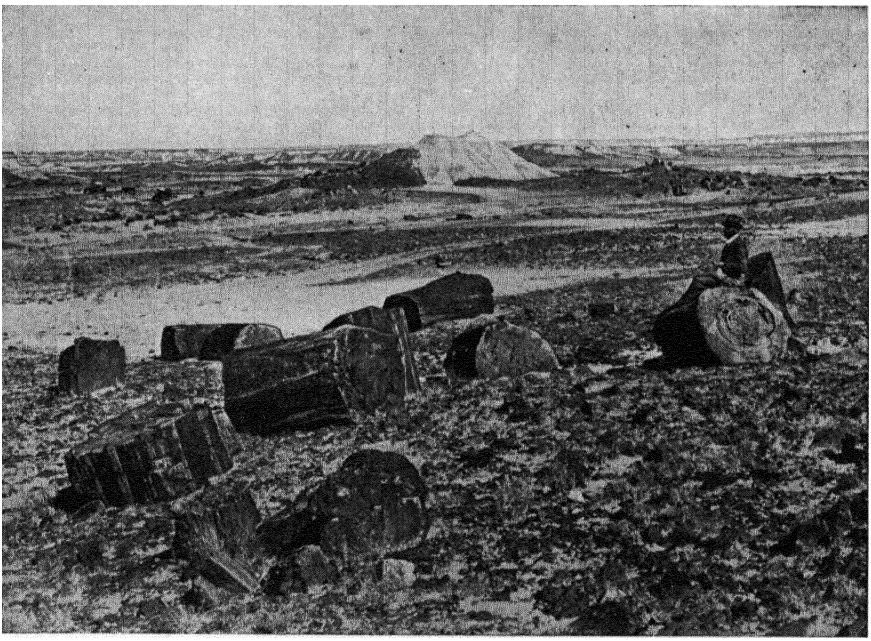
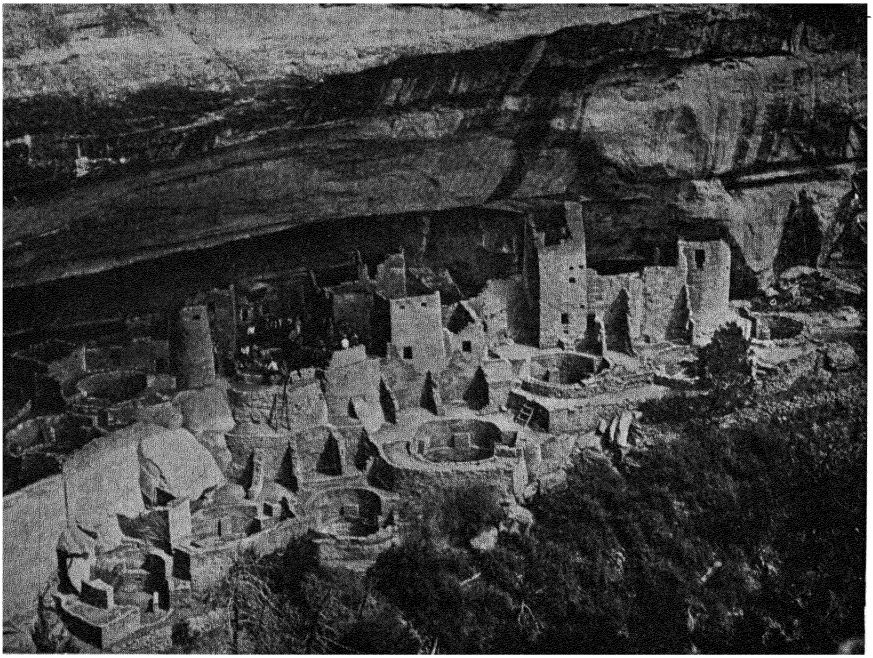


Figure 223 · In the Petrified Forest of Arizona. These specimens indicate that formerly, in the southwestern portion of our country, rainfall was abundant; great forests were present; the sea advanced over the region; the trees rotted at the base and fell into that sea and were buried with muds; the woody matter was very slowly replaced by varieties of quartz brought by ground waters; later the land was uplifted and streams dissected the ancient sea bottom uncovering the trees that had been changed to stone. By this time the climate had become very dry, perhaps because of new mountains that had risen in the west and cut off the rain-bearing winds

The early communities. In the highlands of Mexico are the ruins of the Toltecs, Aztecs, and other associated tribes. The story of human occupancy goes far back, even to the days of the Mayan culture. Here dwelt a primitive people who erected great pyramids, temples, citadels, and elaborate tombs. They cultivated the fields and developed a high degree of artistic ability. Into that scene came Cortez with his Spanish warriors in the early part of the sixteenth century, and by 1540 he had conquered the native peoples and set up a new form of government. From that time on, the influence of the Spaniards upon the economic life of the people, upon their customs, their religion, and all phases of their culture has been very important.



National Park Service

Figure 224 · Cliff Palace in the Mesa Verde National Park in southwestern Colorado. Such ancient dwellings are common in caves on the walls of the Mesa Verde canyons. In this dwelling there are over three hundred rooms, and several hundred people may have lived here. The circular rooms are ceremonial chambers called kivas. They were formerly covered

The Spaniards migrated northward and settled, to some extent, north of the Rio Grande in the lands now included in New Mexico, Arizona, and southern California. They established missions and worked among the native peoples who lived in the southwestern portion of the territory now within the United States. In that section of the continent there are ruins of many prehistoric settlements. In British Columbia and in the Yukon, where the climate is more severe than farther south in the plateau region, the primitive peoples left but meager records. Indians and Eskimos have lived for many generations in the lower Yukon district, but conditions have never led to a very high state of human development. The communities located in the warmer sections were chiefly of agricultural and pastoral people; those living in the Far North were hunters and fishermen. See Figures 224 and 225.

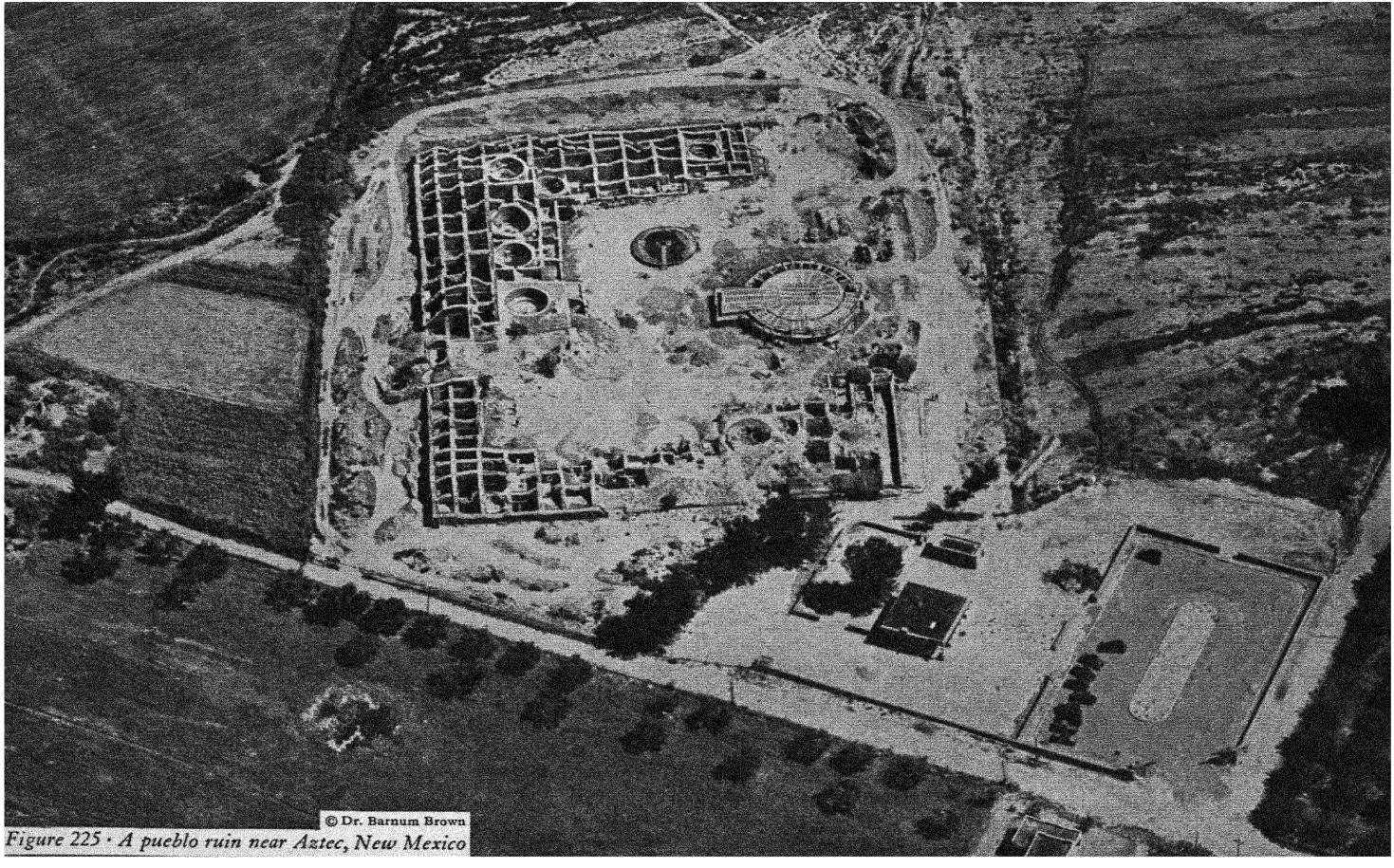


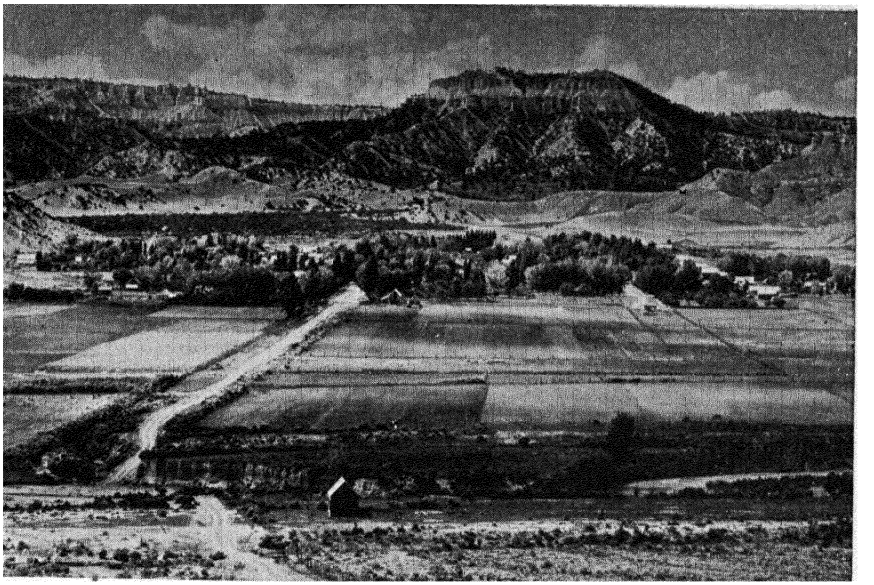
Figure 225 · A pueblo ruin near Aztec, New Mexico

The modern communities. As more and more pioneers settled in the warmer portions of this plateau belt the pastoral life expanded and the areas under irrigation were enlarged. In the plateaus of the Columbia and Snake rivers dry farming has been undertaken on a very large scale, and there we find one of the modern wheat-producing regions of the continent. Near the margins of the semiarid plateaus in Mexico and the United States, streams from the bordering mountains have made possible the development of prosperous oases where the farmers specialize in the production of fruit and vegetables. Ranchmen in this section commonly send their sheep into the mountains during the summers and care for them on the plateaus during the winters. In the higher latitudes, where the growing season is very short, hunting, trapping, and fishing are commonly practiced by the local inhabitants. There is very little agriculture in the plateau portion of British Columbia, but in that section and even in the Yukon Plateau small "kitchen gardens" are found associated with the miners' cabins. Those men try to raise lettuce, cabbages, carrots, peas, and in some places potatoes. See Figures 226 and 227.

The most notable changes that have come with the advance of time are in the field of mining. In the Mexican Plateau and in those plateau provinces included within the United States rich deposits of gold, silver, copper, lead, and zinc have been discovered. In the Great Basin region large quantities of salt, potash, soda, and borax are obtained. In British Columbia metal ores have been found, and in that province there are rich deposits of coal. Still farther north in the Yukon Plateau we find the famous Klondike gold fields that are not far from Dawson, the rich placer deposits near Fairbanks, and also those on the modern and ancient beaches at Nome. The mineral wealth has led to the establishment of mining communities and added a new element to the economic life in these plateaus. See Figures 228 and 215.

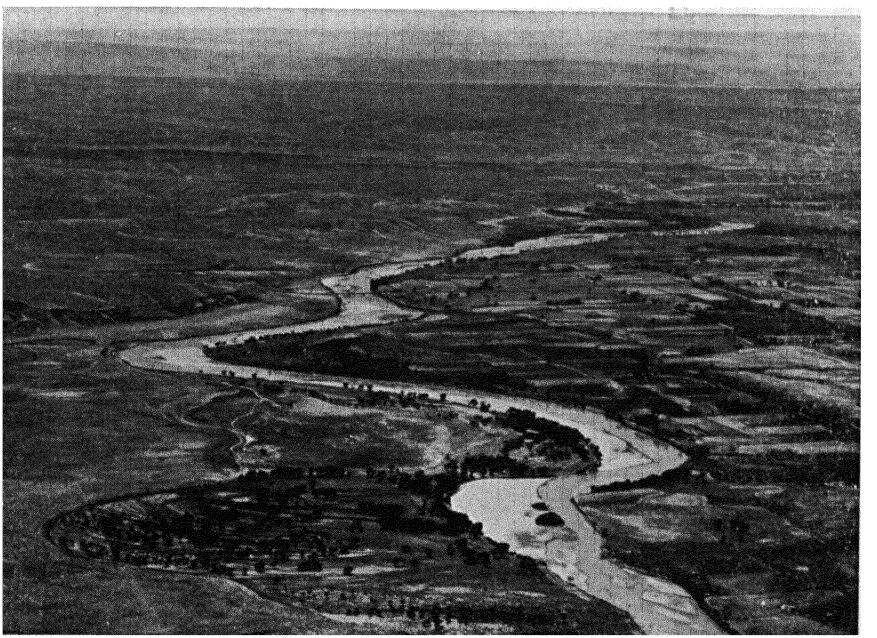
The forests of the Interior Plateau of British Columbia are now being used for the production of lumber and construction timber. Portions of this section of the continent are attractive as summer recreational grounds. The long valley lakes are exceedingly picturesque.

Distribution of people. A glance at the population map, Figure 6, shows clearly that nowhere in this intermontane-plateau belt of the



Grant, National Park Service

Figure 226 · A small agricultural community on the lowlands adjoining Bryce Canyon National Park in southern Utah



© Dr. Barnum Brown

Figure 227 · Modern farm lands on the Colorado Plateau near Jensen, Utah

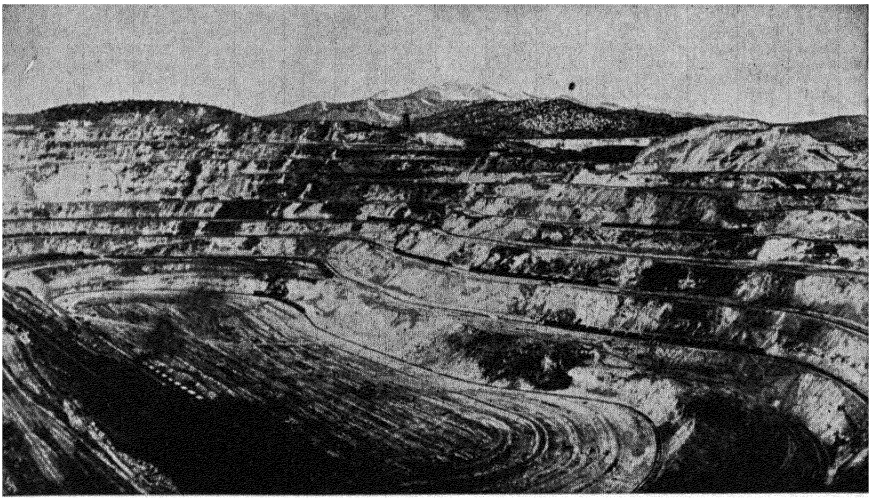


Figure 228 · The great pit 800 feet deep at Ruth, Nevada, from which, during the last thirty-five years, huge quantities of copper ore have been taken

cordilleran portion of the continent is the population dense. In large areas of the plateaus there are not, on the average, more than two people per square mile. There are a few fairly large cities in Mexico and about the margins of the intermontane plateaus in the United States. The city of Mexico has a population of about two million. It is in the midst of an agricultural section, but it has become one of the chief manufacturing centers in Mexico. Salt Lake City, with a population of about 182,000, Ogden with 57,112, and Provo with 28,937—all in Utah—owe their prosperity in large part to irrigation agriculture and in part to mining. See Figure 229. Boise, Idaho, and Spokane, Washington, are good-sized cities. Each is located near irrigated lands. Yakima, Washington, has developed because of a great irrigation project in that vicinity. There are no large cities in the Interior Plateau of British Columbia, and in the Yukon region Dawson, Fairbanks, and Nome are the chief commercial centers and their growth and prosperity are due primarily to placer mining.

In looking to the future we must recognize that these plateaus are never likely to be densely populated. Climate is the limiting factor. Wherever precious metals are found there will always be those who



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Figure 229 · Salt Lake City, at the west base of the Wasatch Mountains

will work hard to secure that form of wealth; wherever there are other resources that can be exported at a profit the economic development in the plateau region will be promoted. There are few places within the plateau area that are well situated for manufacturing; and, since agriculture is limited, it is unreasonable to expect that many people will seek out this portion of the continent for their permanent homes.

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SELECTED LIST OF TOPOGRAPHIC MAPS FOR THE CORDILLERAN PLATEAUS

Alaska Railroad Route (Yanert Fork to Fairbanks)
Seward Peninsula, Alaska

Fraser Lake, British Columbia[1]

Beverly, Washington
Corfu, Washington
Malaga, Washington
Moses Lake, Washington
Pasco, Washington
Walla Walla, Washington
Wallula, Washington
Wenatchee, Washington
Pullman, Washington–Idaho

Bend, Oregon
Ironside Mountain, Oregon
Maiden Peak, Oregon
Newberry Crater, Oregon
Pendleton, Oregon
Three Sisters, Oregon
Arlington, Oregon–Washington
Umatilla, Oregon–Washington

American Falls, Idaho
Bisuka, Idaho
Boise, Idaho
Craters of the Moon National Monument, Idaho
Idaho Basin, Idaho
Michaud, Idaho
Mountain Home, Idaho
Preston, Idaho–Utah

Avawatz Mountains, California
Barstow, California
Holtville, California
Lovejoy Springs, California
Ballarat, California–Nevada
Furnace Creek, California–Nevada

Carson Sink, Nevada
Halleck, Nevada
Lovelock, Nevada
Roberts Mountains, Nevada

Acord Lakes, Utah
Fairfield, Utah

[1] Published by Surveys and Engineering Branch, Department of Mines and Resources, Ottawa, Canada.

Henry Mountains, Utah
Kanab, Utah
Stockton, Utah
Logan, Utah–Idaho

Grand Valley, Colorado
Highmore, Colorado
Mesa Verde National Park, Colorado
Parachute Creek, Colorado
Paradox Valley, Colorado
Roan Creek, Colorado

Ajo, Arizona
Camp Verde, Arizona
Casa Grande, Arizona
Christmas, Arizona
Flagstaff, Arizona
Fortuna, Arizona
Gila Butte, Arizona
Grand Canyon National Park, Arizona
Linskey, Arizona
Wellton, Arizona
Moon Mountain, Arizona–California
Needles, Arizona–California

Capitan, New Mexico
Columbus, New Mexico
Hachita, New Mexico
Hermanas, New Mexico
Lordsburg, New Mexico
Noria, New Mexico
Pelona, New Mexico
Playas, New Mexico
Reserve, New Mexico
Ship Rock, New Mexico
Tularosa, New Mexico
Chimney Rock, New Mexico–Colorado
Rattlesnake, New Mexico–Colorado
Canutillo, New Mexico–Texas

Hood Spring, Texas
Santiago Peak, Texas
Terlingua, Texas

Valle de México[1]
Ciudad de México[2]

[1] Dirección de Geografía, Meteorología e Hidrología, México, D. F., Mexico.
[2] Published by American Geographical Society of New York (scale 1 : 1,000,000).

XI

THE PACIFIC BORDERLANDS

Mountain Ranges and Lowland Troughs

Extent and subdivisions. West of the chain of intermontane plateaus which we have been considering in the last chapter there are two chains, or zones, of young rugged mountains that extend from Mexico to the Alaska Peninsula. Between these mountain chains there is a disconnected series of lowland troughs. All these physical features near the western margin of the continent are here included in the Pacific Borderlands.

In California the Sierra Nevada forms the eastern mountain belt; the Coast Ranges are at the west; and between the two mountain zones is the Valley of California. In Washington and Oregon the Cascade Mountains are at the east, the Olympic and Coast ranges are at the west, and the Willamette Valley–Puget Sound Lowland is in the middle zone. The mountainous peninsula of Lower California is the westernmost highland of Mexico; the Salton Sea depression and its southward extension into the Gulf of California is here the middle member; and the western Sierra Madre of Mexico forms the eastern mountain barrier.

On the Pacific border of British Columbia and in southeastern Alaska we find the so-called Coast Range serving as the inner mountain barrier; a chain of islands, including Vancouver, the Queen Charlotte group, several smaller islands farther north, and the Fairweather Range, are at the outer margin bordering the open ocean; between these two mountain chains there is a somewhat poorly defined area of depression in which is located the famous Inland Passage to Alaska.

In southwestern Alaska the Aleutian Range blends northeastward into the Alaska Range and Kodiak Island into the mountains of the Kenai Peninsula. Between these two mountainous zones there is a distinct geosynclinal trough occupied in part by Shelikof Straits, Cook Inlet, the lowlands at the west margin of the Kenai Peninsula, and those bordering the Susitna River at the head of Cook Inlet.

The Alaska Peninsula extends far to the westward into the Pacific, and is represented beyond its westernmost tip by the Aleutian Islands. The peninsula and islands form the southern boundary of Bering Sea.

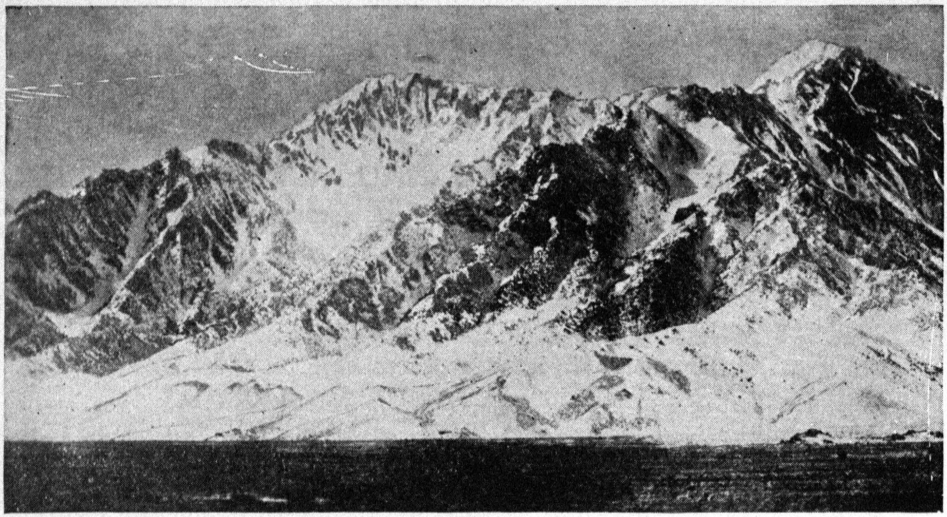


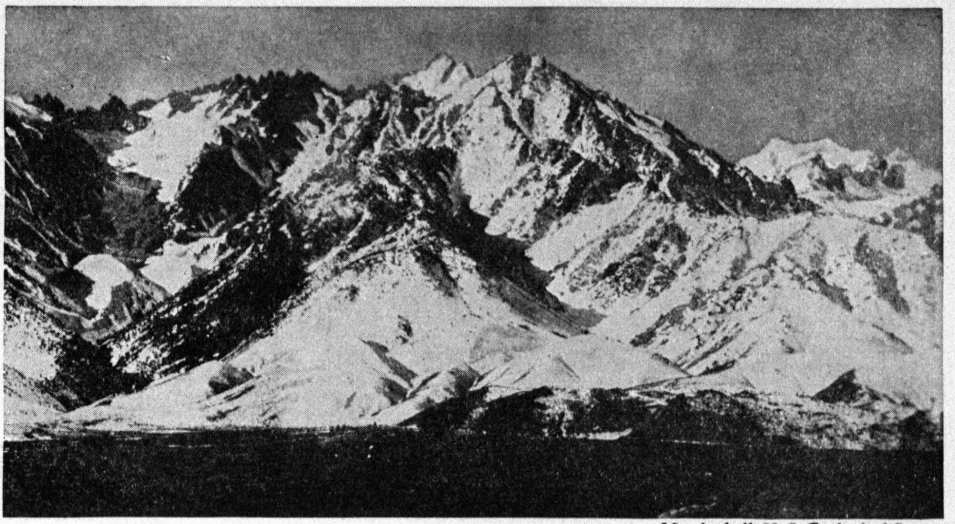
Figure 230 · The east face of the Sierra Nevada. The summits rise 5000 to 10,000 feet valleys on this slope. Volcanic eruptions have

The treatment of the physical features of the Pacific Borderlands will be presented in this book under the following ten subheadings:

1. The Sierra Nevada
2. The Cascade Range
3. The Puget Sound–Willamette Valley Lowland
4. The Valley of California
5. The Pacific Coast Ranges within the United States
6. The Angeles Section of California
7. The Salton Sea Area and the Sonoran Desert
8. The Western Sierra Madre
9. The Pacific Border of Alaska and British Columbia
10. The Pacific Shore Line

The Sierra Nevada

West of the Great Basin rises the magnificent range of the Sierra Nevada. See Figures 230 and 236. Eleven of its higher summits reach elevations over 14,000 feet above sea level. In this range is Mount Whitney, 14,501 feet in elevation, the highest peak in the United States.



Mendenhall, U. S. Geological Survey

above the basin floor in the foreground. Alpine glaciers formerly occupied most of the occurred at the base in the zone of faulting

The Sierra Nevada of today is carved out of a huge block 400 miles long and from 50 to 80 miles wide. It is a block which has been uplifted at the east and tilted gently to the westward. The steep eastern face rises abruptly from 5000 to 10,000 feet above the alluvial-filled basin in the adjoining province to the east. On this great rocky escarpment there are bold and fantastic spurs and pinnacles of striking ruggedness. Here on the east face of the Sierra block, in a basin due to faulting, is Lake Tahoe, one of the most beautifully situated of the large lakes among the high mountains in the United States.

On the west slope of the Sierra block there are several of the most noted canyons in the whole cordilleran region of North America. Here we find the famous Yosemite Valley (see Figure 231), the canyon of the Tuolumne, and the canyons of the Kern and Kings rivers. Many of the canyons in this range are from 4000 to 5000 feet deep, and at one place the canyon of Kings River has a depth of 8000 feet. This is the greatest depth of any stream-cut gorge in North America.

Among the bare, rugged summits of the High Sierras the topographic features have been shaped in large measure by alpine glaciers. See Figure 232. There are two conspicuous crest lines. The one at the east

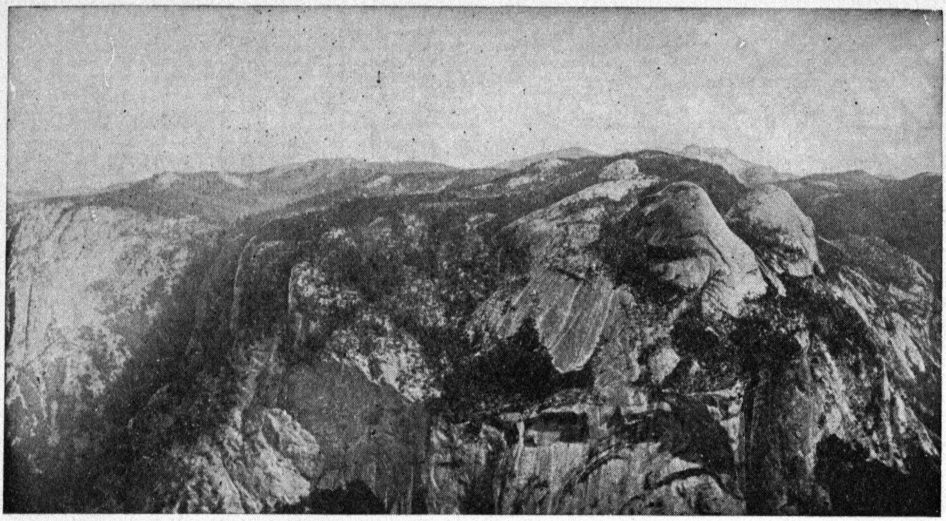


Figure 231 · Looking eastward from Glacier Point in Yosemite National Park. Yosemite in the crest line of the range, and most of the upland surfaces are parts of

including Mount Whitney is called the John Muir Crest, and the other is known as the Great Western Divide. Each crest line consists of a double chain of cirques riveted together by lofty peaks that overlook these great catchment basins that were formerly occupied by ice. In this high mountain area there are literally hundreds of beautiful mountain lakes, many perennial snow fields, and a few small remnants of glaciers.

Materials and structure. The huge Sierra block consists in large part of a granite batholith or of several associated batholiths of light gray color. This is the largest batholithic mass in the United States. In it one may detect with the naked eye large crystals of feldspar, quartz, mica, hornblende, and pyroxene. The rock has been called a granodiorite. It rose as a molten mass toward the surface of the earth and cooled and crystallized slowly under a great load of overlying rock that has since been removed. At the western margin of the range there are sedimentary strata now tightly folded and much metamorphosed. These altered sediments are known to be in part of Paleozoic age and in part of early Mesozoic age. See Figure 233.



Photograph by Wallace W. Atwood, Jr.

Valley is near the center and at the left of Half Dome. The high peaks in the distance are the Sierra Peneplain. At the right there is a hanging valley with waterfalls

In the northern portion of the range there are extensive flows of Tertiary lavas that formerly occupied valleys but which in the present cycle of erosion have come to occupy intervalley ridges and to form many of the secondary crest lines in that portion of the range.

At the east base of the range there are hot springs and evidence of recent volcanic outbursts. There are very recent fault scarps in unconsolidated sediments and glacial moraines which indicate where fault planes reach the surface. The earthquakes associated with this zone of faulting prove that movements are still in progress. Some of the recent displacements have been horizontal and others have been vertical.

Many of the details in the topographic features of the High Sierras appear to be due to faulting. The alignment of bold cliffs from one canyon to another, from one peak to another, suggests that the faulting in the Sierra block is not limited to the eastern margin where the major movement took place but is distributed throughout a considerable portion of the higher part of the uplifted block. The canyon of Kern River is believed to be located in a zone of faulting that is roughly parallel to the eastern margin of the range. Lake Tahoe is between the main fault scarp of the Sierras and the Carson Range. That range is carved out of

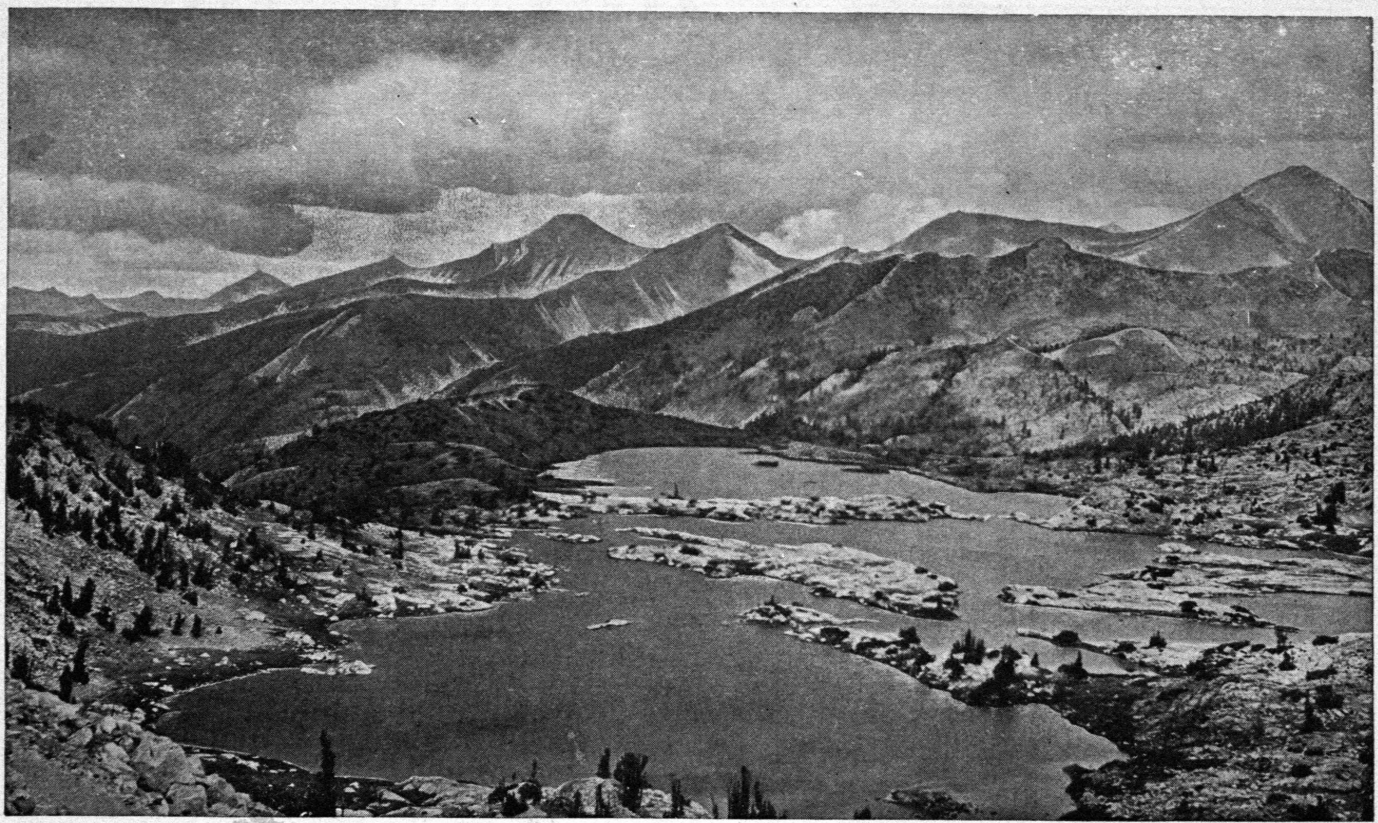


Figure 232 · Lake Marie, one of the many lakes in the High Sierras that are due to glaciation

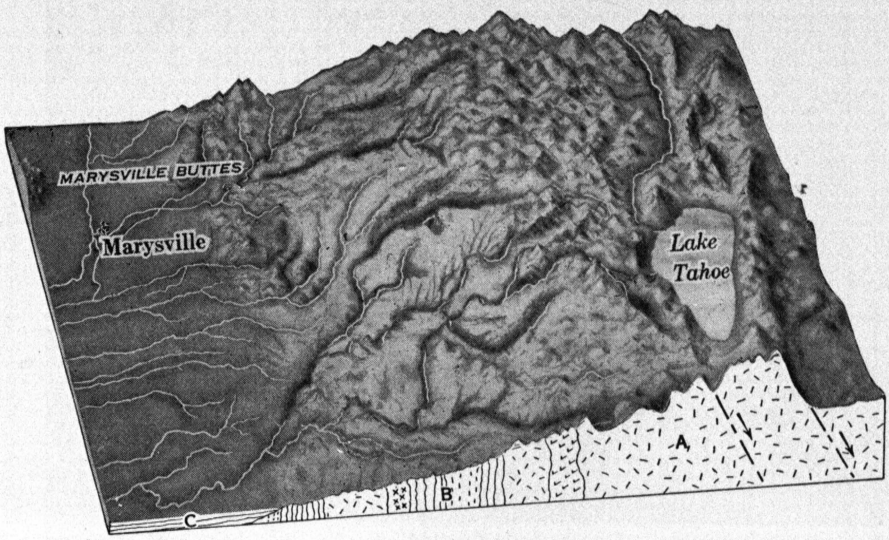


Figure 233 · A drawing to show the geologic structure, topography, and topographic relations of the Sierra Nevada in the section which includes Lake Tahoe. The Marysville Buttes are of volcanic origin

a fault block which is part way down the east face of the Sierras. North of Lake Tahoe the Sierras are divided into three somewhat distinct ranges each of which is a fault block tilted to the southwest.

The more significant physical features. In the summit region of the High Sierras many of the peaks, including Mount Whitney and Table Mountain, retain what appear to be beveled or tabular surfaces. They are not level surfaces but are somewhat inclined. They are not glaciated surfaces, and they could not have been produced by weathering and erosion at such altitudes. See Figure 234. These surfaces are interpreted as portions of an ancient peneplain that must have been developed a long time ago and near sea level.

Gently rolling plateaulike areas high among the mountains, but distinctly below all the lofty summits in the Muir Crest and in the Great Western Divide, and a series of intervalley ridges which descend westward to the Valley of California suggest very strongly another erosion

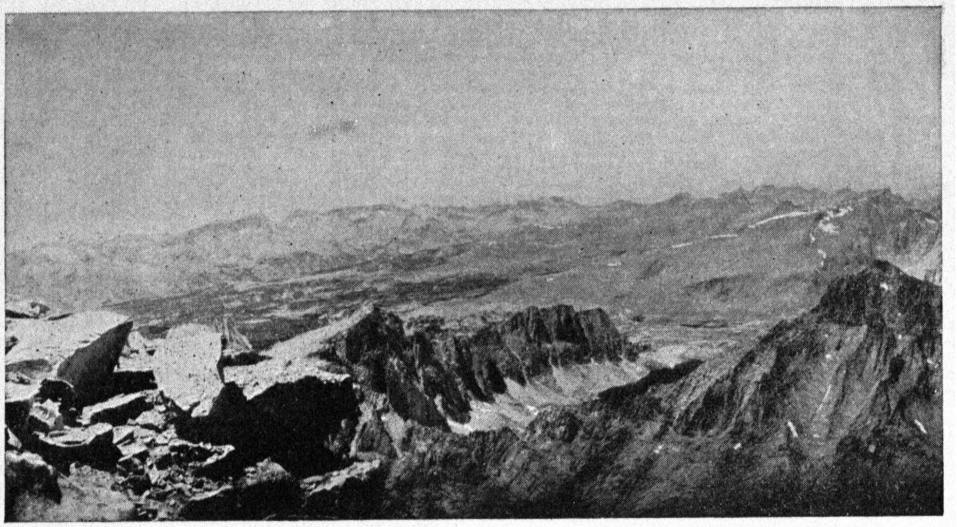


Figure 234 · Looking northward from the summit of Mount Whitney. The sharp, rugged smooth surfaces that are interpreted as parts of an ancient peneplain. The lower slope at the left are some of the peaks

surface which has been uplifted and dissected. This surface is commonly referred to as the Sierra Peneplain. It is the most widespread and well-preserved old surface in this range of mountains. In the region about the headwaters of the Yosemite Valley, this peneplain is a rolling upland with a few prominent monadnocks rising 2000 or 3000 feet above its general surface. Large areas of this surface are preserved near the canyon of the Kern River.

The cirques among the High Sierras are magnificent amphitheatral basins. Their boundary walls rise, at many places, 1000 to 2000 feet as precipitous cliffs. On the floors of these catchment areas, where the snows that formed the mountain glaciers accumulated, there are rock basins that were gouged out by the ice and that now contain lakes. There are thousands of lakes in the High Sierras, and most of them are due to glaciation. See Figure 232.

Most of the great canyons of the Sierras have been cut by streams flowing westward toward the lowland Valley of California. Kern Canyon is an exception in that it extends from north to south, approximately parallel to the trend of the range. On the east slope the streams descend



Photograph by Wallace W. Atwood, Jr.

peaks in the center of the view are parts of the Muir Crest. On some of them there are the left, in the middle ground, extends to the canyon of the Kern River, and beyond at of the Great Western Divide

over very steep gradients with many falls and rapids. All the valley walls on the east side of the range are precipitious, and the intervalley crests are very ragged. See Figure 230.

On the walls of many of the Sierra canyons there are waterfalls by which tributary streams, which occupy hanging valleys, reach the major canyons. In the Yosemite it is clear that there are at least three sets of hanging valleys.[1] At the lower ends of such valleys are the famous falls of Yosemite National Park. Bridalveil Falls and the Yosemite Falls were formed in streams issuing from hanging valleys. See Figure 235.

The physiographic history of the Sierra Nevada. The geologic structure of the Sierra Nevada indicates that there was a period of folding near the close of the Paleozoic era at about the same time that the great Appalachian revolution took place in the eastern part of the continent. The structure indicates also that there was a renewal of mountain-making at the close of the Jurassic period. At that time the huge

[1]F. E. Matthes, "Geologic History of the Yosemite Valley," *U. S. Geological Survey, Professional paper*, No. 160 (1930), 137 pages.

batholithic mass or masses already referred to rose toward the surface of the earth, lifting a very large amount of overlying rock material, and folding and deforming the sediments which were near at hand.

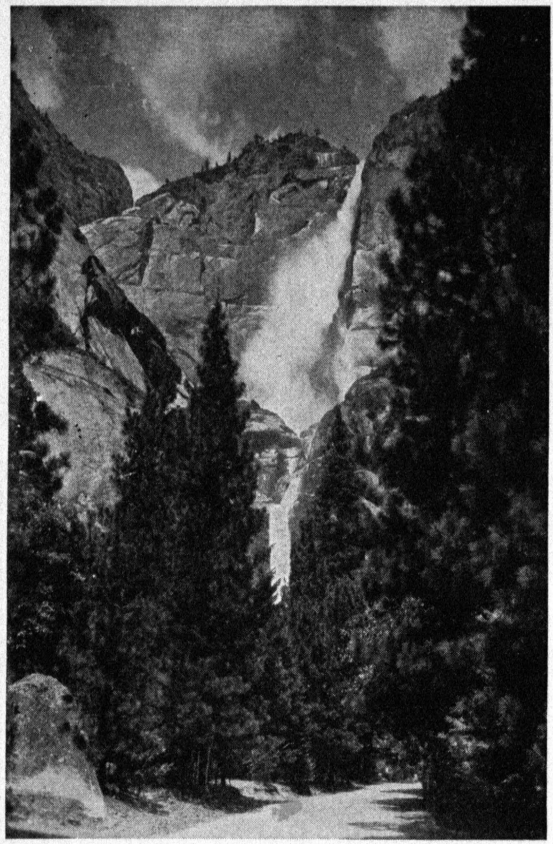
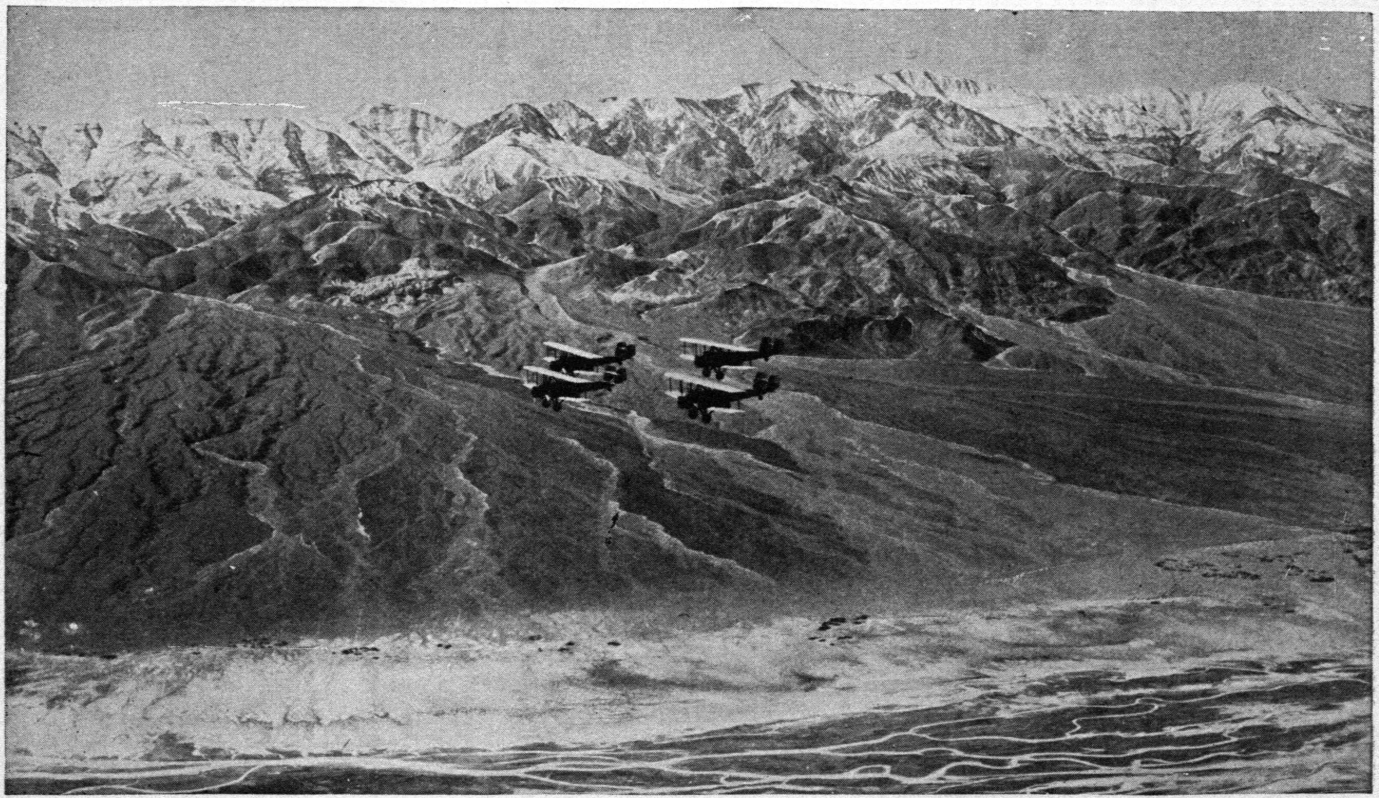


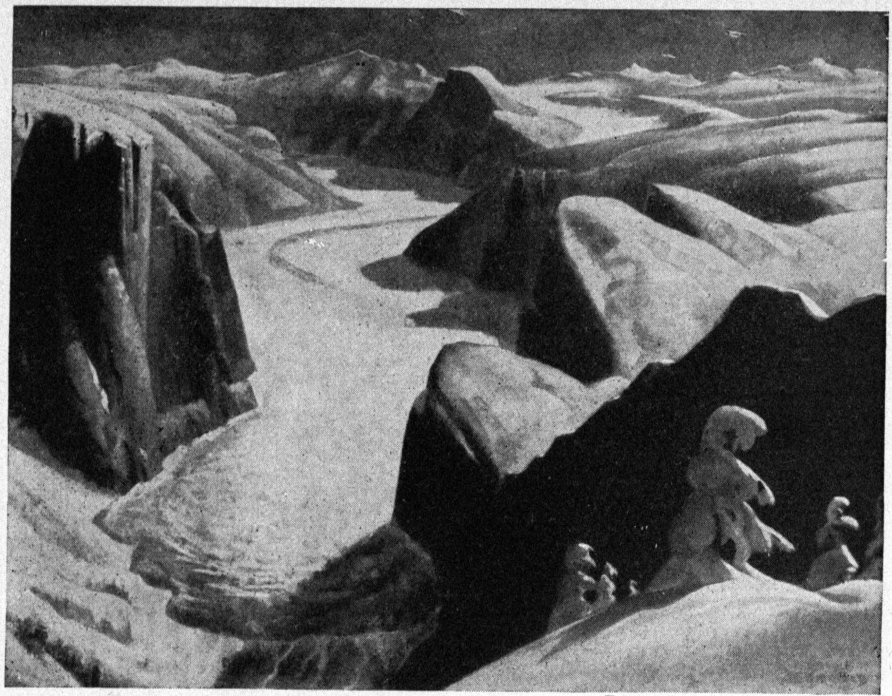
Figure 235 · Yosemite Falls. The first plunge is about 1430 feet. In the middle section the water descends about 675 feet in rapids and cascades. The lower fall is about 320 feet. The stream comes from a tributary hanging valley

During the erosion cycle which followed the mountain-making movement at the close of the Jurassic period, the very old erosion surface which appears on the tabular tops of many of the high summits was presumably developed. Later came a series of uplifts at the east, each of which tilted the great mountain block westward. The first uplift may have amounted to about 3000 feet, and during the erosion cycle which followed, the Sierra Peneplain was developed. This was a gently rolling surface with many mountain monadnocks rising above it. When it was developed, the Sierra Peneplain was not far above sea level, but with the renewal of movement in the eastern fault zone, after the peneplain cycle was completed, there was an uplift of about 6000 feet. All streams were rejuvenated and the modern valleys began to be carved out of the uplifted Sierra Peneplain surface. By then the geologic clock had moved on to late Tertiary time or possibly to the beginning of Quaternary time. See Figure 236.



Official Photograph U. S. Army Air Corps

Figure 236 · The east slope of the Sierra Nevada, where a series of gigantic torrential fans have been built by streams that are dissecting the range



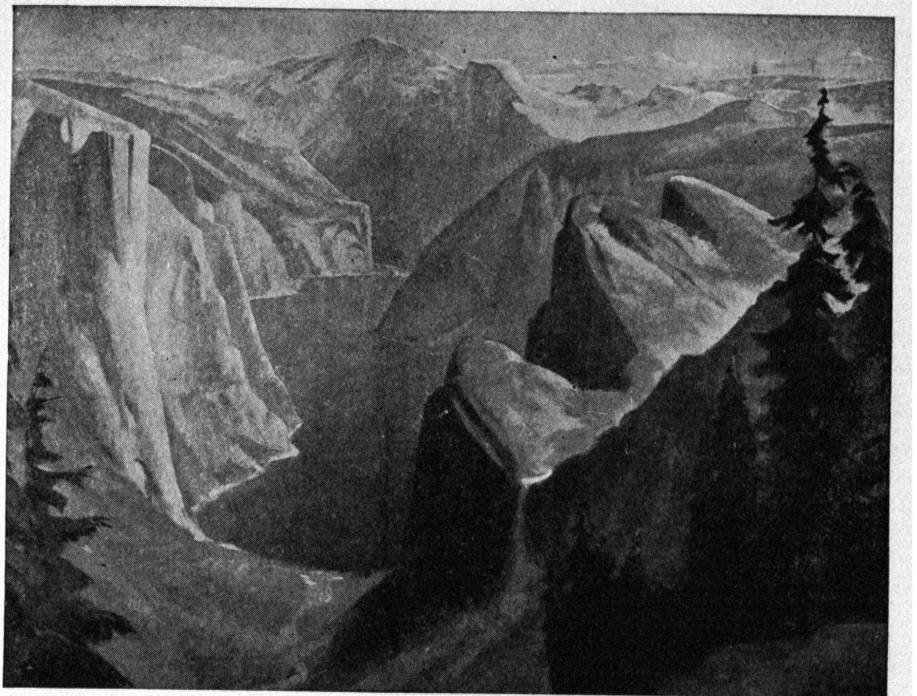
From painting by Eugene Kingman

Figure 237 · Yosemite Valley as it appeared during the last, or Wisconsin, stage of glaciation. The inner gorge is being deepened, and sands and gravels are being washed down the valley. The view on this page and the one on the opposite page are based upon field studies of François Matthes. They were first reproduced in color[1]

When the cross-section profiles of the canyons of the Sierras are examined in detail their forms suggest three distinct stages in erosion since the development of the Sierra Peneplain. There is an upper, outer valley stage represented by gentle contours which suggest maturity in an erosion cycle; lower down there are steeper valley slopes; and still lower, the nearly vertical walls of the inner gorges. See Figures 237 and 238.

The topography near the headwaters of Kern River suggests four cycles of erosion. On the summits of many of the high peaks in the Muir crest line at the east the tabular surfaces are from 13,000 to 14,000 feet above sea level. At about 11,000 feet the Boreal Plateau surface appears to represent a distinct stage in downward cutting by the streams. At

[1] Wallace W. Atwood, Jr. and Eugene Kingman, "Crater Lake and Yosemite through the Ages," *National Geographic Magazine*, March, 1937.



From painting by Eugene Kingman

Figure 238 · Yosemite Valley soon after the last glacier melted away. A frontal moraine across the valley ponded the stream and formed ancient Lake Yosemite. Sediments accumulated in that lake and developed a nearly level floor. The outlet of the lake was lowered by erosion; the lake was drained, and the floor of the lake provides sites for the hotels, lodges, and camping grounds in the present-day park

9000 feet another surface called the Chagoopa Plateau suggests an erosion surface, and below that is the modern gorge of the Kern River.

As the canyons were being developed by stream erosion, climatic changes occurred which caused the formation of huge alpine glaciers. The ice transformed the V-shaped canyons made by streams into more open U-shaped gorges. At least three distinct stages of glaciation are recorded in this range. During each interglacial stage and after the disappearance of most of the ice, the streams have been actively at work. The amount of canyon-cutting and weathering which has taken place since the disappearance of the valley glaciers is, however, relatively slight.

In the northern portion of the Sierra Nevada the lavas that were poured forth filled many of the valleys. At the time this occurred there

were gold-bearing gravels in the stream beds. At present those lava flows form the crests of intervalley ridges and the gold-bearing gravels that were deposited in stream channels are high above the modern stream courses. A totally new system of valleys has been developed since the outpouring of those lavas. As the streams lowered their channels and exposed the buried gravels on the valley walls, some of the loose gold-bearing material came down the slopes into the modern stream courses. In this way the gravel in the present river beds became auriferous, and it was in these beds that the discoveries that led to the gold rush to California in 1849 were made. After the gold in the modern channels was exhausted, the prospectors searched the hillsides for the sources of the yellow material. Today the older gold-bearing gravels are being mined by driving tunnels into the hillsides below the lava caps.

The Cascade Range

The Cascade Range is west of the Columbia Plateau and north of the Sierra Nevada. It may be divided, for convenience, at the Columbia River gorge, into a northern and a southern section. The southern section is made up of a large amount of lava, many volcanic cones, and a great variety of fragmental volcanic debris. The volcanic material was piled upon an old erosion surface, probably the northward extension of the Sierra Peneplain, and later uplifted. The northern section contains much volcanic material but consists in large part of much older rock formations, long subject to erosion and later uplifted as a long narrow plateau with steep flanks to the east and west. The relief features in the southern section are due chiefly to upbuilding, while many of those in the northern section have been carved out of the uplifted mass by streams and alpine glaciers. There are several conspicuous volcanic peaks in the northern as well as in the southern section.

The Southern Cascades

In the southern section of the Cascade Mountains there are at least 120 volcanoes. Lassen Peak, which is one of them, rises 10,437 feet above sea level and was last active in 1914 and 1915. There are many cinder cones, extensive lava flows, hot springs, and boiling mud pools about



Official Photograph U. S Army Air Corps

Figure 239 · Mount Shasta from above the clouds

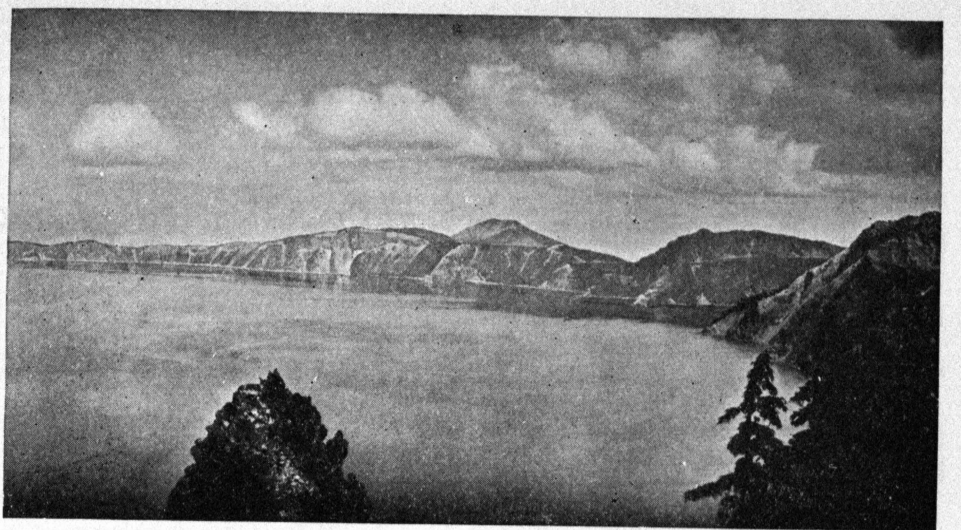


Figure 240 · Panorama of Crater Lake, Oregon. Wizard Island is a secondar

the base of this peak. Several small lakes and meadows near the mountain were formed when the outpouring of lavas obstructed certain valleys. An area centering in Lassen Peak has been set aside as a national park.

One of the most strikingly picturesque of the volcanic peaks in the southern Cascades is Mount Shasta, which rises to an elevation of 14,161 feet above sea level and fully two miles above the land at its base. See Figure 239. It is the most prominent of all the volcanic cones in the United States. Mount Shasta is composed of alternating layers of lavas and tuffs built upon a base that is now 17 miles in diameter. Clusters of cinder cones, each representing an independent center of eruption, form a ring about this mountain. Because many of these cones are so symmetrical in form and have so little soil, they indicate very recent volcanic activity in this region.

The upper portion of Mount Shasta is divided into two parts. On the western slope, a mile and a half distant from the main summit and 2000 feet lower, is Shastina, a very young volcanic cone which retains an almost perfect crater. On the main summit there are perennial snow fields, and in five of the great catchment basins glaciers which descend radially over the mountain slopes have formed. The Whitney Glacier, which is about two miles long, descends to an altitude of 9500 feet.

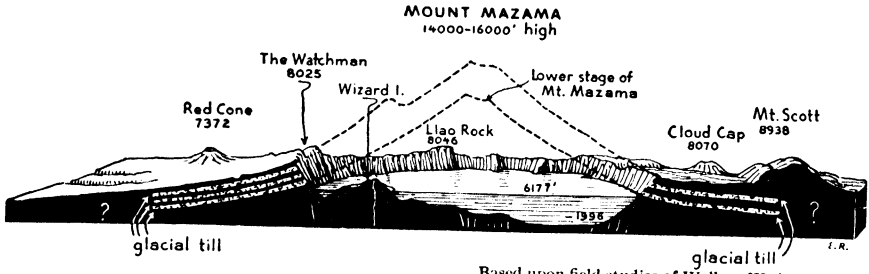


Photograph by Wallace W. Atwood, Jr.

volcanic cone developed since the lake came into existence. See also Figure 241

Mount Mazama, in the summit of which is the world-famous Crater Lake of Oregon and which is the center of interest in another of the great national parks of the Pacific Coast region, is in the midst of the southern section of the Cascade Range. See Figure 240. This volcano, which has lost its head, is made up of alternating layers of lavas, beds of pumice, volcanic breccia, and glacial till. There are numerous dikes which radiate from the center of the lake and now appear in the wall of Crater Lake. See Figure 241.

At several horizons in the bold escarpment facing Crater Lake, glacial debris has been found interbedded between the flows of lava. Furthermore, glacial striae have been discovered on lavas that underlie the bodies of till. The rim rock of the lake basin is also marked at various places by glacial scratches, and the mountain slopes near the lake are mantled at several places with glacial debris. There is abundant evidence that ice formed on a central peak and moved radially down the slopes of Mount Mazama at different stages in the growth of the mountain. The glacial advances preceded the formation of the great caldera-like basin now in the summit of the mountain. Since alpine glaciers did not form during Pleistocene time in basins below 9000 feet in elevation in this part of North America, the glacial evidence alone



Based upon field studies of Wallace W. Atwood, Jr.

Figure 241 · A structure section through Crater Lake and Mount Mazama, with associated relief features shown in perspective

indicates that there must have been a considerable peak over the present basin of Crater Lake.[1]

After the earlier stages of glaciation, thousands of feet of lava were added to the mass of the mountain and flowed radially down the slopes of the great volcanic mass. The growth of the central peak must have been reasonably slow, for during periods of dormancy the mountain slopes were deeply etched by running water, so that deep valleys were excavated. Into these valleys subsequent lava flows descended and mountain glaciers moved from the summit of the mountain.

If the disappearance of the peak were due to a violent explosion, a vast amount of volcanic debris, equivalent to several cubic miles, should be found on the surface bordering the rim and on the present slopes of Mount Mazama. Such material should overlie the glacial moraines; but there is no such material overlying moraines. All evidence thus far collected supports the conclusion, first reached by investigators who studied the volcanic history of the mountain, that the disappearance of the peak is due to collapse.[2] The mountain has swallowed its head.

Since the formation of the great caldera in which Crater Lake is located, a renewal of volcanism has resulted in building upon the floor of the lake basin a lesser cone which now rises about 700 feet above the surface of the lake. See Figure 240. This youthful cone, which forms Wizard Island, retains a true crater in its summit. Many of the lava

[1]W. W. Atwood, Jr., "The Glacial History of an Extinct Volcano, Crater Lake National Park," *Journal of Geology*, Vol. 43 (1935), pp. 142–168.

[2]J. S. Diller and H. B. Patton, "The Geology and Petrography of Crater Lake National Park," *U. S. Geological Survey, Professional Paper*, No. 3 (1902), 167 pages.

flows on its slope are exceedingly fresh, indicating very recent outpourings. A thin soil at places on this cone supports a sparse scattering of trees.

Crater Lake is about 2000 feet deep. It is nearly circular in form and five to six miles in diameter. From the rim the waters appear to have a deep-blue color, which enhances the beauty of this scenic feature. The bordering walls of volcanic debris are weathered into fantastic forms, and colored, through oxidation and hydration, into various shades of brown and brilliant yellow. The lake in this setting furnishes a picture difficult to surpass anywhere in the continent.

A few miles south of the Columbia River gorge is Mount Hood (11,225 feet), a very sharp volcanic cone rising abruptly above the general surface of the Cascade Range.

The Gorge of the Columbia River

After crossing the plateau to the east of the mountains, the Columbia River flows in a deep gorge which it has cut through the Cascade Range. In a portion of that canyon the walls are steplike and the face of each bench or terrace is precipitous. This section is called the Dalles of the Columbia. Here the stream has falls and rapids in its course, and these features add much to the scenic beauty of the Dalles. If the Columbia River established its course before the mountain mass was elevated and maintained that route as the mountains rose, it is an antecedent stream. This type of history is duplicated in the case of many rivers farther north that cross the Coast Range of British Columbia from the interior plateau to the Pacific Ocean.

An alternative hypothesis explains the early location of the Columbia in a low pass which was due in part to faulting. The valley was later blocked by lava flows from Mount Hood which ponded the river. In time the waters upstream from the lava obstruction rose until they overflowed. Since then the gorge has been cut, and the youthful features of the Dalles are explained without calling upon the theory of antecedence. A combination of these explanations is probably the solution of this problem. See Figure 242.



Official Photograph U. S. Army Air Corps

Figure 242 · Here the Columbia River has cut a gorge through the Cascade Range. In the distance is the Columbia River Plateau

The Northern Cascades

The northern Cascades are composed in large part of metamorphic sedimentary rocks and a large granitic mass which has been thrust upward toward the surface of the earth, much as was the Sierra batholith farther south. The combined mass of granitic and metamorphic rocks was subject to erosion for a long period of time during which a mature topography was developed. That surface was buried, at least in part, by lava flows and fragmental debris from Cascade volcanoes and has since been uplifted, uncovered in part, and redissected. That erosion surface is believed to extend eastward and pass beneath the basaltic lava floors of the Columbia River Plateau. Many deep canyons of great scenic beauty have been carved in the uplifted mass of the Cascade Range.

Mount Rainier, with an elevation of 14,408 feet, is located in the northern Cascades southeast of Tacoma, Washington. This is one of the most famous of the high volcanoes in the United States, and the entire mountain has been set aside as a national park. The summit of the mountain is mantled with ice, and that ice descends radially to about 6000 feet



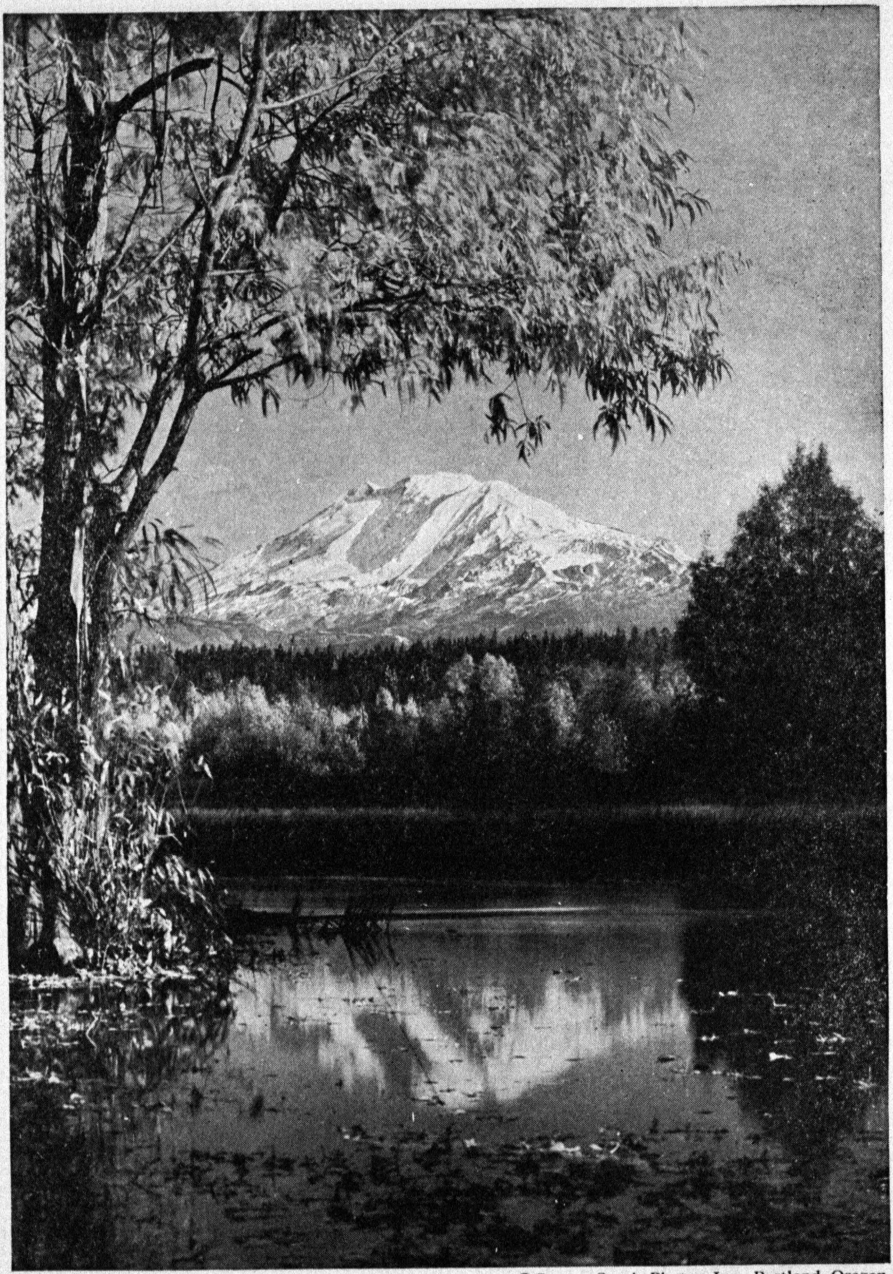
Photograph by Wallace W. Atwood, Jr.

Figure 243 · Mount Rainier (14,408 feet), with its many glaciers, is the center of interest in the Mount Rainier National Park

above sea level. See Figure 243. Glacier Peak, about 100 miles north of Mount Rainier, is a volcano which rises 10,436 feet above sea level and about 3000 feet above the level crest of the northern Cascades. From the summit of this peak fifty glaciers can be counted. Mount Baker, 10,827 feet in elevation, is an isolated volcanic cone at the northwest corner of the Cascade Range, a few miles south of the Canadian border. It is snow-capped and partially covered with ice. It rises about 5000 feet above the average summit elevation of the Cascade Range. Eruptions from Mount Baker are recorded for 1854, 1858, and 1870. The volcanoes, such as Mount Adams, Mount St. Helens, Mount Rainier, Mount Glacier, and Mount Baker, were built up, in part at least, after the cutting of the present mountain canyons. See Figures 244 and 246.

In the northern Cascades there are hundreds of small glaciers and hundreds of cirques which were formerly occupied by glaciers. No one of the present glaciers is very long, and most of them are shrinking. Below the amphitheatral catchment areas located near the summit, the deep canyons through which the glaciers formerly moved are U-shaped in form. They have been intensely glaciated.

Lake Chelan occupies one of the great canyons on the east side of the northern Cascades. It is eighty-eight miles long and has a depth of 1419 feet, but the surface of this lake is only 1079 feet above the sea. This means that the bottom of the lake basin at its greatest depth is



© Sawyer Scenic Photos, Inc., Portland, Oregon

Figure 244 · Mount Adams from Trout Lake



Grant, National Park Service

Figure 245 · Looking eastward from Slate Peak into one of the great U-shaped valleys in the Cascade Range formerly occupied by alpine ice

340 feet below sea level. This is one of the most conspicuous examples of the erosion accomplished by alpine glaciers in the western mountains of North America.

The Chelan glacier advanced to the Columbia River and even pushed against the farther wall of the canyon. Downstream from that crossing, the valley of the Columbia contains well-defined terraces composed of outwash from the glacial ice. The great Chelan trough through which the glacier moved does not continue to the Columbia River. There is a rock ledge over which the outlet stream from the lake cascades as it descends to join the Columbia.

The valley glaciers in the Cascades were huge masses of ice. Some are known to have been more than 4000 feet in thickness. See Figure 245. As they moved down the canyons, deepening the valley troughs, they were vigorous agents of erosion. When they disappeared they left the lower ends of the tributary valleys hanging hundreds of feet above the floors of the main gorges. From these tributary valleys the waters tumble through steep V-shaped notches which have been cut in post-glacial



Official Photograph U. S. Army Air Corps

Figure 246 · Mount St. Helens and Mount Rainier

times. Several hanging valleys appear on the rock walls above the surface of Lake Chelan. The canyon-cutting period in the Cascade Range is called the Twisp stage. Into these canyons came the valley glaciers. The post-glacial work of re-excavating the valleys has been called the Stehekin stage.[1]

The amount of work which the streams have done since the final disappearance of the ice is relatively slight. Some glacial debris has been removed, and at a few places narrow inner gorges have been cut into the bedrock of the range.

The Puget Sound–Willamette Valley Lowland

Between the Cascade Range at the east and the Olympic Mountains of Washington and the Coast Ranges of Oregon at the west there is a lowland trough in which Puget Sound and the Willamette Valley are located. Between the Puget Sound area at the north and the Willamette Valley at the south there is a small area drained to the Pacific Ocean by the Chehalis River and its tributaries.

Glacial features at the north. Bordering the submerged area occupied by Puget Sound there is a land with a gently rolling or hilly topography formed for the most part of morainic deposits. Ten to fifteen miles south of Puget Sound there is a belt of heavy morainic deposits that marks the terminal position of a lobe of the great Cordilleran ice sheet which formed in British Columbia and moved southward into what is now the state of Washington. This moraine is composed for the most part of unstratified deposits left there as the ice melted. South of this hilly morainic land and extending nearly to the Columbia River, there are vast accumulations of outwash sand and gravel which were placed there by waters issuing from the margin of the great ice sheet. In this area of stratified deposits and bordering the Columbia River, there are a number of basaltic hills of preglacial origin. These hills are somewhat conspicuous features, for they rise several hundred feet above the level of the glacial outwash.

[1]B. Willis, "Physiography and Deformation of the Wenatchee-Chelan District, Cascade Range," *U. S. Geological Survey, Professional Paper*, No. 19 (1903), pp. 41–97.

The Willamette Valley at the south. The Willamette River flows northward to join the Columbia through a broad alluvial plain, one hundred twenty-five miles long and from fifteen to thirty miles wide, in which a number of stream channels are intricately braided. The main stream is so overloaded that it has divided, and the distributaries are constantly shifting their courses. In this valley the streams tributary to the Willamette are building alluvial fans, and the Columbia River at an earlier stage built a huge delta which crosses the lower part of the valley.

The lower Columbia. The Columbia is a drowned river, so much depressed that the tides extend for 140 miles upstream to the cascades or rapids forty miles east of Portland. During the glacial period there must have been ice jams that ponded the lower portion of the Columbia River Valley, for huge boulders from five to seven feet in diameter that came from far upstream in the basin of that river were transported by icebergs and left in the Columbia and Willamette valleys. Some of these erratics are 400 feet above the present-day tidal waters.

The physiographic history. At the close of the Mesozoic era when the Cascade Mountains began to rise, the Puget Sound trough sank and began to receive sediments of Tertiary age. These sediments are now tightly folded and faulted at places. In the vicinity of Tacoma the folded beds contain the best of all the coal deposits in the United States section of the Pacific Borderlands. A late Tertiary or early Quaternary uplift and deformation of this area resulted in the dissection of the lowlands. At the north a number of river valleys were developed which united in the section now occupied by Puget Sound. There the rock floor is about 1000 feet below sea level, which indicates that there has been a marked depression since the valleys were developed. The Willamette Valley was below sea level when the ice of the Pleistocene period melted away.

Following the valley development and the depression of the trough, the huge lobe of ice which advanced southward from British Columbia occupied the area of Puget Sound and much of the lowland immediately bordering that body of water. From the mountains to the east, and to some extent from those on the west, local glaciers descended to the

margin of the lowland trough and thus nearly completed the mantling of the lowland area with ice.

Since the disappearance of the ice, the land has stood at times between 250 and 280 feet lower than it stands today. The evidence of this submergence and later uplift is found in certain shelves cut into the glacial deposits by the waves of that inland body of water.

The Valley of California

Location and extent. Between the Sierra Nevada and the Coast Ranges of California is the Valley of California, another geosynclinal trough comparable to the Puget Sound–Willamette Valley trough of Oregon and Washington. This valley is about 400 miles long and has an average width of fifty miles.

The surface and materials. When the floor of the Valley of California is examined in detail, it is found to include a number of broad flood plains with numerous channels, some of which are bordered by natural levees, a series of alluvial fans where streams issue from the neighboring mountain canyons, and a number of sand dunes. The streams from the mountains to the east and to the west have brought into this trough, during many centuries, great quantities of sand, gravel, and silt. This alluvial material is known at places to have a depth of at least 2000 feet. Most of the valley floor is less than 400 feet above sea level, and some of it is a little below that level.

Drainage systems. On the basis of drainage the Valley of California may be divided into three parts. In the north is the Sacramento drainage basin, in the middle section is the drainage basin of the San Joaquin, and farther south there is an area of interior drainage called the Tulare Basin. In the northern section the Feather River is approximately parallel to the Sacramento for a long distance, and both rivers have very low gradients. The Feather River appears to be in the backswamp area of the Sacramento River Valley. Much of the land below sea level in the Valley of California is in the downstream portion of the Sacramento Valley. In the middle of the Sacramento Valley stand the only con-

spicuous topographic features in this lowland trough. They are known as the Marysville Buttes. They are of volcanic origin; they rise about 2000 feet above the valley floor and cover an area about ten miles in diameter. The San Joaquin drainage basin is for the most part a broad, flat alluvial land but high enough above sea level to permit cultivation.

The area of interior drainage lies south of Fresno. It is due to an unusually large alluvial fan formed by Kings River. A portion of this area of interior drainage is occupied by Tulare Lake, which occasionally overflows to the sea. Two small bodies of water, Buena Vista and Kern lakes, are in similar basins formed by other alluvial fans built by streams from the Sierra Nevada. These lakes are of the playa type; they exist during wet seasons but during very dry periods they disappear, exposing the lake bottoms as clay flats.

The physiographic history. As the Sierras were uplifted the Valley of California was depressed, and with the uprising of the mountains to the west the valley became clearly defined as a geosyncline. It has been thus defined as a trough since the opening of Quaternary time, and since then has been receiving sediments and perhaps sinking as it received the additional load.

The western boundaries at the border of the Coast Ranges are defined at places by faulting. At the northern end of the valley there is an area where a peneplain, which is probably an extension of the great Sierra Peneplain, appears in the foothills of the bordering mountains.

The Golden Gate outlet is an antecedent course. It was established as a valley before the last uplift of the Coast Ranges, and its present form and that of San Francisco Bay are due to a very recent sinking along the Pacific coast.

The Pacific Coast Ranges within the United States

Bordering the Pacific coast at the western margin of the United States there are a number of somewhat distinct mountain ranges. They include the Olympics of Washington, the Coast Range of Oregon, the

Klamath Mountains, which form a kind of knot connecting the Coast Range to the north and south with the Cascade Range at the east, and the Coast Ranges of California.

The Olympic Mountains

The Olympic Mountains are located in a densely forested wilderness region and occupy an area of 3000 to 4000 square miles. Their upland surface suggests, by a uniformity of summit levels, and the truncation of geologic structures, a peneplain similar to the old-age erosion surface in the northern portion of the Cascade Range. A renewal of mountain growth has raised this peneplain to an elevation of about 5000 feet. This movement caused the rejuvenation of all streams and the cutting of the modern canyons. Mount Olympus (8200 feet) is the highest peak in the range and one of a group of monadnocks that rise 2000 to 3000 feet above the summit peneplain.

A few small glaciers remain in the higher portion of this mountain area. They are remnants of much longer alpine glaciers which existed there during the Pleistocene period and which deepened and broadened most of the valleys in this range. The details in the physiographic history of the Olympics are not known.

The lowlands to the west of the Olympics are due to a very recent uplift. They form a narrow coastal plain which has been somewhat deeply eroded. Along the present shore line there are sea cliffs 30 to 300 feet high, numerous rock terraces, sea caves, and rock pillars that have been isolated from the mainland. Here the powerful waves of the Pacific are actively at work, and in their attacks upon the land they are producing many picturesque features.

The Oregon Coast Range

South of the Columbia River and north of the Klamath Mountains is the Oregon Coast Range, a belt of mountains chiefly of Tertiary rocks including many of volcanic origin. Their summits are about 4000 feet above the sea. The range consists of from two to five low anticlines that are roughly parallel and have north-south axes.

The area as a whole appears to be an uplifted and dissected old-age erosion surface. At the north this surface stands at about 1700 feet above

sea level and at the south at about 3500 feet. The main streams are in valleys that are deeply entrenched. They retain their meandering courses and are remarkably good examples of the effect of rejuvenation in an area which reached an old-age stage in one cycle of erosion and was then uplifted. The streams with their winding courses are today in young valleys. Above the inner narrow gorges there are broad open valleys which are distinctly below the general level of the subsummit surface. These conditions indicate that there have been at least two stages in the dissection of the old erosion surface.

At the west margin of the Oregon Coast Range there is a coastal plain from one to two miles wide. This plain is from 200 to 250 feet above sea level at places, and is marked by several distinct terraces. High on the mountainside facing the ocean there are other wave-cut terraces up to 1500 feet above the sea. These terraces prove recent uplift.

Since Miocene strata have been truncated in the development of the subsummit erosion surface of the Oregon Coast Range, that surface is interpreted to be not older than Pliocene. It corresponds in age approximately to the great Sierra and Cascade peneplains. The monadnocks that rise above this surface are chiefly of igneous material which has proved to be of superior resistance.

This land area was uplifted higher than it stands at present, and at that time streams, which crossed from this mountain region to the sea, cut canyons in the continental shelf. Later sinking has caused the drowning of the river courses. There is some reason for believing that the coast is again rising.

Klamath Mountains

This range is much older than the Coast Range of Oregon and those of California and more complex in geologic history. The entire area appears to be a dissected plateau which rises from north to south and from west to east. In Oregon the plateau surface varies in elevation from 2000 to 4000 feet, but in northern California it reaches an elevation of 5000 feet. The summit plateau is commonly known as the Klamath Peneplain. There are monadnock ridges between the main valleys that rise as much as 3500 feet above the peneplain, and in a few instances monadnock forms rise 5000 feet above that surface.

Most of the valleys in the Klamath Mountains are deep-cut canyons with broad older upper valleys. Several uplifts are recorded and therefore several partial erosion cycles. The higher mountains supported alpine glaciers that transformed the V-shaped gorges cut by streams in preglacial time into U-shaped valleys. The ice left large quantities of morainic material as far down the valleys as the glaciers extended.

The summit peneplain of the Klamath area is probably of late Tertiary age and the canyon-cutting is therefore Quaternary. The cycles of erosion thus recorded probably correspond in a general way to the erosion periods when the great Sierra Peneplain was developed and when the canyons in that range were excavated.

On the coastal slope of the Klamath Mountains there are terraces up to 1500 feet above the sea, and at the shore there is a narrow coastal plain. The shore terraces at 500, 1000, and 1500 feet are the most conspicuous of the uplifted shore features.

The Coast Ranges of California

The mountain ranges west of the Valley of California, and bordering the Pacific Ocean, contain rocks of pre-Jurassic age, and the structure of those older formations indicates that there were mountain-making movements in these ranges near the close of Jurassic time. There are, however, many Tertiary formations in these ranges, and these have been folded and much faulted, which indicates that the ranges have been subject to very recent movements. The ranges are nearly parallel and vary from 2000 to 4000 feet in height, although altitudes of 5000 feet are attained at a few places. The ranges extend diagonally to the coast, and the valleys between the ranges have been so cut off as to suggest faulting at the margin of the land. The even crests of these mountain ranges, though they have no broad summit areas, suggest an Appalachian type of sky line. They are less continuous than the Appalachian ridges.

Many of the valleys in the Coast Ranges of California follow zones of faulting, and in the submarine topography bordering the coast there is additional evidence of faulting. See Figure 247. Even the youngest of the local erosion surfaces have been faulted. The San Andreas rift is the best-known of the recent fault lines. Movement along this zone caused the San Francisco earthquake of April, 1906. At that time the movement,

which was chiefly horizontal, affected a belt about 500 miles long. Faulting has produced many bold escarpments which give straight margins



Figure 247 · Submarine topography off the coast of southern California. Several of the islands near the coast are fault blocks. At the outer edge of the continental shelf there are sharp gorges or canyons

to the mountains, such as appears at the east front of the Santa Lucia Range overlooking the Salinas Valley. The whole mountain belt is divided into fault blocks, some of which are tilted one way and some another, and some have been moved horizontally. There is much complexity in the structure and therefore in the resulting topography.

The last great mountain-making movement was near the close of the Pliocene period. In middle Pleistocene time there was sinking of 1000 to 2000 feet throughout the Coast Ranges, followed by a renewal of uplift with pronounced movement along several fault planes.

Shore terraces cut by the waves appear at many places on the western slope of the California Coast Ranges as high as 1500 feet above sea level. See Figure 248. The most pronounced of these terraces are at 800 and 1000 feet. Borings of marine animals, elevated delta deposits, sea cliffs, and beach gravels record the very recent uplift along this coast.

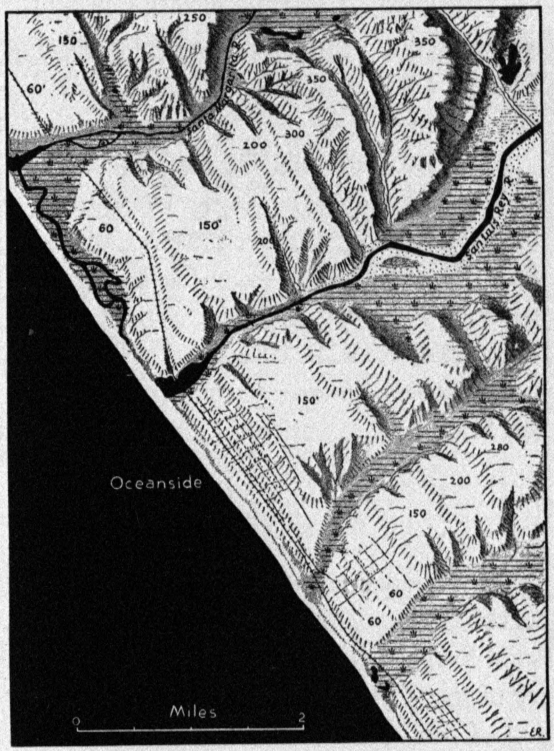


Figure 248 · Near Oceanside the marine terraces, found at many places on the California coast, are very clearly defined. Here several stream courses have been closed by barrier beaches and the shore line has been made smooth and regular by the work of littoral currents

Summits of some of the Coast Ranges are undoubtedly parts of peneplains, but it is impossible at present to correlate these remnants. They lie at various altitudes, and some of them are inclined in one direction, some in another. Certain of the peneplains may have been but local affairs. In the Santa Lucia Range there are remnants of a Pliocene erosion surface which might be called a peneplain, and in the Gabilan Range there are subdued erosion surfaces on the summit. Two distinct peneplains, or remnants of peneplains, appear near together in the Salinas Valley. The younger is some hundreds of feet lower than the Santa Lucia Peneplain, but it rises to the southward until the two levels merge. North of the San Francisco area there is an old erosion surface commonly referred to as the Mendocino Plateau. This appears to be a peneplain, or part of one. It may be an extension of the Klamath Summit Peneplain.

The last event in the physiographic history was a moderate amount of sinking along the coast, which caused the river mouths to be drowned for a distance of five or six miles. Sinking of the land caused the sea waters to enter through the Golden Gate and form San Francisco Bay. There is a little evidence of local uplift of a few feet since the last general submergence.

Many of the stream courses in the Coast Ranges of California are such as to indicate that they were formed on old erosion surfaces, such as peneplains. They have entrenched their old-age meandering courses deep into the uplifted mountains. This is well illustrated in the present valley of the Russian River. Some of the streams cross the mountains transversely, cutting directly across the main structures, which means that they are antecedent streams. The Santa Clara, the Salinas, and the San Benito are in structural troughs due to faulting.

The Angeles Section of California

In the southern portion of California the axis of the Sierra Nevada curves to the westward and meets the eastward-trending axes of the Coast Ranges. Jointly these mountain barriers form the southern boundary of the Valley of California and the northern boundary of that portion of the Pacific Borderlands that may be thought of as the Angeles Section. In this section we find a number of distinct mountain ranges, large areas of alluvial-filled lands, and several groups of rocky hills that rise like islands above the lowland plains.

The highlands. The San Gabriel and San Bernardino ranges are the most extensive of the mountains in southern California. Their combined length is a little more than one hundred miles. They are uplifted fault blocks composed, in large part, of granitic rock. Their summit elevations are about 6000 feet and those summits are so remarkably even that they suggest old erosion surfaces. Among the higher peaks there is the southernmost evidence as yet found of glacial ice in the United States. See Figure 249.

A little south and west of the San Bernardino is the San Jacinto Range. This range is another fault block. It rises between 7000 and



Official Photograph U. S. Army Air Corps

Figure 249 · The San Bernardino Mountains of southern California and the associated foothills and alluvial lands. The alluvial wash from the mountains has nearly buried a group of hills at the right

9000 feet above the sea. The Santa Ana Range is a granitic spur from the San Jacinto and is a separate fault block which has been tilted seaward. This range presents a very steep escarpment to the northeast and an inclined peneplain surface to the southwest.

The lowlands. In the lowland area of southern California between the ranges already described and the sea, there are many subdued ridges and groups of hills that rise above the alluvial lands. Near the coast the San Pedro Hills are completely surrounded by alluvium. They stand out conspicuously as islands in the sea of sand, gravel, and silt. Their slopes have been terraced by wave action, which means that they were surrounded by water somewhat recently. Here the alluvium is constantly advancing seaward. Locally the filling about the hills of the lower lands is several thousand feet deep. It consists of a combination of deltas and alluvial fans formed by the Los Angeles, San Gabriel, and Santa Ana rivers.

At its inner edge the lowland of southern California is 200 to 300 feet above the sea and slopes seaward from 10 to 20 feet per mile. Many of the streams, when they leave the mountains and start across the lowlands, divide and subdivide and thus form a number of distributaries. As the separated parts of a stream become smaller the velocity of the running water decreases, and the material carried in suspension is certain to be deposited. As the stream continues on its way much of the water sinks into the ground, and a portion is evaporated. Thus many of the streams disappear, but interestingly enough most of them reappear several miles down the slopes of the alluvial fans. In the belt where there are no surface waters, the supply of underground water makes possible a number of wells from which water is secured for irrigation purposes.

The physiographic history. The most reasonable hypothesis for explaining the relief features of this section is that the summit peneplains in the major mountain ranges of southern California, especially in the area of granitic rocks, may be parts of the same erosion surface as the Sierra Nevada subsummit peneplain. The subsequent breaking up of the area into many distinct fault blocks has produced a region of small

mountain ranges, residual hills, and waste-filled lowlands. The fault blocks have been displaced in different ways and at different times. Many of them may still be moving. Each block presents a unit problem in physiography. Wave-cut terraces on the mountain slopes at elevations from 800 to 1500 feet and facing the sea are unmistakable evidence that this portion of the continent has recently been uplifted.

The main drainage lines in the mountains were evidently established before the last uplift, since they cut directly through mountain ranges. They are, therefore, antecedent streams. The locations of many of the stream courses, however, are due to faulting.

The Angeles Section has a semiarid climate, but it has become one of the chief citrus-fruit-producing regions of the continent. All agriculture is carried on by means of irrigation, and the steady increase in the draft upon the well water has lowered the ground water table. Additional supplies of water for irrigation purposes will become necessary. Water for domestic and urban purposes is now brought hundreds of miles; this comes in part from reservoirs in the High Sierras and in part from the Colorado River. In no other densely settled portion of the United States has the population-carrying capacity been so directly dependent upon the amount of fresh water that could be provided.

The Salton Sea Area and the Sonoran Desert

A range and basin region. Southwest of the Great Basin region and including the Gila and Mohave deserts and extending southward into Mexico is an area which may be designated the Salton Sea–Sonoran Desert region. This part of the continent resembles the Great Basin region. Here there are many small mountain ranges rising above alluvial plains. The ranges are, on the whole, smaller than those farther north, and the alluvial plains are relatively more extensive. See Figure 250.

The lowland waste-filled areas decline in elevation from Nevada southward through the southeastern portion of California, and in Mexico they slope from the mountain barrier toward the coast. Portions of these lowland alluvial lands are undrained areas and may be called bol-

sons. Some of them are true playas, for the shallow water ponds that form in them periodically shrink or entirely disappear and leave broad, flat, clay-covered plains exposed. At places the alluvial filling in the intermountain troughs is known to be as much as 1800 feet deep.

Erosion in a desert. The stream courses in this section of the continent are dry much of the time, though they are occupied during the occasional cloudbursts that characterize the climate in this section and for a little time after the cloudbursts have taken place. Such stream courses are called *arroyos*, a Spanish term descriptive of a sharply incised channel that is often dry. Following a cloudburst such a channel in a desert region may carry a raging torrent and present serious difficulties to those who may attempt to cross it. Running water when it does come is quickly overloaded and the rivers become streams of mud.

In desert areas where there are no distinct channels or arroyos, cloudbursts cause "sheet floods." These flood waters may be from a few inches to one or two feet in depth. The soils of the desert are so dry that the sheet floods commonly disappear within a mile or two of their origin.

As the desert cycle advances—and it is here far more advanced than farther north—the mountains shrink, rock pediments increase in breadth, and alluvial fans become more extensive. This section includes the driest part of the United States. Here we find the so-called soda lakes and borax lakes, dry lakes, and alkali marshes. In the northern portion of this region is the Mohave Desert.

"The Nile of America." Across this subprovince flows the Colorado River, which here has been called "the Nile of America." It is a stream which receives its main supply of water from high mountains far in the interior of the continent. It has its annual periods of floods and these floods help irrigation. For centuries the Colorado River has deposited at the head of the Gulf of California vast quantities of sand, gravel, and mud, and has built there a great delta similar to the delta of the Nile. At Yuma, Arizona, this delta rises 40 feet above the level of the sea.

The floods that built this delta came in early summer, during May, June, and July. They were due to heavy rains and melting snows in the Rocky Mountains. The sediment carried by this river each year was

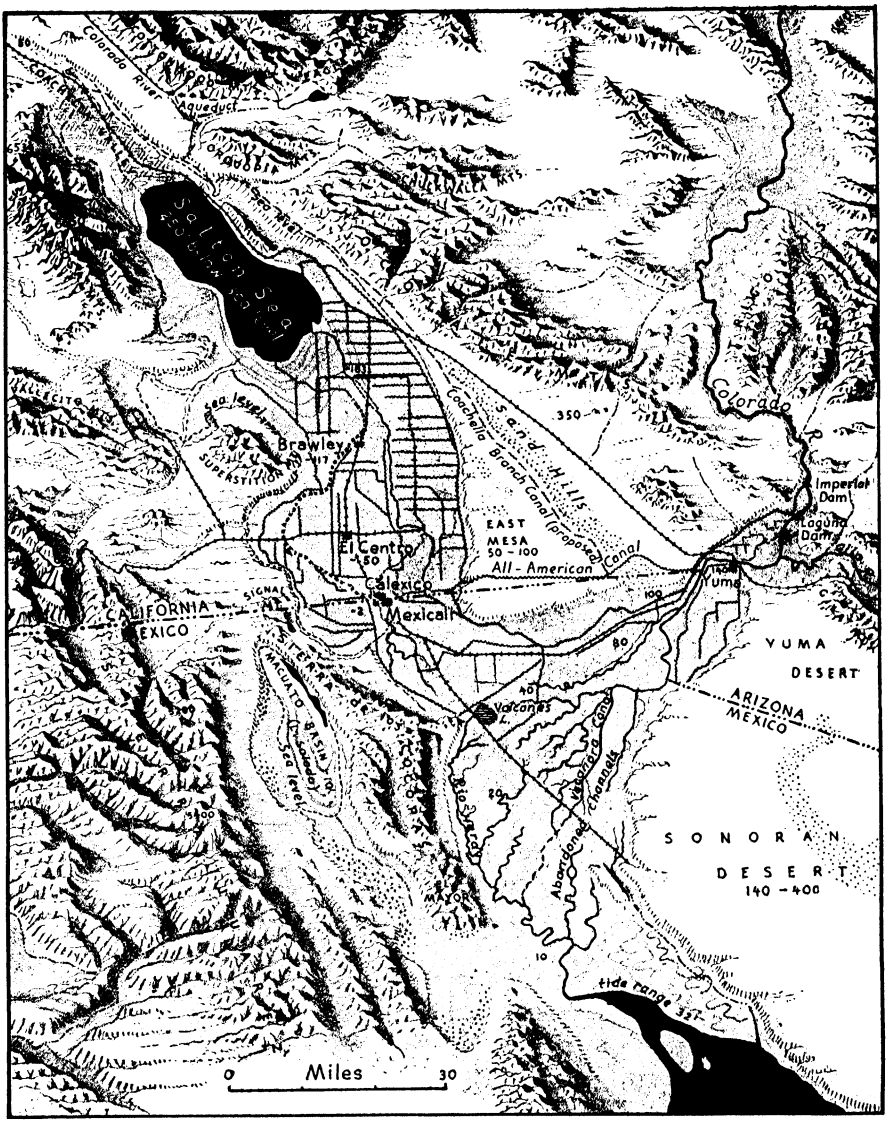


Figure 250 · The Salton Sea district and the delta of the Colorado River. Note the basin ranges, the sea-level line, and the many irrigation canals. The former shore lines of Salton Sea are shown

until recently equivalent to a square mile of dry earth 125 feet deep. Much of that load was left on the flood plains bordering the lower Colorado, but a large part of it was used in the building of the great delta at the head of the Gulf of California. A small fraction of the stream-borne material was carried out to sea. With the construction of Boulder Dam, the great load of sediments which the Colorado carries is being deposited at the upper end of a long lake formed by the ponding of the Colorado River waters. That lake serves as a settling basin and the waters that issue below the dam are essentially clear. They will pick up some material as they move down the valley and deposit it on the delta or carry it into the Gulf of California.

The Salton Basin. At the head of the Gulf of California and extending inland 80 to 90 miles there is a very low basin cut off from the upper end of the Gulf by the delta of the Colorado. This long lowland belt is a down-warped or down-faulted area and its deepest place is about 270 feet below sea level. The part cut off from the Gulf of California is known as the Salton Basin.

North of the Colorado delta is the Imperial Valley and beyond that to the northward is the Salton Sea. Waters from the Colorado River are diverted in ditch lines into the Imperial Valley, where they are used for irrigation purposes, and this lowland has become a prosperous agricultural land.

In 1905 a break in the right bank of the Colorado River resulted in a great flood of water which for some time entered the Salton trough. This caused the formation of the Salton Sea. Waters rose about 67 feet in that lake and covered an area of about 440 square miles. The outward flow from the Colorado was stopped in 1907 and the lake has since been shrinking. See Figure 250.

The Western Sierra Madre

Location and extent. Bordering the central plateau area of Mexico on the west is the Western Sierra Madre, or Sierra Madre Occidental. This is a series of mountain chains that are roughly parallel to the Pacific margin of the continent and have a southeast-northwest struc-

tural orientation. They extend from the volcanic province south of the city of Mexico to the international boundary, and for convenience in description may include the Chiricahua Range and associated mountains of Basin Range type that cross Arizona in a southeast-northwestward direction to the Great Bend in the Colorado River.

The western boundary of the Sierra Madre Occidental is the base of a bold escarpment at the east margin of the Sonoran Desert. This marked topographic break, or change, has been chosen as the boundary between the Mexican states of Chihuahua, Durango, and Zacatecas on the east and Sonora, Sinaloa, and Tepic on the west. The abrupt change from the lower lands on the west to the mountain area is due to movement along a fault line that extends N 45° W.

The eastern boundary is a somewhat ragged or irregular margin which forms the west boundary of the Mexican Plateau. At the south the limit of the Sierra Madre Occidental is placed at the canyons of the Rio Grande de Santiago and Rio Lerma where the downward cutting by streams gives way to the building up processes of volcanic activities.

Drainage features. Most of the eastward-flowing streams from the Sierra Madre Occidental are lost soon after they reach the desert lands of the Mexican Plateau, but many of the westward-flowing streams have cut magnificent canyons fully a mile in depth. The gorges of the Aros, Fuerto, and Rio Grande de Santiago are now cut more than a mile below the plateaulike summit of the mountain area, but the Grand Canyon of the Bolanos, a tributary of the Santiago, is the deepest of these canyons. In boldness and picturesqueness these canyons rival the Grand Canyon of the Colorado in Arizona.

Between the mountain folds and fault blocks there are longitudinal valleys that for a long time were closed basins. In these troughs vast quantities of loose material were deposited, but later through the headward erosion of westward-flowing streams the drainage in these basins was captured and provided with outlets.

Materials and structure. In structure the Sierra Madre Occidental consists of a series of great anticlines, broken along several fault lines that are nearly parallel to the axes of the folds. Over the beveled edges

of the sedimentary strata there are, at many places, lava flows and heavy accumulations of fragmental volcanic debris. The fault lines extend from southeast to northwest, and the uplifted blocks commonly have their steep faces to the west and their gentle slopes to the east, resembling in an east-west profile the teeth of a gigantic saw.

The physiographic development. In its physical history this province has been closely associated with the Mexican Plateau. About the opening of the Tertiary period there was uplift and pronounced folding along north-south lines in both provinces. A long period of erosion ensued during which the Cordilleran Peneplain, referred to on page 361, was developed. In mid-Tertiary time another uplift occurred with renewal of mountain-making and pronounced faulting along northwest-southeast lines. The fault-line breaks provided comparatively easy exits for molten rock, and lavas were soon poured out at several localities. In the canyon of the Aros, nineteen separate flows have been counted. Fragmental material accumulated and formed tuffs and breccias.

The uplifted Cordilleran Peneplain, now 7000 to 10,000 feet above the sea, became subject to vigorous erosion, and the deep canyons that give character to much of this province were carved. The details in the evolution of the physical features of this province have not as yet been worked out in many places. Presumably there have been several interrupted cycles of erosion in the late history of the Sierra Madre Occidental.

Recently King[1] has presented a report on a section of this high mountain country west of the city of Chihuahua. Here he finds the upland or plateau surface to have a mature to old-age erosion topography. There are broad flat-bottomed valleys which are, at places, marshy. The streams in these valleys flow westward and plunge into barrancas, some a mile in depth, that are working headward into the plateau country. The barranca section is a deeply dissected portion of the summit plateau. The west margin of the belt of barrancas is marked by a bold escarpment, and farther to the west there is a belt of nearly parallel ranges and valleys. Here the mountain forms are fault blocks and most of the escarpments face westward. Beyond the parallel ranges comes the Sonoran Desert province, which descends to the margin of the Gulf of California.

[1] R. E. King, "Geological Reconnaissance in Northern Sierra Madre Occidental of Mexico," *Bulletin of the Geological Society of America*, Vol. 50 (1939), pp. 1625–1722.

The Pacific Border of Alaska and British Columbia

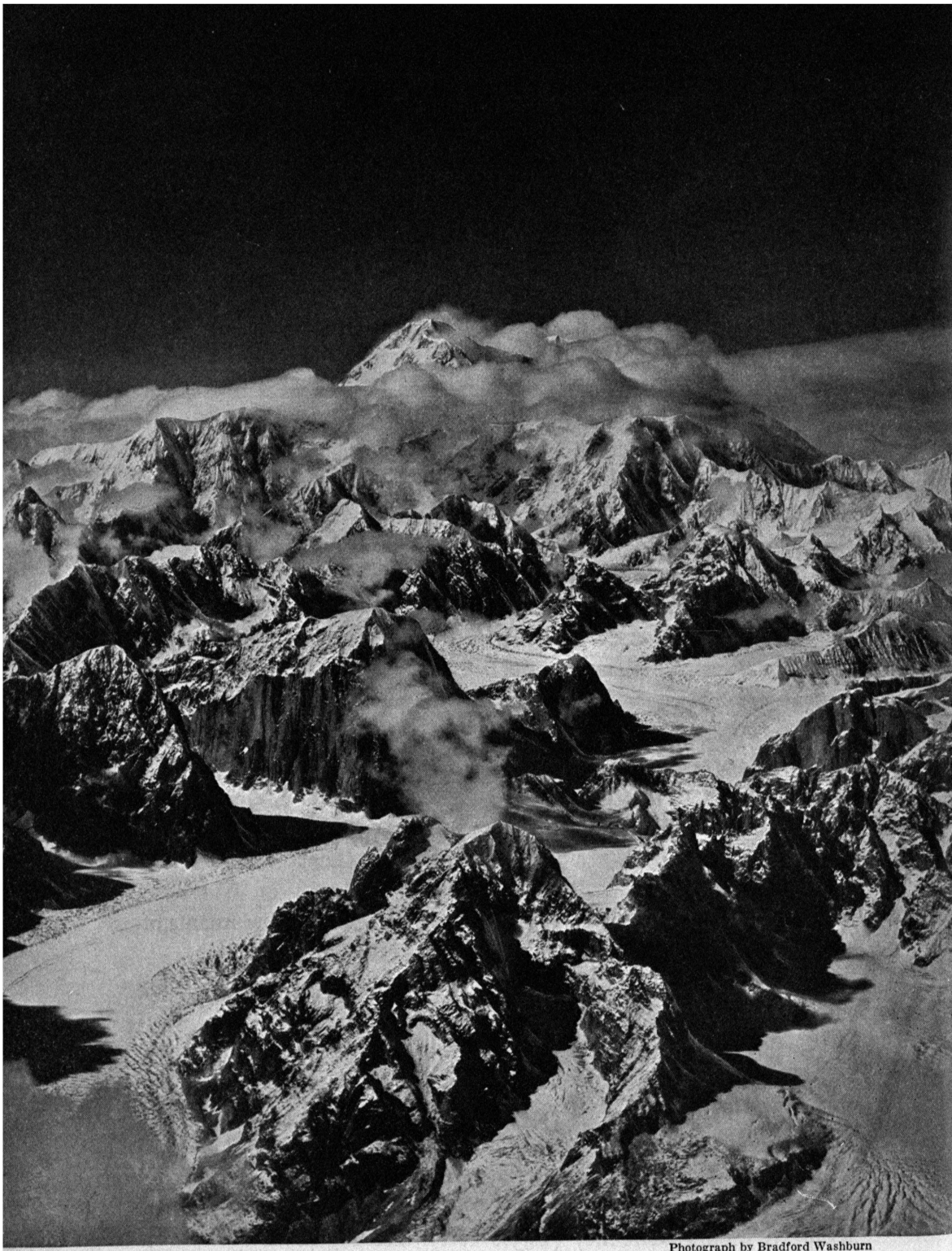
The Coast Ranges of British Columbia and Southeast Alaska

Northward from the international boundary line, the mountains of British Columbia which correspond in position to the Cascades in Washington are known as the Coast Ranges. They extend for about 900 miles and have an average width of about 100 miles. The general summit elevation in this range is from 7000 to 8000 feet, but there are a few peaks that exceed 9000 feet in elevation. This is a magnificent mountain barrier as seen from the Inland Passage. From the catchment basins near the summits numerous glaciers descend part way down the western slope of the range and several descend into tidal waters. See Figure 253.

The summit of this range, where examined by the writer and as described by Canadian fellow workers, suggests very strongly an old-age erosion surface. Throughout the range there are a number of magnificent canyons cut by streams that rise in the plateau area to the east. These canyons resemble, in some respects, the gorge of the Columbia River. They were cut by the Fraser, Skeena, Naas, Stikine, and Taku rivers. Where the streams cross the mountains their valleys are deeper and more canyonlike than in the uplifted plateau to the east, and they are probably antecedent streams. They established their courses to the westward before the Coast Range was uplifted and they maintained those courses as the mountains rose. This evidence strongly supports the hypothesis that somewhere high among the mountains there must be remnants of an old erosion surface.

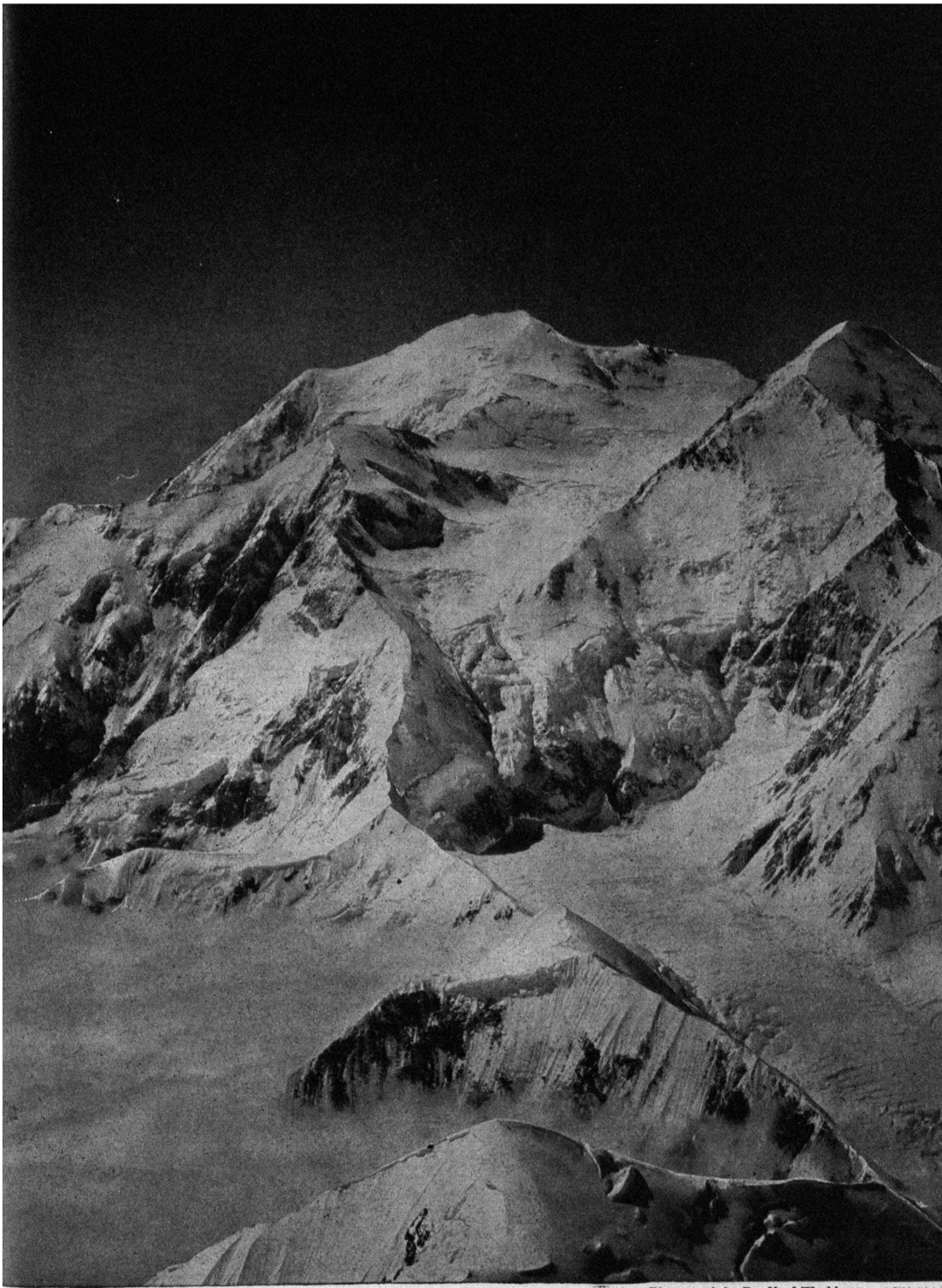
The Nutzotin and Alaska Ranges

Northwestward from the Chilkoot Pass the extension of the Coast Range of British Columbia and southeastern Alaska blends into the Nutzotin Mountains and then into the Alaska Range, which together form a great arc roughly parallel to the margin of the Gulf of Alaska. See Figure 255. This range continues westward to the Aleutian Range of the Alaska Peninsula and far into the Pacific Ocean. In the Alaska Range is Mount McKinley (20,300 feet). See Figures 251 and 252.



Photograph by Bradford Washburn

Figure 251 · The southeast face of Mount McKinley taken from the air at an elevation of 14,000 feet. Ruth Glacier is in the foreground

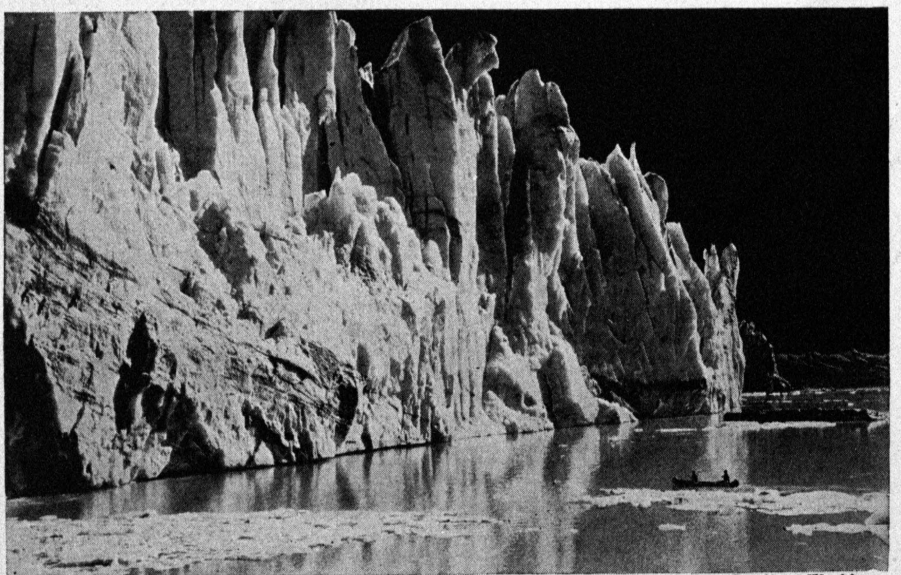


Photograph by Bradford Washburn

Figure 252 · A close-up of Mount McKinley from above the clouds. This is a birthplace of glaciers



Figure 253 · In the Inland Passage on the way to Alaska. The Coast Ranges of British Columbia are at the right. The route is through a partially submerged system of mountain canyons



Photograph by Bradford Washburn

Figure 254 · A close-up of the front of South Crillon Glacier, which is about 300 feet high. Here icebergs are born

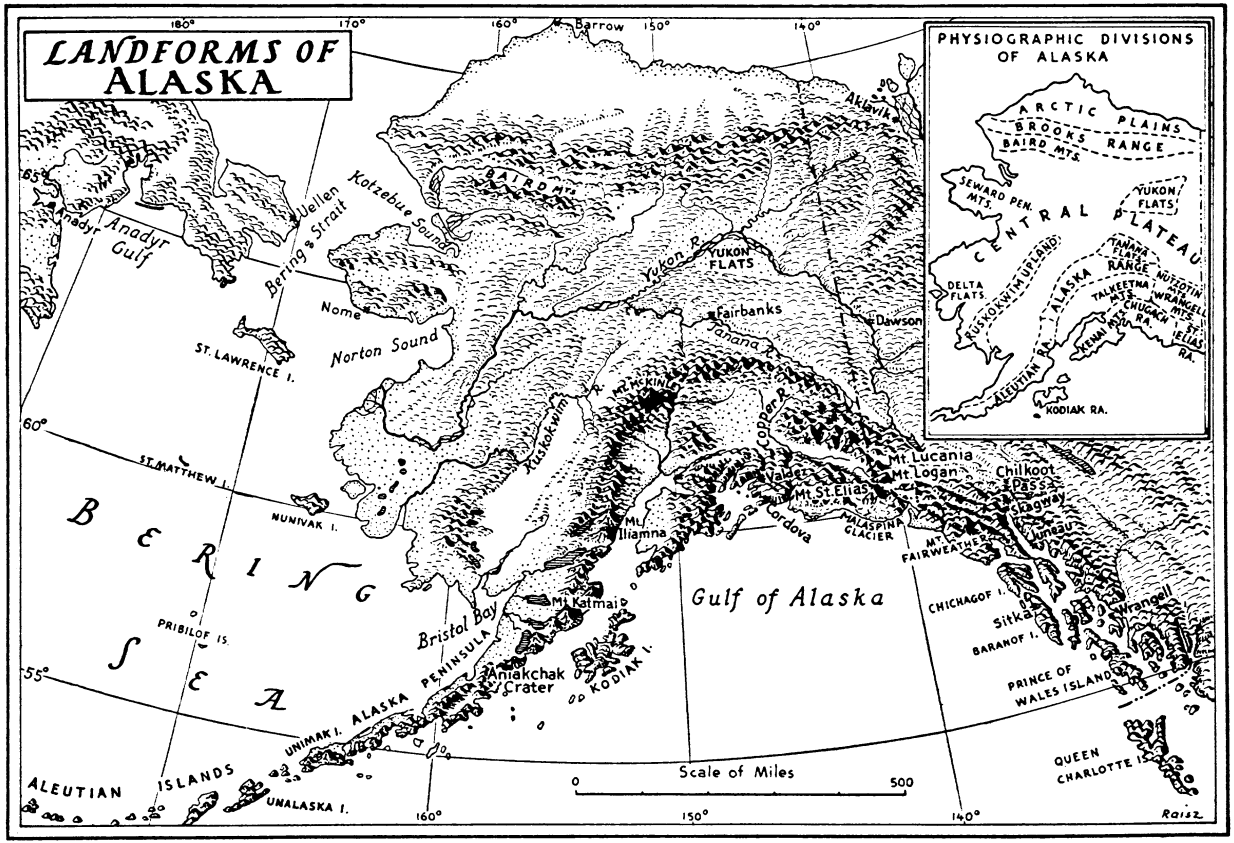


Figure 255 · The landforms of Alaska

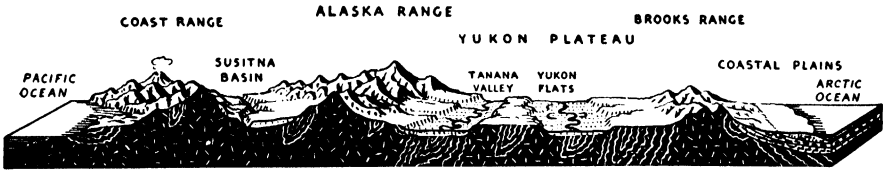


Figure 256 · A diagrammatic and simplified structure section across Alaska, with major associated relief features shown in perspective

Mount McKinley is the highest mountain in North America. Most of the Alaska Range, in which it is located, is covered with perennial ice fields, and in the valleys below the great catchment basins there are scores of alpine glaciers. It is a wilderness of ice and snow. See Figure 254.

The Aleutian Range

The Aleutian Range, which forms the backbone of the Alaska Peninsula, has a general summit elevation of from 3000 to 6000 feet. It declines to the westward and is represented by the chain of islands that reach nearly to the peninsula of Kamchatka. The Alaska and Aleutian ranges include a number of volcanic peaks, and in the latter range several of the volcanoes are intermittently active. In the Aleutian Range west of Kodiak Island there is a region of active volcanism in which are located the Valley of Ten Thousand Smokes and the famous crater of Aniakchak. See Figures 256 and 257.

The Seaward Belt of Mountains

The outer belt of mountains in the British Columbian section has been called the Vancouver system. It is represented on Vancouver Island and also on the Queen Charlotte Islands. The outermost islands in southeastern Alaska are the continuation northward of this outer belt of mountains. Still farther north, and immediately bordering the Pacific Ocean, is the Fairweather Range. See Figure 258. Then comes the magnificent St. Elias group which connects to the westward with the Chugach Range bordering the coast near Copper River and Prince William Sound. This range blends into the Kenai Mountains, which form the backbone of the Kenai Peninsula, and farther to the southwest it is represented in the low mountains of Kodiak Island. See Figure 259.

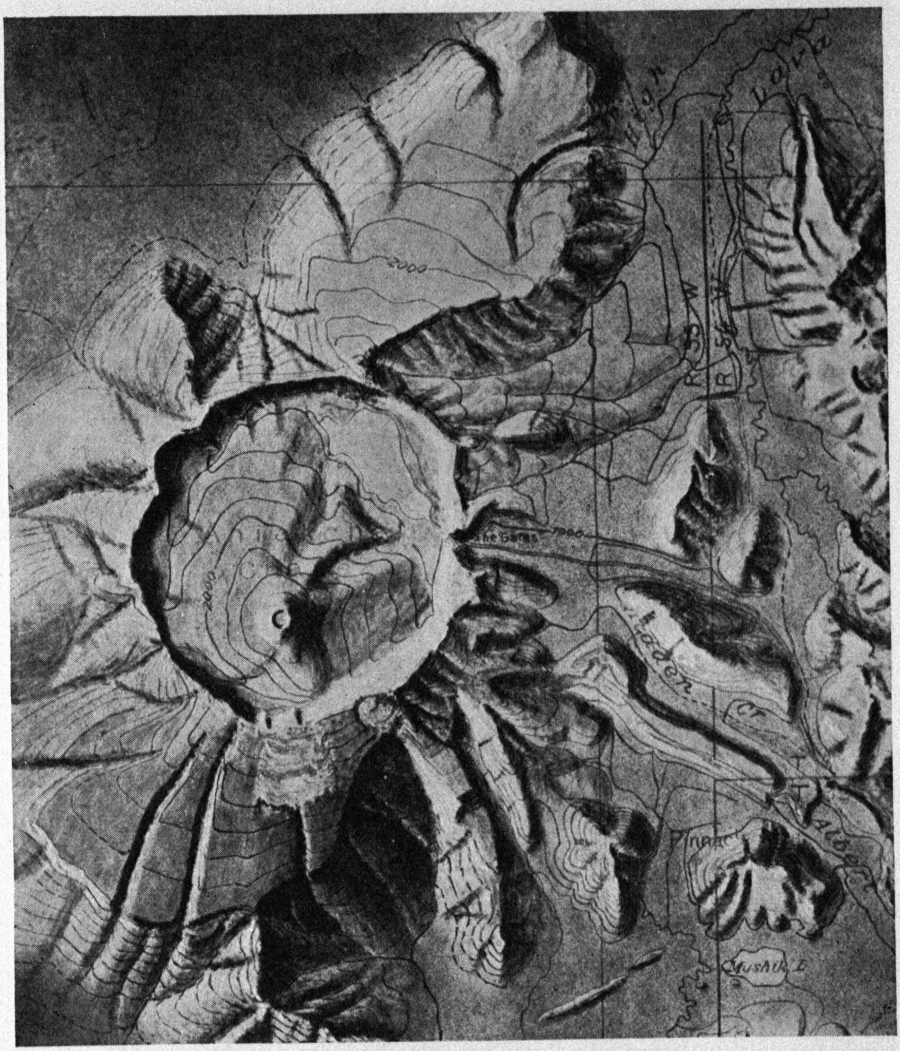
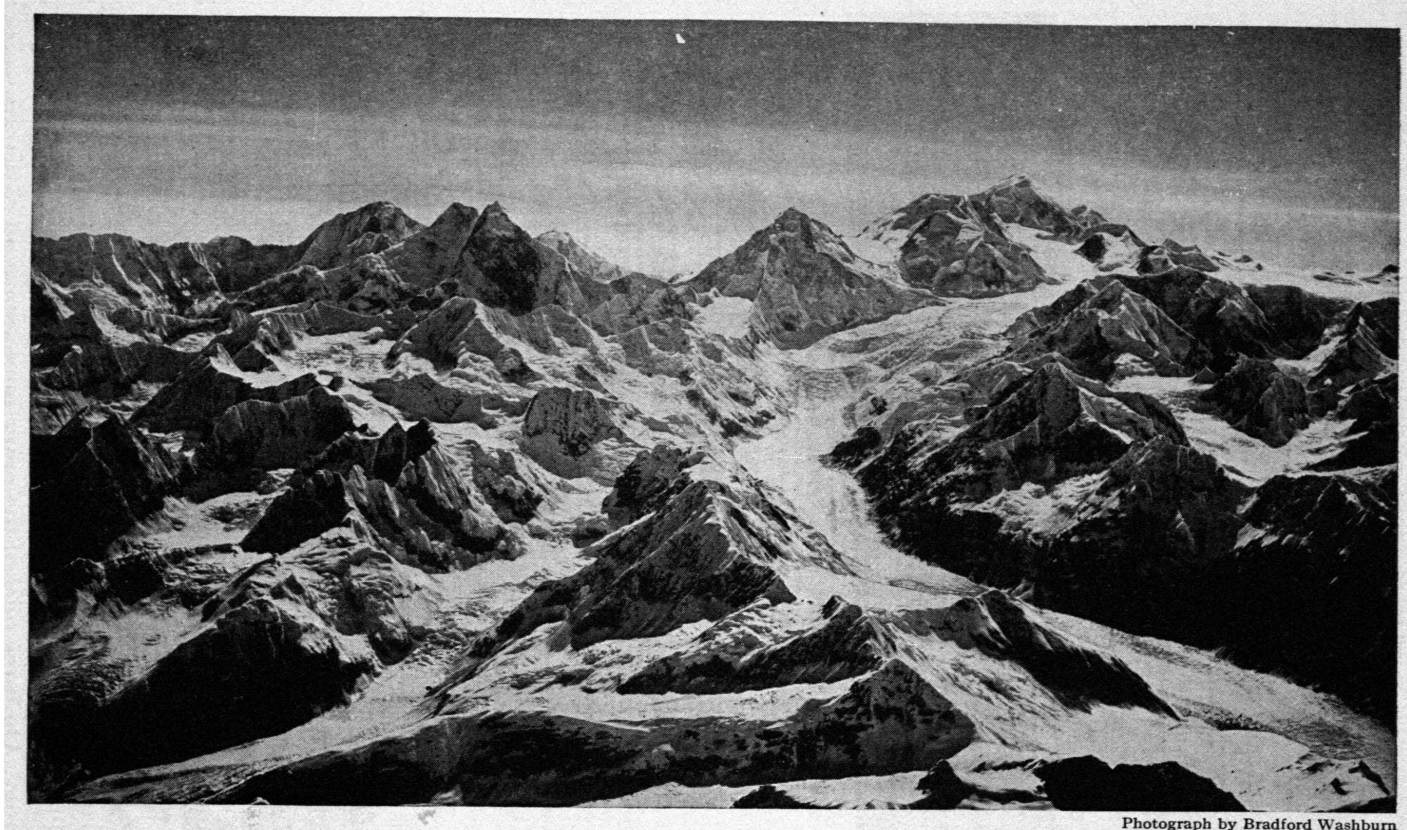


Figure 257 · Aniakchak Crater is in a chain of volcanoes near the divide on the Alaska Peninsula. The crater varies from five to six miles in diameter, and the walls rise from 1200 to 3000 feet above the level of Surprise Lake. The small cone, which is made of cinders, rises 2200 feet above the floor of the crater

The mountains on Vancouver Island, the Queen Charlotte Islands, and the outer islands of southeastern Alaska are much subdued by erosion and for the most part are heavily forested. Northward the tree line descends, and the summit areas in these mountainous islands come



Photograph by Bradford Washburn

Figure 258 · The east face of the Fairweather Range from an elevation of 1000 feet over Glacier Bay. Mount Fairweather (15,318 feet) is at the right, as is the Margerie Glacier, which descends to Tarr Inlet



Mendenhall, U. S. Geological Survey

Figure 259 · Mount Wrangell, an active volcano near the Copper River Basin north of Valdez

to be in the tundra belt. Northward from Glacier Bay the Fairweather Range, with Mount Fairweather rising to an elevation of 15,300 feet, is a magnificent sight from the Pacific Ocean. It is almost completely covered with snow and ice throughout the year, and several of the glaciers on the western slope reach to salt water. Northwest from Yakutat Bay is the St. Elias Range. On a clear day an observer cruising near the coast can see the entire 18,000-foot height of Mount St. Elias. At few places in the world can one see a greater amount of relief in a single view. The peak is a snow-white pyramid, and the middle and lower slopes of the mountain are so mantled with ice that very little rock appears. A score of glaciers descending from the range unite and form the largest piedmont glacier on the continent. This is the Malaspina Glacier, which reaches to the margin of the Pacific and at times, because of onward movement, breaks off and gives rise to icebergs.

The St. Elias Range has an average width of about 150 miles. It is a huge block with a nearly vertical wall on the north side. There is an abundance of evidence that this range has been uplifted during and since Pleistocene time. It is an example of an extremely youthful mountain range. On three sides of the range remnants of an old erosion sur-

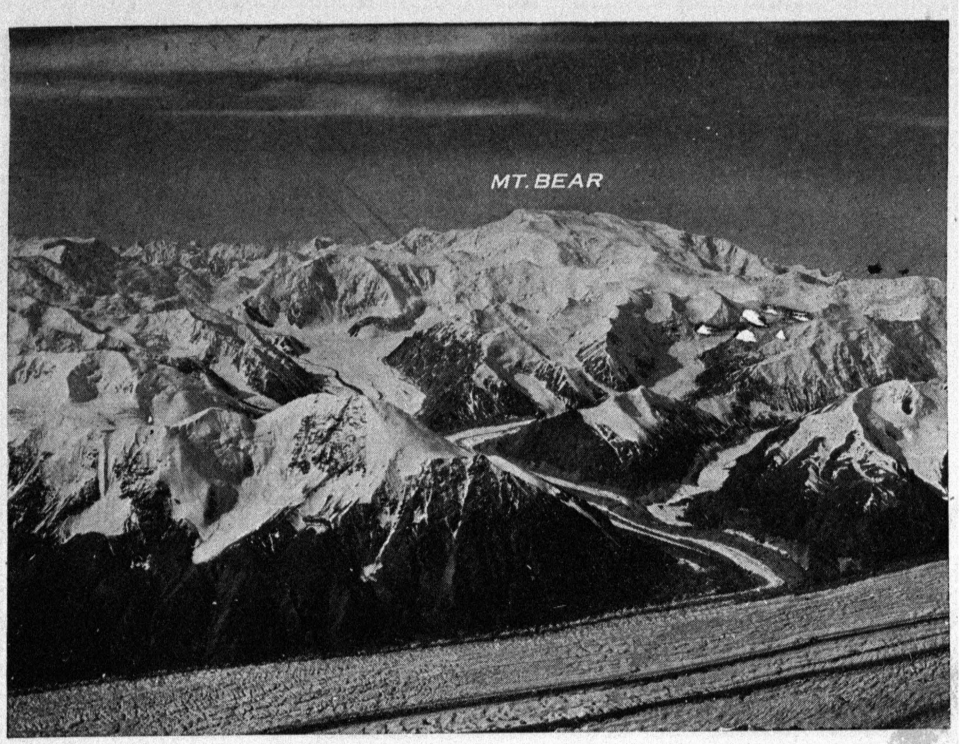
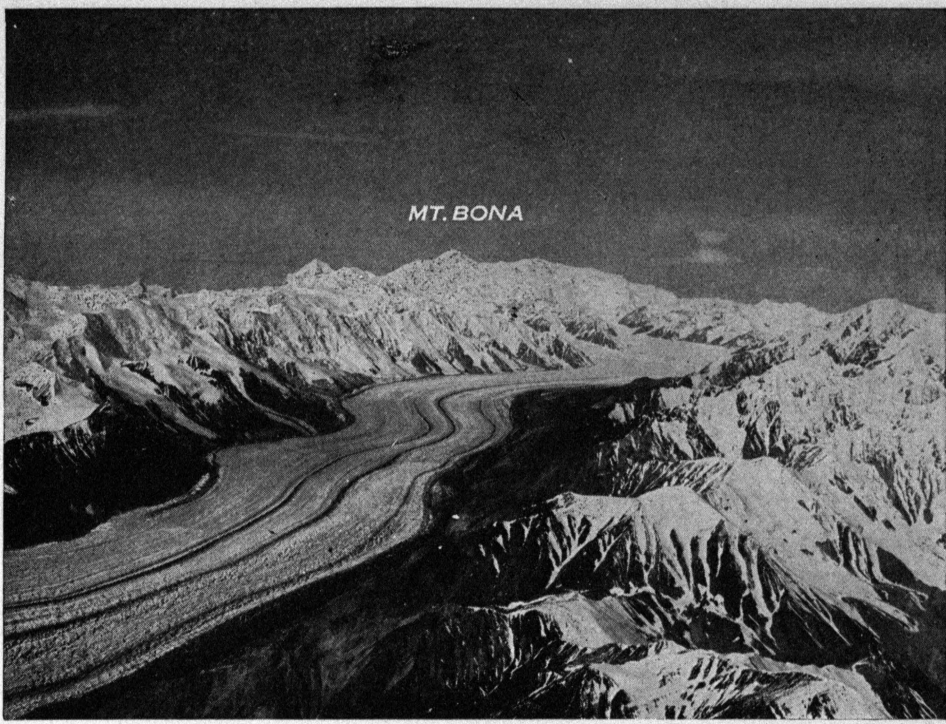


Figure 260 · Klutlan Glacier is near the east end of the Wrangell Mountains. Near the glacier crosses from Alaska into the Yukon Territory of Canada, and the drainage from Yukon. The mountain topography, catchment basins,

face have been reported, which may correspond in age to the peneplain remnants in the Yukon Plateau to the north. The north face of the St. Elias Range is undoubtedly a fault scarp. That bold mountain front rises at least 7000 feet above the adjacent plateau at its base.

Inland from the St. Elias Range there is a wilderness of snow-covered mountain ranges with long alpine glaciers in the valleys. They have been seen and photographed from the air by a few explorers. Here are Mount Logan (19,850 feet) and Mount Lucania (17,152 feet), the second and fourth highest peaks on the continent. Mount McKinley is the highest and Mount St. Elias is the third highest peak in North America. Between Mount Lucania and Mount St. Elias is a large basin almost completely filled with ice. The rugged beauty of this section is difficult to surpass, and in boldness the area resembles the high



Photograph by Bradford Washburn

catchment basin are Mount Bear (14,950 feet) and Mount Bona (16,400 feet). This the ice flows through the Klutlan River to the White River, which is a tributary of the and medial moraines are particularly well shown

Himalayas. Here is the most superb mountain scenery on the continent. See Figure 260.

In the vicinity of Yakutat Bay and in the fiords of Prince William Sound, there are numerous glaciers that reach to tidal waters and break off as they attempt to move beyond the border of the land. See Figures 262 and 263.

Few will ever observe a landscape such as that shown in Figure 261. The ice in the distance has recently retreated. Two unmodified esker ridges cross the lowland; the mud surface over which the ice advanced retains deep grooves which will soon disappear; an unmodified ice contact wall and an associated outwash appear at the left in the foreground. This photograph was taken from the air on the Alaska coast by Bradford Washburn.



Figure 261 · In front of a glacier

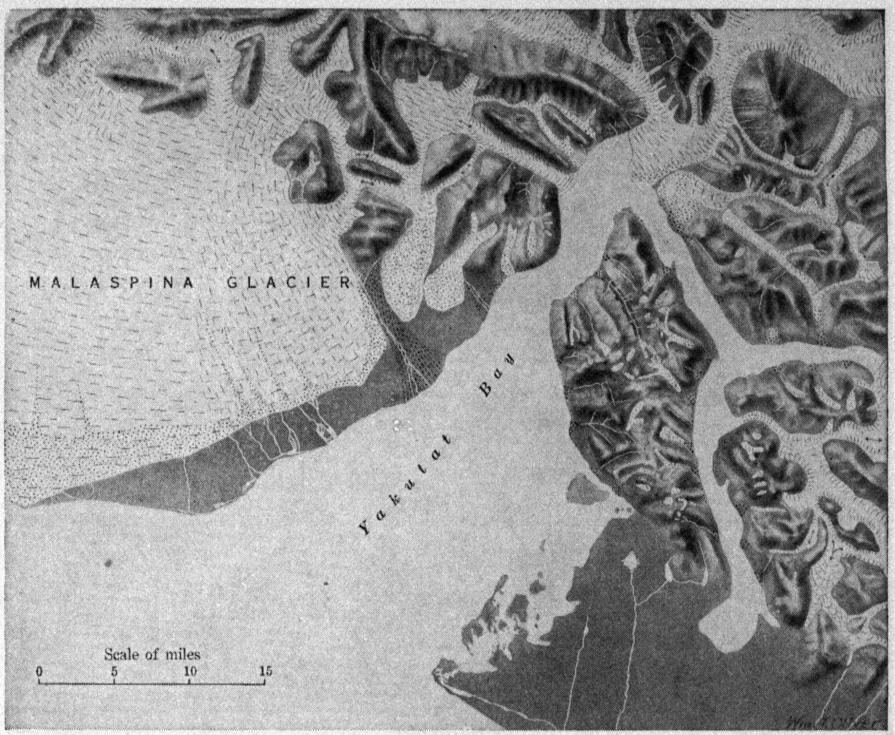
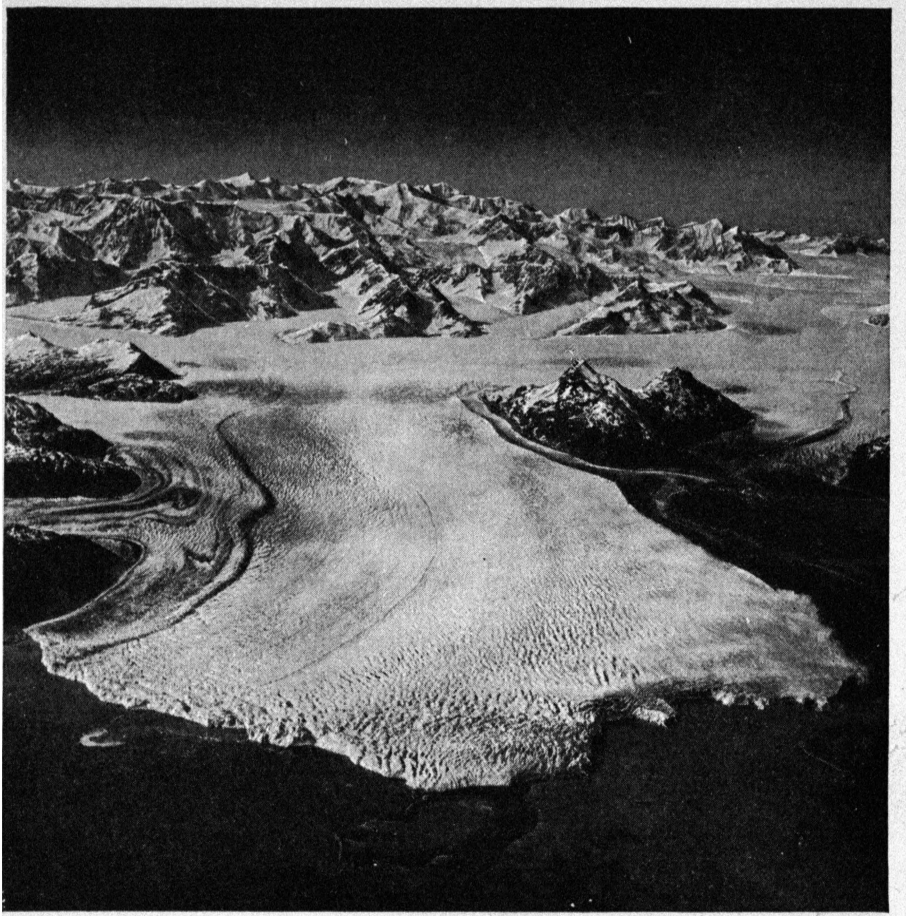


Figure 262 · The Yakutat Bay section of the Alaskan coast. The Malaspina Glacier, of which a small portion is shown, is formed by the union of several alpine glaciers that form on the slopes of Mount St. Elias. It is an excellent example of a piedmont glacier. Several of the smaller glaciers reach to tidal waters at the head of fiords and contribute icebergs to the sea waters. The flat lands near the coast are due in part to stream deposition and in part to recent uplift of the land

The Pacific Shore Line

The Pacific coastal features differ so markedly from those of the Atlantic seaboard regions that they deserve special consideration. Much of the Atlantic and Gulf coast is bordered by a lowland plain, with sand bars and tidal marshes near the coast. The New England and Acadian sections provide a few rocky headlands and picturesque islands, but nowhere in the East are there such bold, rugged, and magnificent coastal features as there are in the West, especially in British Columbia and Alaska.



Photograph by Bradford Washburn

Figure 263 · Columbia Glacier, taken from the air over Prince William Sound

Nowhere on the Pacific coast is there an extensive coastal plain. This shore line is characterized for many miles by modern sea cliffs, rock terraces, or old sea cliffs that indicate former horizons at which the waves have been at work. Shore-line pillars, sea caves, submarine benches, which are being worked over actively today by the powerful waves from the Pacific, give character to this margin of the continent. At a few places, sand and gravel spits, hooks, and barrier beaches have been built by the shore currents. The details of these shore-line features are well shown on the topographic sheets of this coastal belt.

Near San Diego. San Diego Bay, in southern California, has been formed by an offshore sand-and-gravel bar. See Figure 264. This curved bar, or hook, has developed as the shore currents have transported sands and gravel northward. The growth has continued until the bar has reached nearly to the bold, rocky headlands at Point Loma. Ballast Point is a minor spit which is growing eastward and making narrower the outlet of San Diego Bay. If not interfered with, the currents will in time close the outlet and make of San Diego Bay a shore-line lake, or lagoon. The mainland bordering this portion of the California coast shows clearly that it has been under water recently. The city of San Diego is on a marine terrace, and National City, South San Diego, Oneonta, and several other small settlements are located on the uplifted sea bottom. If the land along this coast should sink 25 feet, a new shore line would be established and the highlands west of Coronado. on which Point Loma is located, would become an island.

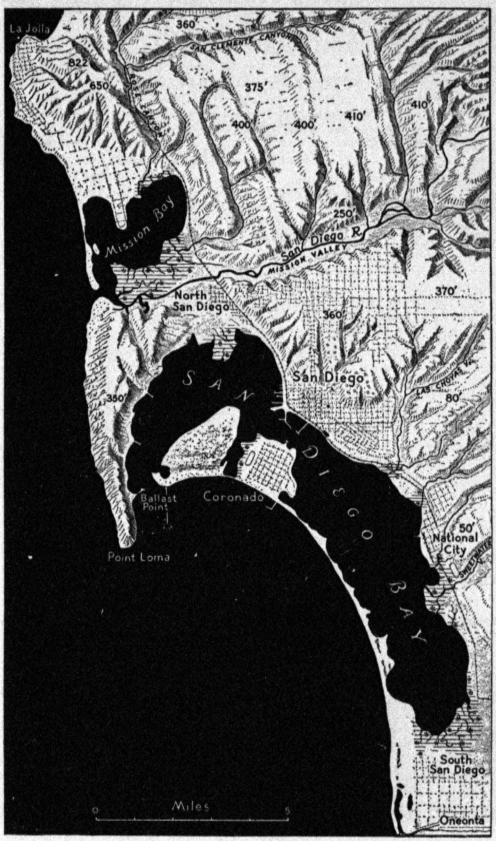


Figure 264 · The coast features near San Diego, California

Mission, or False, Bay. The bay near North San Diego is nearly shut off from the open ocean by the shore-line deposits. A rise of sea level of less than 25 feet would mean the joining of San Diego Bay with False Bay and the submergence of most of the town of North San Diego as well as San Diego proper, and a large part of Coronado.

La Jolla coast. In the La Jolla Quadrangle the marine terraces extend nine to ten miles inland from the coast and rise to at least 600 feet above the sea. They are here dissected by numerous streams which have sharply incised their courses into this recently uplifted land. The coast is bordered at places by precipitous cliffs notched by extremely youthful gullies. In several localities sand bars and spits have been developed by the shore-line currents.

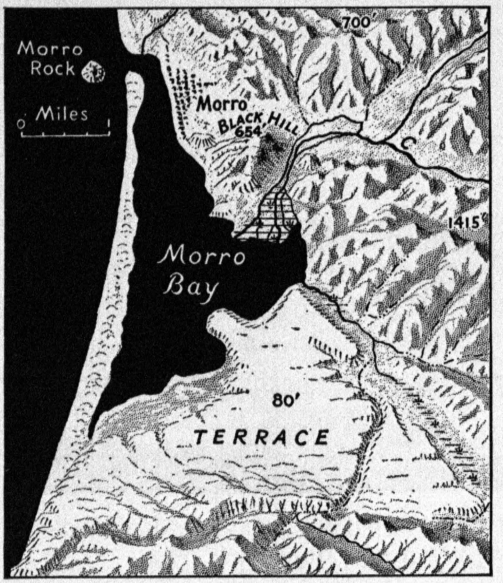


Figure 265 · Morro Bay on the California coast

Near Oceanside. North and south of Oceanside for several miles the immediate shore line has been made exceedingly regular by the deposition of sands and gravels. These deposits have closed in the mouths of several streams and thus formed lagoons or shore-line lakes. See Figure 248. These sand and gravel deposits are true barrier beaches. With the ponding of the streams the shore-line lakes have become sites of deposition and for the accumulation of vegetable matter. Many of them are now marshes or swamps. The estuaries and bays that existed at an earlier stage have been closed in by the shore-line activities, and the land margin has changed from one of irregularity to one of regularity. Unless there is some further change in the elevation of the land relative to sea level, we may anticipate that the coast will remain regular. An unusual storm may break through the barrier beaches at places and thus form outlets, but in time these breaks will be repaired by the shore-line currents. Exceedingly heavy flood waters might cause the overflowing of a shore-line lake and thus form a breach in a barrier beach, but in time that also would be repaired. The villages on the immediate coast are on a low sea bench, and inland a remarkable series of marine terraces rise as gigantic steps to an elevation of at least 500 feet.

Near Santa Clara. The Santa Clara River now fails to reach the ocean. Its lower channel is a broad expanse of sandy land in which the

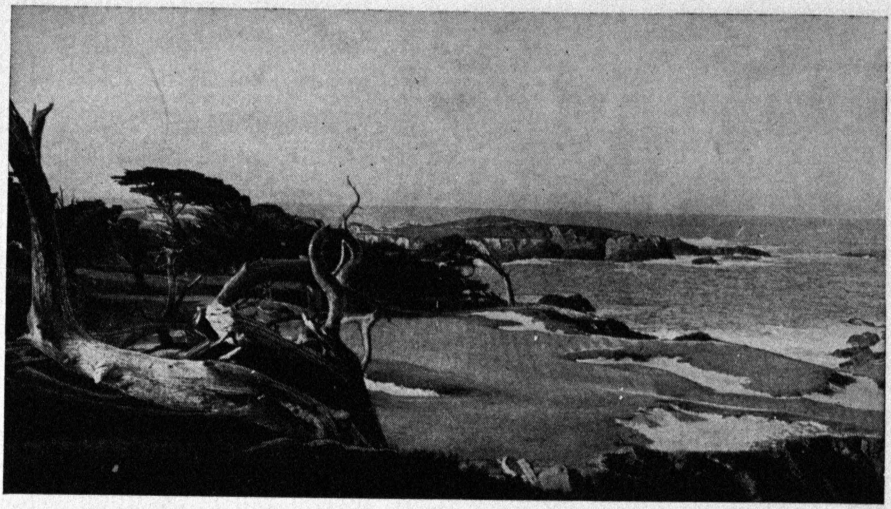


Figure 266 · Point Lobos, now a State Reservation, is a very picturesque headland at the south margin of Carmel Bay near Monterey Peninsula

river loses itself before reaching the coast. The immediate coast has become exceedingly regular and smooth. South of the Santa Clara, and especially south of the coastal village of Hueneme, there are numerous shore-line lakes. Inland from this coast there is a broad expanse of very low land. The 50-foot contour line is from three to seven miles back from the coast. This is an area recently uplifted from the sea.

Near Santa Barbara. The popular Santa Barbara district, which is today somewhat densely settled, is characterized by sea cliffs at places and elsewhere by low sandy shores. There are clearly defined marine terraces extending two or three miles back from the shore margin. These former sea-bottom lands extend inland and provide the building site of the city of Santa Barbara.

Morro Bay. Morro Bay is another example of a lagoonlike area nearly shut off from the sea by the drifting sand and gravel brought sometimes from the north but more often from the south by the shore-line currents. See Figure 265.

Near Point Lobos. The Monterey Peninsula, Point Lobos, and the coast for many miles to the south have sea margins that are strikingly beautiful. Here the hard rock formations which must meet the attack of the waves from the open ocean have been carved into picturesque headlands. Sea caves have been excavated in the cliffs, and rock pillars and rocky islands are just off the coast. There are but few coastal margins of the continent that present more strikingly the spectacular changes that are taking place along a rocky coast subject to the vigorous attack of ocean waves. Gnarled cypress trees cling to the wind-beaten headlands of this coast. See Figures 266 and 267.

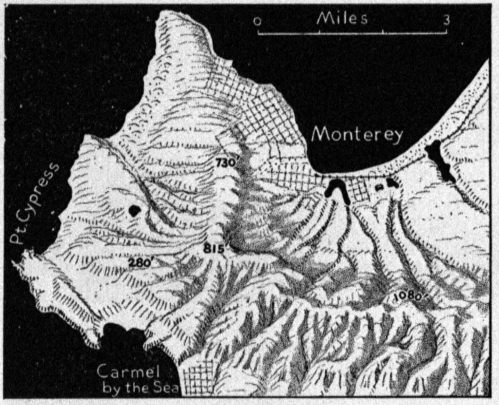
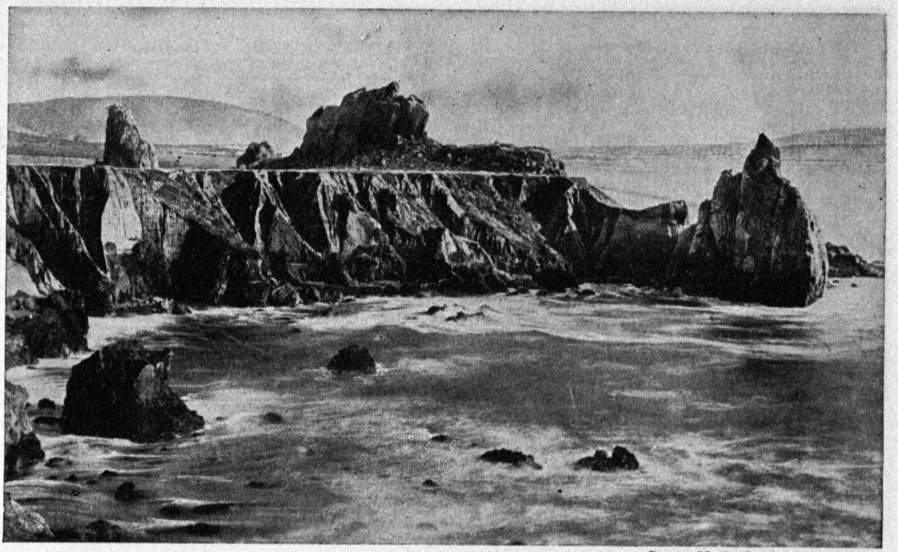


Figure 267 · On the ocean side of Monterey Peninsula the waves are actively at work. Sea caves, cliffs, and shore-line pillars are being carved at each of the rocky headlands facing the Pacific Ocean

The Golden Gate. The Golden Gate is by far the best known and the most significant break in the California coast line. Through this gateway vessels pass into the broad expanse of San Francisco Bay and thence northward into San Pablo Bay. The lowlands bordering these inland bodies of water are clear evidence of recent uplift of the land above the sea waters, and along the outermost coast there is an abundance of evidence in marine terraces of that same movement, but the gateway itself and the large bays are evidences of partial submergence.

The gateway is bordered by bold, rocky, and very picturesque headlands that make it, on a clear day, a passageway of striking beauty. The Pacific sea margin, south of the gateway, is bordered for some miles by a low sand-and-gravel beach, but this condition soon changes to a rocky sea cliff which extends for several miles and then blends into another lowland beach of sand and gravel. It is clearly a cut-and-fill coast which is reaching a stage of stability.

North of the gateway for about fifteen miles the sea margin is characterized by bold cliffs. Here the evidences of active wave erosion and



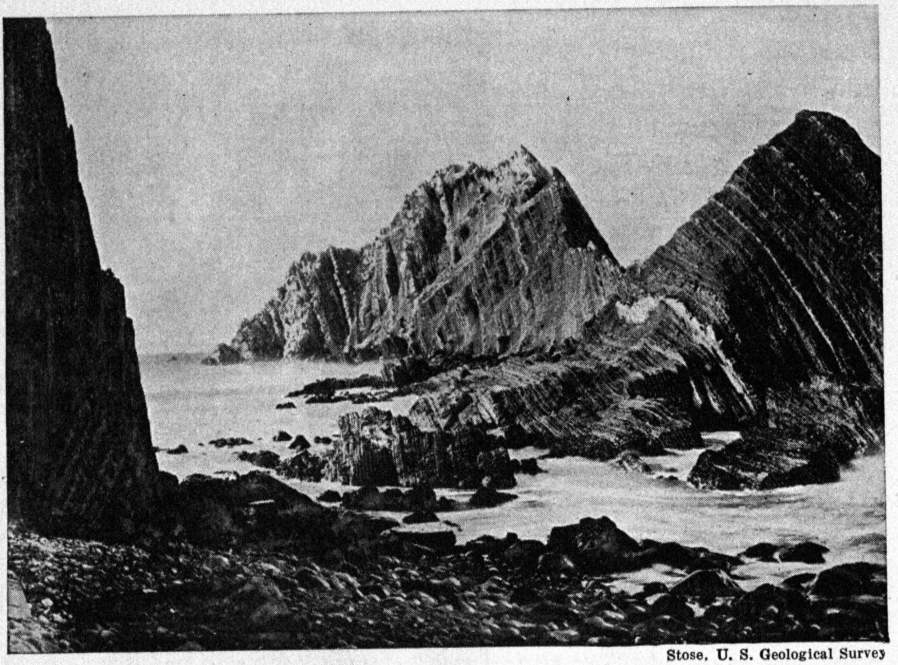
Stose, U. S. Geological Survey

Figure 268 · One of the best wave-cut terraces on the California coast. Marine planation on this terrace was not completed when uplift occurred, and the waves began work on another bench at a lower level

the destruction of the land are abundant. The coast appears to be growing more and more irregular in detail as the waves cut into the softer or less resistant portions of the terrain. Strikingly beautiful headlands and chimney rocks, or shore-line pillars, are common. Sea caves and shore-line grooves are carved in the cliffs by the attacking waves. See Figures 268 and 269.

Near Drakes Bay. At Drakes Bay the immediate coast line is a sand-and-gravel beach with a hooked end. Drakes Estero is nearly closed in by the shore-line deposits. Point Reyes stands out conspicuously because of its bold sea cliffs and rugged picturesque rock features. Many chimney rocks and islands appear just at the west end of Drakes Bay. Northward from that point the outer coast is exceedingly even. There the waves and shore currents have smoothed the outer margin of the land. Near Tomales Point, a little farther north, the sea margin is again marked by cliffs and rocky headlands. See Figure 270.

Northward from Port Orford. On the coast northward from Port Orford for thirty miles there is a well-defined terrace which is about



Stose, U. S. Geological Survey

Figure 269 · The Pacific Ocean waves are here attacking a series of upturned strata and carving them into bold and picturesque coastal features

500 feet above sea level at its inner edge. This terrace is mantled with marine sands that are underlain with hard rock formations which are exposed in bold headlands at Cape Blanco and at Coquille Point. Sea cliffs, offshore pillars, and little rocky islands have been developed by recent wave action and at these points they add a picturesqueness to the margin of the land. Between the rocky headlands the shore line has been made even and smooth by the sand and gravel which the littoral currents have distributed along that coast. The marine terrace continues northward to the bold headland region of Cape Arago, where there are other spectacular features known as Seven Devils. See Figure 271.

North of Cape Arago. Northward from Cape Arago for about thirty miles, the immediate shore is bordered by a zone two to three miles in width where the surface is mantled with sand and where there are

many sand dunes. The outer margin of the land is very even and regular. See Figure 272. Here the drift of the shore-line sediments is southward, and the accumulation of sand and gravel on the beach has turned the Umpqua River southward for at least five miles. The Coos River, which empties into Coos Bay, has had its mouth shifted southward at least five miles by the deposition of shore-line sediments locally known as North Spit.

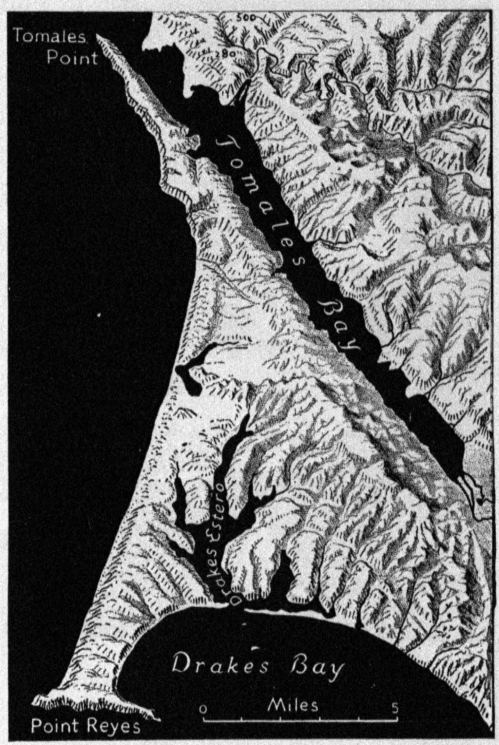


Figure 270 · The California coast in the vicinity of Point Reyes and Tomales Point

At various other points along the Oregon coast the marine terraces are mantled with sand and gravel and the outer margin of the land is characterized by little headlands joined together by sand and gravel deposits. On such a coast, where cutting and filling alternate, the land margin of the continent comes in time to be a somewhat regular or even line. That represents a late stage in the evolution of coastal features.

Grays Harbor. At Grays Harbor on the west coast of Washington the sand and gravel have drifted along the coast so that they have approached the harbor outlet both from the north and the south. See Figure 273. The drifting is so active that long jetties have been constructed to keep open the mouth of the harbor.

Near Port Angeles. The south margin of the Juan de Fuca passageway presents a large variety of shore-line features. Here sea cliffs rise

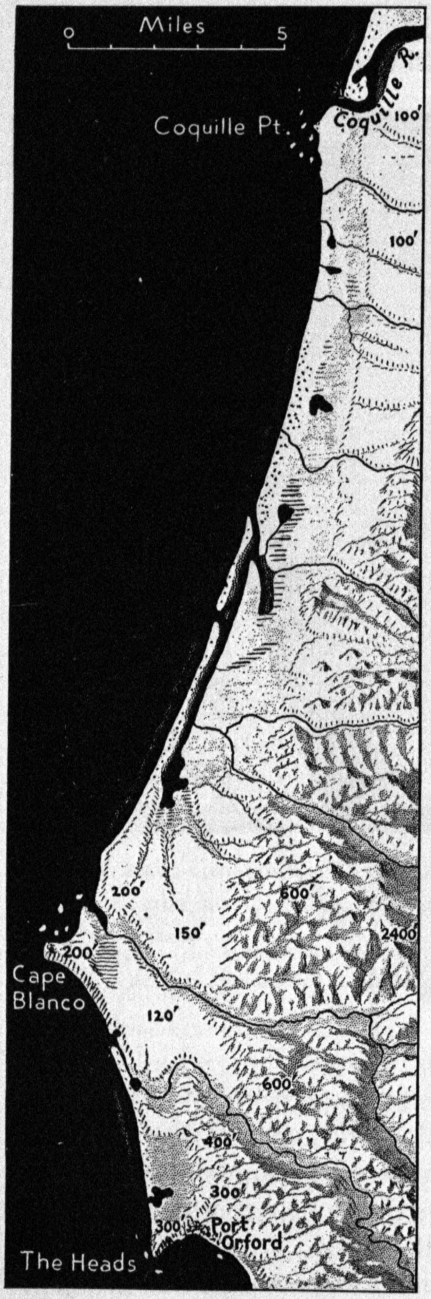


Figure 271 · The Oregon coast near Cape Blanco

600 to 700 feet above the tidal waters, bold headlands stand at Pillar Point as a precipitous wall nearly 500 feet in height, and marine terraces and numerous sand and gravel deposits are present. The harbor at Port Angeles is due chiefly to the development of the Ediz Hook. See Figure 274. The rivers along this coast all reflect in their sharply incised channels the effect of recent changes in the level of the sea water relative to the land.

Many Pacific coast shore-line features are illustrated on the topographic maps that are used in the laboratory exercise to accompany this chapter.

The coast of British Columbia and Alaska. In British Columbia and Alaska lofty mountains border the Pacific coast and at places the lands have been so depressed that the sea waters advance far into the mountain canyons and thus provide a deeply fiorded shore line. This combination of lofty snow-clad ranges with glaciers reaching to the sea and the numerous fiords cannot be matched except in Norway and southern Chile. Nowhere in the world is there a coast line with more striking scenic beauty than on the Pacific border of British Columbia and Alaska.

The famous "Inland Passage," which extends between the islands and the coast of British Columbia and southeastern Alaska from Vancouver to Skagway, is through a mountainous region that has been so depressed that the sea waters have come in and covered all the former park-like areas, and partially filled the great valleys and canyons. This coast is so beautiful that it is visited by many tourists. In an ocean-going vessel one may now drift peacefully over the alluvial-filled lowland of an intermontane basin, pass through a narrow canyon in which the side walls come in closer and closer, and in time move directly over a submerged divide. From there on, the walls of the passageway begin to recede, for we have entered at the head and are moving down a valley. The mouths of tributary streams, now drowned and occupied by salt waters, are parts of this fiorded coast line, and far off to the east are the snow-capped summits of the Coast Range, where glaciers are forming and descending seaward.

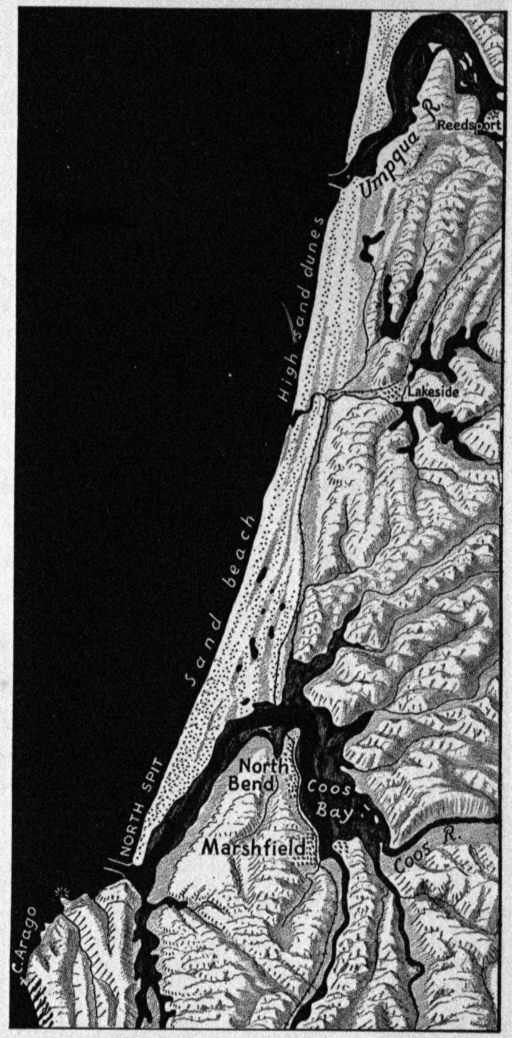


Figure 272 · The Oregon coast northward from Cape Arago

The numerous islands along the route are the tops of hills or mountains that are partially submerged. The peninsulas are the intercanyon ridges that now project into the sea waters. The great fiords are the

valleys, first cut by streams and later deepened and widened by rock-shod ice from the huge catchment basins near the mountain summits.

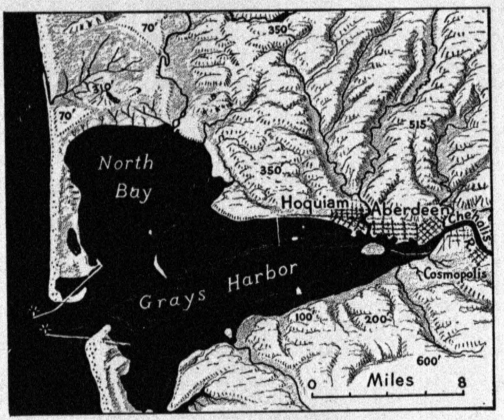


Figure 273 · Grays Harbor, Washington

As we move northward, the glaciers become longer and some of them reach to the sea water at the heads of the fiords. Their onward movement produces icebergs, and at places the Inland Passage may be so occupied by huge blocks of floating ice that our vessel must slow up and gently push away the ice so that no harm is done to the timbers below the water line.

At Taku the captain may, by a short detour, take us within a few hundred feet of the face of an active iceberg-making glacier. At the head of Glacier Bay we may visit Muir Glacier, which has been receding somewhat rapidly during the last three decades.

If we pass through Icy Straits into the open Pacific and follow the coast within view of the Fairweather and St. Elias ranges, we have one of the really great treats that come to travelers. These lofty mountains rise abruptly from the salt water to elevations of 13,000 to 18,000 feet. They are almost completely covered with snow and ice, but the underlying rock surface is so rough that there are deep shadows in the whitened surface, and where the glaciers pass over precipitous walls great crevasses disclose the blue and emerald shades of the ice and add variety to the color scheme in the picture. At the base of Mount St. Elias is the huge Malaspina Glacier, which reaches at places to the sea. See Figures 262 and 275.

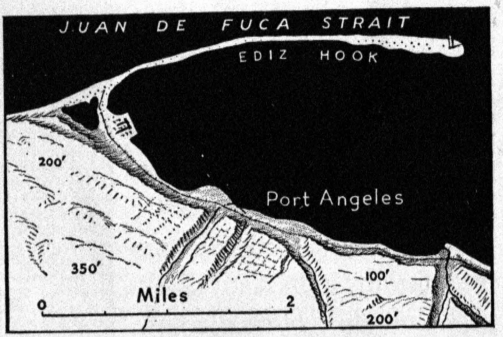


Figure 274 · Port Angeles, Washington



Photograph by Bradford Washburn

Figure 275 · The Johns Hopkins Glacier and Inlet. The ice was in the foreground in 1916, and by December of 1937 it had retreated six miles to the position shown in this view. Mount Crillon (12,728 feet) is at the left

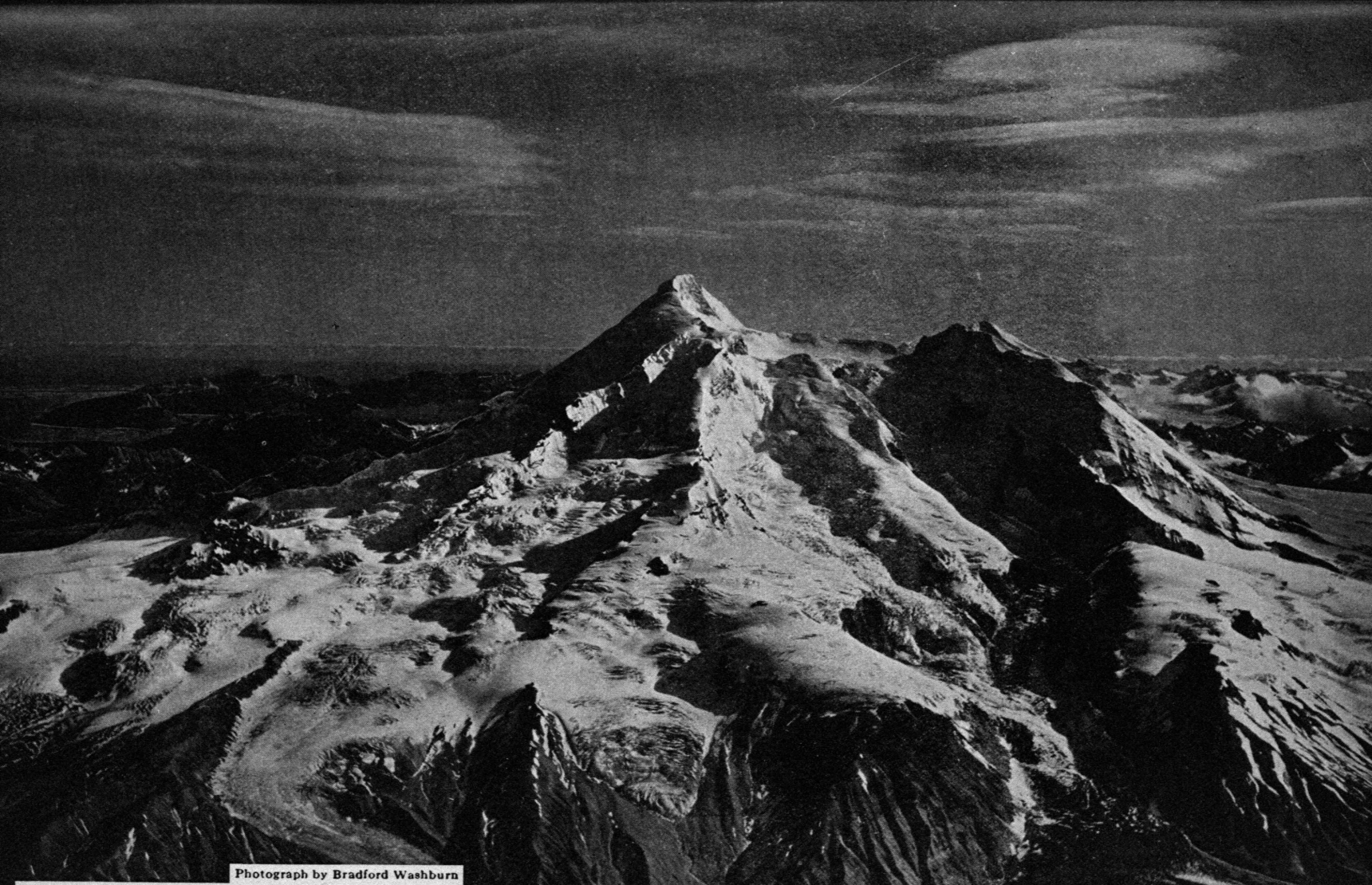
In the Yakutat Bay region and in the various arms of Prince William Sound there are more than a score of glaciers that reach to the sea. Many others come nearly to the coast. They are melting rapidly and they give rise to milky streams that commonly build alluvial plains in front of the receding ice and deltas at the heads of the bays. See Figure 262.

Westward from Prince William Sound the coastal features become less bold and picturesque. The shore lines of Cook Inlet are bordered by low grass-covered lands and a few hills. The mountains of Kodiak Island are softened and subdued by long erosion and clothed with forests. The Pacific margin of the Alaska Peninsula is indented, for that land has been somewhat depressed and there are neighboring islands that indicate that the sea has risen and invaded the land area. Back from the coast the crest line of the Alaska Peninsula presents a beautiful panorama of snow-covered summits and bold volcanic peaks. See Figures 276 and 277.

The great anticlinal arch that forms the Alaska Peninsula declines to the westward and is represented there by the chain of Aleutian Islands that reach nearly across the north Pacific Ocean. These islands are volcanoes that have formed along the submerged crest of the anticlinal fold.

The continental shelf. Bordering the Pacific margin of North America, the continental shelf is, at most places, much narrower than on the Atlantic coast. The 100-fathom, or 600-foot, depth of the ocean on the Atlantic coast is commonly 100 miles offshore, and at many places 150 miles away from the land. At that depth there is commonly found an abrupt slope into the abysmal portions of the Atlantic Ocean. On the Pacific side of the continent the 100-fathom depth is very near the present shore. Along the western borders of the United States and Mexico it is less than 50 miles offshore, and at many places less than 20 miles. Beyond that depth the sea bottom, at most places, descends very rapidly.

There is a wide platform off the coast of southern California. Here the abrupt change in slope, into the ocean basin, is about 150 miles offshore, and it begins at a depth of about 1000 fathoms. See Figure 247. The 100-fathom depth is just west of the chain of islands off the coast of British Columbia and southeastern Alaska, but in the Gulf of Alaska and on the south shore of the Alaska Peninsula the shallow-water



Photograph by Bradford Washburn

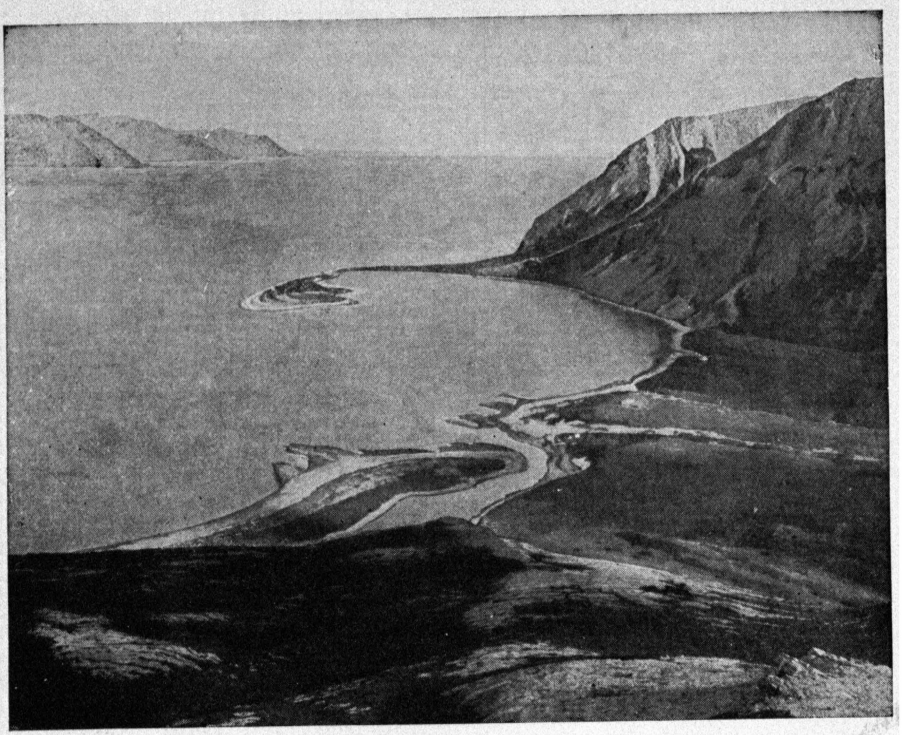


Figure 277 · Hook Bay, on the south shore of the Alaska Peninsula. The sand-and-gravel hook forms a harbor used by small vessels during severe storms

zone is 100 to 150 miles wide. At the Pacific Ocean margin of the continental platform, just as at the Atlantic Ocean margin, there is everywhere present a sudden drop-off to the great depths of the ocean basin.

The topography of this submarine bench is known in detail at a few places. In southeastern Alaska and off the coast of British Columbia the soundings are sufficient to indicate that many of the great canyons which are now fiords continue across the belt of shallow water to the outer margin of the continental shelf. To the east of Queen Charlotte Island, in what is known as Hecate Strait, there are no known depths in excess of 100 fathoms.

At the outer margin of the shelf west of the United States there are a number of submarine canyons similar to those described at the outer margin of the Atlantic portion of the continental shelf (page 29). Some of these submerged canyons extend nearly across the shelf and appear

to be related, in a general way, to valleys on the present land surface. More commonly these outer marginal canyons, or gulches, are extremely youthful and in no way related to the drainage on the lands of today.

The submarine land surface off the coast of southern California has been surveyed with the help of sonic depth-finders, and for that area there is detailed information available. Here there are long, bold escarpments that suggest a continuation offshore of the type of faulting which characterizes the seaward margin of the lands in California. Many of the islands, and certainly Santa Catalina and San Clemente, are fault blocks, and in that respect they resemble certain of the coast ranges. These islands are bounded on one side by steep walls, and on their gentle slopes there are numerous wave-cut terraces which indicate recent changes in level relative to the sea. The summits of these islands resemble parts of an old peneplain and remind us of similar features in the Coast Ranges of California. The entire seaward area included in Figure 247 is one in which structure is of prime importance in explaining the islands and the major relief features in the submarine land surface. In the clifflike margin of this platform there are a number of short, steep-sided canyons or gorges.

The submarine canyons at the outer margin of the shelf present an unsolved problem here, as they do on the Atlantic coast. If they are due to stream erosion when the land was much higher, there must have been an uplift of the continent of several thousand feet. That hypothesis may be correct, but it cannot as yet be accepted with full confidence. The suggestion has been made that these gorges date far back into geologic history, before the formation of the continental shelf, and have since been filled with material which has moved out as landslides or mud flows into the deeper portions of the ocean. Another idea is that they are due to faulting or folding and are, therefore, of structural origin. The suggestion has been made that tidal currents may have taken part in excavating these gorges. Even springs at the outer edge of the shelf have been appealed to in the search for some way to explain these rather remarkable valleys. In a recent article the various hypotheses for the origin of the canyons in the continental shelf have been analyzed.[1]

[1]D. W. Johnson, "Origin of Submarine Canyons," *Journal of Geomorphology*, Vol. 1, No. 2 (1938), pp. 111–128; Vol. 1, No. 3 (1938), pp. 230–243.

An Approach to the Modern Human Drama

As early as 1578 Sir Francis Drake visited the Pacific coast of North America, and in 1741 Vitus Bering, a Danish navigator sent by Empress Anne of Russia, explored the portions bordering Alaska, where his name has been indelibly impressed upon world maps. Captain Cook, the courageous British explorer, visited the western coast of the continent in 1778 and traveled far to the north. His name was given to Cook Inlet on the coast of Alaska. Spanish explorers and adventurers, as we have already noted, moved northward from Mexico into the southwestern portion of what is now the United States, and played a considerable part in the settlement of what is now southern California. The imprint of their culture is still evident in architecture and customs in that section.

When news of the discovery of gold in California reached the rest of the world there was a grand stampede for the valleys in the Sierras. The discovery was made in a very simple, accidental way by one who was working at a lumber mill, but who from curiosity was washing some of the gravel from the channel of a stream. An effort was made to keep the news of his discovery from spreading, but that was impossible. Soon there were thousands washing the stream gravels of California.

Up to 1849, the year of the great gold rush, gold mining had been of comparatively little importance in this country, but in 1850 the gold yield of California alone was valued at approximately fifty million dollars. During the next few years thousands of people went westward and attempted to cross the plateau deserts with horses or ox teams. Some trudged on foot for many a weary mile. Many of those who started westward never reached the gold fields. Others instead of crossing the cordilleran portion of the continent went southward by sea, crossed the Isthmus of Panama, and sailed northward. Some went by boat from the eastern seaboard by way of Cape Horn and thence northward along the west coast of the Americas until they reached California.

With the coming of multitudes of gold-seekers there were many who, disappointed in mining, took to farming, and the rich valley lands of California began to produce food crops. The population of California increased from 92,597 in 1850 to 365,439 in 1860. See Figures 278 and 279.

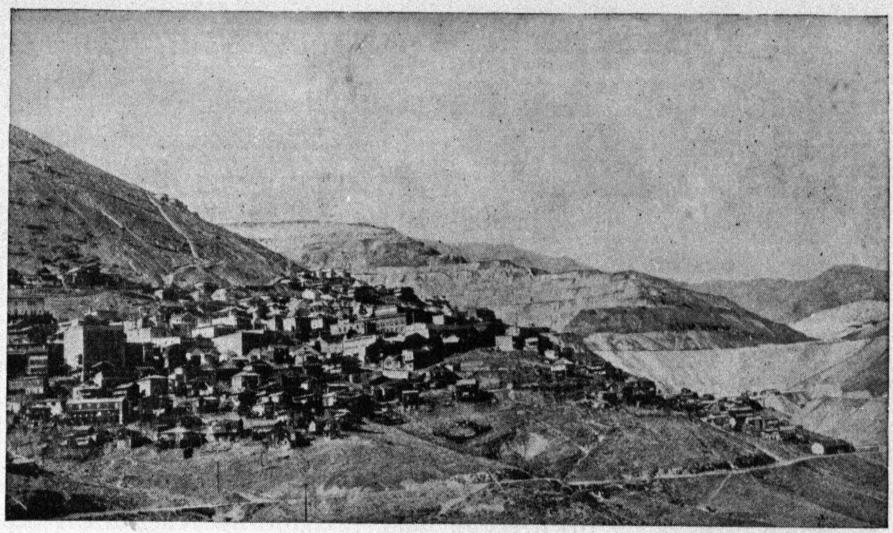


Figure 278 · Jerome, Arizona. A copper-mining camp in the mountains just west of the Colorado Plateau

The great forests of the West provided a wonderful supply of timber, and some people, becoming interested in that resource, began to export building material from the west coast to other parts of the world. See Figure 280. Many came to be traders. In time prosperous communities were established, which have continued to expand and develop and to make more and more varied the agricultural, industrial, commercial, social, and cultural phases of life near the Pacific coast.

In southern California, near the coast, a great citrus-fruit region has developed, and here many of the best of our moving pictures have been produced. This section of the continent has a very healthful climate with an abundance of sunshine and it has attracted a large permanent population. Each year thousands of travelers choose this section of the country as a vacation land. Near and at the coast in California there are several productive oil fields.

Active trading is now carried on between the Pacific ports of this continent and the ports of Hawaii, New Zealand, Australia, the Philippine Islands, and all Oriental countries. Thousands of tourists turn their faces westward and make plans to leave a Pacific coast port to visit the centers of the very old Asiatic civilizations.

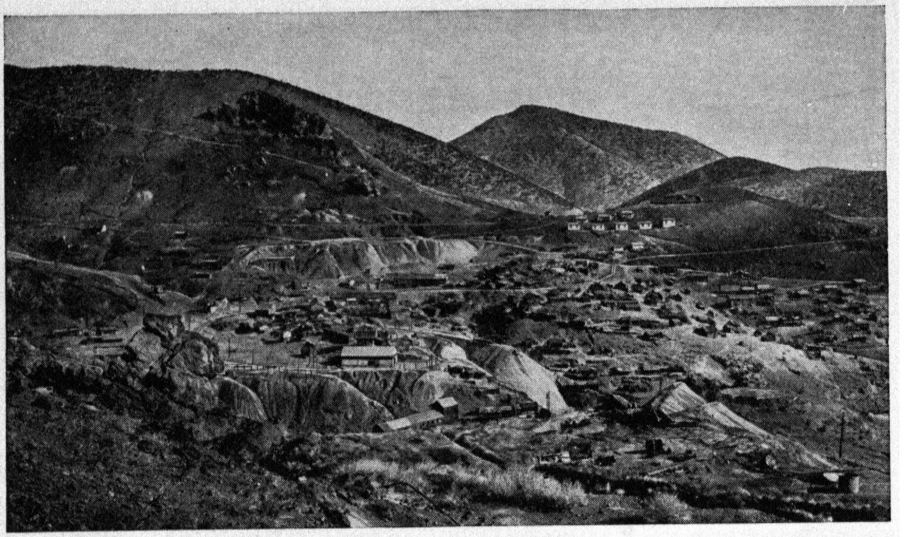


Figure 279 · Cananea mining district in the Western Sierra Madre of Mexico

Washington and Oregon, with their mountain valleys and the Puget Sound–Willamette Valley Lowland, furnished attractive opportunities to settlers. The forests in the northwest, of Douglas fir, spruce, and pine, constitute the largest forest reserve in the United States. As in California, water power and water supply for cities and towns and for irrigation purposes are abundant.

In addition to the gold which first attracted the mining men, silver, lead, zinc, copper, coal, and oil have been found. As exploration pushed northward into British Columbia and Alaska, more gold and large supplies of copper were found and some new coal fields were located.

The settlement and economic development had proceeded far when the discovery of gold in the Yukon Territory of Canada attracted other thousands of people to the Pacific coast. Fully forty thousand people left their homes in various parts of the world and rushed to the Pacific northwest. Many of them crossed through Chilkoot Pass to the headwaters of the Yukon. Others went by way of White Horse Pass; some went to the mouth of the Yukon and worked their way up that stream for 1600 miles to the Klondike district near Dawson. A few who stopped on the beach where Nome, Alaska, is now located, discovered gold there. The great gold discoveries in Alaska and near Dawson were not strictly



Grant, National Park Service

Figure 280 · A log of Douglas fir going to market. This log is over nine feet in diameter and scales 7000 board feet of lumber. The picture was taken near Baker Lake, Washington

in the Pacific Borderlands as we have defined them, but the gold discovered near the Yukon and on the beach bordering Bering Sea brought great hordes of people to San Francisco, Seattle, Vancouver, and to many of the less important ports on the western coast. It attracted many who have since made their homes on the Pacific coast of the United States, British Columbia, or Alaska.

As settlement and economic development continued, the fisheries of this western coast came to have great importance. There are no streams in the world which provide so vast a supply of salmon as do those of Oregon, Washington, British Columbia, and Alaska. There are salmon canneries far out on the Alaska Peninsula. Whaling, cod fishing, and various other phases of the fishing industry have been developed on this coast.

In the High Sierras, and in their logical northward continuation, the Cascades, are found some of the most attractive of the wonderlands on

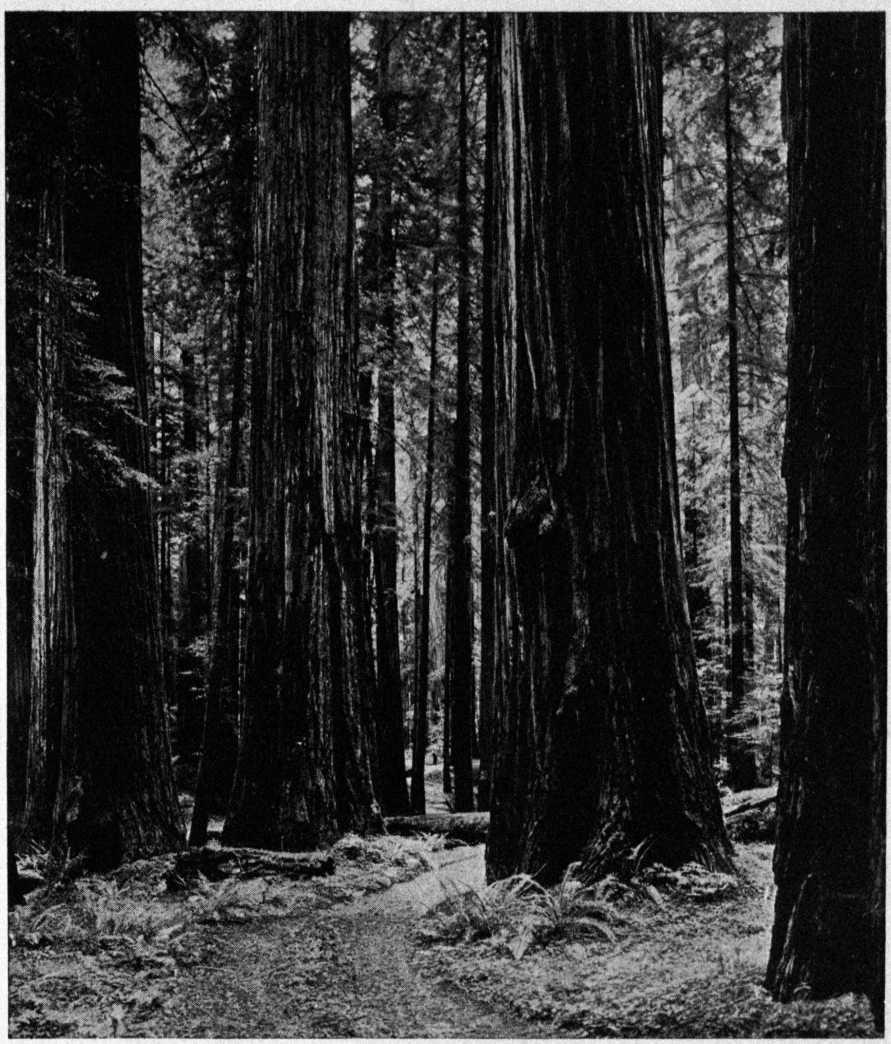
the continent, and several of these have been set aside as national parks. The Sequoia National Park, Yosemite Valley, Lassen Peak, Crater Lake, and Mount Rainier are areas unique in their educational, scientific, and inspirational values.

Much of the Pacific Borderlands region is still a wilderness and exceedingly attractive for recreational purposes. Thousands of people visit the High Sierras and the Cascades each year during their vacation periods, living perhaps in the national parks or in the national forests. Many now come in the winter to enjoy winter sports among the mountains. A winter life comparable to that in Switzerland is developing in portions of the high mountain areas of the Pacific Borderlands.

Near the shores of the Pacific, north of San Francisco, are the groves of the famous redwood trees. These trees are limited to that section of the continent. Such trees are found nowhere else in the world, and in beauty and sublimity are unsurpassed among the plant forms on the surface of this earth. See Figure 281.

The harbors which, we recall, are due in almost every instance to a recent depression of the coastal region have played a very important part in the location of many of the chief cities and in the commercial development of this portion of the continent. Seattle and Tacoma are located on Puget Sound, which furnishes extensive harbor facilities. Portland, in large part on the Willamette River, near its junction with the Columbia, can be reached by seagoing vessels. San Francisco and Oakland are on San Francisco Bay where sea waters enter the continent. Vancouver and Victoria and the small ports farther north in British Columbia and in Alaska are all located on drowned river mouths or on bays that have been formed by the sinking of the land at the margin of the sea. Los Angeles was located inland, but the city has been extended to the coast where, at considerable expense, good harbor facilities have been provided.

Turn to the population map (Figure 6) and notice the relative density of population in the Pacific Borderlands, especially within the United States, as compared with the density in other parts of the western half of the continent. That map presents convincing evidence of the attractiveness of the lands in California, Oregon, and Washington. The southwestern portion of British Columbia is well settled, but farther north the bold, rugged coastal area remains a primitive wilderness.



Photograph by Gabriel Moulin

Figure 281 · Among the redwoods on Bull Creek Flat near the coast in northern California. This is one of the groves that have been set aside as a State Reservation through the efforts of the "Save the Redwoods League"

The European immigrants who reached the Atlantic seaboard and there established new nations kept their faces turned eastward for several generations. As the population increased and adventurous souls pushed westward, the frontier of settlements in the United States and in Canada moved slowly toward the Pacific Ocean border. Near that

coast new communities were established and those communities have maintained their loyalty to the new nation and to the people of the East, but in many respects their faces are turned westward to distant lands where new contacts are being established.

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SELECTED LIST OF TOPOGRAPHIC MAPS FOR THE PACIFIC BORDERLANDS

Aniakchak District, Alaska
Controller Bay Region, Alaska
Kamishak Bay, Katmai Region, Alaska
Pavlof Region, Alaska
Valdez and Vicinity, Alaska
International Boundary, Alaska–British Columbia (Sheet No. 10)[1]
International Boundary, Alaska–British Columbia (Sheet No. 13)[1]
Sumner Strait and Vicinity, Alaska–British Columbia

Schoen Lake, British Columbia[2]

Cedar Lake, Washington
Chelan, Washington
Hoquiam, Washington
Mount Rainier National Park, Washington
Mount St. Helens, Washington
Ocosta, Washington
Olympia, Washington
Port Angeles, Washington
Port Crescent, Washington
Pysht, Washington
Snohomish, Washington
Sultan, Washington
Tacoma, Washington
Hood River, Washington–Oregon

Boring, Oregon
Coos Bay, Oregon
Crater Lake National Park, Oregon
Eugene, Oregon
Halsey, Oregon
Heceta Head, Oregon
Mount Hood, Oregon
Oregon City, Oregon
Siltcoos Lake, Oregon
Medford, Oregon–California

Carson, Nevada

Bishop, California
Brighton, California
Buena Vista Lake, California
Caliente, California
Canoas Creek, California
Capitola, California
Cayucos, California
Colfax, California
Copperopolis, California
Cucamonga, California
Deepwell Ranch, California
Dinuba, California
Dunsmuir, California
Elizabeth Lake, California
Hollywood, California
Inglewood, California
Kaiser, California
Kernville, California
Kettleman Plain, California
La Cima, California

[1] Published by the International Boundary Commission, Washington, D. C., or Ottawa, Canada

[2] Published by Surveys and Engineering Branch, Department of Mines and Resources, Ottawa, Canada.

Lovdal, California
Marysville Buttes and Vicinity, California
McKittrick, California
Monterey, California
Mt. Goddard, California
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Venice, California
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Yosemite Valley, California
Zelzah, California

Culiacan, Mexico[1]

[1] Published by American Geographical Society of New York (Scale, 1:1,000,000).

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