

*TEXT IS LFY
WITHIN THE BOOK*

UNIVERSAL
LIBRARY

OU_156819

UNIVERSAL
LIBRARY

OSMANIA UNIVERSITY LIBRARY

Call No. 556/F98 G Accession No. 45002
Author Furon, R.
Title Geology of Africa. 1963.

This book should be returned on or before the date last marked below.

Geology of AFRICA

Geology of AFRICA

RAYMOND FURON

Assistant Director of the French National
Museum of Natural History

Translated by

A. HALLAM and L. A. STEVENS

OLIVER & BOYD

EDINBURGH AND LONDON

OLIVER AND BOYD LTD.

Tweeddale Court
Edinburgh 1

39a Welbeck Street
London, W.1

A translation of the second edition of *Géologie de L'Afrique*
by Raymond Furon, published in 1960 by Payot, Paris

ENGLISH EDITION

First published 1963

© Translation 1963, Oliver and Boyd Ltd.

Printed in Great Britain
by T. and A. CONSTABLE LTD., Hopetoun Street
Printers to the University of Edinburgh

TRANSLATORS' PREFACE

The achievement of independence by many African countries in the last few years has necessitated bringing up to date the political geography of Professor Furon's book. In the case of the Malagasy Republic, however, the older and very familiar name of Madagascar is retained. The coming into existence of two new republics of the Congo is a potential source of confusion. In our translation the former French Congo is called the Congo Republic and the former Belgian Congo translated simply as the Congo.

The other main change concerns the references, present as footnotes in the original. These are now treated as in the standard English geological literature and placed at the ends of chapters. The index has not been expanded.

Stage terms have been left unchanged, even though there might be differences between French and English usage. Generally speaking, geographical names in French-speaking countries have been left untranslated. Similarly, such well-known stratigraphical terms as "Continental intercalaire" and "Continental terminal" have been retained as there is no satisfactory English equivalent.

We have found that a little confusion may arise with two frequently occurring words. *Schiste* can variously be rendered in Furon's book as schist, slate or shale. In deciding which, we have been obliged to consider the context and also, in a few cases, to check the relevant English literature. The term *série* has a more comprehensive use than the English "Series", which, as usually understood today, is merely the member of a whole hierarchy of specific stratigraphical terms. It is often best translated as "succession".

We should like to acknowledge our gratitude for the help received from Professor Furon in the translation of several difficult words and phrases.

One of us (L. A. S.) was responsible for the translation of the first nineteen chapters and the other (A. H.) for the remainder, but there has been a good deal of mutual consultation and discussion.

A. HALLAM
L. A. STEVENS

FOREWORD

Although Africa is renowned for its richness in such minerals as petroleum, gold, diamonds, iron and manganese, its geology is still inadequately known. Except for a few favoured areas, Africa is poor in fossils. The geologist must therefore utilise all the resources at his disposal to establish sound stratigraphical successions and correlations. The first stage in the study of African geology has been the determination of local successions without consideration of age, and correlations between neighbouring areas have only been tentative. Geologists in Europe have tended to look down on this type of stratigraphy, worked out laboriously by a small number of geologists often working under exceptionally difficult conditions.

The four volumes of Krenkel's *Geologie Afrikas*, published between 1925 and 1938, summarise the knowledge acquired by the inter-war period. Slowly the blank areas on the maps have been filled by tenacious Belgian, British, French, Italian and Portuguese geologists. Progress has been so rapid that a committee of specialists has been able to agree on certain stratigraphical correlations and on the outlines of the *Carte géologique internationale de l'Afrique*, published by the Bureau d'Études géologiques et minières coloniales, Paris. This consists of nine 1:5,000,000 sheets, the last of which appeared in 1952. The first edition of this book (1950) summarises the state of work up to that time.

Much new work has been done in recent years. Application of new techniques in geochronology in the southern part of the continent and fossil discoveries in the northern part have thrown new light on matters which had hitherto been obscure.

In 1960 the geology of Africa required a new account, which is presented here. It is divided into two parts: (1) *General Geology*, which deals with the stratigraphical succession peculiar to Africa, and the broad outlines of the palaeogeography; (2) *Regional Geology*, divided into twenty-five chapters dealing with the present state of knowledge in each region. The Mediterranean domain of North Africa ("Outer Africa") is not considered. Other omissions will certainly be found.

Numerous references have been included to enable original texts to be consulted. Illustrations, reduced to a minimum, are

confined to sketch-maps and sections. Cartographic details will be found in the maps and works cited.

A beginning has been made in the understanding of the geological reasons for the long-recognised difference between the northern and southern parts of Africa, separated by the swell of crystalline rocks extending from Cameroun to East Africa.

The geology of Africa is the work of only two generations, of a small number of courageous men who have dedicated their lives to their passion, for which some have died, through assassination or by succumbing to the desert and tropical forest. The geology of the African continent has not yet fallen into the public domain. Each area evokes the name of a particular geologist. I have summarised the work of all of them, hoping to arouse fresh curiosity and stimulate new enthusiasm.

R. F.

Paris, 15th December 1959

CONTENTS

TRANSLATORS' PREFACE	v
FOREWORD	vii

PART ONE

GENERAL STRATIGRAPHY

I	THE PRE-CAMBRIAN	3
II	THE LOWER PALAEOZOIC (?): INFRA-CAMBRIAN The Stromatolite Sea.	8
III	THE PALAEOZOIC: CAMBRIAN-SILURIAN, DEVON- IAN AND CARBONIFEROUS	11
	1. Africa north of the Equator. 2. Africa south of the Equator.	
IV	THE PERMO-TRIAS OF AFRICA NORTH OF THE EQUATOR	25
V	THE UPPER CARBONIFEROUS AND PERMO-TRIAS OF AFRICA SOUTH OF THE EQUATOR: THE KARROO	29
	1. Glaciation (Dwyka Formations). 2. Lower Permian: Ecca Formations. 3. Upper Permian-Lower Trias: Beau- fort Formations. 4. Upper Trias: Stormberg Formations. 5. The Marine Permo-Trias of the Eastern Coast and Madagascar. 6. Triassic Volcanic Activity.	
VI	THE NORTHERN LIMIT OF POST-HERCYNIAN AFRICA	36
	1. The south-Atlas Structural Line. 2. The Saharan Sill. 3. The Major Palaeogeographic Units of Barbary.	
VII	THE JURASSIC	40
	1. Continental Jurassic. 2. Marine Jurassic.	
VIII	THE CRETACEOUS	47
	1. Continental Infra-Cretaceous. 2. Marine Cretaceous.	
IX	THE PALAEOGENE	53
	1. Lower and Middle Eocene. 2. Upper Eocene-Oligocene.	
X	THE NEOGENE	61
	Marine Miocene. Continental Tertiary. Flora of the "Continental Terminal".	

xI	THE QUATERNARY	68
	Continental Quaternary. Quaternary and Recent Volcanic Activity. Notes on Laterites.	
xII	TECTONIC DEFORMATION OF THE AFRICAN BASEMENT	76
	Fractures, Domes and Basins.	

PART TWO

REGIONAL GEOLOGY

xIII	CENTRAL SAHARA	87
	1. Pre-Cambrian of the Hoggar. 2. The Tassilian Enclave. 3. "Continental Intercalaire" between the Hoggar and the Saoura. 4. Continental Post-Tassilian and Intercalaire of Djoua and Fort-Polignac. 5. The Tademaït and Tinghert Plateau. 6. Quaternary of the Hoggar.	
xIV	WESTERN SAHARA	106
	1. The Tindouf Syncline. 2. Saoura Basin. 3. The Colomb-Béchar-Kénadza Basin. 4. The Hamada du Guir. Continental Cretaceous and Tertiary Formations. 5. Pre-Cambrian of the Dorsale Reguibat. 6. Taoudéni Syncline. 7. The Recent Formations of Western Mauritania.	
xV	EASTERN SAHARA	135
	1. The Depressed region between the Hoggar and the Tibesti. 2. The Tibesti, Borkou and Ennedi.	
xVI	LIBYA	142
	1. Tripolitania and Cyrenaica. 2. The Fezzan. 3. The Djebel Ouenat.	
xVII	EGYPT AND THE SUDAN	152
	1. Egypt. 2. Sudan.	
xVIII	ARABIA	170
	1. Pre-Cambrian. 2. The Sedimentary Cover.	
xIX	SENEGAL	175
	1. Pre-Cambrian. 2. Infra-Cambrian (or Falemian). 3. Palaeozoic. 4. Cretaceous. 5. Eocene. 6. Miocene. 7. Dakar Lava Flows.	
xx	ATLANTIC ISLANDS	181
	1. The Canary Islands. 2. The Cape Verde Islands.	

CONTENTS

xi

xxi	SOUTHERN MAURITANIA AND WESTERN MALI	185
	1. The Aouker. 2. From Nioro to Falémé. 3. From Néma to Bamako. 4. The Macina. 5. The Fossil Delta of the Middle Niger. 6. Volcanic Activity in the Daounas.	
xxii	EASTERN MALI, NIGER AND CHAD	197
	1. The Adrar des Iforas. 2. The Bend of the Niger. 3. The Tilemsi Valley, The Asselar Plateau and the Adrar Tiguirirt. The Gao Trough. 4. The Adar Douchi. 5. The Damergou and the Tegama. 6. The Wadi Azaouak Basin and the Tamesna. 7. The Aïr. 8. The Chad Basin.	
xxiii	GUINEA AND SIERRA LEONE	215
	1. Pre-Cambrian. 2. Palaeozoic. 3. The Nepheline Syenites of the Isles de Los. 4. The Upper Cretaceous and Palaeogene of Portuguese Guinea.	
xxiv	THE IVORY COAST AND UPPER VOLTA	222
	1. Pre-Cambrian. 2. Palaeozoic. 3. Cretaceous and Tertiary.	
xxv	GHANA	227
	1. Pre-Cambrian. 2. Palaeozoic. 3. Cretaceous and Tertiary of the Coast. 4. Quaternary Volcanism and Earthquakes.	
xxvi	TOGO AND DAHOMEY	235
	1. Pre-Cambrian of the Atacora. 2. "Continental Intercalaire". 3. Cretaceous and Eocene of the Coast.	
xxvii	NIGERIA	242
	1. Pre-Cambrian. 2. "Continental Intercalaire". 3. Marine Cretaceous. 4. The Coal Measures. 5. Eocene. 6. "Continental Terminal".	
xxviii	CAMEROON AND RIO MUNI: ISLANDS OF THE GULF OF GUINEA	249
	1. Pre-Cambrian. 2. "Continental Intercalaire". 3. Marine Cretaceous. 4. Tertiary. 5. Dschang Lignites and Balangi Tuffs. 6. Cretaceous and Tertiary of Rio Muni and the Islands. 7. Large Fractures and Volcanism. 8. The Volcanic Islands.	
xxix	GABON, CONGO REPUBLIC AND CENTRAL AFRICAN REPUBLIC (UBANGI)	261
	1. Gabon and Middle Congo. 2. The Ubangi Basin.	
xxx	CONGO AND CABINDA	277
	1. Pre-cambrian of the Western Congo. 2. Pre-Cambrian of Katanga. 3. Younger Rocks. 4. Quaternary. 5. Marine Cretaceous of the Coast. 6. Marine Tertiary of the Coast. 7. Volcanoes.	

xxxI	ANGOLA	295
	1. The Pre-Cambrian Basement. 2. Continental Beds: Karroo, Calonda, Kalahari, Quaternary. 3. Marine Cretaceous of the Coast. 4. Tertiary of the Coast. 5. Marine Quaternary.	
xxxII	ETHIOPIA AND SOMALIA	304
	1. The Pre-Cambrian Basement. 2. The Jurassic and Cretaceous Sedimentary Succession. 3. Eocene. 4. Oligocene. 5. Miocene. 6. The Volcanics of the Plateaux. 7. The Afar.	
xxxIII	EAST AFRICA: KENYA, UGANDA, TANGANYIKA	317
	1. Pre-Cambrian. 2. The Karroo. 3. From the Jurassic Transgression to the Dinosaur-bearing Wealdian. 4. Cretaceous and Tertiary of the Coast. 5. Neogene of Zanzibar and Pemba. 6. Continental Post-Cretaceous.	
xxxIV	THE RHODESIAS AND NYASALAND	329
	1. Pre-Cambrian. 2. The Pre-Karroo Palaeozoic. 3. The Karroo. 4. Tectonic Movements, Kimberlites and Continental Cretaceous. 5. The Kalahari System.	
xxxv	PORTUGUESE EAST AFRICA: MOZAMBIQUE	336
	1. The Pre-Cambrian Basement. 2. Pre-Karroo Palaeozoic. 3. Karroo. 4. Cretaceous. 5. Tertiary.	
xxxvi	SOUTH AFRICA	341
	1. Pre-Cambrian. 2. Pre-Karroo Palaeozoic (Cambrian—Lower Carboniferous). 3. The Karroo. 4. "Continental Intercalaire". 5. Marine Cretaceous. 6. Tertiary.	
xxxvII	MADAGASCAR	354
	1. Pre-Cambrian. 2. Pre-Karroo Palaeozoic. 3. The Madagascan Karroo (Sakoa, Sakamena, Isalo). 4. Bajocian-Bathonian. 5. Upper Jurassic. 6. Cretaceous. 7. Palaeogene. 8. Marine Neogene. 9. Plio-Pleistocene. 10. Mascarene Islands, Reunion, Mauritius, Rodriguez.	
	INDEX	371

PART ONE

GENERAL STRATIGRAPHY

CHAPTER I

THE PRE-CAMBRIAN

The African basement of granites and associated metamorphic rocks is of Pre-Cambrian age. It outcrops mainly in Mauritania, the Hoggar, Sudan, West Africa (from Guinea to Cameroun), equatorial Africa (Gabon, Congo, Central African Republic), East Africa, Angola, South Africa and Madagascar.

Its geographical importance is equalled by its economic importance because the Pre-Cambrian contains rich beds of gold, copper, iron, uranium, tin, manganese, etc. Its beds record the evolution of Africa through several thousand million years.

Dating by radio-active minerals gives an age of more than 3,500 million years. The Earth's crust began to solidify at least 5,000 m.y. ago; and this represents a reasonable order of magnitude for the age of the Earth.

All the African Pre-Cambrian is intensely folded (as in other continents) with general fold directions of N.-S. or NE.-SW. Most of the rocks are of sedimentary origin but have been modified by folding, igneous intrusions and metasomatic phenomena. In the absence of fossils it is necessary to use other methods for determining the orogenic cycles. These include a study of unconformities, conglomerates, extrusive phases, mineralisation and finally the absolute age, calculated from radio-active minerals.

The 1 : 10,000,000 Structural Map of Africa, published late in 1958, was a difficult undertaking. It was produced after six years of discussion between specialists because the stratigraphical succession of the Pre-Cambrian, on which it is based, is still disputed.

Holmes and Cahen (1957) published a very important document on African chronology which gave 320 measurements of the relative age of 230 rock groups. By improved methods of analysis, the authors were able to show that the analyses published in the preceding year contained errors of about a thousand million years—lepidolite from Letaba: 2,815 m.y. instead of 3,850; galena from Stavoren: 2,010 m.y. instead of 880; lepidolite from Hombolo: 2,440 instead of 3,250; lepidolite from Southern Rhodesia: 2,810 instead of 3,740, etc. These dates are still liable to modification, but in view of the large number of analyses and the

improved knowledge of sources of error they may be regarded as reasonable.

Holmes and Cahen (1957) distinguished seven Pre-Cambrian orogenic cycles, mainly in Africa south of the equator.

In the oldest cycle, 3,200 to 3,400 m.y., the authors included the Western Nile System (Congo and Uganda), the Fig Tree and Onverwacht Series, the Swaziland and Eastern Transvaal System and doubtless the Sebakwian of Rhodesia. In West Africa the Dahomeyan should be included in this cycle. It is older than the Mount Sula Schists, which are 2,955 m.y. old.

2,800 to 3,100 m.y. The minerals of the Mt. Sula Schists in Sierra Leone (2,955 m.y.) define a cycle older than the Birrimian, but *perhaps* younger than the undated Dahomeyan. The Bulawayan of Southern Rhodesia and Nyasaland in East Africa may be part of this cycle, or younger (2,825 m.y.).

2,650 m.y. *Shamwaian Cycle*. A cycle only recognised in the two Rhodesias.

2,000 m.y. *Limpopo Cycle*. This cycle occurs in the south of Southern Rhodesia and in the north-east of South Africa.

A number of analyses give figures averaging 2,200 m.y. in West Africa; this may possibly indicate the occurrence of a Birrimian cycle.

1,040 m.y. *Karagwe-Ankolian Cycle*. This is an important cycle in central and equatorial Africa. It may link up with the Gordonian cycle in South Africa and the Witwatersrand formations dated between 1,100 and 2,000 m.y. The definition of this cycle is still uncertain.

875 to 900 m.y. A cycle uniquely defined by the age of monazite from a pegmatite at Goodhouse (South Africa).

620 m.y. *Katangan Cycle*. This is widespread in equatorial Africa—e.g. Katanga Group, Western Congo Group.

The number of cycles recognised since the beginning of the Cambrian (four or five during 500 million years) suggests that one might expect to find twenty or thirty during the entire Pre-Cambrian.

However, two facts are interesting: first, that experience in the preparation of the 1 : 10,000,000 Structural Map of Africa has shown that subdivision into seven cycles is not always possible for the whole continent, since some are only “known” at one place and by a single date; secondly, in the northern half of Africa, which has been studied more, and is better exposed, only two

large orogenic cycles are found: Dahomeyan-Suggarian and Pharusian-Birrimian, and two less important, comprising a *maximum of four cycles*.

Age determinations indicate intermediate ages for the phenomena of metamorphism and granite intrusions. I think, with M. Lelubre (personal communication), that one age determination of a granite does not signify an orogenic cycle, and that the succession can only be established by geological observations in the field; so that whilst absolute ages give the chronology of the events, this is not always the same thing.

It therefore seems to me that the subdivisions shown in the Structural Map of Africa, which divide this great extent of time (4,000 m.y.) into four cycles, should provisionally be adopted.

Lower Pre-Cambrian (Pr I) (3,000 m.y. +): this includes all the series actually dated and also the oldest undated series. Sahara: Suggarian and Amsaga; West Africa: Dahomeyan; equatorial Africa: Pre-Mayombe; Congo: Gangu (3,325 m.y.), Banzyville System; Congo and Uganda: Western Nile Formation; East Africa: Basement Complex, Dodoma Series (3,250 m.y.); Southern Rhodesia: Sebakwian (older than 2,980 m.y.); South Africa: Swaziland System (3,350 m.y.); Madagascar: Androyan.

All these series are essentially granito-gneissic, strongly folded and invaded subsequently by granitic batholiths.

In the earliest Pre-Cambrian the old eroded structures have locally variable fold directions but, taking Africa as a whole, they follow the meridians, with a few peculiar "noyaux" or nuclei (as in Sudan and Sierra Leone-Liberia). The Suggarian of the Hoggar is at least 20 km. thick.

These are the "dark ages" of African geology.

Middle Pre-Cambrian (Pr II) (2,000 to 3,000 m.y.): this includes folded and granitised series in many places but fewer metamorphic rocks. Morocco: Kerdous Series; Sahara: Lower Pharusian and Akjoujt (?); West Africa: Atacorian and Birrimian; equatorial Africa: Mayombe, Kibali, Ruzizi; East Africa: Toro System, Kavirondian and Nyanzan, Muva, Mozambiquian; Northern Rhodesia: Upper Basement; Southern Rhodesia: Bulawayan (2,850 m.y.), Shamvaian (2,650 m.y.); South Africa: Limpopo (to 2,000 m.y.); Madagascar: Graphite Series (2,420 m.y.).

The Pre-Cambrian II exhibits fine eroded groups: a large NE.-SW. range from the Hoggar to the Gulf of Guinea; the Kibali Range of the Congo which at first has a N.-S. virgation and then

bends SE. to continue into the Toro range. From there the Kavirondian-Nyanzian Range extends E.-W. to the south of Lake Victoria. In Madagascar the Graphite Range is at first N.-S. and then turns NW. towards Mozambique.

The main sediments of Pre-Cambrian II are schists, quartzites and marbles with the first authentic traces of life in stromatolite reefs.

Upper Pre-Cambrian (Pr III) (between 1,000 and 2,000 m.y.): Morocco: Zenaga Series (1,860 m.y.); West Africa: Tarkwaian (verified by a pegmatite of 1,850 m.y.?), Nigritian (?); Congo: Kibara and Urundi Groups (1,050 m.y.), Sansikwa and Upper Shiloango; Angola: Oendolengo (part); East Africa: Karagwe-Ankola (1,040 m.y.); Southern Rhodesia: Great Dyke (1,250 m.y.); South Africa: Ventersdorp, Witwatersrand.

Terminal Pre-Cambrian (Pr IV) (from 600 to 1,000 m.y.): the Terminal Pre-Cambrian includes the rocks between the intensely folded Pre-Cambrian and the fossiliferous Cambrian. It includes: Morocco: Ouarzazate Series; West Africa: "Falemian", Rokell Series and Buem (?); equatorial Africa: Western Congo System; Congo: Katanga Group (Roan, Mwashya, Great Conglomerate and Kundelungu) (620 m.y.), Bushimaie, Lindi, Western Congo Group; Angola: Bembé System; East Africa: Bukoban and Bunyoro; South Africa: Waterberg, Matsap, Transvaal, Otavi and Damara.

Isotopic analyses of galena from Kipushi (Katanga) and Hapilo give the age of this succession (Kundelungu and Western Congo) as about 620 m.y. This interpretation is disputed and M. Robert, in particular, thinks that the uranium and copper mineralisation of the Roan Series took place well before the Cambrian, but that the veins cutting the Kundelungu are younger, probably Palaeozoic, and consist of reworked lead. Such a phenomenon is known for uraninite in the Witwatersrand; and in Morocco, where galenas found in the Mesozoic have all given Palaeozoic ages. The international congresses have, however, accepted the age of 620 m.y. for the veins cutting the Kundelungu and the Western Congo.

The Falemian and the Rokell Series are still so poorly defined that it is possible that a part of this Late Pre-Cambrian should be included in the Lower Palaeozoic. The majority of field geologists hold this opinion, and I only mention these two series as I personally consider them to be Infra-Cambrian.

I have mentioned the existence of "young granites" and "old granites", such as the "Younger Granites" of Nigeria, which are widespread, and are studied for their tin mineralisation. They often occur as ring complexes, and have intruded the Pre-Cambrian II. Their relationship with Pre-Cambrian III-IV is unknown, but Holmes and Cahen (1957) have given an age of 435 to 485 m.y. for a monazite from a "Younger Granite" of Nigeria.

REFERENCE

- HOLMES, A. and L. CAHEN, 1957. Géochronologie africaine 1956. Résultats acquis au 1^{er} juillet 1956. *Mém. Ac. R. Sc. Col.*, Brussels 1957 (n.s.), **5**, 1, 169 pp.

CHAPTER II

THE LOWER PALAEOZOIC (?): THE INFRA-CAMBRIAN

It is generally understood that the Cambrian began about 520 m.y. ago and that the first fossiliferous zone contains olenellids. However, in many parts of the world there is a more or less concordant sedimentary series, unfossiliferous or without determinable fossils, below the fossiliferous Cambrian. These are considered either as the base of the Palaeozoic or as the top of the Pre-Cambrian. Menchikoff (1949) and Pruvost (1951) have named these intermediate rocks the Infra-Cambrian.

The Infra-Cambrian is particularly important in Africa because a major unconformity occurs above the Pre-Cambrian. Thus it may be described either as Terminal Pre-Cambrian (Pr IV), early Palaeozoic or true Cambrian. I consider it as Lower Palaeozoic because of the structure: a major unconformity above the folded basement. It was marked by volcanic activity, glaciers and the transgression of an extensive but shallow sea containing stromatolites.

At the western end of the Moroccan Anti-Atlas mountains, near Ifni, Bourcart (1936) has recorded a series of rhyolites covering the folded and eroded Pre-Cambrian, then an alternation of volcanic tuffs and dolomites and finally a last extrusion of rhyolite before the basal Georgian conglomerate. The same series has been seen in other parts of Morocco by Choubert and Nelter and by Menchikoff in the Ougarta Ranges as far away as Guinea. Thus in a large part of north-western Africa the final Pre-Cambrian movements were accompanied by volcanic activity producing outpourings of rhyolite.

THE STROMATOLITE SEA

The Infra-Cambrian of north-west Africa was marked by the broad extension of a stromatolite sea. The sediments are shales, mudstones, phtanites and dolomitic limestones with stromatolites.

These stromatolites are not determinable fossils to which generic or specific names can be given; they are reefs formed by

blue or green algae and bacteria which caused the precipitation of calcium carbonate. The classification of stromatolites is not by the form of the organism but by the shape of the calcareous structures.

Two principal forms exist: *Conophyton* and *Collenia* (Menchikoff 1946; Maslov 1937, 1939).

Conophyton comprises a homogeneous group with a cylindrical structure of 5 to 50 cm. diameter and reaching tens of metres in height. It forms compact reefs in which the individuals are isolated from one another. In transverse section there are concentric zones, while the longitudinal section shows a series of close-fitting cones, with the apex upwards. Past collectors have often confused the stromatolites with the trunks of calcified trees.

Collenia are more generalised forms occurring as successive convex beds, whose folds are an aid to determination.

At certain places in the western Sahara Menchikoff has recorded some arched structures of 2 to 3 m. in diameter, recalling the domed reefs of the Cambrian of Carteret. There are no other recognisable structures.

Stromatolites range in age from the Pre-Cambrian (Pharusian of the Central Sahara) to the Cretaceous (North America). Although it was hoped that they could be utilised in Africa this has proved impossible. In north-west Africa, the dolomitic limestones with stromatolites may be traced from Morocco to Upper Volta passing through Mauritania and Mali. However, stromatolites are found in both the Infra-Cambrian and the Cambrian, as we understand them today.

The Lower Infra-Cambrian (?) of the Anti-Atlas may be represented by the Ouarzazate Series—or Pre-Cambrian III of Moroccan geologists. It is a volcanic and detrital series with rhyolites and andesites, and is overlain by beds of shales, mudstones and lenses of stromatolites (*Collenia*) marking a marine transgression. This group, 1,000 m. thick, is overlain by 3,000 m. of unquestionably Infra-Cambrian rocks (the Adoudounian) which are mostly made of stromatolite limestones.

South of these areas stromatolite limestones are found in the Sahara, Ghana, and in numerous dolomitic formations south of the equator: Gabon, Congo, Angola, South-West Africa, British East Africa and the Rhodesias. Now it seems certain that these formations are older than the true Cambrian with olenellids. They are older than 620 m.y. which I have previously described

as Terminal Pre-Cambrian. Their *stratigraphic* position is no longer disputed. What remains to be decided is the theoretical base—the boundary between the Pre-Cambrian and the Palaeozoic. This boundary should be below the Cambrian transgression and correspond to the major unconformity of the Infra-Cambrian. This point of view has been discussed at an International Congress on the relationship between the Pre-Cambrian and the Cambrian (Paris, 1957). “*La coupure entre l’Infracambrien et le Cambrien serait marquée par un refroidissement général du climat, indiqué par le dépôt d’une tillite, ou plus exactement d’une dernière tillite, puisque l’Infracambrien peut montrer plusieurs niveaux de conglomérats glaciaires.*”

“*Dans l’Ouest africain, la grande masse des calcaires dolomitiques à Stromatolithes appartient à cet Infracambrien. La tillite n’a peut-être pas la valeur qu’on lui accorde, en l’absence de discordance, et il reste parfaitement possible que les schistes, pélites et calcaires dolomitiques postérieurs à la tillite, appartiennent encore à l’Infracambrien (et non au Cambrien).*”

It is interesting to recall here Graindor’s (1957) view that in the Armorican Massif the tillite occurs between the Middle and Upper Brioverian. This Upper Brioverian has been correlated with the Ouarzazate Series (or Pre-Cambrian III of Choubert) in Morocco. It seems that if these series are comparable we are not so far from a solution.

REFERENCES

- BOURCART, J., 1936. Un grand volcan “algonkien” à l’extrémité occidentale de l’Anti-Atlas marocain. *C.R. Soc. Géol. Fr.*, pp. 232-234.
- GRAINDOR, M.-J., 1957. Le Briovérien dans le Nord-Est du Massif armoricain. *Mém. Serv. Carte Géol. Fr.*, p. 168.
- MASLOV, V. P., 1937. On the nature of the Stromatolite *Conophyton*. Problems of Palaeont., Moscow, 2-3, 327.
- 1939. The genus *Collenia*. Problems of Palaeont., Moscow, 5, 297.
- MENCHIKOFF, N., 1946. Les formations à Stromatolithes dans le Sahara occidental. *Bull. Soc. Géol. Fr.* (5), 16, 451-461.
- 1949. Quelques traits de l’histoire géologique du Sahara occidental. *Ann. Hébert et Haug*, 7, 308 and 309.
- PRUVOST, P., 1951. L’Infracambrien. *Bull. Soc. Belg. Géol. Pal. Hydr.*, 60, fasc. 1, p. 43.

CHAPTER III

THE PALAEOZOIC: CAMBRIAN-SILURIAN, DEVONIAN AND CARBONIFEROUS

1. AFRICA NORTH OF THE EQUATOR

1. *Cambrian*

The Cambrian transgression spread over the greater part of north-west Africa, covering a tillite left by a preceding glaciation.

In Morocco the Cambrian sediments accumulated in a subsiding region, reaching 1,000 m. in thickness in the Haut-Atlas (Choubert 1952). They extend widely to Djebilet and the Meseta in the north and to the Anti-Atlas and further south.

The type succession of the Moroccan Cambrian includes from the bottom to the top:

- (a) Conglomerates and “*série lie-de-vin*” (200 to 500 m.).
- (b) Impure Upper Limestones (75 to 450 m.) containing archeocyathids in the western Anti-Atlas to about 500 m. above the Adoudounian. These limestones belong to the horizon which is now included in the Lower Georgian.
- (c) The “*série schisto-calcaire*” (300 to 450 m.), in which Hupé (1952) defined the following trilobite zones:
 - zone 1—*Æallotaspis tazemmourtensis* (the oldest of the known Olenellidae);
 - zone 2—*Choubertella*;
 - zone 3—*Daguinaspis* and *Resserops*.
- (d) Green and grey shales:
 - zone 4—*Antlatasia*;
 - zone 5—*Neltneria* and *Bondonella*;
 - zone 6—*Longianda*, *Saukianda*, *Gigantopygus*.
- (e) Sandstone and volcanic ash; then shales:
 - zone 7—*Termierella* and *Gentilaspis* (= “*Olenellus*”) *gigas*;
 - zone 8—*Myopsolenus magnus* and *Kingaspis*.

The greatest thickness of the Georgian cycle of sedimentation is about 2,000 m.

The Acadian begins with *Paradoxides* shales; it is transgressive on the Georgian and reaches several thousands of metres in thickness in the Haut-Atlas, but decreases to 1,000 m. in the western Anti-Atlas and is only 100 m. near Djebel Sahro.

The Middle Acadian marine sedimentation of 150 m. of sandstone, with *Conocoryphe* and lingulae, was ended by the Cadomian movements accompanied by volcanic eruptions. Therefore there is no Potsdamian.

In the east the sea did not extend beyond the Tafilalet. In the Ougarta Ranges to the south-east, above the Infra-Cambrian rhyolites, are found 5,000 m. of sandstones. Some consider these rocks to be Ordovician, but the base with tigillites is definitely Cambrian. This tigillite sandstone facies is found further east around the Hoggar and south in Mauritania and Mali, where it succeeds the shales, mudstones and limestones which transgress over the tillite. The tigillites are not fossils of stratigraphic importance.

2. Ordovician

(a) *North Africa (Mediterranean region)*. The Algerian Ordovician is largely metamorphosed and is little known. Nevertheless, there is an Ordovician succession with dendroid graptolites on the northern border of the Kabylie Massif 4 km. from Tizi-Ouzou, between Algiers and Bougie (Barbier *et al.* 1948). It is considered to be Upper Llanvirnian. A little to the south, on the northern side of the Djurdjura, Lambert *et al.* (1948) have found calcareous and micaceous shales belonging to the Upper Ordovician (Ashgillian). It seems that the Ordovician is widespread in Algeria but it needs to be systematically surveyed.

The Moroccan Ordovician is better known (Termier 1947; Choubert and Termier 1947; Gigout 1948). It is complete and has a continuous succession from the Cambrian shales, but since the passage beds are unfossiliferous, the Tremadocian has not been identified.

The following succession is recognised in Morocco:

1. *Skiddavian*: Bani Shales with *Onchometopus volborthi*; El Ank Shales (Casablanca) with *Didymograptus simulans* and *Schizograptus quebecensis*. (Middle Arenig = Upper Skiddaw), and *Didymograptus bifidus* (Upper Arenig = Lower Llanvirn).

2. *Upper Llanvirn and Llandeilo*: 1,500 m. Harcha Shales (central Morocco) with *Synhomalonotus aragoi*, *Dalmania atava*, *Redonia bohémica*; the same horizon at Bani and the beds with *Didymograptus murchisoni* at Imini.
3. *Lower Llandeilo*: 300 m. of Bani Quartzite with *Synhomalonotus tristani* and *Iliaenus perovalis*.
4. *Upper Llandeilo*: beds with *Trinucleus ornatus* in central Morocco and with *Pinodema redux* at Tafilalet and Dra.
5. *Caradocian*: 200 m. of sandstones of the second Bani with *Calymene incerta* and *Hyolithes elegans* and a bed of quartzite with *Brongniartia brongniarti*, which is frequently repeated throughout Morocco.
6. *Ashgillian*: shales with *Chonotoidea radiatula* from Oulmès (central Morocco).

(b) *Sahara and western Africa*. In the type section of the Tassilis in the Hoggar (north of Amguid) petroleum geologists have established the following succession, from bottom to top (Tempère: 1959).

1. Psammites with *Dinobolus* at the very base and Tremadocian lingulellas throughout. These psammites are conformable on the Cambrian sandstones.
2. Tigillite quartzites, glauconitic at the base, with a small Arenig fauna (*Synhomalonotus* and graptolites in the Ahnet).

A slight uplift followed and the subsequent erosion is recorded in a discontinuity at the base of the Caradoc.

3. Caradocian quartzites, with *Calymene*. These are transgressive, and rest variably on older Ordovician, Cambrian sandstones or Pre-Cambrian.

The Ordovician sandstones are less compact towards the top and pass gradually into shales with Silurian graptolites.

These sandstones of many hundreds of metres in thickness are found in the Tassilis, and also to the west near the Adrar of Mauritania, in Tagant, in the plateau bordering the Aouker, the Manding Plateau of Mali, Guinea and the Bandiagara Plateau. After an erosional discontinuity the same sandstones are found in the Volta Basin plateaux, where they overlies the Oti Beds (Ghana).

The Ordovician transgression therefore covered the whole of western Africa north of the equator. The sea was shallow with almost exclusively sandy sedimentation, suggesting that there was high land near by. In this connection it is known that the central Hoggar was emergent in the Caradocian and there was a land mass to the west of Mauritania.

3. Silurian

(a) *North Africa (Mediterranean region)*. In North Africa the Silurian sediments are graptolitic shales, with limestone nodules containing orthoceroids and cardiolas.

In Algeria, graptolites and orthoceroids in the Beni-Afeur area have given a precise age to the Djidjelli Shales (Ehrmann 1924). Durand Delga (1955) has studied the Silurian stratigraphy of the Petite Kabylie, defining Lower Silurian shales with tentaculites; Lower and Middle Silurian psammities with graptolites; Upper Silurian limestones with orthoceroids. In the Oran area Lucas (1942, 1948) discovered graptolites in the black phanites from Tifrit (north-east of Saïda). The species found were: *Monograptus vulgaris* Wood of the Wenlock (zones 28-32) and *Petalograptus folium* His. of the Tarannon (zones 22-25). The Silurian shales and phanites of Tifrit have been metamorphosed by a granitic intrusion. Lucas has also described similar beds in the Djorf Ouazzène (Algero-Moroccan frontier).

Between these two regions, in the Grand Kabylie, the Silurian has been found at Ihamziène (on the Fort-National sheet). This is a high horizon of shales and limestones with *Scyphocrinus elegans* Zenker, *Favosites gothlandica* Goldf., some cardiolas and orthoceroids (Barbier *et al.* 1948).

In eastern Morocco, south of Oudja, near the Djorf Ouazzène horizon, eleven phanite horizons have yielded species of graptolites of zones 18-22: *Monograptus fibriatus* Nich., *M. communis* Lapw., *M. revolutus* Kurck, *M. regularis* Tornq., *Petalograptus palmaeus* var. *tenuis* Barr., *Glyptograptus sinuatus* Nich., and *Climacograptus scalaris* His. (Waterlot 1941, 1945).

On the northern slope of the Haut-Atlas, graptolitic shales are dated as between Middle Llandovery (zone 19) and Wenlock. The Middle Llandovery is also found in central Morocco south of Naïma.

In the Meseta the first graptolites were discovered by Gentil in 1905. Since then the work of Lecointre (1931), Bourcart and Le

Villain (1930), Roch and H. Termier has shown that the Silurian is complete both in the Meseta and in the surrounding regions, consisting of graptolitic shales and beds of fetid limestone with orthoceroids and *Cardiola interrupta*.

(b) *Sahara and West Africa*. In the Zemmour and the Seguiet el Hamra, the Upper Silurian sediments consist of limestones with *Orthoceras* and *Monograptus priodon*.

There are graptolitic shales in the Mauritanian Adrar-Tagant, at Charania, which contain *Monograptus turriculatus* Barr., *M. halle* Barr., *M. cf. undulatus* Elles and W., and must therefore be of Lower Silurian age (Nicklès 1947).

The same facies is found in the north-west of Mali between Tichitt and Oualata. The El Ghatt Shales contain *Climacograptus cf. medius* Tornquist and *Diplograptus magnus* Lapw. (Llandovery).

Still further south, in Guinea, the widespread Silurian Shales contain two palaeontological horizons: a lower zone (Valentian) with *Monograptus sedgwicki*, *Climacograptus hughesi*, *Glyptograptus tamariscus* var. *incertus*, etc., and an upper zone with *Monograptus priodon* and *Gladiograptus geinitzianus* with some *Orthoceras* at the top (Pobeguín 1947).

Towards the east, the graptolitic facies is recognised in the Ougarta Range (Llandovery, Wenlock and Ludlow), in the Ahnet and in the Infra-Tassilian syncline of the Hoggar. It is found in the Tassili des Ajjer, where Kilian has described Lower Llandovery with *Mesograptus modestus* Lapw. and *Glyptograptus persculptus* Salt., and between Serdelès and Ghat.

The eastern limit of the graptolite shales appears to be in the central Fezzan, where Lelubre (1946) has found them in the Chati and south of the Hamada el Homra.

Beyond, in the south-east Fezzan, the Silurian is not shaly but sandy. The highest sandstones with *Harlania* form the Silurian in the Tibesti.

It appears that the Silurian sea did not invade north-east Africa, nor has any evidence been found of it south of Guinea, but it extended to Ghana.

Caledonian Movements

The Caledonian movements, *sensu lato*, occurred from the end of the Ordovician to the Upper Devonian. In Europe these important orogenic movements gave rise to the Caledonian mountain ranges. In Africa one finds widespread evidence of

epirogenic movements which have controlled changes in sedimentation.

The oldest and most important movements are post-Ordovician. In Morocco, the Sahara and West Africa as far as Guinea there is no unconformity between the Ordovician and the Silurian, but a sharp change in facies, from Ordovician sandstones to Silurian graptolitic shales. The Silurian indicates a transgressive and slightly deeper sea although always of an epicontinental character.

The second series of movements is post-Silurian; both in Morocco and the Sahara there were small epirogenic movements. It appears that there was emergence in several places, but few unconformities.

The third series of movements was at the beginning of the Devonian, but these were only of minor importance.

In the Adrar Ahnet, Bourcart and Monod (1931) found a series of barren sandstones between the Silurian shales and the fossiliferous Coblencian. There is no unconformity, but a sharp change of facies, with probably no marine Gedinian.

In the Amserha area (Emmidir), Kilian has recorded shaly Silurian with graptolites separated from the Coblencian by a lagoonal or continental phase of conglomerates and sandstones representing the Late Silurian and Gedinian. In addition, between the fossiliferous Coblencian and the blue limestones of the Middle Devonian there is another group of ferruginous conglomerates. The Coblencian is thus enclosed between two Caledonian movements.

The Caledonian movements are still more important in the east, and caused the erosion of older Palaeozoic deposits so that the continental Upper Devonian and Carboniferous sediments lie directly on the Pre-Cambrian (Kilian 1935).

Further south, in Mauritania, Mali and Guinea, there is no unconformity, but everywhere a sharp variation of facies, which changes from graptolitic paper shales to sandstones.

4. Devonian

(a) *North Africa.* A lack of fossils makes it impossible to locate the Silurian-Devonian boundary exactly.

The Gedinian appears to be extremely rare. Sometimes it is absent, and the Coblencian transgresses directly on to the Silurian. In Morocco there is Siegenian with *Spirifer primaevus*, *S. hystericus* Schloth., *Pentamerus sieberi* v. Buch and Emsian with *Spirifer*

paradoxus Gieb., *S. arduennensis* Schnur, *Tropidoleptus carinatus* var. *rhenanus* Frech., *Atrypa reticularis* L. Goniatites appear in the Coblencian at Tafilalet.

In the Middle Devonian the Eifelian begins with beds containing *Anarcestes subnautilus* Schl., *A. lateseptatus* Beyr. and *Spirifer cultrijugatus* Roemer, and ends with *Spirifer speciosus* Sch. and *Pinacites jugleri* Barr as typical fossils. In central Morocco the Eifelian transgresses on to the Silurian (H. Termier).

Ehrmann has discovered Middle Devonian with tentaculites and corals in the Djidjelli area of Algeria. In the Grande Kabylie, the Silurian is directly overlain by shales and limestones containing poorly preserved goniatites, orthoceroids, trilobites, tentaculites, *Novakia acuaria* Rein. and *Styliolina* sp. This group of beds is Eifelian in age (Barbier *et al.* 1948).

The Givetian in Morocco is often regressive with coral limestones and goniatite beds. In many places there are sandstones containing land plants.

During the Upper Devonian a Frasnian limestone with corals was laid down in the north while a goniatite facies occurred in the Maïder and Tafilalet towards Columb Béchar.

Many goniatites from the Tafilalet Famennian, studied by Clariond, Fallot, Roch and H. Termier, have defined the classic zones: zone II with *Cheiloceras amblylobus* Sdbg., zone III with *Pseudoclymenia planidorsata* Münster and zone IV with *Cyrtoclymenia plicata* Münster.

(b) *Sahara and West Africa.* The Gedinian has not been recognised in the absence of fossils. No break occurs between the Silurian and the Coblencian: there is only a change in facies.

The complete Coblencian is found in the Tindouf Syncline (Menchikoff), in Mauritania (Jacquet and Monod), in the Saoura, the Ahnet (Bourcart and Monod) and in the Emmidir (Bourcart and Kilian).

The Middle Devonian frequently begins with blue limestones and is found in the same places. The richness of the goniatite fauna occurring in the Saoura Trough must be emphasised. The goniatite facies extends into the Ahnet.

The Middle Devonian extends as far as Ghana, where the Accra Sandstones contain *Dipleura (Homalonotus) dekayi* Green—a trilobite from the American Hamilton Group fauna.

The same facies occurs in the Upper Devonian, and the sea covered a similar area. *Spirifer verneuili* occurs as far as Mauritania.

The most important palaeogeographic feature was a large trough with goniatites and clymenias, the Saoura Trough (defined by Menchikoff in 1930). This developed during the Silurian and remained in a similar form from the Eifelian to the Tournaisian, finally disappearing after the Hercynian movements. Its uniquely rich cephalopod fauna has made it famous.

To the east, in the Tadrart, Tibesti and Ennedi, there are only sandstones with *Spirophyton* and impressions of large arthropods (probably eurypterids) (Freulon 1953).

5. Carboniferous

Although the Lower Carboniferous sea covered North Africa, in the east its sediments are metamorphosed and difficult to recognise. In western Algeria and Morocco there is a fine succession conformable (or transgressive) on the Upper Devonian, beginning with an Etroeungt Zone with *Spirifer strunianus*, Tournaisian with *Spirifer tornacensis*, Visean with *Davisiella comoides*, *Chonetes parapilionacea*, *Productus giganteus*, and Lower Namurian with *Glyphioceras*. Hercynian movements later interrupted the marine succession, and this was replaced by a continental series with coals (Djerada and Kenadza) (Termier 1936; Delépine 1939; Clariond 1937; Deleau 1951).

In Morocco the Carboniferous resembles the paralic basins of Europe, but with a N.-S. marine gulf which advanced far into the Sahara: the Saoura Trough. Here the cephalopod facies persisted until the Upper Westphalian. This gulf remained in connection with the sea covering the Haut-Atlas and the western Meseta until the Namurian.

The goniatite horizons are numerous in the eastern Morocco (Djerada) and Kenadza (south Oranais) coal basins where the successions have been correlated with each other and with similar successions in other parts of the world.

At Djerada and Kenadza, the Carboniferous was marine during the Namurian and most of the Westphalian. In the Djerada Basin, a shaly facies predominated. It was only in the Upper Westphalian that the régime became increasingly continental, with important coal seams and a freshwater fauna.

The Namurian is represented by beds with *Eumorphoceras pseudo-bilingue* Bisat, *Homoceras diadema* Beyr., *Reticuloceras bilingue* Salter and *Gastrioceras cancellatum* Bisat, the two last species being

characteristic of the Upper Namurian. The complete Namurian of Djerada is 300 m. thick.

Above the Namurian and below the conglomerates which precede the productive coal measures (H₃), there are 1,000 m. of shales. In these Owodenko (1947) has identified eleven horizons of marine fossils.

Above the lower beds with *Gastrioceras listeri* Martin, there are two thin seams of coal, then a bed (Mokta) which Clariond includes in the Lower Westphalian (Vicoigne and Anzin Groups of northern France). These are followed by marine beds with *Anthracoceras aegiranum* Schmidt, *Metacoceras costatum* Hind., and *Productus rimbertyi* Wat. Finally, the conglomerate at the base of H₃ is overlain by a final marine horizon with *Spirifer mosquensis* Fisch. (Lower Moscovian). This is the *Grand Poudingue* at the base of H₃ which marks the boundary between the *Anthracoceras aegiranum* horizon and the Upper Westphalian. It was only in the Upper Westphalian that the régime became clearly continental.

The character of the North African Carboniferous resembles that of Asturias, where the first coal seams are at the Rimberty horizon and the main bed at the Bruay horizon. In the Franco-Belgian Basin the Westphalian differs by being a continental formation with marine horizons. The coal episode is not contemporaneous because it had a slightly different tectonic history.

The North African basins, like those of Asturias, remained for a long time under a sea connecting with the Mediterranean. Their fauna is in consequence much richer in genera and species than that of the marine horizons of the Franco-Belgian Basin. Moreover there are species similar or identical to those from Russia (Urals and Novaya Zemlya), central Asia and North America (Delépine).

The coal measures are 400 m. in thickness, and the productive seams have been clearly dated by their flora and by their fresh-water fauna, with *Anthracomya* (Owodenko 1947).

The productive seams A-F are apparently part of the Bruay group, with *Neuropteris heterophylla*, *Pecopteris miltoni* and *Anthracomya phillipsi*. Above Bed G there is a horizon with *Anthracomya* aff. *prolifera* of the English Lower Radstockian and of the Houve group in the Saar. Above Bed G and below Bed H there is a horizon with *Mixoneura* cf. *sarrana* P. Bertrand and *M.* cf. *delfinei* P. B., species from the upper seams of the Saar. Finally, the top

of Bed H contains *Pecopteris* species which are known from the Rive-de-Gier horizon (Upper Stephanian).

Therefore it may be concluded that the upper beds of the Djerada Coal Basin have a flora like the English Radstockian, the Houve beds of the Saar, the Ottweiler (Saar) and Rive-de-Gier (Massif Central), namely the Lower Stephanian.

The succession is exactly the same in the Kenadza Basin (Deleau).

Extension towards the south. The marine Lower Carboniferous stretches far to the south. It is known in the Hamada de Tindouf, in the Taoudéni region of the Central Sahara, north of the Hoggar and west of Aïr.¹

The Middle Carboniferous (Moscovian) with brachiopods is known as far as the Fort-Polignac Basin, Edjelé and the Fezzan border.

Extension towards the east. In the Fezzan, Lelubre and Menchikoff have demonstrated how far the Lower Carboniferous sea extended. This sea, which sometimes transgressed onto the continental Upper Devonian, extended to the Mourdi and the south-east Tibesti. It retreated after the Visean.

In north-east Egypt the continental sandstones of the Palaeozoic are covered by beds of a Lower Carboniferous transgression, recognised on the western shore of the Gulf of Suez. In the Abou-Darag, Cuvillier has discovered black crinoidal limestones, glauconitic sandstones, marls and sandstones with *Spirifer* aff. *fasciger* Keys., *Productus* sp., *Edmondia oblonga* McCoy, *Aviculopecten aegyptiacum* Walt., *Bellerophon* and *Orthoceras*.

A little further south, in the wadi Araba, beds with *Productus semi-reticulatus* Martin and *Productus longispinus* Kon., also contain *Spirifer mosquensis*, indicating a Moscovian horizon.

Everywhere else the Carboniferous is continental, and is represented by sandstones with rare plant remains of the Culm (Defirou in the Tibesti, Djebel Ouenet, Aïr, etc.).

Hercynian Movements

Following Haug's definition, the Hercynian movements occurred during the Anthracolithic period, that is during the Carboniferous and the Permian.

¹ The Carboniferous succession in the wadi el Abid (Mauritania), recorded by Chudeau, has never been re-examined; and a closer study of the material suggests that the samples may have been mixed. The existence of these beds is therefore in doubt. Further to the south the Ghana succession is now considered Devonian.

The oldest Hercynian movements occurred between the Upper Devonian and the Carboniferous. H. Termier has emphasised that, in many parts of Morocco, the Tournaisian and even the Lower Visean are absent. This pre-Visean phase was followed by a Visean transgression spreading as far as the central Sahara (to Taoudéni).

The second phase, post-Visean, brought about the Namurian regression, and epeirogenic and orogenic movements continued throughout the Westphalian. The sea retreated, remaining only in the Djerada Basin and the Saoura Trough, where the Westphalian sediments are concordant with those of the Namurian. They have been dated by marine incursions with goniatites. During the Westphalian there was also some deposition of detrital sediments containing plant remains and coal. These can be found in the centre of the Sahara at Taoudéni. The final phase of regression occurred during the Stephanian.

The third phase had its paroxysm between the Namurian and the Autunian. This was the most important phase in north-west Africa.

The present uplands in the Sahara and West Africa have apparently been produced by the Hercynian orogeny. In North Africa the Hercynian folds are accompanied by granitic intrusions. In Morocco, in the Khourigba-Oulmés region, H. Termier recorded five batholiths, which cut the Namurian and provided material for the Autunian conglomerates at Khénifra. The intrusion is therefore perfectly dated.

In the Sahara the Hoggar emerged definitively, and since then erosion has cut down into the Pre-Cambrian. North of the Hoggar, as in Morocco, several north-south structures are distinguished. Many other folds are recognised in West Africa with varying orientations: the Tindouf Syncline, the Eglab (or Reguibat) Anticline, the immense Taoudéni Basin, the Léo Anticline, the Voltaian Syncline in Ghana and the Atacora Anticline.

2. AFRICA SOUTH OF THE EQUATOR

The Palaeozoic, beginning after the major orogenic movements at the end of the Pre-Cambrian, is much more difficult to decipher in Africa south of the equator than in the northern part of the continent. Except for certain parts of South Africa, the Palaeozoic sedimentary rocks are unfossiliferous.

For convenience the Palaeozoic can be terminated at the top of the Lower Carboniferous, as in the north. South of the equator, the top of the Palaeozoic is bounded by the Dwyka Tillite, which indicates that a glaciation occurred during the Upper Carboniferous (*sensu lato*).

The oldest rocks in the Congo and surrounding regions are believed to be Palaeozoic, but the veins of galena which cut them have been dated to 620 to 630 m.y. This is older than the Cambrian.

The Palaeozoic of southern Africa, excluding the ancient Katanga Group, does not amount to much. This subject has been discussed by Cahen (1958).

1. Cambrian

The Cambrian seas perhaps covered Africa south of the equator, but little evidence remains of them.

In the Congo, Cahen places the "upper formation II of the Bilati" (in Kivu) in the Cambro-Ordovician. But this evidence is based on two poorly preserved cephalopods which may not have been *in situ*. He also cites a small and doubtful outcrop in Tanganyika.

In South Africa, Haughton maintains that the dolomitic limestones with stromatolites of the Nama system are of Cambrian age.

2. Silurian

South Africa. The Table Mountain Sandstone (Cape Province) rests on the Cambrian dolomites of Nama, and is overlain by the fossiliferous Devonian Bokkeveld Series. There seems to be little doubt that it is Silurian.

3. Devonian and Lower Carboniferous

South Africa. The Devonian of Cape Province is locally fossiliferous. The Bokkeveld Series is of Lower Devonian age and is characterised by numerous *Leptocoelia flabellites* with *Homalonotus herscheli* Murch., *Spirifer orbignyi* M. and Sh., *Chonetes falklandicus* M. and Sh., *Bellerophon quadrilobatus* Salt, *Tentaculites crotalinus* Sh., *Canularia africana* Sh., etc. This is a cosmopolitan fauna common to South Africa, the Falkland Islands, Brazil, Bolivia and the United States (at Oriskany).

In these regions the Hercynian movements uplifted the Capides Range.

The passage from the Upper Devonian to the Lower Carboniferous is found in the Witteberg Series with *Lepidodendron*, *Sigillaria* and *Knorria*—a flora resembling that of the Sahara region.

REFERENCES

- BARBIER, A., H. TERMIER and G. TERMIER, 1948. La géologie de la Grande Kabylie (Algérie). *C.R. Ac. Sc.*, **226**, 1385-1388.
- BOURCART, J. and G. LE VILLAIN, 1930. Les Graptolithes du Gothlandien de l'Oued Akrech, près de Rabat (Maroc). *C.R. Soc. Géol. Fr.*, pp. 214-216.
- and TH. MONOD, 1931-1932. L'Adrar Ahnet. *Rev. Géogr. Phys. et Géol. dynam.*, **4** et **5**.
- CAHEN, L., 1958. Compléments et modifications à la Note: "Le Cambrien existe-t-il au Congo Belge?" (Mexico 1956). *C.R. Colloque Intern. Precambrien-Cambrien*, CNRS 1957.
- CHOUBERT, G., 1952. Histoire géologique du domaine de l'Anti-Atlas. in *Géologie du Maroc. Publ. XIX^e Congr. Géol. Intern.* (Algiers), Monogr. rég. (3): Maroc, No. 6, pp. 75-195.
- 1956. *Lexique stratigraphique international*. Vol. 4: Afrique. fasc. 1a: Maroc.
- and H. TERMIER, 1947. Sur la stratigraphie de l'Ordovicien marocain. *C.R. Soc. Géol. Fr.*, pp. 335-337.
- CLARIOND, L., 1937. Les Bassins houillers du Maroc français. *XVII^e Int. Geol. Congres*, Moscow.
- DELEAU, P., 1951. Les bassins houillers du Sud-oranais dans la région de Colomb Béchar-Abadla. *Bull. Serv. Carte Géol. Algérie*, 275 pages, 102 fig.
- DELÉPINE, G., 1939. Extension et caractères des bassins houillers de Djerada (Maroc) et de Kenadza (Sud oranais). *C.R. Ac. Sc.*, **208**, 1035-1036.
- 1941. Les goniatites du Carbonifère du Maroc et des confins algéromarocains du Sud. *Notes et Mém. Serv. Mi. Maroc*, No. 56, pp. 1-105.
- DELGA, M. DURAND, 1955. Études géologique de l'Ouest de la chaîne numidique. *Bull. Serv. Carte. Géol. Algérie* (2), No. 24.
- EHRMANN, F., 1924. Stratigraphie et tectonique de la Kabylie des Babors et des régions voisines. *Bull. Serv. Carte Géol. Algérie*, pp. 121-191.
- GIGOUT, M., 1948. Sur l'Ordovicien inférieur de Casablanca. *C.R. Soc. Géol. Fr.*, pp. 155-156.
- HUPÉ, P., 1952. Contribution à l'étude du Cambrien inférieur et du Precambrien III de l'Anti-Atlas marocain. *Notes et Mém. Serv. Géol. Maroc*, No. 103, 402 pages.
- JONGMANS, W., 1952. Note sur la flore des terrains carbonifères de Djerada (Maroc). *Notes et Mem. Serv. Géol. Maroc*, No. 91.
- KILIAN, C., 1935. De la coupe d'Amserha et des mouvements caledonien au Sahara. *C.R. Soc. Géol. Fr.*, pp. 219-220.

- LAMBERT, A., H. TERMIER and G. TERMIER, 1948. Découverte de l'Ordovicien en Algérie atlasienne. *C.R. Ac. Sc.*, **226**, 824-825.
- LECOINTRE, G., 1931. Les terrains paleozoïques de Sehoul et des Zemmour (Maroc occ.). *C.R. Soc. Géol. Fr.*, p. 35.
- LELUBRE, M., 1946. Sur le Paleozoïque du Fezzan. *C.R. Ac. Sc.*, **222**, 1403.
- LUCAS, G., 1942. Étude géologique et pétrographique des Monts de Ghar Rouban et du Sidi el Abed. *Bull. Serv. Carte Géol. Algérie*, No. 16, pp. 28-46.
- 1948. Phtanites gothlandiens de Tifrit. *C.R. Soc. Géol. Fr.*, pp. 152-153.
- NICKLÈS, M., 1947. Les faunes de Graptolithes récoltés par F. Jacquet dans le Gothlandien de Mauritanie. *C.R. Ac. Sc.*, **224**, 355-356.
- OWODENKO, B., 1947. Memoire explicatif de la carte géologique du bassin houiller de Djerada et de la région du Sud d'Oujda. *Ann. Soc. Géol. Belg.*, 70, fasc. hors série.
- POBEGUIN, TH., 1947. Sur le Palcozoïque du Fezzan. *C.R. Ac. Sc.*, **224**, 137-138.
- TEMPERE, C., 1959. *C.R. Soc. Géol. Fr.*, pp. 194-5.
- 1959. *Bulletin* (7), **1**.
- TERMIER, H., 1936. Études géologiques sur le Maroc central. (Thesis.)
- and G. TERMIER, 1947. Les principaux niveaux paléontologiques de l'Ordovicien marocain. *C.R. Soc. Géol. Fr.*, pp. 254-256.
- WATERLOT, G., 1941. Les niveaux stratigraphiques des phtanites à Graptolithes du Maroc. *C.R. Soc. Géol. Fr.*, pp. 77-79.
- 1945. Les Graptolithes du Maroc. *Notes et Mém. Serv. Mi. Maroc*, No. 63.

THE PERMO-TRIAS OF AFRICA NORTH OF THE EQUATOR

The Permian of North Africa is mainly continental, but in Tunisia, at Djebel Tebaga de Médenine, there are marine Permian deposits (Douvillé *et al.* 1933).

The Permian of Djebel Tebaga. Djebel Tebaga and the neighbouring hills of Souinia and Saikra form a monoclinal range orientated ENE.-WSW. The basal beds dip towards the south and are covered unconformably by the horizontal Cretaceous of Dahar.

The stratigraphical succession first observed by Berkaloﬀ and Solignac is as follows, from north to south and from bottom to top:

1. Alternation of friable yellow sandstones, grey limestones and clays. Thickness: 135 m. The beds have yielded *Fusulina exilis* Schwager, *Neoschwagerina* cf. *craticulifera* Schw. and *Medlicottia orbignyana* Vern.
2. Marls and green limestones of Baten Beni Zid (160 to 180 m.), with *Neoschwagerina* cf. *globosa* Yabe, *Richthofenia lawrenciana* Waag., *Meekella striatocostata* Cox, *Athyris roissyi* Lev., *Martinia polymorpha* Gemm., *Bellerophon asiaticus* Roem, etc.
3. White or grey siliceous or dolomitic limestones with corals (60 m.).
4. Marls, sandstones and limestones (450 m.) with *Neoschwagerina* aff. *multiseptata* Dep., *Lyttonia nobilis* Waag., *Richthofenia lawrenciana* Waag., *Meekella uralica* Tschern., *Athyris roissyi* Lév. and *Orthoceras cyclophorum* Waag.
5. Mineralised siliceous limestones with crinoids forming the southern crest of the Djebel Tebaga (50 m.).
6. Conglomerate with pebbles derived from different layers of the underlying limestones.
7. Alternating yellow argillaceous sandstones and yellow and green marls (40 m.) with *Cyathocrinus goliathus* Waag.,

Reticularia lineata Martin, var. *affinis* Gemm., *R. indica* Waag., *Martinia uralica* Tschern., *Athyris gerardi* Dien., *Richthofenia* cf. *lawrenciana* Waag., *Pleurotomaria mariani* Gemm., *Bellerophon crassoides* Reed, etc.

8. Sandstones and yellow and red marls (60 m.) with sponges and brachiopods, frequently appearing reworked.
9. Sandstones (265 m.).
10. Marls and gypsiferous clays (250 to 300 m.).
11. Brown and black cross-bedded sandstones (70 m.).

This last horizon passes conformably into red sandstones at the base of the Trias, of which detailed sections have been given by Pervinquière.

The fauna is undoubtedly Permian. Of eighty-four species, thirty-three occur in the Middle Permian of Sicily, thirty in the Salt Range of Pakistan and four in the Urals (Douvillé 1934).

Further east, in the Djebel es Souïnia, the Permian succession is completed with fossiliferous limestones containing *Archaeocidaris barroisi* Mathieu, *Lytonia nobilis* Waag. and *Orthoceras guadalupense* Girty exposed above Bed 7 with bellerophons (Ciry and Mathieu 1947; Mathieu 1949; Termier 1958). The microfauna contains yabeinas, parafusulinids and many fusulinids of the species *Dunbarula mathieui* Ciry, which alone forms 60 to 70 per cent. of the sediment.

The fossiliferous limestones are included in the Kazanian *sensu stricto* (or the lower part of the Kazanian in the broader sense). The end Permian seems to be absent and there is a gap between the Permian marine succession and the overlying Werfenian continental red sandstones, but there is no angular unconformity. On the other hand the Jurassic conglomerates of Sidi-Stout are discordant on the Werfenian. Therefore the folding of the Permian of south Tunisia is post-Werfenian and pre-Bathonian.

Sinaï Trias. In the north-east of Sinaï at Djebel Araïf el Naga, there is an outcrop of marine Trias with ceratites, *Myophoria laevigata* Alb., and conodonts (Awad 1945; Eicher 1946).

The continental and lago-marine facies of the Permo-Trias. The Permo-Trias is a red complex which contains conglomerates, sandstones and mottled clays with salt and gypsum. This facies continues into the Infra-Lias. Except for the marine Permian of

Tunisia, described above, all the Permian of North Africa is of continental origin.

It has been possible to date the base of the Permian at two places in Morocco, Khénifra and Bou-Achouch, by the occurrence of *Walchia piniformis* Schl., and by an unconformity (Termier 1928).

It is difficult to separate the Trias from the Permian as there are no fossils nor a change in facies. Fortunately, however, the Trias can be separated from the Lias in two ways:

1. By the frequent doleritic basalt flows containing pigeonite at the top of the Trias.
2. By the discovery of a Rhaetic horizon. In Morocco the Rhaetic is recognised in two places: around Tétouan and in the Rehamna (at Mechra bou Abou) where Dubar (1935) has re-examined the beds found by Gentil.

Gentil, Roch and H. Termier have shown that the Moroccan Trias exhibits two facies:

1. Continental mottled and salt-bearing clays in the south and south-west, but no calcareous rocks. These are strictly desert deposits, with dunes and salt lakes.
2. Laguno-marine clays containing salt and gypsum in the north and east with thin bands of limestone, dolomites and marls. Marçais has collected a Keuper fauna from this laguno-marine facies, including *Promathildia theodorii* Bey., *Modiola*, *Macrodon*, *Myophoriopsis* cf. *keuperina* Qu. (Marçais 1934).

Exactly the same facies of continental Permian and laguno-marine Trias is found in Algeria and Tunisia. Myophoria beds found in the Djebel Chettabah and near Souk Ahras (dept. of Constantine) (Flandrin 1932) correspond to the German Muschelkalk. Further south on the borders of the Sahara there were lagoons in which salt and gypsum formed true "salt rocks".

The Trias outcrops in the Jeffara Plain south of the Tunisian Sahara, where it comprises 1,000 m. of red continental sandstones underlying 100 m. of marine limestones of Muschelkalk age (Pervinquièrre 1912). The Muschelkalk has yielded an important fauna (Castany *et al.* 1951), including *Ptychites*, numerous pelecypods and marine reptiles of the genus *Nothosaurus* and an amphibian stegocephalian transported by flood water. The

Muschelkalk extends from Tripoli to Djebel Gharian (Brichant 1952).

In the central Sahara, Lehman (1957) has found amphibian stegocephalians (capitosaurs) in the Triassic Zarzaïtine Series. Also in this series de Lapparent *et al.* (1958) have discovered large dinosaurs (teratosaur).

REFERENCES

- AWAD, G. H., 1945. *Bull. Inst. Egypte*, 28.
- BRICHANT, A., 1952. Sur la découverte du Trias au pied du Djebel Garian (Tripolitaine). *C. R. Ac. Sc.*, **234**, 1456.
- CASTANY, G., C. DOMERGUE, C. GOTTIS and A.-F. DE LAPPARENT, 1951. Sur un gisement remarquable d'Invertébrés et de Vertébrés dans le Trias moyen de l'Extrême-Sud tunisien. *C.R. Ac. Sc.*, **232**, 1500-1502.
- CIRY, R. and G. MATHIEU, 1947. Sur la faune des calcaires dits à Bellerophons du Permian supérieur de l'Extrême-Sud Tunisien. *C.R. Géol. Soc. Fr.*, pp. 189-191.
- DOUVILLÉ, H., 1934. Les Fusulinidés de la Tunisie. *Mém. Serv. Carte Géol.*, No. 1.
- M. SOLIGNAC and E. BERKALOFF, 1933. Découverte du Permien marin au Djebel Tebaga (Extrême-Sud Tunisien). *C.R. Ac. Sc.*, **196**, 21.
- DUBAR, G., 1935. Études paléontologiques sur le Lias du Maroc. *Notes et Mém. Serv. Mi. Maroc*, f. 34.
- EICHER, D. B., 1946. Conodonts from the Triassic of Sinaï. *Bull. Amer. Ass. Petrol. Geol.*, pp. 613-616.
- FLANDRIN, J., 1932. Nouvelles observations sur le Trias de Souk Ahras (Algérie). *Bull. Soc. Géol. Fr.* (5), **2**, 497-504.
- DE LAPPARENT, A.-F., P. CLARACQ and F. NOUGARÈDE, 1958. Nouvelles découvertes de Vertébrés dans les séries continentales au Nord d'Edjeleh (Sahara central). *C.R. Ac. Sc.*, **247**, 2399-2402.
- LEHMAN, J. P., 1957. Les Stégocéphales sahariens. *C.R. Ac. Sc.*, **245**, 551-552.
- MARÇAIS, J., 1934. Découverte de fossiles dans le Trias du Prérif oriental. *Bull. Soc. Sc. Nat. Maroc*, **14**, 159.
- MATHIEU, G., 1949. Contribution à l'étude des Monts Troglodytes dans l'Extrême-Sud Tunisien. *Ann. Mi. Géol. Tunisie*, No. 4, 82 pages.
- TERMIER, G. and H., 1948. *Bull. Soc. Géol. Fr.* (5), **18**, 395-405.
- TERMIER, H., 1928. Une hypothèse concernant le Permian et le Trias. *C.R. Ac. Sc.*, **186**, p. 640.
- H., 1930. Un nouvel affleurement de Permien et le Trias. *C.R. Soc. Géol. Fr.* p. 32.
- H. and G., 1958. Les Echinoderms permien du Djebel Tebaga. *Bull. Soc. Géol. Fr.* (8), **8**, 51-64.
- VALETTE, Dom. A., 1934. Les Crinoïdes. *Mém. Serv. Carte Géol. Tunisie*, No. 1.

THE UPPER CARBONIFEROUS AND PERMO- TRIAS OF AFRICA SOUTH OF THE EQUATOR: THE KARROO

An important glacial period succeeding the Hercynian movements has been dated as Upper Carboniferous—*sensu lato*. Glacial sediments are found in South Africa and the Congo Basin. Continental sediments, containing plants and reptiles, were deposited during the Permian and Trias and reached 7,000 m. in thickness. These beds are called the “Karoo”, because the first succession was studied in the Karroo of South Africa.

1. Glaciation (*Dwyka Formations*)

After the Hercynian movements continental sediments, including sandstones and shales with plant impressions, were laid down. Above there is a bluish tillite with striated pebbles and large boulders: the Dwyka Tillite. In the true Karroo Basin, the tillite outcrops over 2,250 sq. km. with the maximum thickness of 400 m. occurring in the south.

On the basis of glacial striations Du Toit has demonstrated four glacial centres in the north. These occur in Namaqualand, Griqualand, the central Transvaal and a submerged area east of Natal. The same tillite is also found in Madagascar at the base of the Sakoa Series. In general, the ice moved from north to south.

On the Atlantic coast of South-West Africa there is a small marine horizon intercalated among the upper fluvio-glacial conglomerates. This bed contains conularias and *Eurydesma globosa*; and thus serves to date the glaciation.

At the same time there was a glaciation in India where the Talchir Tillite corresponds to the Dwyka Tillite. Conularias and *Eurydesma* are again found amongst the fauna of intercalated marine beds in the Punjab and Kashmir. An overlying marine horizon with *Spirifer marcoui* and *Productus cora* passes upwards into the Umaria Beds with *Richthofenia sinensis* and *Fusulina katteansis*. Although *Productus cora* is common in the Uralian, in the Urals this stage is characterised by *Spirifer marcoui*.

Richthofenia sinensis and *Fusulina kattaensis* are found in the passage beds between the Uralian and the Permian. Thus the lower marine beds with *Eurydesma* and the tillites are older, and are probably of Lower Uralian age. It seems, therefore, that the glaciation occurred during the Upper Carboniferous *sensu lato*.

The homologue of the Dwyka Tillite is found in the Congo Basin and in Angola. Glaciation of the Lukuga region, west of Lake Tanganyika, is evident from the striated glacial pavements, roches moutonnées, striated pebbles, tillites and varves.

In the Congo the ice movement was usually from south to north, as if there had been a vast ice-cap in southern Africa from which melt waters had flowed north and south. In the north the tillites actually cross the equator, while in the Congo tillites cover the bottoms of valleys and depressions cut into the pre-Karoo basement (Sluys 1950).

In East Africa the Karroo is often found in tectonic troughs bounded by faults. In Bechuanaland, near Palapye, Du Toit and Maufe have recorded two tillites separated by black shales and covered by varves; and thus provided evidence of an interglacial period. The centres of glaciation slowly moved from west to east along a line corresponding to the Tropic of Capricorn (Du Toit).

When the glaciers retreated the sedimentation changed, and the formation of the "Upper Dwyka Shales" began. These are well developed in the south and west of the Karroo. In north Cape Province, however, the presence of intercalations of glacial conglomerates suggests that there was a fluctuating glacial margin. Further north, in the Orange Free State, Transvaal and Natal, the glaciation continued longer; and so no deposition of Upper Shales occurred.

In a few places, the plants from the Upper Shales are identifiable. They belong to the genera *Lepidodendron*, *Gangamopteris* and *Phyllothea*. Fish (*Palaeoniscus*) and crustaceans (*Pygocephalus* and *Anthrapalaemon*) are also present.

In several parts of South Africa the Dwyka Beds are overlain by a white limestone (White Band) containing a small marine reptile, *Mesosaurus*; this marks the passage between the Upper Carboniferous and the Permian.

2. Lower Permian: *Ecce* Formations

The large basins of South Africa, West Africa and the Congo are filled with sediments known as the *Ecce* formations. These

are nearly 1,800 m. in thickness and contain many beds of coal. The same horizon exists in the Sakoa of Madagascar.

The Ecça formations contain a flora with characteristic Gondwanaian elements such as *Glossopteris indica*, *Gangamopteris cyclopteroides*, *Noeggerathiopsis hislopi*, *Phyllothea*; and plants with Mediterranean and European affinities: *Ptygmophyllum kidstoni*, *Sigillaria brardi*, *Bothrodendron leslii*, and the complete trunks of *Vereeniging*, which resemble the cordaites from Europe. This is a classical Lower Permian Gondwana flora with association of *Gangamopteris* and *Glossopteris*.

The fauna includes two reptiles: *Archaeosuchus* and *Eccasaurus*.

The Ecça formations are recognised in South Africa, Mozambique, Rhodesia, Congo (Lukuga), Angola (Lutôc) and Madagascar.

3. Upper Permian-Lower Trias: Beaufort Formations

The Beaufort formations overlie the Ecça, and reach their maximum thickness of 3,000 m. in the southern zone. They are renowned for their reptile fauna, which enables them to be subdivided into six zones:

1. *Tapinocephalus* zone at the base with forty-five genera of reptiles—corresponding to Zone III of Russia, which contains pelycosaurs.
2. *Endothiodon* zone with dicynodonts.
3. *Cisticephalus* zone with dicynodonts and pareiasaurs, indicating the top of the Permian in South Africa—as in Russia.
4. *Lystrosaurus* zone—passage to the Trias. Equivalent to Zone V of Russia.
5. *Procolophon* zone.
6. *Cynognathus* zone. (Zone 6 = Zone VI with *Capitosaurus* of Russia.) These zones, which belong to the Lower Trias, also contain fish (*Ceradotus*) and a flora with *Glossopteris*, *Phyllothea* and *Thinnfeldia* but no *Gangamopteris*. The climate of the Upper Permian was warm and rather arid.

South Africa has an extraordinary development of reptiles. A large herbivore, *Pareiasaurus*, is known from the Cape to Russia. Its massive body, reaching 3 m. in length, was covered with dermal plates. Another herbivore, *Moschops*, the size of a rhinoceros, is found with *Tapinocephalus*. Others were carnivores, such

as *Titanosuchus*. Together with these large creatures appeared a group of small reptiles with mammal-like teeth: dicynodonts and ictidosaur, at first the size of rats but later reaching a larger size like *Cynognathus*. There have been long discussions over the question of whether some of these, like *Tritylodon*, should be accepted as reptiles (Bohlin 1946; Kuhne 1943; Watson 1942).

Amphibians are found in the upper part of the Beaufort, including *Rhinesuchus senekalensis* and *Capitosaurus*: a genus known from the Cape to Spitzbergen.

The Lower Trias seas contained fish, *Ceratodus* being especially common.

In the Congo Basin the Beaufort formations (Upper Permian-Lower Trias) are unknown.

In Angola, the Lutôe Series (Ecca) is overlain by sandstones and shales of the Cassange Stage, which contain an abundance of fish, including *Ceratodus* (*Angolaichthys*) *lerichei* Teixeira (= Upper Permian-Lower Trias).

4. Upper Trias: Stormberg Formations

(a) *South Africa*. In South Africa the Upper Trias begins with the Molteno Beds: 50 to 100 m. of shales and sandstones with some beds of coal. The flora includes the last *Glossopteris* with *Thinnfeldia*, *Taeniopteris*, *Baiera*, etc.

The overlying Red Beds contain dinosaurian theropods and silicified trunks of trees, probably of the genus *Rhexoxylon*. They are overlain by the Cave Sandstone, which again contains a few reptiles, fish (*Semionotus capensis*), ostracods and phyllopods. The Stormberg Series records an increasingly warm and dry climate. The only floral remains are silicified trunks of trees—a facies known as far as Rhodesia.

At the end of the Trias continental movements gave rise to rifts and large-scale volcanic activity. Basaltic lavas poured from fissures and covered a large part of South Africa. These Drakensberg Lavas, cut by doleritic intrusions, reach 1,000 m. in thickness in Cape Province and 2,000 m. in Basutoland. The age of these lava flows is not known precisely, but they are presumed to be very late Trias or Rhaetic—as in north-west Africa.

(b) *Madagascar*. The Upper Trias is represented by barren sandstones, covered by a Liassic marine horizon, of the lower part of the Isalo Group.

(c) *Tanganyika*. The upper Karroo layers in the Ruhuhu Basin, called the Manda Beds, comprise 150 m. of feldspathic sandstones with numerous reptiles, molluscs (*Unio karrooensis* Cox) and silicified wood (*Rhexoxylon tetrapteroides* Walton).

(d) *Angola*. Red beds with *Estheria lerichei* Marlière and *Estheria moutai* Leriche.

5. The Marine Permo-Trias of the Eastern Coast and Madagascar

An East African coast, bounded by an ocean or a gulf, was in existence at the end of the Lower Permian (*sensu lato*).

The first marine sediments were discovered on the west coast of Madagascar, at Vohitolia in the south and Ankitokazo in the north. These are limestones with *Productus* cf. *curvirostris* Schellw. and *Spirifer* cf. *rectangulus* Kut. which overlie the continental deposits of the Sakoa.

The Upper Permian is also known in Madagascar in the Barabanja and Ankitokazo Basins. In the latter the *Productus* limestones are covered by argillaceous sandstones with *Productus abichi* W. var. *ankitokazo* Astre, *Spiriferina roissy* Lev., *Xenaspis carbonarius* Waag., and *Cyclolobus walkeri* Diener. This fauna is typical of the lower half of the Upper Permian—a formation which is better known in India.

The upper half of the Upper Permian is represented by argillaceous shales with fish remains, some *Claraia*, but no ammonites; and by a horizon intercalated in the continental Sakamena Beds with *Modiolopsis stockleyi* Cox and *Gervillia elianae* Cox. These two species are particularly interesting because they are found in the late Permian of Tanganyika. The western border of a late Permian gulf is found on the Tanganyika coast, while the eastern border is on the west coast of Madagascar.

The Lower Trias is still only known on the west coast of Madagascar, where the succession begins with ammonite and fish beds. The Abilobe ammonites include: *Glyptopliceras besairei* Collignon, *G. gracile* Spath, *Flemingites* sp., *Clypeoceras crassus* Krafft, *Meekoceras ambilobensis* Coll., *M. aff. hodgsoni* Diener, *Prionolobus spathi* Coll.

Among the fish, likewise found in nodules, Piveteau (1934) records *Australosomus merlei* Priem, *Parasemionotus labordei* Priem, *Pteronisculus macropterus* White, *Whiteia woodwardi* Moy-Thomas, *W. tuberculata* M. T., *Coelacanthus madagascariensis* Sm. Woodw.,

Bobasatrania mahavavica White, *Saurichthys*, *Birgeria* (Lehman 1948), *Perleius*, etc. Piveteau has emphasised the similarity between the ichthyosaur faunas from Madagascar, Spitzbergen, Greenland and western Europe (Piveteau 1935, 1937). The genus *Ceratodus* has been discovered in the Lower Trias of Madagascar (Dechaseaux 1948). An upper horizon of the Lower Trias is represented in Madagascar by the sandstones, shales and limestones of Barabanja, containing a large ammonite fauna including *Vishnuitesournieri* Collignon, *Flemingites compressus* Waag., *F. pulcher* W., *Meekoceras khoorensense* W., *Clypeoceras spitiensis* Krafft, *Proptychites cottreaui* Collignon, etc.

6. Triassic Volcanic Activity

Although it is generally thought that there was little epeirogenic and orogenic activity in the Trias, a closer study reveals considerable activity throughout the world.

In Africa there was a marked increase in volcanic activity near the end of the Trias. The classic example is in North Africa, where doleritic basalt flows are intercalated with Triassic beds. The Tunisian Permo-Trias was folded between the Werfenian and the Bajocian-Bathonian.

In West Africa dolerite sills and dykes cut the entire Palaeozoic including the Westphalian of Taoudéni, but are older than the "Continental intercalaire".

The Karroo of South Africa is overlain by 1,000 to 2,000 m. of Drakensberg basaltic lavas which have been cut by dolerite dykes. The majority of the extrusions are apparently of the fissure type, and their alignments (NE.-SW. and NW.-SE.) are permanent directions in Africa and the whole system of fractures was to culminate in the formation of large troughs like the Gregory Rift Valley. It is very probable that some extrusions are of Liassic age.

REFERENCES

- BOHLIN, B., 1946. The Jurassic Mammals and the origin of the mammalian Molar Teeth. *Bull. Geol. Inst. Univ. Uppsala*, pp. 363-388.
DECHASEAUX, C., 1948. Sur le présence du genre *Ceratodus* dans le Trias inférieur de Madagascar. *C.R. Soc. Géol. Fr.*, pp. 157-158.
KUHNÉ, W. G., 1943. The dentary of *Tritylodon* and the systematic position of the *Tritylodonidae*. *Ann. Mag. Nat. Hist.*, 10, 589.

- LEHMAN, J.-P., 1948. Sur la présence du genre *Birgeria* dans l'Eotrias de Madagascar. *C.R. Ac. Sc.*, **226**, 426.
- PIVETEAU, J., 1934. Les Poissons du Trias inférieur (de Madagascar). *Ann. Paléont.*, **23**.
- 1935. Ressemblance des faunes ichthyologiques du Groenland du Spitzberg avec celle de Madagascar, au Trias inférieur. *C.R. Soc. Géol. Fr.*, pp. 113-144.
- 1937. Remarques sur les Poissons du Trias inférieur de Madagascar appartenant à la famille des Paléoniscides. *C.R. Soc. Géol. Fr.*, p. 42.
- SLUYS, M., 1950. Le système du Karroo dans le Bassin du Congo. *Bull. Inst. R. Col. Belge*, **21**, 4, 979-1019.
- WATSON, D. M., 1942. On Permian and Triassic Tetrapods. *Geol. Mag.*, **79**, 81-116.

THE NORTHERN LIMIT OF
POST-HERCYNIAN AFRICA1. *The south-Atlas Structural Line*

There is a remarkably sharp contrast between the Sahara region and the Atlas mountain zone. Brives (1909), Gentil (1906, 1920), Roch (1930), Moret (1931) and Neltner have described a series of tectonic features in Morocco occurring between the foot of the Grand-Atlas and the border of the Sous Plain.

Further to the east, near the Algerian-Moroccan border, Ficheur, Flamand (1910) and Russo (1927) have figured and described well-marked folds, which dip southwards in some localities.

South of the Aurès, Savornin (1930) has demonstrated the importance of the "*fosse sud-aurasienne*", a zone of weakness resulting in a subsiding trough and forming a natural frontier between Barbary and Saharan Africa.

Russo (1934) has reconsidered the question, and has demonstrated the existence of the south-Atlas structural line, more than 700 km. in length, extending south of the Moroccan Atlas. This line of diastrophism is continuous with the Saharan Barrier of south Algeria. The total length of this feature may be estimated at at least 1,200 km., since it stretches from south of Agadir to near Figuig. This "*muraille saharienne*", stretching from the Atlantic to Tunisia, has been shown to coincide very well with the stratigraphic and tectonic boundaries (Menchikoff 1936). The southern limits of the Jurassic outcrops in Algeria and Morocco, south of the Saharan Atlas, coincide exactly with the original shore-line for 200 km.

The marine formations become thinner towards the southern border of the outcrop, where sandstones and conglomerates appear intercalated among the limestones, the reef formations merge into beach deposits, and the youngest beds thin into the continental red beds preserved beneath the Cretaceous. These shores of the Jurassic sea mark the true border of the African continent. This permanent natural boundary, marked by a flexure, folds or

faults, has been studied in the Figuig region (Laffitte 1939) and Tunisia (Castany 1956).

The latest folds and fractures are of Recent age. The South Constantine Miocene marine sediments and the Pontian and Pliocene red beds of south Tunisia have all been folded. In the Aurès, the basal horizon of marine Miocene has been uplifted to a height of 1,400 m. Evidence of an important uplift is provided by the profile of wadi el Arab, near Khenchela, where nearly 2,000 m. of post-Pontian sediments have accumulated in the deep valley. Everywhere the Saharan Atlas has been uplifted more recently than the Saharan basement.

The folds, uplifts and faults are contemporaneous with the large faults of East Africa and the less important ones of West Africa. The very recent age of the latest movements can be deduced from both ends of the structural line, which has been rejuvenated during the Quaternary. In Tunisia, the Gafsa Beds, containing human artifacts of Acheulian age, have been folded. In the west, Bourcart and Roch have shown that the Pliocene and the Quaternary have risen as much as 200 m. to the north of Agadir and sunk below sea-level in the south.

Magnetic anomalies confirm the great importance of the south-Atlas structural line (Savornin 1935). This feature is a permanent structural boundary separating the geology of Barbary as part of Mediterranean geology; and Africa proper which begins immediately to the south.

2. *The Saharan Sill*

Jurassic, Cretaceous and Tertiary sediments (more or less marine) outcrop south of the south-Atlas structural line, in the Low Sahara, or northern border of central Sahara. The character of these deposits reveals that there is a sill to the south of the Saharan Atlas Geosyncline. The reality of this sill is shown by a diminution in the thickness of the sediments, by a barrier reef and by lagoonal deposits found further to the south.

In Tunisia the Djeffera Dome has this succession:

Trias: multi-coloured sandstones, shelly limestones, gypsum (more than 1,000 m.);

Lias: massive gypsum for 300 m. overlain by intercalations of marls and dolomites;

Middle Jurassic: gypsum, marls, dolomitic limestones (200 m.).

Lower Cretaceous: lagoonal and continental marls, sandstones with wood “(Grès à Bois)” (150 m.).

Upper Cretaceous: limestones and marls with beds of gypsum (150 m.).

Northwards the beds rapidly decrease in thickness, and at Djebel Tebaga de Mèdenine the Upper Cretaceous rests directly on the Permian, because of erosion of the older Mesozoic. At this latitude a sill existed throughout the Mesozoic.

In southern Algeria, south of the Aurès and the Chotts, there is a basin filled with Cretaceous lagoonal deposits—as proved by borings. At Touggourt a boring of 899 m. in depth penetrated many beds of gypsum, including one of 53 m. thickness in the Senonian. At Ouargla a boring of the same depth reached the same gypsiferous horizons, and in addition some Cenomanian salt between 621 and 737 m.

In the north the facies changes in the Biskra area, immediately south of the Aurès: the formations are only half as thick and frequently contain reefs. The maximum thickness is from 500 m. to 1,000 m. in the lagoonal basin of the Low Sahara. At El Kantara, in the northern Aurès Trough, neritic deposits reach 3,500 m.

South of the Department of Algiers, 150 km. south-west of Laghouat, at Djebel Djelouadj, there is a further thinning and an unconformity between the Turonian and the Cenomanian.

The northern boundary of the African continent is marked by the south-Atlas sill, which was an obstacle to most of the marine transgressions from the north but was overcome in the Cretaceous.

3. *The Major Palaeogeographic Units of Barbary*

The folded zones of Barbary, so complex in detail, occur between well-defined palaeogeographic and structural limits which appeared during the Mesozoic.

A good account has been given by Glangeaud (1933). This synthesis includes the detailed work of North African geologists. I may mention for Morocco the work of Blumenthal, Bourcart, Daguin, Fallot (1932), Lacoste, Marçais, Marin, Moret, Russo and H. Termier; for Algeria: Dalloni, Deleau, Durand Delga, Flandrin, Glangeaud, Joleau, Laffitte and Savornin; in Tunisia: Pervinquièrre, Joleaud, Solignac and Castany (1956); an incomplete list, much too short and one covering all the years.

REFERENCES

- BRIVES, A., 1909. *Voyage au Maroc*.
- CASTANY, G., 1956. Essai de synthèse géologique du territoire Tunisie—
Sicile. *Ann. Mi. Géol. Serv. Mi. Tunisie*, **16**, 101, 12 pl.
- FALLOT, P., 1932. Essai de définition des traits permanents de la paléogéographie secondaire dans la Méditerranée occidentale. *Bull. Soc. Géol. Fr.* (5), **2**, 533-553.
- FLAMAND, G.-B.-M., 1910. Recherches géologiques sur l'Oranie et sur le Sahara.
- GENTIL, L., 1906. Dans le Bled Siba. Exploration au Maroc.
- 1920. Carte géologique provisoire du Maroc.
- GLANGEAUD, L., 1933. Unités paléogéographiques et structurales de l'Atlas méditerranéen (Algérie, Tunisie, Maroc). *Actes Soc. Linn. Bordeaux*, **85**, 173-220.
- LAFFITTE, R., 1939. Les plissements post-nummulitiques dans l'Atlas saharien. *Bull. Soc. Géol. Fr.* (5), **9**, 135-158.
- 1947. Faciès, épaisseur des sédiments et paléogéographie dans le Bas-Sahara pendant les temps secondaires. *Bull. Soc. Géol. Fr.* (5), **17**, 213-216.
- MORET, L., 1931. Recherches géologiques dans l'Atlas de Marrakech.
- MENCHIKOFF, N., 1936. Études géologiques sur les confins algéro-marocains du Sud. *Bull. Soc. Géol. Fr.* (5), **6**, 131-148.
- ROCH, E., 1930. Étude géologique sur la région méridional du Maroc occidental.
- RUSSO, P., 1927. Recherches géologique sur la territoire des Haut-Plateaux.
- and L. Russo, 1934. Le Grand Accident Sud-atlasien. *Bull. Soc. Géol. Fr.* (5), **4**, 375-384.
- SAVORNIN, J., 1930. Les territoires du Sud de l'Algérie. Esquisse géologique et hydrologique. Algiers.
- 1935. Topographie souterraine et déclinaison magnétique (Algérie et Territoires du Sud). *C.R. Soc. Géol. Fr.* (5), p. 157.

CHAPTER VII

THE JURASSIC

1. CONTINENTAL JURASSIC

The "Continental intercalaire"

The "*Continental intercalaire*", as defined by Kilian (1931), includes the continental sediments deposited after the Hercynian movements and before the Cenomanian transgression. These are marked JK on the International Map of Africa. The Karroo of South Africa is contemporaneous with part (Permo-Trias) of these continental sediments, but deposition in the Karroo began and ended earlier.

The "*Continental intercalaire*" corresponds to the upper part of the Nubian Sandstone (*grès de Nubie*) which, in the Arabo-Nubian shield, begins at the base of the Palaeozoic.

The Infra-Lias flora of the Gulf of Suez (Carpentier and Farag 1942). In the Djebel el Galala el Bahariya, west of the Gulf of Suez, a complex of multi-coloured sandstones contains a small flora: *Phlebopteris* aff. *muensteri* Schenk, *Todites williamsoni* Brong., *Zamites* similar to *schmiedeli* Stern. This flora is considered to be of Infra-Liassic age.

Liassic dinosaurs of Demnat (Morocco) (Plateau *et al.* 1937). 100 km. east of Marrakesh, near Demnat, there are red beds younger than the Pliensbachian and older than the Bajocian. Large dinosaur footprints are found here, on the desiccated surface of impure limestones. These footprints are 0.5 m. in length, and 1.35 m. apart: measurements which suggest that they were made by large bipeds—probably carnivorous theropods.

Bathonian dinosaurs of the Sgatt Cuvette (Morocco). Above the marine Bajocian in the Sgatt-Taguelt (175 km. ENE. of Marrakesh) there are red continental deposits (conglomerates, arkoses and pelites) containing dinosaur bones (Termier 1942).

Bathonian dinosaurs of El Mers (Morocco) (Termier *et al.* 1940; de Lapparent 1955). At El Mers, 100 km. south of Fez, the marine Upper Bathonian contains skeletal fragments of carnivorous theropods and large herbivorous sauropods, whose femurs reach 1.60 m. in length.

Kimmeridgian of the Monts de Ghar Rouban (Algero-Moroccan frontier) (Carpentier and Lucas 1938). A small flora discovered by Lucas near Ghar Roubain serves to date the bed as Kimmeridgian. It includes *Equisetites* sp., plants with fern-like fronds (*Sphenopteris*, *Coniopteris*) resembling *S. hymenophylloides* Br., *S. quinqueloba* Phill. and *Thinnfeldia* (?). The stratigraphical position of this bed is comparable to the plant-bearing sandstones described by Fallot in the Beni-Snasson.

Tunisian Jurassic (Boureau 1952 and de Lapparent 1951). *Weichselia reticulata*, well known from the Lower Cretaceous throughout the world, has been discovered by de Lapparent in the Tunisian Sahara, 20 km. south of Fom Tatahouine, below a marine Bathonian limestone with *Trigonia pullus*, and in the Portlandian. Boureau has pointed out that this species is known by other names in the American and European Jurassic. In addition, *Weichselia reticulata* of the Bathonian is accompanied by homoxyulous wood (*Brachyoxylon brachyphylloides* (Torrey) Kräusel)—the earliest wood with parenchymous structure.

Fort-Polignac Jurassic (Sahara) (Boureau et al. 1957). Boureau, Claracq and Nougarede have published a description of the Jurassic flora in the Fort-Polignac Basin in the Taouratine Plateau. *Weichselia reticulata* is accompanied by *Cladophlebis* and *Phlebopteris*, which apparently are Jurassic forms. In the Taouratine beds there are remains of sauropods which de Lapparent (1958) includes in the genus *Brachiosaurus*—the largest dinosaur, which belongs to the Upper Jurassic.

Messak Jurassic (Sahara) (Boureau and Freulon 1959). The Messak flora, collected by Lelubre and Freulon, contains the same species: *Weichselia reticulata*, *Cladophlebis* and *Phlebopteris*; and also numerous *Yuccites* resembling species from the Upper Bathonian.

Tanganyika, Portlandian. The Upper Jurassic of Tendaguru contains marine Portlandian horizons and beds with dinosaurs: *Brachiosaurus brancai*, *B. fraasi*, *Kentrurosaurus aethiopicus*, *Nanosaurus* sp. *Elaphrosaurus bambergi*, *Allosaurus* (?) *tendagurensis*, *Ceratosaurus* (?) *roechlingi*, *Megalosaurus ingens* (Fraas 1908).

The brachiosaurs were larger than *Diplodocus*; and probably reached a total length of 25 to 35 m., as judged from the length of their femurs.

Madagascar, Bathonian. The upper beds of the Isalo Group (Isalo III) occur between Betsiboka and the Ampasindava Peninsula. A lower horizon with silicified wood is distinguished

from an upper horizon with dinosaurs such as *Bothriospondylus madagascariensis* Lyd.

2. MARINE JURASSIC

1. North Africa

The Lias begins with the Rhaetic with *Avicula contorta*, found in the Rif (Blumenthal, Fallot and Marin), the Rehamna (Gentil and Dubar) and the Djurdjura (Lambert). The Liassic transgression sometimes began in the Lower Lias and sometimes in the Middle Lias. In Morocco, the Bajocian is transgressive, and cephalopod marls were deposited. Outside the Rif Trough the Bathonian is regressive. A new transgression began in the Callovian.

The southern limit of the Jurassic outcrops in the Algerian-Moroccan Sahara coincides for 200 km. with the Mesozoic shoreline.

In the Bou-Denib and Bou-Anane areas Menchikoff has described the following beds:

- (a) Basal red beds, with many doleritic intrusions, probably Triassic or early Liassic.
- (b) Sinemurian limestones with *Arnioceras ceratitoides* Q.
- (c) Middle Lias bedded limestones with *Seguenziceras* and rare *Lytoceras*. The reef facies is well-developed as can be seen at Djebel bou Dahar, where the thick dolomitic limestones contain seventy species of coral and a hundred species of molluscs (sixty gastropods, pectens and a large species of *Perna* 60 cm. long), echinoids and crinoids (Menchikoff 1936; Dubar 1936; Dubar and le Maître 1935; Termier 1936; Roch 1950). There were fringing reefs along the Saharan Liassic coast. Near Menabha the Liassic limestones disappear in the midst of conglomerates and red continental sandstones.
- (d) Toarcian limestones with *Hildoceras bifrons*, Brug.
- (e) Aalenian limestones with *Lioceras opalinum* Rein.
- (f) Bajocian marls and limestones with *Cadomites* and *Oppelia*.
- (g) Bathonian oolitic limestone with *Gymnocidaris pustulosa* Ag.
- (h) Post-Bathonian, pre-Cenomanian red continental sandstones.

The Jurassic makes up the land forms in Morocco and in the department of Oran, where it forms the Moroccan Grand-Atlas, the Moyen-Atlas and southern Oran Plateau. The beds are correlated by the same ammonite horizons as are found in the European Jurassic. At the end of the Jurassic a thick deposit of Tithonian limestones was formed in eastern Algeria and Tunisia (Solignac 1927).

Lucas (1942) has been able to reconstruct some of the oceanography and palaeogeography of Algeria and Morocco. Rivers flowing from the Saharan massifs brought down very fine material in the Lias and coarser sediment subsequently. The Dogger covered the Haut-Atlas Trough, which disappeared in consequence, and in eastern Morocco and Oran there was developed an immense alluvial sheet comparable to the submerged plain of the Ganges Delta. This deltaic phase, with transgressions and regressions, persisted until the Cenomanian transgression.

Cape Verde Islands. The oldest siliceous limestones in Maio Is., containing *Lamellaptychus rectecostatus* (Peters) Trauth, have been dated as Portlandian by Pires Soares. These *Aptychus* horizons are probably a little older than the Neocomian, and resemble those of Algeria.

Libya. The marine Tunisian Jurassic extends a little into the Tripolitanian region south-west of Tripoli.

Egypt. The first Jurassic marine transgression in Egypt is the Bajocian-Bathonian, whose sediments extend to Sinai and to the western border of the Gulf of Suez.

The Sinai Series is transgressive over the Nubian Sandstone of Djebel Moghara and comprises 200 m. of Bajocian marls and limestones with *Coeloceras humphriesi* Sow., 500 m. of Bathonian limestones with *Eudesia cardioides* Douv. and *Rhynchonella orbignyi* Oppel and 230 m. of Oxfordian limestone with *Perisphinctes martelli* Oppel. Since the upper beds are absent the Oxfordian is overlain directly by the Lower Cretaceous (Barthoux and Douvillé).

On the western bank of the Gulf of Suez, Sadek Pacha and Farag have recorded Bajocian with *Pholadomya orientalis* Douv. and Bathonian with *Eudesia cardium* Lmk. and *Rhynchonella concinna* Sow.

2. East Africa

The coast of the Indian Ocean, already evident in the Permian-Triassic, became more clearly defined during the Jurassic.

(a) *Ethiopia and Somalia*. Evidence of the transgression has been found around Lugh, on the Juba and in northern Somalia. This horizon is thought to be Trias and lagoonal, and consists of 20 m. of sandstones and fish-bearing gypsiferous saline clays. It transgresses onto the Pre-Cambrian basement. The overlying partly marine Liassic sandstones are rarely fossiliferous, and were deposited as far inland as the Harrar and the Choa.

The main transgression began in the Bajocian-Bathonian when it covered Somalia and advanced north into the Antalo region (Ethiopia) and the Dankalie Alps (Eritrea). The sea continued to exist during the Kimmeridgian, when the Jurassic transgression was at its maximum.

The sea retreated from the Tigrai and French Somaliland, where the Portlandian is continental. Marine Portlandian is found in the Harrar and southern Somalia.

(b) *Kenya-Tanganyika*. Doubtful Lias, with indifferent fossils, was described by Hennig in Ngerengere, Tanganyika. Here again the Jurassic begins with Bajocian-Bathonian. Spath re-examined the fauna and recognised Bajocian with *Posidonomya alpina*, Bathonian with *Phylloceras*, Callovian with *Oppelia* (*Sindeites*) *sindensis* Spath (a species known in Cutch and Madagascar), Oxfordian with *Perisphinctes subcolubrinus* and Lower Kimmeridgian with *Perisphinctes major*. They are all found at Mombasa (Kenya). The Portlandian outcrops in Tanganyika as the lower layers of the renowned Tendaguru reptile beds which contain *nerineas*, *Trigonia smeei* and *Oppelia kobelli*.

Locally, the Jurassic transgression reached as far as 150 km. inland. If the marine origin of certain Kimmeridgian fish from Stanleyville (Congo) is definitely confirmed this will suggest that the transgression was exceedingly extensive. But confirmation is still awaited.

(c) *Madagascar*. Jurassic beds are unknown on the South African coast, but the western coast of Madagascar has an extensive series. The oldest marine horizon is a bituminous sandstone at Morafenobe, south of Majunga, overlain by Lias with *Spiriferina rostrata*. In the Ampasindava Peninsula there is a marine horizon with *Dumortieria* cf. *dumortieri* and *Harporoceras*. In the north-west of the island, at Ambilobe, the Upper Lias is covered by Bajocian limestones. The Lower Bathonian is known locally all along the coast. The Upper Bathonian marine trans-

gression covered most of western Madagascar. Its fauna includes *Macrocephalites madagascariensis* Lemoine, *M. formosus* Sow., *Phylloceras mediterraneum* Neumayr, etc. This horizon is known in the NE. of Madagascar, and corresponds to the lower *Macrocephalus* beds of Cutch.

Above this are found the complete Callovian, Oxfordian, Argovian, Kimmeridgian and Portlandian. Except to the south of Onilahy, the Madagascar Jurassic forms a continuous fossiliferous series in which all the classic zones have been recognised, and correspond particularly well with those of Cutch.

After the Bajocian-Bathonian the connection between Madagascar and the African Continent was very tenuous. Eventually its existence was confined to short periods of regression, when it probably appeared in the southern region. This region lacks marine sediments—although these may have been eroded.

The possibility that there was a connection with Australia is excluded by the presence of marine sediments on the western coast of this continent. India alone maintained a connection with Madagascar.

REFERENCES

- BOUREAU, E., 1952. Sur un échantillon de *Brachyoxylon* du Jurassique moyen de Tunisie. *Bull. Soc. Géol. Fr.* (6), **2**, 169-174.
- and A.-F. DE LAPPARENT, 1951. Découvertes de structures de *Weichselia reticulata* dans le Jurassique du Sud de la Tunisie. *C.R. Soc. Géol. Fr.*, pp. 108-109.
- P. CLARACQ and F. NOUGARÈDE, 1957. Sur la paléobotanique et la stratigraphie du bassin de Fort-Polignac (Sahara). *C.R. Ac. Sc.*, **245**, 544-545.
- and J. M. FREULON, 1959. Sur les flores jurassiques du Continental intercalaire saharien. *C.R. Soc. Géol. Fr.*, pp. 53-54.
- CARPENTIER, A. and G. LUCAS, 1938. Sur un gisement de plantes du Jurassique supérieur, situé près de Ghar Rouban (frontière algéro-marocaine). *Bull. Soc. Géol. Fr.*, **8**, 587-591.
- and I. FARAG, 1942. Sur une flore probablement rhétienne à El Galala El Bahariya (Égypte). *C.R. Ac. Sc.*, **226**, 686-688.
- DUBAR, G., 1936. Faune liasique de l'Atlas marocaine. *Ann. Soc. Géol. Nord*, 1932-34-36.
- and D. LE MAÎTRE, 1935. Études paléontologiques sur le Lias du Maroc. *Notes et Mém. Serv. Mi. Carte Géol. Maroc*, No. 34.
- FRAAS, E., 1908. Ostafrikanische Dinosaurier. *Palaeontographica*, **55**, 10-144.
- KILIAN, C., 1931. Des principaux complexes continentaux du Sahara. *C.R. Soc. Géol. Fr.*, pp. 109-111.

- DE LAPPARENT, A.-F., 1955. Étude paléontologique. *Notes et Mém. Serv. Géol. Maroc*, No. 124.
- 1958. Sur les Dinosauriens du Continental intercalaire du Sahara central. *C.R. Ac. Sc.*, **246**, 1237-1240.
- P. CLARACQ and F. NOUGARÈDE, 1957. Nouvelles découvertes de Vertébrés dans les séries continentales au Nord d'Edjeleh (Sahara central). *C.R. Ac. Sc.*, **247**, 2399-2402.
- LUCAS, G., 1942. Description géologique et pétrographique des Monts de Ghar Rouban et du Sidi el Abed. 2 vol. (Thesis.) *Bull. Serv. Carte Géol. Algérie* (2), No. 16.
- MENCHIKOFF, N., 1936. Études géologiques sur les confins algéro-marocains du Sud. *Bull. Soc. Géol. Fr.*, **6**, 131-148.
- PLATEAU, H., G. GIBOULET and E. ROCH, 1937. Sur la présence d'empreintes de Dinosauriens dans la région de Demnet (Maroc). *C.R. Soc. Géol. Fr.*, pp. 241-242.
- ROCH, E., 1950. Histoire stratigraphique du Maroc. *Notes et Mém. Serv. Mi. Carte Géol. Maroc*. No. 34.
- SOLIGNAC, M., 1927. Études géologique de la Tunisie septentrionale. *Mém. Serv. Mi. Tunisie*.
- TERMIER, H., 1936. Études géologiques sur le Maroc central et le Moyen-Atlas septentrional. *Notes et Mém. Serv. Mi. Carte. Géol. Maroc*.
- 1942. Données nouvelles sur le Jurassique rouge à Dinosauriens du Grand et Moyen-Atlas. *Bull. Soc. Géol. Fr.*, **12**, 199-207.
- J. GUBLER and A.-F. DE LAPPARENT, 1940. Reptiles et Poissons du Bathonian d'El Mers (Moyen-Atlas marocain) *C.R. Ac. Sc.*, **210**, 768.

CHAPTER VIII

THE CRETACEOUS

1. CONTINENTAL INFRA-CRETACEOUS

The Infra-Cretaceous forms the upper and better known part of the “*Continental intercalaire*”. At present, numerous fossiliferous beds are known whose faunas have been studied in most detail by de Lapparent (1958) and the flora by Boureau (1958). The lower limit is difficult to define, but we have seen previously that the Jurassic is well defined in several places. The upper limit is marked by the Upper Cenomanian transgression (where it exists) or where it merges with the “*Continental hamadien*” of the Upper Cretaceous.

In Egypt Stromer has described a fauna from the Baharia Oasis where the top of the Nubian Sandstone (*grès de Nubie*) contains fish: *Ceratodus africanus* Haug, *Onchopristis numidus* Haug, *Lamna appendiculata* Ag.; dinosaurs such as *Aegyptosaurus baharijensis* Stromer and *Carcharodontosaurus saharicus* Depéret. The plants which accompany the fauna are: *Dadoxylon aegyptiacum* Ung. and *Weichselia reticulata* St. and W. The Baharia Beds are directly overlain by indubitably marine deposits of Cenomanian.

Further to the west, in the Madama and Fezzan, Boureau and Corsin have described a flora collected by Dalloni and Lelubre: *Dadoxylon dallonii* Boureau, *D. aegyptiacum* Ung., etc., and *Weichselia reticulata* St. and W.

On the northern border of the Hoggar from the Libyan frontier to Reggan, the Foureau-Lamy Expedition, Lelubre and de Lapparent have collected the following silicified wood from the “*Continental intercalaire*”: (*Dadoxylon* and *Weichselia reticulata* St. and W.), fish (*Ceratodus africanus* Haug, *Onchopristis numidus* Haug), and the dinosaurs (*Carcharodontosaurus saharicus* Depéret, *Aegyptosaurus baharijensis* Str., *Iguanodon mantelli* M., etc.).

Near the Moroccan frontier, at the base of the Hamada de Guir, Lavocat discovered a sandstone bed with *Onchopristis numidus* Haug, *Ceratodus* sp., *Megalosaurus*, etc. *Protopodocarpoxylon teixeirae* Boureau is recorded in Morocco.

The “*Continental intercalaire*” is widespread south of the

Central Saharan Massif. South of the Air in the Tegama and Damergou, Chevalier, Chudeau, Lambert and de Lapparent have collected silicified wood (*Dadoxylon*), fish (*Ceratodus africanus* Haug, etc.), crocodiles (*Aegyptosuchus*) and dinosaurs. These fossiliferous beds are overlain by Upper Cenomanian marine deposits with *Neolobites vibreyanus*.

Boureau has described much silicified wood of the genus *Dadoxylon* (*Araucarioxylon*) throughout the Sahara. This author observes that these trees show an araucarioid structure in their tracheid cells. However, the crushed areolan perforations of *Cycadeomyelon chevalieri* Boureau are more like those of the true Araucariaceae and, in addition, this example shows a typical cycad pith. The Saharan *Dadoxylon* therefore may not belong to the Araucariaceae. On the other hand, in certain protopinaceans the secondary wood contains tracheids with araucaroid areolan perforations. It is a case of a generalised structure containing elements both of araucarioid and abietinous types.

It should be emphasised that the first dicotyledons appeared in the "Continental intercalaire", accompanied by podocarpaceans especially in the Dibella Flora, seemingly Albian or Cenomanian (overlain by the Upper Cenomanian marine transgression).

In north-east Africa in the Darfour (Sudan), 75 km. east of El Facher, the Nubian Sandstone has yielded the same Infra-Cretaceous flora with *Weichselia reticulata* S. and W., *Frenelopsis hoheneggeri* Ett. and *Dadoxylon aegyptiacum* Unger (Edwards 1926).

Likewise, in Cameroun and Chad there are Wealdian beds with silicified wood: *Cupressinoxylon* (?), *Frenelopsis hoheneggeri* Ett., *Protopodocarpoxylon rochii* Boureau.

These horizons correspond to the "gres sublittoraux" on the equatorial coast of Africa. These are continental, estuarine and lagoonal deposits with marine intercalations.

In the Congo Basin there is some continental Cretaceous, the Kwango Series, whose top appears to reach into the Upper Cretaceous.

In East Africa the Wealdian is represented by beds with silicified wood (*Dadoxylon dantzii* Potonié, similar to the Saharan wood), fish (*Lepidotus minor* of the Wealdian) and dinosaurs (*Gigantosaurus africanus*, etc.). (It should be emphasised that the first reptile horizons are found in the Portlandian.)

In Cape Province, the Uitenhage Series begins with conglomerates, sandstones and clays with *Estheria* and continues with beds

containing plants (*Zamites recta*, *Acaucarites rogersi*, *Cladophlebis browniana*, etc.) and dinosaurs. This is also Wealdian.

The Infra-Cretaceous is very important and singular in Africa. It is remarkable for the unity of facies, flora and fauna, implying that there was a uniform climate from the north to the south of Africa and a continuous transition from the Jurassic to the Cretaceous.

2. MARINE CRETACEOUS

1. *The Atlantic Coast*

The modern Atlantic Ocean and the west coast of Africa were formed in the Cretaceous.

A continuously marine phase existed from earliest Cretaceous times in the Cape Verde Isles, where Valanginian-Hauterivian, Barremian and Aptian beds occur. There is nothing similar on the west coast of Africa except one section of the coast which extends from the end of the Gulf of Guinea to Angola. These are the "grès sublittoraux" of Cameroun, Gabon and Angola, which include lagoonal and marine Aptian sediments. Reliable evidence of the proximity of the shore is provided by estuarine beds with woods, bituminous and saline lagoonal beds and limestone lenses with marine fossils. These "grès sublittoraux" are dated by fish, in particular by *Parachanos aethiopicus* Weiler from the Aptian of Gabon and Rio Muni, and *Leptolepis congolensis* from Gabon.

The great Cretaceous transgression began during the Albian. Evidence is found in Angola (beds with *Inflatoceras* of Lobito, etc.), in Gabon (horizon with *Douvilleiceras* of Ogooué), in Rio Muni (fauna with *Elobiceras* from the Elobi Isles) and in Nigeria (beds with *Elobiceras* of the Benue).

The Lower Cenomanian is regressive; it is doubtfully present in Angola, absent from the Congo and perhaps from Gabon, as well as further to the north.

Another transgression began in the Upper Cenomanian and the Lower Turonian. Traces of this last stage exist in Angola, the Congo, Gabon, Cameroun, Nigeria and the Ivory Coast. Apart from Nigeria, the transgression involved only a coastal strip or a series of small gulfs which never penetrated far into the interior.

The Senonian is found in the same places from Angola to the

Ivory Coast. In addition, the Maestrichtian occurs in Senegal. Generally the Danian is present only as a regressive facies.

2. The Saharan Sea

We have seen that the Infra-Cretaceous of the Sahara is continental. One has an impression of low-lying ground with estuarine

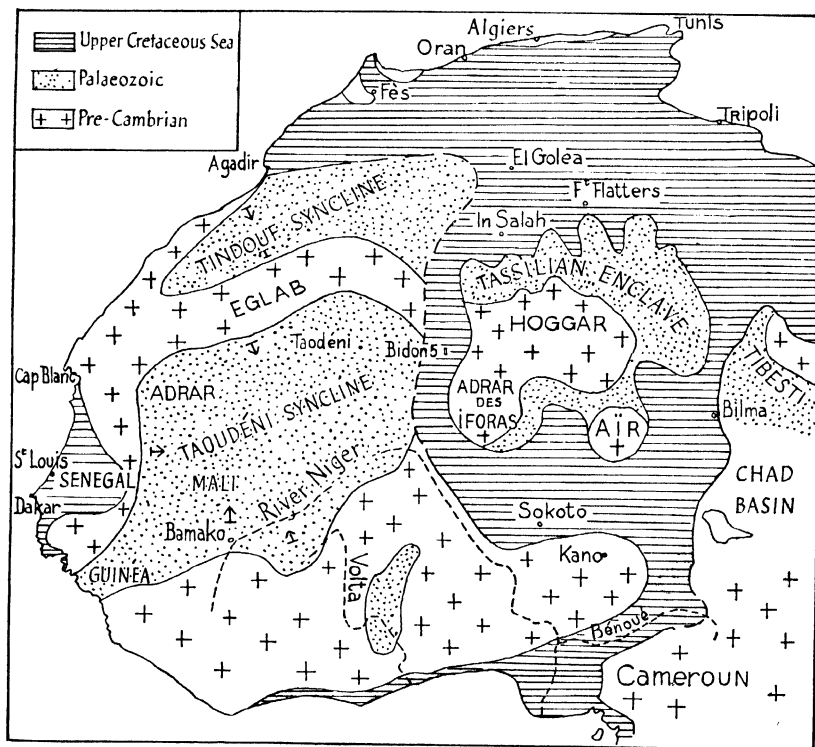


FIG. 1. The Upper Cretaceous Transgression.

and lagoonal deposits, forming a marginal zone between sea and land.

An extensive transgression occurred in the Upper Cenomanian when the waters of the Mediterranean penetrated deep into the Sahara as far as the Hoggar. One Cenomanian species, *Neolobites vibrayeanus*, is found not only in the Tademaït cliffs, north of the

Hoggar, but also south of the Hoggar in the Ténéré du Taffassasset, in the Damergou, and in the Adar Doutchi (in Niger). The Mediterranean waters may have joined the Lower Niger by two routes: to the east via the depressed zone between the Hoggar and the Tibesti; to the west via a depressed zone on the western border of the Hoggar and the Adrar des Iforas. This second route has not yet been properly established by the discovery of fossils, but it is confirmed for the topmost Cretaceous.

In the Lower Turonian (which is always difficult to separate from the Upper Cenomanian) faunas with *Vascoceras* and *Hopliotoides* extended from the Mediterranean to the Lower Niger. The fauna is known south of Bilma (north of Chad), south of the Adrar des Iforas and the Aïr (Damergou, etc.), in the Benue Valley (Nigeria) and Cameroun (Moungo valley).

In the Senonian the sea returned, bringing an Indo-Mediterranean fauna into the Gulf of Guinea. The route can be traced by means of *Peroniceras dravidicum* from the Coniacian of India, Cameroun and Gabon, *Trigonoarca curvatodonta* and *Rostellaria* aff. *palliat*a from the Indian Campanian and the Congo; *Libycoceras maestrichtiens* from the eastern Mediterranean, Mali and Angola.

Here one must draw attention to the frequent and erroneous records of *Venericardia beaumonti* in the Maestrichtian-Danian of the west coast of Africa. It now seems that the actual species concerned is *Venericardia ameliae* Peron of the Maestrichtian-Danian or *V. nauliensis* Cox of the Campanian. The Danian is usually regressive.

3. The Coast of the Indian Ocean

The coast of the Indian Ocean, broadly delineated in the Jurassic, became gradually defined during the Cretaceous. The end of the Jurassic is generally regressive and the basal Cretaceous appears to be missing from the northern part of the coast.

The marine Valanginian is found at Uitenhage (near Port Elizabeth, Cape Province) and on the Mozambique coast, with beds containing *Rogersites schenki* Oppel, as well as on the western coast of Madagascar.

During the Barremian the sea invaded the coast of Tanganyika and Somalia. This was a period of very marked transgression followed by the Lower Aptian, which was stable or a little regressive, while the Upper Aptian sea spread anew from Arabia to both coasts of the Mozambique Strait. Ethiopia must have been

covered because limestones with *Exogyra couloni* Defr. are found in the Aroussis and Harrar regions.

Elobiceras newtoni Spath. from the Gulf of Guinea arrived in the Albian on the Mozambique coast, south of Lorenzo Marquès; whilst the Indo-Mediterranean fauna continued to reach Madagascar.

The Cenomanian and Turonian do not show any noteworthy characteristics.

The Indian fauna is found on both coasts of the Mozambique Strait in the Senonian. The Santonian is present as a regressive facies.

The Upper Campanian is particularly interesting because it is the earliest marine stage recognised on the east coast of Madagascar. It contains a good Indian fauna with *Pseudophyllites indra* Forbes, *Alectryonia unguolata* Sch., *Noetlingia boulei* Lb. and *Lepidorbitoides socialis* Leymerie. The isolation of Madagascar dates from Upper Campanian times.

The Maestrichtian occurs in the same places and continues into the Danian with hercoglossas both in Madagascar and Mozambique, passing insensibly into the Eocene by intermediate beds. In Madagascar, these contain fossils like those known from beds of Montian age in Baluchistan with *Venericardia vredenburgi* Douv.

REFERENCES

- BOUREAU, E., 1958. Paléobotanique africaine. Évolution des flores disparues de l'Afrique nord-équatoriale. *Bull. scient. Com. Et. hist. et sc.*, 64 pp., 8 pl.
- EDWARDS, W. N., 1926. Fossil plants from the Nubian Sandstone of eastern Dafur. *Q.J.G.S.*, 82, 94-100.
- DE LAPPARENT, A.-F., 1958. Sur les Dinosauriens du Continental intercalaire du Sahara central. *C.R. Ac. Sc.*, 246, 1237-1240.

CHAPTER IX

THE PALAEOGENE

LOWER AND MIDDLE EOCENE

Southern Rif Trough. On the northern border, Lacoste (1934) has described transgressive and unconformable Lower Eocene above the Cretaceous. The succession begins with the Thanetian, which consists of glauconitic sandstones, phosphates and white marls with *Nummulites aquitanicus* Benoist and *N. girondicus* Benoist. The Ypresian has the same facies but is dated by nummulites: *N. planulatus* Lmk., *N. globulus* Leym., *N. bolcensis* M. Ch.

In the Taza region of the southern Rif Trough, Gentil (1918) discovered Thanetian beds with *Voluta depressa* Lmk. and *Cucullaea crassatina* Lmk. in the wadi Ladhar. Above come marly siliceous limestones and the Ypresian of El Ksar with *N. planatulus* Lmk. and *N. globulus* Leym. (Brives 1913).

The Montian has not been definitely demonstrated but its presence is suggested by Daguin's (1927) discovery of small nummulites of the *fraasi* group in the limestones at Beni-Amar (Zerhoun) and at Djebel bou Kennfoud (south of Tselfat). These slightly phosphatic and glauconitic limestones contain some nummulites and algae and transgress onto the Jurassic.

Atlantic Morocco. The transgressive Lower Eocene was laid down in a large gulf in the Tadla and the Sous. This gulf was divided into two parts by a peninsula or an island corresponding to the western end of the Haut-Atlas. The northern part is called the "Tadla Gulf" and the southern one the "Sous Gulf".

The Lower Eocene of western Morocco is very different from that of the southern Rif Trough; it is very rich in phosphates and does not contain nummulites. The phosphatic zones have been studied in detail by Brives, Gentil, Joleaud, Lemoine, Arambourg, Moret, Rochand and Russo.

In the Tadla Gulf, north of the Grand Atlas, there are three enormous phosphatic rock groups: at Ouled Abdoun (with Wadi Zem and Kourigba), Ganntour and Meskala. South of the Haut-Atlas there are other less important beds in the Sous. In the phosphatic basin of the Tadla Gulf (Ouled Abdoun and Gann-

tour), the Lower Eocene follows closely on the Upper Cretaceous phosphates, and from bottom to top the succession, described by

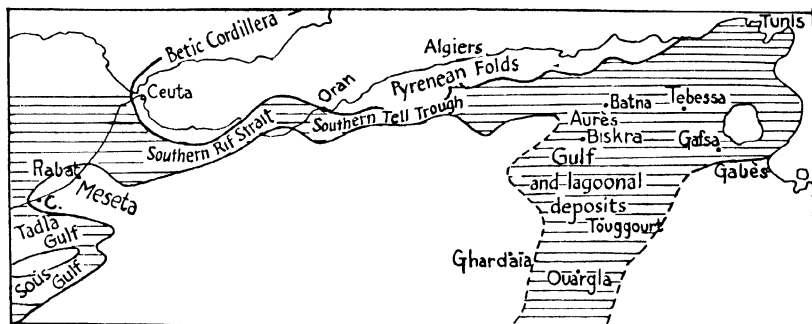


FIG. 2 The extent of the Lower Eocene in North Africa.

Arambourg (1935) and Arambourg and Joleaud (1943), is as follows:

Danian: Phosphatic Bed III with *Corax pristodontus* Ag., *Enchodus libycus* Quaas, *Leiodon anceps* Owen.

Montian: phosphatic beds with *Dyrosaurus phosphaticus* Thom., *Lamna appendiculata* Ag., *Odontaspis macrota* premut. *striata* Winkler, *Cynglimostoma africanum* Ler. (Montian of the Congo), *Mauritanaster gentili* Lambert.

Thanetian: Phosphatic Bed II with *Dyrosaurus phosphaticus* Th., *Lamna obliqua* Ag., *Ostrea heteroclita* Deufr.

Ypresian: Phosphatic Bed I with a fauna similar to the Thanetian with, in addition, some typically Ypresian species: *Xiphyrhynechus prisus* Ag., *Pristis* cf. *lathamii* Gal., *Brychaetus muelleri* Ag. Above there are some beds with thersites, *Carolia placunoides* and *Ostrea multicostata*, whose stratigraphical position appears to be doubtful. (Ypresian or Lutetian? but apparently Ypresian in Senegal.)

In the Sous Gulf (Imini, Tamdahkt and Skoura region), the succession is a little different and does not contain the rich fish fauna of Tadla. Moret (1938) has established this succession:

Danian: Fauna A of Tamdahkt with *Glaucania marocana* Moret, *Ostrea prechudeaui* Moret, *Archaeolithothamnium* cf. *lugeoni* Pf.

Montian: beds with *Odontaspis macrota* mut. *striata* Winkler and *Mauritanaster gentili* Lamb.

Thanetian: marls with *Ostrea heteroclita* Defr., *Meretrix proxima* Desh., of Fauna C.

Ypresian: Fauna B with *Pseudotheresia moreti* Sav., *Athleta marocana* Moret, *Ostrea submissa* Desh.

Beds containing *Ostrea multicostata* and *Carolina placunoides* are found in the Tamdahkt. Their age is doubtful; perhaps Ypresian or Lutetian.

Algeria-Tunisia. The Palaeogene of Algeria has been the subject of two fine memoirs by Flandrin (1938, 1948).

Danian-Montian: in the greater part of the Tellian and Saharan regions the lower limit of the Palaeogene is difficult to define for there is no discontinuity between the Upper Cretaceous and the Eocene. Very often the Danian and Montian are represented by a great thickness of globigerinous marl formerly called the "suessoniennes".

At Djellal in the Aurès, the Nemencha, Négrine and in the Gafsa Mts., the Danian with *Venericardia beaumonti* d'Arch. is overlain by fossiliferous Montian. The fauna is never very rich; it includes *Gitolampas tunetanus* Th. and G., *Venus grenieri* Coq., *Cardia numida* Coq., *Ostrea multicostata* Desh. var. *strictiplicata* R. and Delb., *Pycnodonta archiaci* d'Orb., *Turritella forgemoli* Coq. and *Pleurotoma ampla* B. and C. The sea covered the same region as in the Danian. Peculiar gastropods of the genus *Pseudoceratodes* are present.

There is an example at Négrine, in south-east Constantine, of the passage beds between the marine Cretaceous and marine Eocene:

- (a) *Maestrichtian* with *Inoceramus crispus* Math. var. *radiosa*, *Exogyra matheroni* d'Orb.
- (b) *Danian*: marls and phosphatic sandstones with *Roudaireia drui* M. Ch., *Omphalocyclus macropora* Goldf., *Lamna appendiculata* Ag., *Scapanorhynchus raphiodon* Ag. (30 m.).
- (c) *Montian*: siliceous limestones with *Ostrea punica* Thomas and *Callianassa* sp.
- (d) *Thanetian*: limestones with *Ostrea multicostata* Desh. and a phosphatic zone with *Dyrosaurus phosphaticus* Thomas.

In these places the Thanetian is only fossiliferous in the phosphatic zones, which always signify shallow water. One finds the same fauna as in Morocco, including the reptile *Dyrosaurus*

phosphaticus. The Thanetian phosphates are exploited over a wide area, at Djebel Onk, Dejbél Kouif, Bordj Rhedir, Mzaïta and at Tocqueville. Outside this region there are no other phosphates or fossils.

Ypresian: the sea occupied its greatest extent and exhibited uniform fine sedimentation. There are some 50 to 100 m. of marls and limestones, some of the limestones being siliceous. Fossils are abundant in the Guelma region (Chavanne 1910) where *Nummulites planulatus* Lmk is associated with species surviving from the Lower Lutetian: *Nummulites atacicus* Leym., *N. globulus* Leym., *N. irregularis* Desh., *N. pomeli* Ficheur.

In south-east Constantine (Ziban, Aurès and Nemencha) there is a fine group of echinoids: *Echinopsis friiryi* Lamb. (known in Senegal), *Scutellina abovata* Ag., *Sismondia desori* Coq., *Mauritanaster arnaudi* Coq. The phosphatic horizons are not very important. Again fish occur: *Myliobatis oweni* Ag., *Glyptorhynchus rectus* Ag.

Lower Lutetian: well marked in the Tellian zones where it contains *Nummulites gizehensis* Forskal and its variety *vasseuri* Douv., *N. irregularis* Desh., *N. globulus* Leym., *N. atacicus* Leym., *Ostrea multicostata* var. *strictiplicata* R. and Delb. (dating from the Montian), *Carolia placunoides* Cantr., *Mesalia locardi* Cossm., *Thersitea ponderosa* Coq. (which survived from the Ypresian) and *Hemithersitea maroccana* Savornin. The poorly phosphatic horizons contain *Lamna aschersoni* Str., *Myliobatis striatus* Buckl., and *Cylindracanthus rectus* Ag.

Towards the end of the Lower Lutetian an early orogenic movement provoked a regression throughout the department of Constantine and gave rise to a sill separating the Tellian Trough with its African fauna, including *N. gizehensis* and thersites, from the transgressive sea which brought with it a Mediterranean fauna with *N. aturicus*.

Upper Lutetian: the transgressive Upper Lutetian extends beyond the limits of the previous seas and overlies Middle or Upper Cretaceous sediments. The beds contain a poor fauna: *N. gizehensis* F., *N. vasseuri* Douv., *N. laevigatus*, *N. aturicus*, *N. uronienensis*, *Orthophragmina pratti* Mich., *Ostrea multicostata* Desh. and its variant *bogharensis* Coq., *Carolia placunoides* Cantraine, *Thersitea coquandi* Loc. and *Hemithersitea ventricosa* Sav. The Hodna Gulf and Low Sahara were covered by lagoons in which clays and gypsum were deposited.

At the end of the Upper Lutetian, following the deposition of

the upper beds with *N. gizehensis*, orogenic movements increased in intensity and caused the emergence of Algeria. Important folds date from this time.

Post-Lutetian Folding.

The larger folds of the Mediterranean Atlas, seen from Tangier to Bizerta, are of Post-Lutetian age (Glangeaud), as are those in the Saharan Atlas (Laffitte 1939).

To the north the ancient and rigid massifs of the Kabylie and Spanish Rif have been raised into an anticlinal horst inclined southwards. The limestone range occupies the southern flank of this horst.

The plastic rocks in the large Tell-Rif Trough were violently compressed, and reacted in all directions, while the Triassic evaporites added complex distortions (diapiric folds, intrusions, pseudo-veins, slides and thrusts). In the south the Saharan border was uplifted. In the Aurès the post-Lutetian movements have produced hills of 300 to 500 m., but the amount of erosion of the beds was nearer 6,000 m. The formation of these immense folds was accompanied by faults of a comparable size. The Chellia Fault, for example, has a throw of 5,000 m. The gypsum and salt-bearing Trias has intruded upwards through the overlying beds and reached the surface as a number of salt domes with disharmonic and diapiric folds.

UPPER EOCENE—OLIGOCENE

Algeria-Tunisia. The Upper Eocene marks the beginning of a new sedimentary cycle between the Pyrenean and first Alpine orogenic phases. The transgression came from the Mediterranean and deposited clayey marls and sandstones of "Numidian" facies in the littoral massifs and the greater part of the Tellian ranges. These are the old stages with Flysch Facies: the Medjanian and Numidian of Ficheur.

During the Upper Priabonian the neo-Palaeogene transgression reached its maximum extent, and covered northern Tunisia and the Tell. Two islands remained emergent in the Kabylie, which is a part of the Biban Range and Sahel of Oran. The commonest fossils are: *Nummulites fabianii* Prever, *N. tournoueri* de la Harpe, *Orthophragmina pratti* Mich. and *O. archiaci* Schlumb.

Oligocene: the Stampian is represented by the Boghari Sandstone facies and Oranaï facies in the south Tellian chains; the Dellysian facies is found only in the Algerian coastal region. The commonest fossils are: nummulites (*N. intermedius* d'Arch., *N. fichteli* Mich., *N. tournoueri* de la H.) associated with lepidocyclines (*Nephrolepidina tournoueri* Lem. and D., *Eulepidina dilatata* Mich. and *E. raulini* Lem. and D.), echinoids, pelecypods (*Pecten arcuatus* Brocchi, *Chlamys biarritzensis* d'Arch., *Pseudamussium corneum* Sow. mut. *tunetanum* Loc.) and gastropods (*Conus ineditus* Mich., *Ficula condita* Brongn., *Voluta multicostata* Bell.).

In central Tunisia the Upper Eocene appears to be missing. At Cape Bon, for example, the Oligocene Sandstones with *Nephrolepidina tournoueri* Lem. and D., *Eulepidina dilatata* Mich. and heterostegines rest directly on marly Upper Lutetian with *Nummulites uroniensis*, *N. aturicus*, etc. In the Upper Eocene central Tunisia was probably an area of positive relief—although it had not been folded.

The character of the Oligocene deposits of Tunisia and the Tell show that the continent was bordered by a slightly uneven continental shelf bounded by low-lying coasts. At the end of the Oligocene the first alpine movements occurred. This was the orogenic paroxysm which provoked the emergence of the Mesogeant tectorogene and the emplacement of compression nappes caused by the contraction of the geosyncline (Glangeaud 1956).

Egypt. The nature of the transition from the Cretaceous to the Tertiary varies from place to place. There may be an uninterrupted succession from the Cretaceous to the Tertiary or a non-sequence with transgressive Ypresian, Lutetian or Bartonian.

The Montian beds in the Farafra Oasis yield very small nummulites: *N. deserti* de la H. and *N. fraasi* de la H. The Upper Eocene is regressive. The rare marine Oligocene is represented by limestones with *N. intermedius* and lepidocyclines.

Sahara-Mali-Nigeria. The faunas indicate marine conditions throughout the Lower Eocene. Epeirogenic movements occurred at the end of the Lower Eocene and the sea finally retreated from the Sahara-Mali region.

The long continental period which followed was marked by the deposition of gravels, sandstones and clays, containing vertebrates and plants. The Tertiary sediments are given the name of "Continental terminal".

Western Coast. A gulf penetrated quite deeply into Senegal.

There one finds Montian and Ypresian deposits with corded nummulites and nummulitic Lutetian. The sea retreated at the end of the Lutetian.

Various Eocene and Oligocene deposits are reported on the coast of Guinea. The Lower Eocene outcrops in Ghana, Togo and Dahomey, where it is represented by limestones with corded nummulites. In Nigeria the molluscan fauna of Bende-Ameki is a mixture of species from the Upper Lutetian and Lower Bartonian (without nummulites). The Eocene is also found in Cameroun, Gabon, the Congo Republic, Angola and the Landana area of the Congo. In South-West Africa, south of Lüderitz Bay, various outcrops have yielded a fish fauna similar to that of the Lower and Middle Eocene of the more northern coasts.

Eastern Coast (Indian Ocean). In South Africa some Eocene deposits with orthophragmines are found around Bathurst and between Port Elizabeth and East London.

On the Madagascar coast of the Mozambique Strait there is Lower Eocene with echinoids, Middle Eocene with *Nummulites atacicus* Leym., *N. uroniensis* Heim and orthophragmines, and Upper Eocene with echinoids. The Oligocene is also recognised on the west of the island (beds with *Nummulites intermedius* d'Arch. and lepidocyclines). On the African side of the strait the nummulitic Middle and Upper Eocene cover the edge of the continent between the Zambezi and Sabi rivers. There does not seem to be any Oligocene, and this might provide evidence for a land connection between Madagascar and the continent.

On the Tanganyika coast the Palaeogene of Lindi is complete: Lower Eocene with *Conoclypeus delanouei*; Middle Eocene with *Nummulites perforatus*; Upper Eocene with *N. fabianii*; Oligocene with *N. intermedius* and lepidocyclines. No nummulitic deposits are known from Zanzibar or the neighbouring coasts.

The Lower Eocene covers northern and south-eastern Somalia to slightly beyond Berbera as well as Sokotora Island. The lower beds contain nautiloids and corals and are overlain by the Ramikot foraminiferous limestones. The Middle Eocene is classical, but the Upper Eocene appears to be absent. The Oligocene is transgressive, with *Nummulites intermedius-fichteli* and lepidocyclines, forming a discontinuous outcrop along the Gulf of Aden Coast from south of Berbera to Cape Gardafui, and on the Indian Ocean coast as far as Illig.

REFERENCES

- ARAMBOURG, C., 1935. Note préliminaire sur les Vertébrés fossiles des phosphates du Maroc. *Bull. Soc. Géol. Fr.*, **5**, 413-439.
- 1936. Nouvelles observations sur les faunes et la stratigraphie des phosphates du Maroc. *C.R. Soc. Géol. Fr.*, pp. 211-212.
- and C. JOLEAUD, 1943. Vertébrés fossiles du bassin du Niger. *Bull. Serv. Mines A.O.F.*, **7**, 31-90.
- BRIVES, A., 1913. Fossiles du Rharb récoltés par M. l'Ingénieur Hupkès. *C.R. Soc. Géol. Fr.*, p. 130.
- CHAVANNE, J. DARESTE DE LA, 1910. La région de Guelma. Étude des terrains tertiaires. *Bull. Serv. Carte Géol. Algérie* (2), **5** and *Thesis, Lyon*.
- DAGUIN, F., 1927. Contribution à l'étude géologique de la région préifaine. (*Thesis*), *Notes et Mém. Serv. Géol. Maroc*, pp. 272-273, 292.
- FLANDRIN, J., 1938. Contribution à l'étude paléontologique du nummulitique algérien. *Mat. Carte Géol. Algérie* (1), No. 8.
- 1948. Contribution à l'étude stratigraphique du nummulitique algérien. *Bull. Serv. Carte Géol. Algérie*, No. 19.
- GENTIL, L., 1918. Notes d'un voyage géologique à Taza (Maroc sept.). *Bull. Soc. Géol. Fr.* (4), **18**, 129-177.
- GLANGEAUD, L., 1956. Corrélation chronologique des phénomènes géodynamiques dans les Alpes, l'Apennin et l'Atlas nord-africaine. *Bull. Soc. Géol. Fr.* (6), **6**, 867-891.
- LACOSTE, J., 1934. Études géologiques dans le Rif méridional (Maroc). (*Thesis*).
- LAFFITTE, R., 1939. Esquisse géologique de l'Aurès. *Bull. Serv. Carte Géol. Algérie*.
- MORET, L., 1938. Contribution à la paléontologie des couches crétacées et éocènes du versant Sud de l'Atlas de Marrakech. *Bull. Serv. Carte Géol. Maroc*, No. 49.

CHAPTER X

THE NEOGENE

Marine Miocene

North Africa. The marine Aquitanian exists perhaps only in the Rif region, where its beds contain *Nephrolepidina marginata* Mich., *N. tournoueri* Lem. and Douv., *Eulepidina elephantina* M. C., and more small Oligocene nummulites (Abrard, Bourcart, Lacoste). The "Dellysian" of Dellys (transgressive on the Oligocene and older than the Burdigalian) is probably Aquitanian.

The Burdigalian began with a large transgression. But although the sea penetrated into the Bizerta region and central Tunisia, large islands remained emergent. In Algeria it filled channels and covered the same area as the Eocene Sea. Further to the south it invaded the valleys on the northern border of the Aurès but left the hill-tops uncovered and never reached the southern border. The deposits are neritic and contain echinoids and pectens (*Pecten tietzei* Fuchs, *P. praescabriusculus* Font., etc.).

The Vindobonian was transgressive with respect to the Burdigalian and a great thickness of grey marls was deposited. The Vindobonian did not reach the Aurès, which was completely emergent. In the southern Rif Trough, to the west, the transgressive Burdigalian deposited calcareous and sandy "mollases". In the Vindobonian, also transgressive, the southern Rif Strait was over 100 km. wide, and covered the area between Ouergha and the Meseta. The Algerian Miocene ends with the Tortonian, which consists of limestones with *Lithothamnium*, Oranic green marls, rotten-stones and fish beds (Arambourg 1927).

Laffitte (1948) has demonstrated that the Sahelian cycle is absent from Algeria and is only doubtfully present in Tunisia. Here it is unconformable on the Miocene, but the fauna is essentially Pliocene (Arnould 1952; Solignac 1927; Stchepinsky 1938).

When the Alpine movements reached their maximum the sea retreated from North Africa. In the west the Mediterranean was joined to the Atlantic by the southern Rif Strait which passed through the Gharb. This is shown by the fauna from Dar-bel-Hamri (Lacoste 1934; Chavan 1944; Roger and Lecoindre 1943). The channel was only closed towards the end of the Miocene.

Tripolitania-Egypt. Evidence of the Lower Miocene Sea is known in Cyrenaica and Egypt. The Vindobonian covered the same regions, but in the eastern part it transgressed to the south, reaching the Tropic of Cancer and the Ras Banas on the coast of the Red Sea. It comprises gypsum, salt and petroleum-bearing formations. The Upper Tortonian is regressive.

Atlantic Coast. The Vindobonian transgression submerged the Canary and Cape Verde Islands and deposited limestones containing *Clypeaster altus*, *Amphistegina lessonii* and *Lithothamnium*. A gulf existed throughout the Neogene in Senegal.

Much further south there are 1,000 m. of Neogene deposits in Gabon and others in Cape Malembe, the lower Congo and Angola. These latter deposits are limestones with lepidocyclines and fish.

Coast of the Indian Ocean. Marine Miocene is known all along the western coast of Madagascar and includes Aquitanian-Burdigalian with lepidocyclines and *Kuphus*, and Vindobonian with *Operculina complanata*. It is also known on the African coast in Mozambique (Laffitte 1948), in the Lindi region (Tanganyika) and on the islands of Zanzibar and Pemba, as well as in Somalia.

Alpine Tectonic Phases. The Lower Miocene was affected by late phases of adjustment after the paroxysm at the end of the Oligocene. The works of Caire, Durand Delga, Glangeaud and Mattauer, in particular, have demonstrated two horizons of Lower Miocene: one before, and one after the emplacement of the nappes. These North African nappes have slid about 100 km. from the coast to the south of the Tell (Caire *et al.* 1953; Durand Delga 1955).

During the pre-Pontian Vindobonian phase, the folded area was refolded and uplifted. The Haut-Atlas was uplifted and enlarged; and it is now framed by large upwarps to the north and south. Initially, the continental Pontian deposits invaded the basins separating the ranges: Guercif Basin at the foot of the Middle Atlas, Sous Basin, Guir and Dra Hamadas. Other deposits are found within the folded ranges. Later, towards the end of the Pontian, a continuous sheet of continental deposits surrounded all parts of the mountain ranges which emerged through it. Later erosion of these ranges resulted finally in a planed surface. This "*surface hamadienne*" of Choubert is exemplified in the south by the pavement of Pliocene lacustrine limestones of the Hamadas. In Algeria the Pliocene is marked by a renewed filling of the lacustrine basins.

An important third phase occurred after the deposition of the Astian. It did not cause much folding in Morocco (outside the Rif zone), but it created the country that we see today by raising the peaks of the Atlas Ranges to their present height, and refolding into further mountains the eroded hills which survived from previous periods.

In North Africa there are two types of Plio-Quaternary deformation: minor folds and the more important epeirogenic movements. After the Pontian a continental flexure caused the downwarp of the marine basins of the western Mediterranean (Bourcart). At the same time the mountain zones underwent a further uplift which brought about a severe erosion cycle. This is contemporaneous, moreover, with the large faults of the Red Sea and the Rift Valleys as well as the rejuvenation of a Miocene feature which produced the present Straits of Gibraltar (Fallot 1945, 1948).

Continental Tertiary

The sediments of the continental Tertiary are termed the *Continental terminal* (Kilian 1931).

North Africa. In North Africa there are four Tertiary continental series: Lower Eocene, Aquitanian, Pontian and Pliocene.

The question of the North African continental series is difficult to resolve because of the similarity of the facies and the rarity of the fossils. The first fundamental discovery was due to Flamand, who described marine Miocene sandwiched between two continental series in the Biskra region. These sediments are found not only in Barbary but throughout the Sahara, where they form plateaux called *Hamadas*.

Lower Eocene. A continental horizon of the Lower Eocene is represented by lacustrine limestones with *Pseudoceratodes*, a gastropod genus which now lives only in the Colombian Province (of Brazil and Mexico) (Jodot 1953b). Jodot has succeeded in utilising these fossils to establish a stratigraphical succession: *Pseudoceratodes jolyi* Jod. (Montian), *P. flandrini* Jod. (Thanetian), *P. laffittei* at a horizon slightly above and *P. clariondi* in the Ypresian.

Oligocene-Miocene (Aquitanian). This term should be deleted from the stratigraphical nomenclature because it includes all the continental red beds of the Tertiary. However, it should be remembered that the continental period was of varying length, and may have begun as early as the Upper Eocene and ended as

late as the Aquitanian. For those authors who include the Aquitanian in the Oligocene, the series is simply incorporated into the Oligocene. For the others, the term Oligocene-Miocene should be used on condition that it is limited to these two precise terms: Stampian-Aquitanian.

The fossiliferous horizon is Aquitanian, yielding terrestrial gastropods of the genus *Clavator*, now living in Madagascar (Jodot 1936, 1938, 1953a). Several groups of beds are known: El Kantara, in the Aurès, with *Clavator* (*Clavator*) *kantarensis* Jodot (Laffitte); lacustrine limestone from southern Algeria and Morocco, with *Clavator* (*Leucotaenius*) *soltanensis* Jodot, *C. menchikoffi* Jodot (Menchikoff, Daguin), *C. (Leucotaenius)* *becharensis* Jodot and *C. lavocati* Jodot (Lavocat and Clariond in the Guir).

Pontian (Choubert 1945). As with the preceeding series the Pontian corresponds to a period of erosion of the Atlas Ranges. It is unconformable on the marine Vindobonian or continental Aquitanian. In the latter case it forms the Upper Hamada. In the Hamada de Guir there are 200 m. of marls and red sandstones with conglomerate horizons at the top and bottom. This group is unconformable on the Aquitanian formations of the Hamada de Bou Denib.

In the Lower Pontian there was a warm and humid phase with lacustrine deposits. These pass laterally into gypsiferous marls, thus signifying a fairly high temperature. Later the climate was less variable and there followed the principal period, which was one of erosion, transportation and accumulation of the detrital red beds. The upper limit is marked by a new humid phase and early Pliocene deposition of more lacustrine limestones unconformable on the folded Pontian.

There was an invasion of asiatic mammals, comprising species of the Pikermi Fauna: *Merycopotamus* cf. *dissimilis*, *Hemitragus* cf. *perimensis*, *Semnopithecus* cf. *palaeindicus*, *Dinotherium cuvieri*, *Hipparion gracile* and various antelopes in Tunisia (Arambourg 1952). *Hipparion gracile* is also known in Algeria and Morocco, where the continental beds are a little older than the Pontian. In addition to these mammals one finds freshwater and continental molluscs including dentate helixes of desert facies, and cyclostomes resembling living littoral forms in the Red Sea. There were rows of lakes and salt lakes or sebkhas.

This continental series is widespread in the Sahara and West Africa and should be grouped as "Continental terminal", because

the ages of the various horizons have not been more precisely determined.

Egypt and East Africa. The Oligocene of Fayoum contains vertebrates: crocodiles (*Tomistoma gavaloides* Andr.), birds (*Eremopezus eoconus* Andr.), and mammals (*Moeritherium lyonsi* Andr., *Palaeomastodon wentoni* Andr., *Tetrabelodon* sp., *Arsinoitherium zitteli* Bead., *Brachyodus andrewsi* Schmidt, *Parapithecus fraasi* Schl. and *Propithecus haeckeli* Schl.).

It is probable that these are beds of the Oligocene-Aquitania boundary and that they are different from those of the Moghara Oasis, with *Aceratherium* and *Brachyodus* (150 km. west of Cairo) which are a little younger and covered by marine Upper Burdigalian.

The Aquitania was a period of considerable faulting. In East Africa new faults provoked fresh lava flows, which began with a series of basalts.

On the shores of L. Rudolph (Ethiopia) Arambourg has found a Lower Miocene fauna in volcanic tuffs: *Mastodon* cf. *angustidens* Cuvier, *Aceratherium* sp., *Pliohyrax championi* Aramb., *Listriodon jeanneli* Aramb. and *Dorcatherium chappuisi* Aramb.

A similar fauna has been found in the lacustrine formations of the ancient L. Victoria (Kenya-Uganda) including *Limnopithecus legetet* Hopw., *Proconsul africanus* Hopw., *Dinotherium hobleyi* Andr., *Aceratherium* sp., *Brachiodus africanus* Andr. and *Listriodon jeanneli* Aramb., etc.

Unfortunately, the Pontian fauna is unknown; at that time the Pontian was a period of large faunal migrations between Asia, Africa and Europe. The route through Israel and Jordan was still open, since the trough of the Red Sea did not yet exist.

The Pliocene is little known and the only evidence comes from the Middle Pliocene fauna of Wadi Natrun in Egypt: reptiles (*Crocodylus*, *Euthecondon nitriae* Fourt. and *Trionyx pliocaenius* Rein.), fish (*Protopterus*, *Synodontis*), mammals: a *Hipparion* resembling *Hipparion albertense* of the Villafranchian, a large giraffe of the *Sivatherium* group, a small hippopotamus similar to *Hippopotamus protoamphibius andrewsi* Aramb., a mastodon, a monkey (*Libypithecus markgrafi* Strom.), a camel and a large member of the pig family (*Sivachoerus giganteus* Falc. and Caut.).

In the Upper Pliocene new fractures were produced in East Africa, and these blocked out the trough of the Red Sea and the Rift Valleys.

Equatorial and Southern Africa. This is the region of the Kalahari deposits which cover part of South Africa, the Congo, Angola and the Congo Republic. These formations are poor in fossils and may be compared with those of the Hamadas of the Saharan region. The principal formation, which extends from the Upper Cretaceous throughout the Palaeogene, is called the Polymorphic Sandstone Series (*série des Grès polymorphes*) and measures 60 to 80 m. in thickness. The Polymorphic Sandstone Series, with fluvatile and aeolian sands and lenses of lacustrine limestone more or less altered to chalcedony, indicate other definite arid phases.

Very rare fossils are found in the limestones and cherty rocks. These include ostracods (*Cypris farnharmi* Leriche), gastropods (*Physa parmentieri* Ler., *P. sp.* *Planorbis* sp.) and characeans (*Chara rauwi* Ler.). The first fossiliferous locality discovered in the Congo was at Mount Bunza, in Kasai, near the Angola frontier. Many others have been found since. In South-West Africa fossiliferous siliceous rocks cover the marine Eocene of Lüderitz Bay.

The general impression is of a large peneplain developed in about Aquitanian times. Fossiliferous chalcedony rocks (absent from the top of the formation) may be Oligocene. The Miocene peneplain is suggested by a lateritic formation. The Mio-Pliocene is represented by coloured muds at the base and aeolian sands at the top.

The only place where the base of the Miocene is recognised is in South-West Africa, in the Namib, where Stromer has described a fauna with a rhinoceros, a phacocherian, *Prohyrax tertarius*, *Miohyrax oswaldi* (known in the Lower Miocene of L. Victoria), *Australagomys inexpectatus* and *Diamantomys luderitzi*. This steppe-type fauna is common throughout Africa.

Flora of the Continental Terminal

The Tertiary floras are characterised by the abundance of angiosperms, but it is seldom possible to use them stratigraphically (Boureau 1958). *Ficoxylon cretaceum* Schenk is found from the base of the Eocene to the Oligocene-Miocene in North Africa and the Sahara. Boureau has determined a large number of species, in particular arborescent leguminous plants and a few palms.

REFERENCES

- ARAMBOURG, C., 1927. Les Poissons fossiles d'Oran. *Mat. Carte géol. Algérie*.
 — 1952. La Paléontologie des Vertébrés en Afrique du Nord français
Monogr. Rég. XIX^e Congrès Géol. Intern., Algiers.
- ARNOULD, M., 1952. Preuves paléontologiques de l'inexistence du "Sahélien"
 aux environs de Bizerte. *C.R. Congrès Géol. Intern.*, Algiers.
- BOUREAU, E., 1958. Paléobotanique africaine. Évolution des flores disparues
 de l'Afrique nord-équatoriale. *Bull. scient. Com. Tr. hist. et scient.*
- CAIRE, A., L. GLANGEAUD, M. MATTAUER and J. POLVÈCHE, 1953. Essai de
 coordination de l'autochtone et de l'allochtone dans l'Atlas tellien de
 l'Algérie centrale. *Bull. Soc. Géol. Fr.*, **3**, 941-972.
- CHAVAN, A., 1944. Étude complémentaire de la faune de Dar-bel-Hamri.
Bull. Soc. Géol. Fr., **14**, 155-171.
- CHUBERT, G., 1945. Note préliminaire sur le Pontien du Maroc. *Bull. Soc.
 Géol. Fr.*, **15**, 677-764.
- DELGA, M. DURAND, 1955. Étude géologique de l'Ouest de la Petite Kabylie.
Bull. Serv. Carte Géol. Algérie (2), No. 25. (*Thesis*.)
- FALLOT, P., 1945. Le problème de Gibraltar. *C.R. Ac. Sc.*, **220**, 611-613.
 — 1948. Les cordillères bétiques. *Estudios geologicos*, **8**, 83-172.
- GLANGEAUD, L., 1956. Corrélation chronologique des phénomènes géo-
 dynamiques dans les Alpes, l'Apennin et l'Atlas nord-africaine. *Bull.
 Soc. Géol. Fr.*, **6**, 867-892.
- JODOT, P., 1936. Une espèce ancestrale des *Clavator* de Madagascar. Pulmonés
 terrestres dans les poudingues aquitaniens du Sud constantinois. *Bull.
 Serv. Carte Géol. Algérie*, **6**, 69-78,
 — 1938. Un nouveau *Clavator* fossile dans les calcaires lacustres ham-
 madiens des confins algéro-marocains du Sud. *Bull. Serv. Carte Géol.
 Algérie* (5), **8**, 185-191.
 — 1953a. Les Mollusques continentaux aquitaniens du Maroc. *Notes et
 Mém. Serv. Géol. Maroc*, No. 117.
 — 1953b. Les *Pseudoceratodes* du Nummulitique continental circumsaharien.
Bull. Serv. Carte Géol. Algérie, No. 17.
- KILIAN, C., 1931. Des principaux complexes continentaux du Sahara. *C.R.
 Soc. Géol. Fr.*, 109-111.
- LACOSTE, J., 1934. *Thesis*.
- LAFFITTE, R., 1948. Sur l'étagé Sahélien POMEL. *Bull. Soc. H.N. Afr. N.*, **39**,
 31-56.
- ROGER, J. and G. LECOINTRE, 1943. La faune de Dar-bel-Hamri est d'âge
 pliocène ancien. *Bull. Muséum H. Nat.*, pp. 359-364.
- SOLIGNAC, M., 1927. Étude géologique de la Tunisie septentrionale. (*Thesis*.)
- STCHEPINSKY, V., 1938. Contribution à l'étude du Sahélien de Tunisie.
Mém. Soc. Géol. Fr., No. 37.

CHAPTER XI

THE QUATERNARY

The African Quaternary is much too large and complex a subject to be described in a few pages. It would be necessary to discuss the famous marine terraces of North Africa (Bourcart 1943; Bourcart, Choubert and Marçais, 1949; Lecoindre 1952; Gigout 1957), climates, fluviatile terraces (Choubert 1953), faunas and prehistory (Alimen 1955; Furon 1958). I shall restrict myself to outlining a general scheme emphasising the importance of the Quaternary which even now is little known.

The Marine Horizons

Apart from the Calabrian which has been found on the Moroccan coast, there is a complete Tyrrhenian represented by three shore-lines at 30 m., 15 to 20 m. and 5 to 8 m. At first there was warm fauna with *Acanthina crassilabrum* and *Trochatella trochiformis*, called the Chilo-Senegalese, then a colder fauna with *Littorina littorea*, and a further warm fauna with *Purpura haemastoma* (which however appears in the fauna of the 30 m. sea). This group corresponds on the Atlantic coast to the Tyrrhenian *Strombus* horizon around the Mediterranean.

The 5 to 8 m. horizon with a present-day fauna was defined by Gigout (1957) and called the *Ouljian*. This horizon is the result of a third Tyrrhenian fluctuation immediately before the last Great Pluvial and before the deposition of the red "Soltanian" muds of Würmian and Flandrian age. As this horizon has been widely recognised it is preferable to give it its name: Ouljian, more especially as it is a definite feature with a constant level of 5 to 8 m.

CONTINENTAL QUATERNARY

An African Quaternary chronology quite parallel to that of the European Quaternary has been erected by study of the sediments, faunas and prehistoric industries. In Africa, the glaciations had repercussions in the form of an alternation of very wet and dry

periods. In the Nile Basin, East Africa, Congo and South Africa traces are found of four main pluvial periods (Bernard 1959). The Pleistocene begins with the Villafranchian.

Lower Pleistocene or Kaguerian

The Kaguerian Stage has been defined by Wayland from the sediments of the River Kaguera which flows into Lake Victoria. There are terraces 70 to 90 m. above the present thalweg which contain an old human industry of worked stones; the *Pebble Culture* or *Kafuan*. This was a humid period to which are attributed the deposits at Kaiso (L. Albert), Kanam (L. Victoria) and the Omo Valley.

Among the vertebrate population, common in several places, may be cited: *Anancus* sp., *Dinotherium bozasi* Aramb., *Elephas recki* Dietr., *E. cf. planifrons* Falc., *Stylohipparion albertense* Hopw., *Equus zebra* L., *Rhinoceras cf. germano-africanus* Hilz., *Hippopotamus protoamphibius* Aramb., *Giraffa camelopardalis* L. and *Sivatherium olduvaiense* Hopw. Of the twenty-five genera of mammals represented, ten are extinct (Wayland 1935; Arambourg 1943-1947).

In South Africa the Uitsoek Beds (Orange Free State) contain *Stylohipparion albertense* Hopw., associated with large zebras. The Australopithecus cave at Taungs contains *Australopithecus africanus* Dart., *Parapapio africanus* Gear, *Crocidura taungensis* Br., *Vulpes pattisoni* Br., *Mystromys antiquus* Br., *Palaeotragiscus longiceps* Br., *Cephalophus parvus* Br., etc.

The slightly more recent Sterkfontein Cave contains: *Plesianthropus transvaalensis* Br., *Dinopithecus ingens* Br., *Parapapio broomi* Jones, *Hyaena hyaena* L., *Lycyaena silberbergi* Br., *Equus capensis* (?) Br., *Bubalus antiquus* Duv., *Hystrix cristatus* L., *Machairodus transvaalensis* Br. (Piveteau 1957).

In 1959 Leakey discovered an australopithecine at Olduvai (Tanganyika) accompanied by an industry of the Lower Pebble Culture. This is a major discovery.

In North Africa the Constantine Villafranchian contains: *Elephas cf. planifrons* Falc., *Mastodon cf. borsoni* Hays., *Anancus cf. osiris* Aramb., *Stylohipparion* (?) *ambiguum* Pomel, *Equus numidicus* Pomel, *Hippopotamus amphibius* L., *H. hipponensis* Gaudry, *Giraffa cf. camelopardalis* L., *Libytherium maurusium* P.

Arambourg (1947, 1949) has collected from the Villafranchian horizons at Ain-Hanech, near Saint-Arnauld (Constantine), several polyhedral stones which have undoubtedly been worked

into this shape. These are the very oldest implements to be included in the Pebble Culture.

Middle Pleistocene: Kamasian-Kanjerian

The Middle Pleistocene is represented by the Kamasian and Kanjerian defined by Leakey. These are two pluvial periods separated by a dry period:

Kanjerian = 3rd Pluvial = Olduvai IV with Acheulian Industry.

Interpluvial = red bed of Olduvai III (lateritic).

Kamasian = 2nd Pluvial = Chellian-Acheulian of Olduvai I and II.

In Kenya and Uganda these are the 10 to 30 m. terraces of the Kaguera, and the Rawe and the Kanjera horizons of Lake Victoria. The Rawe horizon (Kamasian) contains: *Elephas recki* Dietr., *Rhinoceras simus* Burch., *Giraffa camelopardalis* L., *Sivatherium olduvaiense* Hopw., *Notochoerus capensis* Br., *Hippopotamus amphibius* L., *H. imagunculus* Hopw., etc. The Kanjera horizon (Kanjarian) contains: *Elephas* cf. *atlanticus* Pomel, *Stylohipparion* sp., *Rhinoceras simus* Burch., *Hippotragus equinus* Geof., *Notochoerus capensis* Br., *Hippopotamus amphibius* L., etc.

The lower beds at Olduvai (Kamasian) contain several species surviving from the Lower Pleistocene: *Dinotherium bozasi* Aramb., *Stylohipparion albertense* Hopw., *Equus oldwayensis* Hopw., *Canis africanis* Thunberg, etc.

In South Africa the Middle Pleistocene is represented by the Younger Gravels of Vaal with the Stellenbosch Industry with *Elephas* cf. *planifrons* Falc., and *Mastodon* sp. (in the 30 m. terrace); *Elephas atlanticus maroccanus* Aramb., *E.* cf. *recki* D., *Bubalus baini* Seeley, *Equus capensis* Br., (in the 12 to 15 m. terrace); *E. recki* D., *E. atlanticus maroccanus* Aramb., *E. africanus* Blum. (in the lower terrace).

In North Africa the Palikao Beds of L. Karar and Aboukir (Oran) contain: *Elephas atlanticus* Pomel, *Rhinoceras simus* Burch., *Equus mauritanicus* Pomel, *Hippopotamus amphibius* L., *Phacochoerus africanus* L., *Giraffa camelopardalis* L., *Camelus thomasi* Pomel, *Boa primegenius* Boj. and *Hyaena spelaea* Goldf.

In a gravel-pit at Ternifine, near Palikao, the remains of an archanthropoid, *Atlanthropus*, were found with a Chellian Industry (Arambourg and Hoffstetter 1954; Arambourg 1954).

This ancient man belongs to the pithecanthropoid and sinanthropoid family.

The fossil men of Casablanca, Rabat and Temara are more recent, as is the archaic *Homo sapiens* of East Africa.

Grimaldian Regression. Kanjerian-Gamblian Interpluvial. Red Clays of North Africa. Tectonic Movements

Between the Kanjerian and the Gamblian (corresponding to the Riss-Würm of Europe) there was a period of regression, drought and notable tectonic movements.

Near Gafsa (Tunisia) Vaufrey (1932) has shown how conglomerates with Acheulian implements have been folded into four domes aligned WSW.-ENE., with dips reaching 40°. These have been covered unconformably by horizontal pebble beds with Mousterian implements. At Monastir the Tyrrhenian *Strombus* shoreline is undulated from 0 m. to 39 m. above sea level. (Castany 1954; Furon 1955). In East Africa the great faults of the Rift Valleys were rejuvenated over a wide area.

In North Africa, in the interpluvial period, the first superficial red clays (*Hamri*) filled the depressions and covered the older deposits with a continuous sheet. At the base there is a Micoquian Industry and a steppe fauna with *Elephas atlanticus* var. *maroccanus* and *Rhinoceras simus*. In addition to the action of streams, aeolian action played a certain part in the transport and deposition of these clays. Therefore it seems that the climate was at first relatively dry. This dry episode could well correspond to the red dune formations in the Sahara whose fauna includes *Equus mauritanicus* and hippopotami which lived in the lakes. The Congo geologists also include in the Post-Kanjerian a phase so dry that the equatorial forest cover was greatly reduced—stifled by deposits of red aeolian sands which stretched into Northern Rhodesia. A little later the last red clays, dating from the beginning of the damp Würmian cooling, floored the caves and preserved the remains of a forest fauna (no longer steppe-type) with bears, deer and wild pig (Arambourg 1952) and a Levalloisian-Mousterian Industry.

Several facts prove that the climate varied during the deposition of the red clays: arid at the beginning and humid at the end—implying some reworking. Moreover, when the humidity increased during the Würmian and Flandrian, yellow and black soils (known locally as *tirs*) formed from the red clays.

Upper Pleistocene: Gamblian = Würmian

The fourth and last pluvial period (corresponding to the Würm Glaciation) is given the name of Gamblian (after the Gamble Cave, at Elmenteita near Lake Victoria). There Leakey has distinguished three humid stages separated by dry episodes. The faunas are of recent type. The successive industries are Mousterian-Levalloisian, Upper Palaeolithic and Capsian. Radio carbon dating has put the age of the Lower Capsian in Kenya as 11,000 B.P., while the Upper Capsian of Kenya and North Africa ended about 5,000 B.P.

QUATERNARY AND RECENT VOLCANIC ACTIVITY

The Tertiary Alpine movements and their posthumous Quaternary action provoked, in continental Africa, the uplift and warping of certain ancient massifs, followed by the rejuvenation of old faults and the formation of large new faults and extensive volcanic activity. The Hoggar and Air are just two areas where the uplifts and warpings have provoked volcanic activity. Subsidence on the Atlantic border was responsible for the volcanism of the peninsula and islands of Cape Verde. The Fezzan volcanoes are very important.

Among the large fault zones the SSW.-NNE. tectonic trough from the Gulf of Guinea to the Tibesti is studded by the volcanoes of Annobon, São Tomé, Principe, Fernando Po, Mt. Cameroun (4,070 m. and still active), the Manengouba and the Bambuto. Beyond these are the large Tibesti volcanoes whose activity is now confined to Toussidé (3,265 m.) and Tarso Voon. The other large fracture zone is the Rift Valley, which stretches from the Taurus to the Mozambique Strait, passing through the Red Sea,¹ Ethiopia and the whole of East Africa. There are still two active volcanoes in the Red Sea, seventeen more or less active in Ethiopia and Somalia, sixteen in East Africa, from the Teleki to Kilimanjaro (the highest mountain in Africa at nearly 6,000 m.) and Meru (4,568 m.). In the western trough the Virungas, near Lake Kivu, are active.

In the Indian Ocean the Karthala of the Grand Comore and the

¹ From the C₁₄ analyses of fossil reefs of the Arabian Coast the last movements have been dated as about 35,000 B.P. (Nesteroff 1959).

Piton de la Fournaise of Réunion are active today, whereas the recent Madagascar volcanoes now have only hot springs.

Amongst the more curious examples of volcanoes are the lines of explosion craters of Mauritania (Monod), the Hoggar (Bordet) and the remarkable manifestations of the Timbuktu region (Monod and Palausi).

NOTES ON LATERITES

Although we are at the boundary of pedology and geology we must say something about laterites, well known to all African geologists. Not all the laterites are Quaternary: Palaeozoic, Cretaceous and Tertiary ones are known. The true Quaternary laterites are perhaps the rarest. One should explain that there are lateritic clays (*argiles latéritiques*) and cemented laterites (*cuirasses latéritiques*) covering immense surfaces from the Mali Sahara to South Africa.

In tropical regions covered by the primitive forest the pedogenetic alteration of siliceous and aluminous crystalline rocks produces lateritic clays or allites composed of quartz, kaolinite, iron and aluminium hydroxides—the residual minerals of the pedogenesis. The alkaline bases and alkaline earths (Ca, Mg, K, Na) and all the silica from the silicates, other than kaolinite, form the soluble migratory phase which is removed in solution. Erhart has thus demonstrated the geochemical role of the forest, which protects 50 m. of lateritic clay while allowing millions of tons of Si, Ca, Mg, K, Na to escape to the sea. This is the theory of biorexistasis (Erhart 1956; Lacroix 1913).

This is the first undisputed fact: the lateritic clays, rich in iron and aluminium, are formed under forest cover in the tropics by the alteration of the most diverse igneous rocks. They are composed essentially of aluminium silicates with varying amounts of quartz. This is easy to observe in a forest zone.

On the other hand many bauxitic or ferruginous laterites occur beyond the igneous areas, forming a cover of varying thickness above sedimentary rocks such as sandstones or limestones, which are no longer protected by the forest. In general these laterites are hard and form the cemented laterites. Some of these are ferruginous laterites while others are bauxitic.

The bauxites, essentially aluminous, are evidently not able to form *in situ* from the alteration of siliceous or calcareous rocks.

The constituents have been transported from their original weathering site both by water and by wind. Roch (1958) has strongly stressed the importance of wind in the transport of lateritic dust.

The phenomenon of cemented laterites needs an explanation, since the laterites are formed as clays beneath a forest cover. Erhart has suggested that the cementing is caused by termites and by desiccation after destruction of the forest by a change in climate or by Man. The ferruginous cemented laterites are more readily explained as acquiring their iron content by the migration of iron oxides from the underlying sediments. The role of bacteria has often been mentioned but not demonstrated.

Maignien (1959) has recently described the cementing of soils in western tropical Africa where he confirmed the findings of Aubert and Erhart. However, this author thinks that the formation of a cemented horizon implies the immobilisation of a sufficient quantity of sesquioxides to cause induration. These sesquioxides have descended through the soil by gravity and percolation and hardened above the water table to form a horizon of variable thickness within the soils. The hard pan only outcrops where the overlying soil has been eroded after the disappearance of the forest cover. Anyway it seems that it is the savanna lands which are most covered by cemented laterites of Cretaceous or Tertiary age.

The genesis of laterites today is still poorly understood; they are regarded as a problem even by African geologists (Roch 1958). Whatever the explanation, the tropical forest zone is covered by lateritic clay while the savanna zone is covered by more or less "fossil" cemented laterites.

REFERENCES

- ALIMEN, H., 1955. *Préhistoire de l'Afrique*. Paris (Boubée).
 ARAMBOURG, C., 1943-1947. Mission scientifique de l'Omo. *Publ. Muséum Nat. Hist. Nat.*
 ——— 1947. Les Vertébrés fossiles des formations continentales des plateaux constantinois. *Bull. Soc. H. Nat. Afr. Nord*, **38**, 45-48.
 ——— 1949. Présentations d'objets énigmatiques provenant du Villafranchian d'Algérie. *C.R. Soc. Géol. Fr.*, pp. 120-122.
 ——— 1952. Paléontologie des Vertébrés en Afrique du Nord française. *C.R. XIX^e Int. Geol. Congress, Algiers*. Monogr. rég., 64 p.

- 1954. L'hominien fossile de Ternifine (Algérie). *C.R. Ac. Sc.*, **239**, 839-895.
- and R. HOFFSTETTER, 1954. Découverte en Afrique du Nord de restes humains du Paléolithique inférieur. *C.R. Ac. Sc.*, **239**, 72-74.
- BERNARD, E. A., 1959. Les climats d'insolation des latitudes tropicales au Quaternaire. *Bull. Ac. R. Sc. Col.*, **5**, 344-364.
- BOURCART, J., 1943. La géologie du Quaternaire au Maroc. *Rev. Scient.*, pp. 311-336.
- G. CHOUBERT, and J. MARÇAIS, 1949. Sur la stratigraphie du Quaternaire côtier à Rabat. *C.R. Ac. Sc.*, **228**, 108-109.
- CASTANY, G., 1954. Le niveau à Strombes de Tunisie: sa place dans la chronologie préhistorique et la paléogéographie du Quaternaire. *C.R. Soc. Géol. Fr.*, pp. 55-56.
- CHOUBERT, G., 1953. Les rapports entre les formations marines et continentales quaternaires. *Actes IV^e Congr. INQUA*, **2**, 576-590.
- ERHART, H., 1935. *Traité de Pedology*.
- 1956. *La Genèse des Sols en tant que phénomène géologique*. Biostasie et Rhéostasie. Paris (Masson.)
- FURON, R., 1955. Notules de voyage sur le Quaternaire de Tunisie. *Bull. Mus. Nat. Hist. Nat.*, **27**, 262-265.
- 1958. *Manuel de Préhistoire générale*. Paris (Payot).
- GIGOUT, M., 1957. L'Ouljien dans le cadre du Tyrrhenien. *Bull. Soc. Géol. Fr.*, **7**, 385-400.
- LACROIX, A., 1913. Les latérites de la Guinée française et les produits d'altération qui leur sont associés. *Nouv. Arch. Muséum Hist. Nat.*, **5**, 255-356.
- LECOINTRE, G., 1952. Recherches sur le Néogène et le Quaternaire marins de la côte atlantique du Maroc. *Notes et Mém. Serv. Géol. Maroc*, No. 99.
- MAIGNIEN, R., 1959a. Le cuirassement des sols en Afrique tropicale de l'Ouest. *Mém. Serv. Carte Géol. Alsace-Lorraine*, No. 16.
- 1959b. Summary by the Author in: *Chron. Mi. Outre-Mer et Rech. Min.*, **281**, 409-418.
- NESTEROFF, W. D., 1959. *C.R. Soc. Géol. Fr.*, p. 74.
- PIVETEAU, J., 1957. *Traité de Paléontologie*, **7**.
- ROCH, E., 1958. Les bauxites du Midi de la France: leur origine. *Rev. Gén. Sc.*, **65**, 151-156.
- 1958. S'élabore-t-il actuellement beaucoup de latérite dans le quart nord-ouest de l'Afrique? *C.R. Soc. Géol. Fr.*, pp. 176-177.
- VAUFREY, R., 1932. Les plissements acheuléo-moustériens des environs de Gafsa. *Rev. Géogr. phys. et Géol. dynam.*, **5**, 299-321.
- WAYLAND, E., 1935. The M. Horizon. A result of climatic oscillation in the second pluvial period. *Bull. Geol. Surv. Uganda*, **2**, 69-76.

TECTONIC DEFORMATION OF
THE AFRICAN BASEMENT

For convenience I have sometimes separated Africa north of the equator from Africa south of the equator because the stratigraphic successions are not exactly comparable. This division should not lead us into supposing that these two parts record very different successions of geological events. Leaving aside Barbary, which is a Mediterranean and Alpine folded area, one must emphasise the individuality of the African continent. As L. C. King (1954) has said of Africa: "*Il ne convient de lui appliquer qu'avec circonspection les idées préconçues dérivant d'études entreprises dans d'autres parties du monde. . . . C'est alors qu'elle commence vraiment à révéler au chercheur son originalité surprenante.*"

It is possible that other continents, South America for example, have similar features, but Africa is the best for studying continental evolution (because it has been emergent for 250 m.y. or more) and is the ideal continent for studying tectonic fractures and the formation of large basins.

Many authors (Dixey 1956; B. C. King; L. C. King; Cahen 1954; Lepersonne 1956; Furon 1952; and others) have studied the many aspects of African geomorphology, its erosion cycles, peneplains and epeirogenic phases.

About ten phases are spaced out between the Pre-Cambrian and the present day. The following cycles are definitely established: post-Pre-Cambrian, Hercynian, Lower Cretaceous, Upper Cretaceous, Lutetian, Lower Miocene, Pliocene, Villafranchian and Middle Pleistocene.

Africa is a rigid and ancient Pre-Cambrian shield. Epeirogenic movements of the basement have directly controlled the erosion and sedimentary cycles of the sedimentary cover. These movements are manifestations of immense stresses causing enormous undulations (upwarps and basins) and fractures (faults, horsts and grabens).

There are certain preferred directions of the basement faults which have been rejuvenated since the Pre-Cambrian so that it is often difficult to give a precise age to a large fault or trough.

These collapses have played a large part in the protection of the sedimentary series from removal by erosion. Most of the "basins" of the Karroo of East Africa owe their existence only to their subsidence into a tectonic trough bounded by faults. They are isolated from one another by areas of Pre-Cambrian completely denuded by erosion.

The essential features of the structure and present morphology are the consequence of Recent, Tertiary and Quaternary movements in the sense that epeirogenic movements and erosion are of the considerable importance in the recent epochs. One should, however, remember that some fundamental features such as the Rift Valleys and other large troughs are of Cretaceous age and that certain directions are even of Pre-Cambrian age. African tectonics has not failed to interest Krenkel (1957) with all its diverse aspects.

Having rapidly reviewed the African tectonic forms, I wish now to express my view that the domes and basins are not simply the effects of a kind of crustal swelling but also the results of faulting and subsidence—both linear and arcuate.

FRACTURES, DOMES AND BASINS

The visible result of the tectonic strains endured by the ancient basement and its covering has been to produce a strange pattern of immense fractures, domes and basins.

I lack space to go into the history of this question. Local geologists, moreover, are not in agreement on the length of some faults and whether they are as important as those of the Red Sea, Nile Valley or the Rift Valleys. The signs of this disagreement are only too obvious in the written accompaniment of the Structural Map of Africa (1 : 10,000,000), published in 1958 (Furon 1959).

I have been able to show that West Africa was folded in two principal directions (NE.-SW. and NW.-SE.) and that all the fine-grained sedimentary beds were deposited in very small rectilinear units (Furon 1932).

At the time of the presentation to the *Société géologique de France* of a sketch of the structural map of Africa in the course of preparation, I revealed for the first time the existence of a very large tectonic trough running SW.-NE. from St. Helena to near Tibesti and passing through the Gulf of Guinea, Cameroun Trough and

Chad (Furon 1953). The *Association de Service géologiques Africains* was opposed to this concept which, however, I have published (Furon 1955) and which has been accepted by Brock (1956), Sonder (1956) and Hupé (1958). This is a major trough equal in importance to the Rift Valleys.

Preliminary Notes on the N.-S. Fractures

We lack adequate information on African stratigraphy. However, I must draw attention to the immense N.-S. structures of Pre-Cambrian age which never affected the Palaeozoic cover. They were probably the first fissures of the Rift Valleys and do not correspond in their general orientation to the NW.-SE. and NE.-SW. trends of more recent faults.

Then there are the immense faults revealed by Lelubre in the Pre-Cambrian of the Hoggar, bounding the N.-S. horsts and grabens, which are found in the Adrar des Iforas and possibly extending as far as Togo and Ghana. The Air, it seems, is a relatively narrow horst elongated N.-S. and continuing into the Hoggar up to the Tassilian cover.

Faults and Tectonic Troughs

Generally speaking, the large faults were produced and rejuvenated in two directions at right angles: SW.-NE. and NW.-SE.

The African continent, it will be recalled, is bounded in the north-west by the large south Atlas structural line which separates it from folded Barbary. In the west the fracture, which extends from Liberia to the Cape Verde Is., is very important; it is marked on the sea floor by the 2,000 m. isobath, aligned 127 to 130° , 70 km. from the shore, and the 4,000 m. isobath 120 km. away. This fault is about 2,000 km. in length from SE. to NW.

There are also the faults of Guinea, upper Senegal and Mali. These structures have become economically important since Bardet (1956) established that the SE.-NW. faults (127 to 130°) are studded by kimberlite pipes in the areas where dolerite sills are found. Pursuing his inquiry further, this author has shown the similarity in the directions of the deep fractures with those of the kimberlitic intrusions in West Africa and South Africa.

The Lower Niger valley follows a rectilinear fracture from the bend at Bourem into Nigeria for 1,500 km. in a NW.-SE. direction. In the NW. zone Radier (1959) has demonstrated that the Gao Tectonic Trough, of Cretaceous age, emphasises the main fault

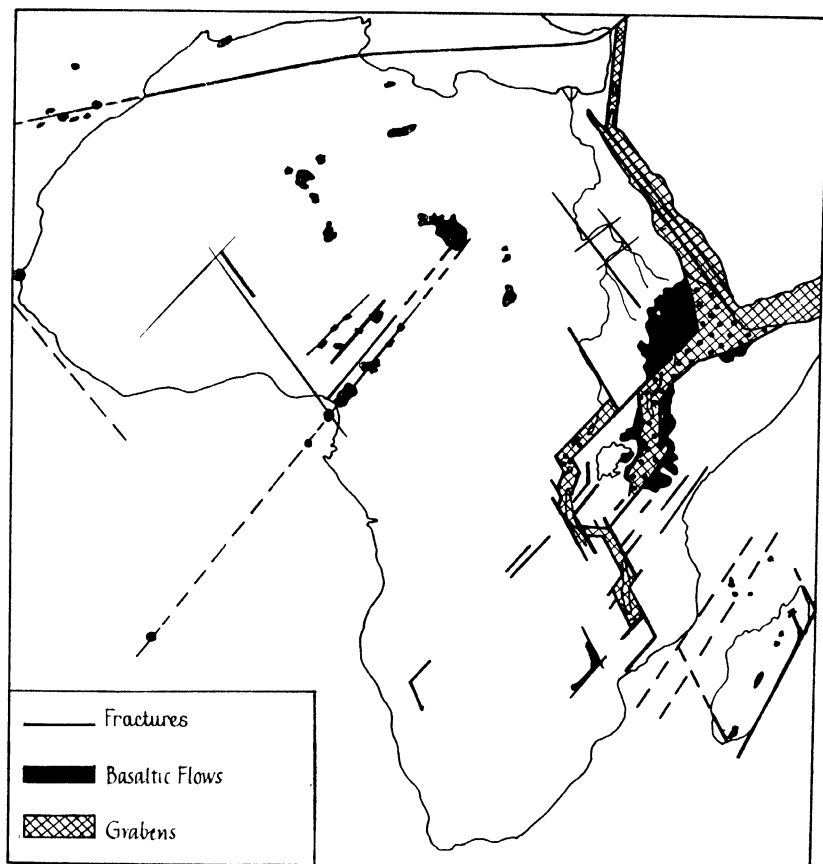


FIG. 3. The fracture system of the African continent.

previously distinguished by Chudeau and Furon. This fracture is parallel to that from Liberia to the Cape Verde Islands.

A third NW.-SE. tectonic trough is that which runs from the eastern Air to Chad, termed the Téfidet Trough by Faure (1959) and dated as Upper Cretaceous. It cuts the Cameroun-Tibesti Trough near Chad as Furon showed from studies of the Maiduguri borehole (Nigeria).

Much further to the east the course of the Nile through the Sudan clearly follows NE.-SW. and NW.-SE. faults which caused the formation of the river's rectilinear route.

Finally we must consider the enormous Red Sea Trough which begins in the Taurus and passes via the Dead Sea. This trough, rejuvenated in the Miocene, Pliocene and Pleistocene, also has a general NW.-SE. direction, but it results from subsidence between right-angled, not rectilinear, faults. Some of these faults have been traced into continental Arabia where they have uplifted the Quaternary of the coastal plain at the end of the Middle Pleistocene, about 35,000 B.P. (Nesteroff 1955).

A SW.-NE. fracture more than 4,000 km. in length extends from the central Atlantic (St. Helena) to the Tibesti, passing through São Tomé, Príncipe, Fernando Po, the Cameroun Trough (described by Gèze), Chad and the Tibesti volcanoes.

In East Africa the two classical Rift Valleys both stretch for more than 4,000 km., from north to south, from the Red Sea to the Mozambique Strait. The trough is 1,400 m. in depth at Lake Tanganyika, where its western border is 800 m. higher than the eastern and more than 2,000 m. at Lake Albert. The presence of NE.-SW. and NW.-SE. right-angled faults should be emphasised in the formation of these grabens. The NE.-SW. direction is known in the Afar and Abyssinian Troughs from the Red Sea to Lake Rudolph (1,500 km.), the trough of Lake Albert, then further to the south a major line, 800 km. long, from Lake Victoria to south of the Upemba Trough. Finally, another fracture extends from near Mombasa to the Zambesi (1,800 km.) and others in the midst of the Mozambique Strait, and there is one which determines the eastern coast of Madagascar (1,300 km.). Crossing this NE.-SW. direction are NW.-SE. fractures, evident particularly from Lake Tanganyika to the Mozambique coast.

The Rift Valleys, whose general orientation is N.-S., are caused by local subsidence between right-angled faults.

Naturally there are many others which have not been deciphered on the ground, although they appear clearly on maps.

The Cuvettes or Basins

Examination of a geological or structural map of Africa immediately reveals a number of large basins. These are all tectonic basins whose true structure is still ignored. They have arisen partly from Hercynian, Alpine and Recent tectonic undulation, but also partly from rectilinear or arcuate fractures.

North of the Hoggar the Low Sahara represents a very complex depression in which the Pre-Cambrian surface is reached at

—3,867 m. depth at Hassi Messaoud, but near Biskra was not reached at —4,422 m.

The *Taoudéni Basin* (more than 1,200 km. in diameter) appears to be essentially a Hercynian synclinal structure, but Fabre and Villemur (1959) have noted that the doleritic dykes which cross the continental Carboniferous are arranged in an arcuate and radial pattern which seems to suggest a subsidence of the central zone.

The *Mourzouk Basin* and the *Libyan Desert* form two other depressions.

The *Chad Basin* (more than 1,000 km. in diameter) is of particular interest. Here two tectonic troughs cross; the one NE.-SW. (Tibesti-Cameroun) and the other NW.-SE. (Téfidet). The Maiduguri borehole (in Nigeria at the latitude of Fort-Lamy) did not reach the Pre-Cambrian basement, even at 1,103 m. depth, while in the Chari-Baguirmi area (between Chad and Ouadai) the basement was reached at 97 m. at Am Sack, 103 m. at Koundjar, 170 m. at Beurso and 370 m. at Abou Bezam. Only geophysical prospecting and borings will enable us to build up a picture of the lie of the Pre-Cambrian basement.

South of the equator the Congo Basin (700 km. in diameter) is of relatively recent origin. In this group the sedimentary series which outcrop on the borders dip towards the centre but there are also subsidiary subsidence troughs and basins. Two deep borings (to 1,680 and 2,040 m.) failed to reach the basement.

The *Kalahari Basin* is separated from the *Okavango Basin* to the north by a sill which has partly subsided.

The *Karoo Basin* is a "fossil" basin, uplifted to form an immense plateau.

The *Mozambique Basin* is known only by its borders: Mozambique in the west and Madagascar in the east. The central zone has subsided and forms the Mozambique Strait.

The Domes and Sills

A certain number of domes and sills have been vertically uplifted at various epochs and subsequently warped and fractured with volcanoes developed locally along the line of faults. Erosion has exposed the Pre-Cambrian.

From east to west should be mentioned: the *Arabo-Nubian Shield*, cut in two by the subsidence of the Red Sea, the *Tibesti Dome* with volcanoes associated with faults, the *Hoggar Dome*

with its annexes (Adrar des Iforas and the Air) and the *Dorsale Reguibat*. West Africa is made up partly of a large dome in the Liberia and Ivory Coast region where the Pre-Cambrian outcrops everywhere. Further south there is a *Cameroun Dome*, faulted in the Cretaceous with its associated volcanoes. It is joined in the east to the important and recent Ubangui Sill separating the Congo and Chad Basins.

In East Africa an immense N.-S. upwarp extends from Ethiopia to Mozambique, and provides evidence of a prodigious epeirogenic movement accompanied by warping and fracturing of the Rift Valleys. Finally the eastern area of Madagascar represents the western part of a crystalline dome, fractured in the Upper Cretaceous by the immense fault which bounds the island in the east.

These are some of the very remarkable and specifically African features entirely unknown in Europe, Asia and North America.

REFERENCES

- BARDET, G., 1956. Note sur la relation probable entre les lignes de fractures profondes de disjonction continentale et les venues diamantifères de l'Afrique. *Chr. Mi. Outre-Mer*, pp. 2-6, 33-38.
- BROCK, B. B., 1956. Structural Mosaics and related Concepts. *Trans. Geol. Soc. S. Africa.*, **59**, 149-197.
- CAHEN, L., 1954. *Géologie du Congo Belge*.
- DIXEY, F., 1956a. Erosion surfaces in Africa; some considerations of age and origins. *Trans. Geol. Soc. S. Africa*, **59**, 1-16.
- 1956b. The East African Rift System. *Col. Geol. Mi. Res. Bull.*, Suppl. **1**, 71 pp.
- FABRE, J. and J. R. VILLEMUR, 1959. Le Carbonifère continental du Bassin de Taoudéni. *Ann. Soc. Géol. Nord*, pp. 89-113.
- FAURE, H., 1959. Géologie des formations sédimentaires à l'Est de l'Aïr (Niger). *Bull. Soc. Géol. Fr.*
- FURON, R., 1932. Introduction à la géologie du Soudan occidental. *Bull. Ag. gén. Gol.*, **283**, 1-90.
- 1952. Réflexions sur la Paléogéographie, la tectonique et la morphologie de l'Afrique nord-equatoriale. *C.R. Congr. Géol. intern., Algiers*, **20**, 41-51.
- 1953. Présentation de la première maquette d'une Carte structurale de l'Afrique. *C.R. Soc. Géol. Fr.*, pp. 84-86.
- 1955. La structure géologique de l'Afrique. *Garcia de Orta*, **3**, 359-375.
- 1959. La carte structurale provisoire de l'Afrique. Historique, présentation et étude critique. *Chron. Mi. Outre-Mer et Rech. Mi.*, pp. 79-88.
- HUPÉ, P., 1958. Aperçus sur le réseau rhéomatique de la croûte terrestre. *Bull. Serv. Inform. B.R.G.G.M.*, **40**, 1-5.

- KING, L. C., 1954. La géomorphologie de l'Afrique du Sud. *Ann. Géogr.*, **336**, 113-129.
- KRENKEL, E., *Geologie Afrikas*. 1st edition, 1925-39; 2nd edition, 1957, Berlin.
- LEPERSONNE, J., 1956. Les aplanissements d'érosion du nord-est du Congo belge. *Mem. Ac. R. Sc. Col.*, **4**, 110.
- NESTEROFF, W. D., 1955. *Résultats scientifiques de la campagne de la "Calypso" en Mer Rouge* (1951-52). Paris (Masson).
- RADIER, H., 1959. *Thesis*, 1957, *B. Dir. Mi. A.O.F.*, **26**.
- SONDER, R. A., 1956. *Mechanik der Erde*. Stuttgart.

PART TWO

REGIONAL GEOLOGY

CENTRAL SAHARA

The central Sahara is dominated by the Hoggar (or Ahaggar) Massif. This large inlier of igneous and metamorphic rocks has been bared by erosion and is surrounded by a plateau of Palaeozoic rocks, the Tassilis. The crystalline basement rises to 2,300 m. in the Téfedest while the recent volcanic hills of Ataqor reach nearly 3,000 m. (Tahat: 2,918 m.).

The Hoggar and its extensions have been studied by Chudeau, Flamand and Gautier, the Foureau-Lamy Expedition and by the officers of the Saharan Companies. Chudeau (1918) had determined the Silurian age of the Lower Tassilis Sandstones and the sandstones with *Harlania*, while the oldest beds of the crystalline basement were included in the Archaean.

The first coherent scheme of the geology of the central Sahara is due to Kilian (1922, 1923, 1933):

In the centre the Pre-Cambrian "crystalline area" is overlain with an angular unconformity (*discordance tassilienne*) by the Palaeozoic (Tassilian Series).

The inner zone of the Tassilis (the rocks nearest the crystalline nucleus) is composed of Ordovician or Cambro-Ordovician sandstones.

The Silurian graptolite shales lie in a topographic depression (the Intra-Tassilian Trough) separating the "Internal Tassilis" from the "External Tassilis" sandstones which are for the most part Eo-Devonian.

The "External Tassilis" plateau extends to the *pays pré-tassiliens* composed of the "*série pré-tassilienne*" of Meso- and Neo-Devonian and Carboniferous age. North of the Hoggar this Pre-Tassilian plain disappears beneath Cretaceous sediments.

The central Saharan massif has been affected by numerous tectonic movements of which the most violent were the Pre-Cambrian. In the Amserha region Kilian observed Caledonian structures between the Silurian and Coblencian of the Emmidir (or Mouydir). Further movements occurred between the Coblencian and the Middle Devonian. These Hercynian movements gave the land its present appearance.

After the deposition of Lower Carboniferous marine sediments the land was uplifted and then folded later than the continental Westphalian. The uplifted dome has since been eroded, leaving a bare crystalline nucleus and a fringe of sedimentary rocks arranged in a discontinuous aureole. The Tassilis bear NW.-SE. folds which have since been eroded.

For a long time the Hoggar massif has been subjected to erosion and quite powerful rivers laid the large peripheral spread of the "Continental intercalaire".

In the Upper Cretaceous (*s. l.*) the sea invaded the low ground of the Southern Sahara and even covered part of the Hoggar and its annexes which had formed an island. During the Tertiary the sea finally retreated and then, due to late Alpine movements, the marine sediments were uplifted with the massif to 700 to 800 m. in height. Volcanoes became active during the late Tertiary and the Quaternary.

1. PRE-CAMBRIAN OF THE HOGGAR

The crystalline Pre-Cambrian basement forms the central part of the central Saharan massif and is subdivided into several groups.

Kilian (1932) has recognised conglomerates in the south-east of the Hoggar which allowed him to divide the Pre-Cambrian into two groups: the *Suggarian* below and the *Pharusian* above.

As a result of the discovery of other conglomerates in the nearby Adrar des Iforas, Karpoff created a *Nigritian*, but Kilian regarded this as the upper part of his *Pharusian*, which he merely subdivided into Lower *Pharusian* or *Relaïdinian* and Upper *Pharusian* or *Nigritian*. Kilian's conclusions have been fully confirmed by Lelubre.

Finally Lelubre (1952, 1955) has published an excellent memoir on the Hoggar thereby making the central Sahara a classic region for the study of the Pre-Cambrian.

Lower Pre-Cambrian. The *Suggarian* is about 20,000 m. thick and mostly formed of cata-metamorphosed crystalline schists. Lelubre recognised two series. The basal Arechchoum Series is formed of biotite and amphibole gneisses with intercalations of marble and quartzite. These form the western and eastern zones of the Hoggar, only appearing in the anticlinal axes of the Egéré-Arefsa Range which separates them but outcropping widely in the Tanezrouft and Adrar des Iforas. Above comes the Egéré Series,

which is richer in quartzites and marbles. In this group the Suggarian folds are aligned N.-S.

This enormous complex suffered an intense general metamorphism before the formation of large Suggarian folds. Migmatization reached all the lower layers. Granites were intruded during the Suggarian folding: Tefedest Granite (migmatic), Ataqr Granite (an elliptical massif) and also post-tectonic granites. Finally a charnockite zone of 600 by 20 km., known as the In Ouzzal Series, extends from Tanezrouft to the Adrar des Iforas.

Middle Pre-Cambrian. The Suggarian ranges were already deeply eroded at the time of the *Pharusian* transgression. From the beginning of the cycle a large tectonic trough formed in the western Hoggar accompanied by intense volcanic activity. Conglomerates, quartzites and stromatolite marbles accumulated (Lelubre 1951; Gravelle and Lelubre 1957) while volcanic activity persisted for a long time producing andesites, dacites and rhyolites. The *Pharusian* succession is about 15,000 m. thick.

All the *Pharusian* has been metamorphosed (but less strongly than the Suggarian) and folded along sub-meridional axes with local deviations. The *Pharusian* forms the second large mountain range in the Sahara and is perhaps comparable to the Birrimian of West Africa. Kilian and Lelubre consider this *Pharusian* Series to correspond to the major phase of a *Pharusian* cycle and call it the *Relaïdinian*.

There are also many granite intrusions: the oldest are migmatitic or in concordant batholiths, then come a group of discordant granites and finally the recent alkaline or hyperalkaline granites sometimes associated with rhyolites as at In Zize.

The best known of these recent intruded granites of the Hoggar are the *Taourirts Granites*. They are analogous to the Younger Granites of Nigeria and sometimes exhibit the same ring structures. These granites are definitely much younger than the *Pharusian*, but they have never been found in the very small zones of the Upper Pre-Cambrian.

Upper Pre-Cambrian. The last phase in the tectonic history has been termed the *Nigritian* by Karpoff (1946) (= Upper *Pharusian* of Kilian). This consists predominantly of 2,000 m. of conglomerates and sandstones, unconformable on the *Pharusian*, in the Timétrine and the Adrar des Iforas (but the outcrops are very small). The *Nigritian* is still poorly defined in the Hoggar proper.

The Crimson Series of Ahnet is unconformable on the Pharusian and composed of 4,000 m. of conglomerates and *lie de vin* sandstones with pebbles of granite and rhyolite, schists and a few white limestones. Lelubre (1957) and Follot include this in the Infra-Cambrian.

Successions of the Cover of the Pre-Cambrian Massif

Immadouézène Series: Lelubre (1952) applies this name to a sedimentary series resting directly on the Suggarian to the west of Anahef. Above the basal conglomerate are sandstones, psammites and red or black jasper. The outcrops cover about 25 sq. km. and reach 1,600 m. altitude. The jaspers resemble the Cambrian of the western Sahara but it is not possible to date this series, which is covered only by recent basalts.

Sérouénout Series: Bordet (1955) has described this sedimentary series, 350 m. thick and 100 km. in diameter, of sandstones, quartzites, silicified beds and lacustrine limestones. The indeterminate silicified wood suggests they belong to the "Continental intercalaire". They are covered by recent basalts (Lelubre 1952).

2. THE TASSILIAN ENCLAVE

The Tassilian Enclave which is discontinuous (particularly to the west and south-west), extends north from Tanezrouft (in the west) to near the eastern edge of Tassili des Ajjer.

1. *The Ahnet* (Bourcart and Monod 1931; Flamand 1911; Follot 1948, 1952; Poueyto 1957)

The Adrar Ahnet proper is only a small massif of Pre-Cambrian quartzites but the name Ahnet, *sensu lato*, is given to the whole region between Tanezrouft in the west and the Emmidir in the east, and from the Adrar Ahnet in the north to the southern depressed region of Tidikelt.

The Internal Tassilis is represented by plateaux elongated in the direction of NNW.-SSE. Hercynian folds: Adafor and Taraït, In Semmen, Igamer'en-Taohenna. The sediments are unconformable and terminate in a cliff on the crystalline lands to the south.

From below, the succession is as follows:

Infra-Cambrian:

Ahnet purple conglomerates (1-2), unconformity.

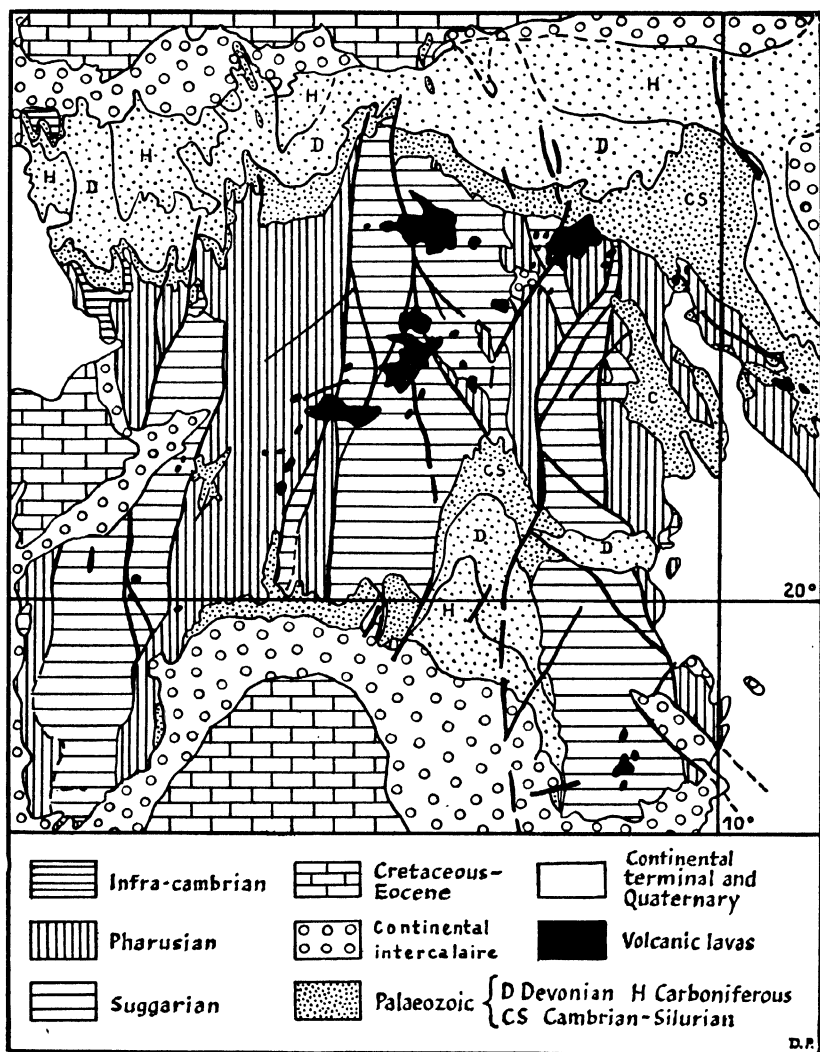


FIG. 4. Sketch map of the geology of the central Sahara by M. Lelubre.

Cambrian:

3. Conglomerates with quartz pebbles.
4. Coarse sandstone.
5. Cross-bedded sandstones.
6. White sandstones with purple spots or white sandstones with *Tigillites*.

Ordovician:

7. Psammites (recalling the Lingula Sandstones of Ougarta).
8. Conglomerates and flagstones.
9. Hard sandstone.

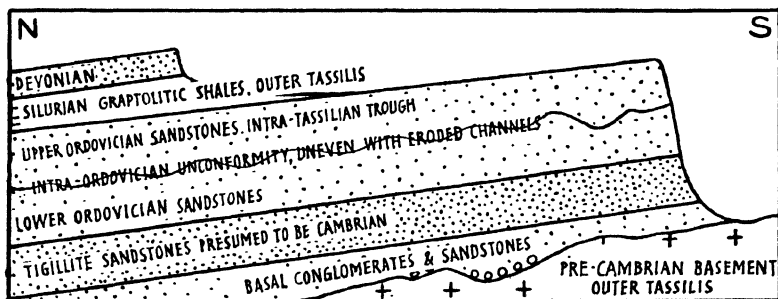


FIG. 5. Diagrammatic section of the Tassilis.

Silurian: Intra-Tassilian Trough.

The Intra-Tassilian Trough is variable in width or absent depending on the thickness and dip of the Silurian graptolitic shales (about 700 m. thick).

The fossiliferous horizon of wadi Ahimer has yielded species belonging to the genera *Mesograptus*, *Climacograptus*, *Glyptograptus* and *Monograptus*, of Middle Llandovery age (horizon 10 of the Ahnet).

Lower Devonian (External Tassilis, upper sandstones):

11. Sandstones and clays marking the passage between the Silurian and Devonian.
12. Hard sandstone with *Spirophyton* (1 m.).
13. Sandstone with *Tropidoleptus rhenanus* and *Tentaculites*.
14. Sandstone with *Spirifer arduennensis* Schnur. and *Sp. paradoxus* Schnur.

Middle Devonian:

15. Eifelian with *Spirifer cultrijugatus* Roemer and *Athyris concentrica* v. Buch.
16. Upper Eifelian with pale blue limestones containing *Pinacites jugleri* Roemer.
17. Givetian: blue limestones with *Agoniatites vanuxemi* Hall and *Tornoceras simplex*.

Upper Devonian:

18. Frasnian with *Spirifer verneuili* Murch.
19. Famennian with *Spirifer aperturatus* Schloth and *Rhynchonella omaliusi* Goss.

Tectonics. The sub-meridional folds include five anticlines from east to west: Tin-Teborak, Ahnet-Adoukrouz, Ahag'e rine-Tiressouine, Taoudrat-Tagsest, Igamer'en. Erosion windows in these anticlines reveal a crystalline core extending far towards the north. The folds are remarkably asymmetrical as in the synclines the easterly dips are between 5 to 15° while the westerly dips reach 70°. Altogether they give the impression of waves coming from the east.

2. *Emmidir (or Mouydir)*

The Emmidir is an area east of the Ahnet bounded in the East by the Igharghar Gap.

The Mouydir has been studied by Gautier, Chudeau, Flamand, Bourcart, Kilian, Follot and by petroleum geologists (Tempère 1959) who have established the type succession for the lower, Cambro-Ordovician, sandstones. These rest with a major unconformity on the folded Pre-Cambrian basement and form the Internal Tassilis. The section is as follows:

1. Conglomerates and feldspathic sandstones throughout, filling the topographic hollows in the basement and of variable thickness.
2. Unfossiliferous tigillites sandstones with a kaolin or siliceous cement attributed to the *Cambrian*.
3. *Lower Ordovician (Tremadoc)* psammities with *Dinobolus* and lingulellas and Arenig (with *Synhomalonotus*).
4. *Caradocian* quartzitic sandstones separated from the underlying layers by an irregular unconformity (*en discordance de ravinement*) (recording a movement at the base of the

Caradoc) and passing gradually into the *Silurian* (this seems to be a discontinuity rather than an unconformity).

The shaly Silurian of Tiounkenin (Kilian 1933) contains *Climacograptus innotatus* Nich., *Petalograptus palmaeus* Barr., *Monograptus exiguus* Nich., and *M. discus* Town., which indicate Llandovery (zones 15 to 25) age (150 m. thick and forming the Infra-Tassilian Trough). At Tanout Mellet the same author described orthoceroids and pelecypods.

The Silurian ends with lagoonal or continental sandstones with *Onchus*. At Amserha there is a gap between the Upper Silurian and the Lower Devonian, whose first fossils are of Coblencian age (Kilian 1935).

The Coblencian sandstones contain *Spirifer primaevus* Stein., *S. hercyniae* Giedel, *S. arduennensis* Schnur. (Siegenian) and *Tropidoleptus* cf. *rhenanus* Frech. (Emsian).

The Middle Devonian is represented by pale blue limestones and sandstones with *Spirifer audaculus* Conrad of the Hamilton Group (Givetian) (Bourcart).

The Upper Devonian is complete: Frasnian with *Cryphaeus australis* Clarke, *Spirifer verneuili* Murch., *Orthotetes crenistria* Phill.; Famennian with *Productus praelongus* Sow., *Spirifer mesacostalis* and *Productella subaculeata* Murch.

The uppermost horizons contain *Spirifer julii* which occurs in the basal Lower Carboniferous. The Tournaisian and Visean are very rich in goniatites.

3. The Palaeozoic of the western Tidikelt (Menchikoff 1939).

In the western Tidikelt, on the borders of the Touat, the wadi Chebbi and its tributaries expose a Palaeozoic succession at Aïn Cheikh and Aïn Chebbi. This is a passage zone from the Saoura facies to that of the Tassilis and forms the southern end of the Saoura Trough.

The *Cambro-Ordovician* is represented by about 1,000 m. of sandstones near the Aïn-Cheikh Oasis. These sandstones contain a horizon with lingulas near the top.

The overlying 300 m. of graptolitic shales (discovered by de Saint-Martin and described by Chudeau (1918) are of Silurian age (top of the Llandovery). The upper layers of the shales contain a few limestone horizons with orthoceroids and lamelli-branches similar to those of the Upper Ludlow shales of the Ougarta

Range. The shales pass upwards into 300 m. sandy beds, whose base is probably still within the Silurian.

The *Devonian* begins with the Middle and Upper Coblencian with *Spirifer rousseaui* Rouault, *Tropidoleptus rhenanus* Frech., *Tentaculites* cf. *velaini* M.-C., etc.

The basal Eifelian limestones (80 m.) contain tabulate and rugose corals, bryozoans, crinoids and brachiopods. The coralliferous beds pass upwards into 500 m. of multicoloured more or less sandy shales, which correspond to the Middle and Upper Devonian of the Gourara and the Saoura.

The oldest *Carboniferous* beds around Ain Chebbi are Tournaisian sandstones. The Lower Visean is calcareous with *Productus undatus* Defr., *Productus semireticulatus* s. l., *Spiriferina laminosa* McCoy and a few corals. The limestones with *Productus auritus* Phill. belong to a higher horizon.

The Palaeozoic rocks disappear to the north beneath the Cretaceous sediments which have preserved the ancient topographic forms. To the south they are covered by recent formations and sebkhas which separate them from the pre-Tassilian zone. The Palaeozoic of wadi Chebbi appears as a north-south anticline whose observable dips reach 75° to the west.

4. The Tassili des Ajjer and the Fort-Polignac Basin

The base of the Tassili des Ajjer is formed of Cambrian (?) sandstones with tigillites resting unconformably on the Pre-Cambrian (Lessard and Bertrand 1958). These are overlain by clayey sandstones of the "Iherir Series" (Ordovician) which, with the Tigillite Sandstones, form the Lower Sandstones and the Internal Tassilis.

The Intra-Tassilian Trough is marked by Silurian graptolitic shales from which Foureau collected the first African graptolites at Djebel Tindesset. These were later examined by Munier-Chalmas (1903). Others were subsequently discovered by Kilian (1933) at Tahiaout and In Djerran. In the latter locality the horizon is of Llandovery age (Zones 16 to 18 of Elles) with *Mesograptus modestus* Lapw. and *Glyptograptus persculptus* Salt.

The oldest sediments of the outer Tassilis are Lower Devonian, found by Foureau: sandstones with *Spirophyton*, *Leptocoelia flabellites* and *Homolonotus herscheli* (of South Africa), *Stropheodonta oriskania* (an American form) and *Spirifer rousseaui*.

The Middle Devonian (Eifelian) of the Irherharène area

(Flamand 1911) has yielded *Calymene* sp., *Strophomena quadrangularis*, *Atrypa prisca*, *A. reticularis* *Tentaculites*. Freulon (1955) has found *Spirophyton* horizons in the Eifelian and Givetian consisting of a calcareous layer with *Orthis* and *Goniatites*. At the eastern end of the Tassilis, between Ghat and Serdélès, Duveyrier has found *Chonetes crenulata* and *Spirifer ostiolatus* (= *S. laevicosta*).

The Upper Devonian with *Spirifer verneuili* appears further to the north under the erg d'Issaouan. The Frasnian is represented by grey-blue shales with fossiliferous limestone lenses and the Famennian by ferruginous sandstones containing silicified wood at the top. This series dips northwards beneath the Fort-Polignac Basin. The Carboniferous of the Tassili des Ajjer has been studied by Foureau, Menchikoff (1939), Desio (1942), de Lapparent (1949) and Lelubre (1948), Freulon (1955), Chanut and Simandoux (1958) and Dubois *et al.* (1959).

The passage beds between the Devonian and the Carboniferous (Etreungt horizon) consist of several metres of sandstones containing *Cyrtospirifer munchisoni* and *Plectospirifer strunianus* Gosselet (gara Mas Melouki).

The conglomeratic, ferruginous and phosphatic Tournaisian contains *Spirifer tornacensis* and *S. bisulcatus* and passes into a bone bed with the remains of plated fishes. The Tournaisian increases in thickness eastward.

The Lower Visean is composed of a sandy-argillaceous series with limestones containing *Productus* and some *Beyrichoceras*. The Upper Visean limestones contain *Collenia* and alternate with oolitic limestones with *Productus* gr. *semistriatus*, *Spirifer striatus*, etc.; *Productus giganteus* at the top.

Above the Visean come sandstones and gypsiferous clays of Namurian age, dated by *Productus*, *Bellerophon* and *Metacoceras costatum* at the top. The Namurian is visible around the erg de Bouraret and in the hills of the Edjelé tan In Azaoua.

A Moscovian horizon, defined by a goniatite (*Eoparalegoceras clariondi* Delépine), was discovered near the track between Ohanet and Fort-Polignac. This species is known in the Colomb-Béchar area at a horizon that is included in the Westphalian. Above comes the continental Upper Carboniferous with silicified wood.

5. Tassili Oua-n-Ahaggar

The Tassili Oua-n-Ahaggar is situated south of the Hoggar between the Adrar des Iforas and the Aïr. It has been studied by

Kilian (1928), Karpoff (1952), Renault (1953), Joulia (1959) and Lessard (1959).

The Palaeozoic stratigraphic succession is as follows, from bottom to top:

1. *In Guezam Series* (purple arkoses and conglomerates) of unknown age (Infra-Cambrian?).
2. Unconformity.
3. *Cambro-Ordovician*—400 m. of sandstones with tigillites and other trace fossils followed by a discontinuity—50 m. of quartzites.
4. *Silurian* with graptolites (40 to 120 m.).
5. Unconformable sandy *Emsian* with *Tentaculites* (40 to 180 m.).
6. *Upper Emsian*—Eifelian with *Spirifer cultrijugatus* Roemer, etc. (70 m.).
7. *Givetian* with *Tropidoleptus carinatus* Conrad and sandstones with *Cancellophycus* (40 m.).
8. *Frasnian* (?): 120 m. of sandstones with *Spirophyton* and *Lepidodendropsis*.
9. *Lower Visean* (?): 280 m. of various sandstones with plant remains.
10. *Upper Visean*: clayey sandstones and blue limestones with *Spirifer striatus* Mart., *Syringothyris suspidata* Martin and *Productus* gr. *semireticulatus* Martin (30 m. exposed).

3. CONTINENTAL INTERCALAIRE BETWEEN THE HOGGAR AND THE SAOURA

For 500 km. between the Saoura and the borders of the Hoggar there are outcrops of the "Continental intercalaire".

The Mèguiden Plateau, 50 to 80 km. wide, extends between the Timimoun salt lake and the Tademaït Plateau which forms the first escarpment. It is composed of sediments of the "Continental intercalaire".

Meyendorff (1938) gave a description of a section containing the dinosaur horizon where Capt. Burté collected *Megalosaurus* teeth. De Lapparent (1947) described a stratigraphical succession of four constant horizons:

1. Basal red clays, pink and white sandstones, red cross-bedded sandstones, containing scattered quartz pebbles, lenses of gravel and conglomerates with silicified wood. The thickness varies from 25 to 300 m.
2. A hard sandstone, 1 to 2 m. thick, which extends from Timimoun to In Salah defining the plateaux or capping the *gour*.
3. Second series of clays, pebbly and gravelly sandstones (*kerboub*). The thickness varies from 40 to 100 m.
4. The top is formed of mottled red clays with intercalated sandstones and a facies of pure Fuller's Earth at El Goléa. The thickness is 60 to 125 m.

This Lower Cretaceous succession rests unconformably on the folded and planed Carboniferous. It is covered by marine Upper Cenomanian. The lower part has furnished fossils such as fish and reptiles: a ganoid fish, a normal sized and a giant crocodile (found at Aoulef) and a dinosaurian theropod (*Megalosaurus* (*Carcharodontosaurus*) *saharicus* Depéret) at the top of the Nubian sandstone. These beds also contain silicified wood.

4. CONTINENTAL POST-TASSILIAN AND INTERCALAIRE OF DJOUA AND FORT-POLIGNAC

In the north-east the Hoggar is isolated from the Tinghert Plateau by the Djoua depression which extends for 200 km. from Fort-Flatters to Ohanet. Foureau recovered the first fossils from Djoua which were studied by Haug (1905; Dechaseaux 1946). A more precise description has been published by de Lapparent (1949).

Below the Upper Cenomanian with *Neobolites vibrayeana*, the 100 m. of "Continental intercalaire" has the same facies as at El Goléa, Timimoun and In Salah except that the band of hard sandstones or quartzites is missing.

The lower 20 to 30 m. horizon of sands and clays at Djoua contains a Wealdian flora and fauna: *Weichselia reticulata* St. and W., lamellibranchs (*Desertella foureaui* Mun. Ch.), teeth of *Ceratodus africanus* Haug and *C. humei* Priem, *Onchopristis numidus* Haug, and vertebrae of *Platyspondylus foureaui* Haug. The beds below these Lower Cretaceous sandstones consist of coarse red sandstones and pass laterally into the folded sandstones of Tan-Elak, representing the "Continental post-Tassilian".

Further east, north of the Tassili des Ajjer, Foureau discovered marine Carboniferous outcropping at Assekhaijaf. This includes Visean with *Productus giganteus* and Westphalian sandstones with *Lepidodendron*, found in the depression covered by the Erg d'Oubari (Edeyen on the maps) and especially widespread in Libya.

De Lapparent and Lelubre (1948) have described the first 200 km. section from the Hamada de Tinghert in the south to El Homra in the north. Discoveries by petroleum geologists of CREPS in the Fort-Polignac Basin have added details to this section. A complete series is now known from the Carboniferous, and including *Trias*, *Jurassic* and *Lower Cretaceous*, comprising a remarkable development of "Continental intercalaire".

The complete section is as follows:

Bourarhet Series: 200 m. of gypsiferous marls with beds of limestone containing *Productus costatus*, *P. pustulosus*, *P. cora*, *P. inflatus*, *P. semireticulatus*, *P. lineatus*, *Spirifer rectangulus* and *Bellerophon* (Visean-Namurian).

Tiguentourine Series (north of the Erg Bourarhet): 70 m. of sandstones and multicoloured and gypsiferous clays (= Continental post-tassilien).

Zarzaitine Series: 120 m. of red or white sandstones, with quartz pebbles and *kerboub* (pebbles of sandstone); this series contains Triassic stegocephalian amphibians (Lehman 1957).

Tauratine Series: a cliff of 50 m. of sandstones and psammities is dated as Jurassic by plant remains (Boureau and Claracq 1957; Boureau and Caillon 1958) and a *Brachiosaurus* (de Lapparent, Claracq and Nougarede 1958).

In Akhamil Series: Lower Cretaceous, containing the Djoua flora and fauna and ending just before the Upper Cenomanian marine transgression.

This succession consistently suggests lacustrine and fluvial deposits. The alluvial material came from the emergent part of the Hoggar, which was covered by gymnosperm forests and inhabited by carnivorous dinosaurs. Ganoid fish and crocodiles lived in the rivers and lakes, while the presence of *Ceratodus* implies that there was a marked dry season. During sudden and violent floods the water courses would have transported rock material, fragments of tree trunks and dinosaurs and spread them in this enormous basin which extended from Djoua to Mzab.

5. THE TADEMAÏT AND TINGHERT PLATEAU

The "Continental intercalaire" is covered by an immense plateau to the north of the Hoggar, the southern border of which stretches for 1,000 km. from the Adrar region to the Tripolitanian frontier.

To the west it is called the Tademaït Plateau while to the east it is called the Hamada de Tinghert, the two parts being separated by the wadi Igharghar depression but having the same geological structure (Flamand 1911; Bourcart 1924; Butler 1924; de Laparent and Basse 1948; Collignon 1957).

The Cretaceous succession begins with the Upper Cenomanian.

Cenomanian. The Cenomanian sandstones, gypsiferous clays and white limestone yield *Neolobites vibrayeanus* d'Orb, *Acanthoceras mantelli* Sow., *Exogyra columba* Lmk., *E. flabellata* Goldf., *E. olisiponensis* Sharpe, *Plicatula auresensis* Coq., *Strombus incertus* d'Orb., *Heterodiadema libycum* Desor, etc. This is an Upper Cenomanian fauna.

Turonian. The facies changes to dolomitic limestones with flint bands. The fauna includes *Thomasites rollandi*, *Vascoceras durandi*, *V. polymorphum* Perv., *Radiolites lefebvrei* Bayle, etc.

The Turonian of the Hamada de Tinghert, on the Franco-Fezzan border, described by Collignon, contains *Mammites subconciliatus* Choffat, *Vascoceras gamai* Choffat, *Discovascoceras tessellitense* Coll., *Hoplitoides* aff. *ingens* v. Koenen, *Bauchioceras nigeriense* Woods, *Furoniceras trumpyi* Coll., *Nigericas* sp., *Leoniceras pavillieri* Perv. This is definitely a Lower Turonian fauna as in the Damergou south of the Hoggar (Furon).

After a gap in the succession there follows a Maestrichtian fauna with *Libycoceras ismaelis* Zittel, *Nautilus (Angulithes) fleuriausii* d'Orb., *Plicatula flattersi* Coq., *Venericardia* sp. and turritellas.

Tertiary of the Hamada. Above the Senonian the Hamada lands descend beneath the sands of the Grand Erg Oriental.

Lefranc (1952) has shown that the Maestrichtian limestones are overlain by Lower Eocene limestones with operculinoids, themselves overlain by the "Continental terminal".

The extent of the Lower Eocene sea has been proved by boreholes (Cornet, Gouskov and Pinard 1959). An Ypresian fauna with *Nummulites globulus*, *N. planulatus* and operculines has been found south of the Aurès at 1,000 m. depth, 40 km. north of Touggourt (at 165 to 255 m.) and also between Touggourt and Tunisia. On

the Tunisian frontier there still exists a little lagoonal Eocene with gypsum beds.

Lefranc collected silicified wood from the "Continental terminal", recorded by Foureau (1893) and Kilian (1930). From these samples Boureau has identified *Leguminoxylon menchikoffi* Boureau and *Euphorbioxylon lefrancii* Boureau.

The Grand Erg Oriental

The Grand Erg Oriental extends about 500 by 200 km. from the Tinghert Plateau in the south to Fort-Lallemand and the Tunisian salt lakes in the north, while to the east it reaches the Libyan frontier. This little-known part of the Sahara is covered by complexes of dunes reaching 200 m. in height.

Oil and water explorations have shown that the erg rests on "Continental terminal" overlying marine Eocene. The tectonics and hydrogeology are complicated as the ground water seepages reach the Continental terminal, also the marine Eocene limestones at wadi Rhir and probably the eroded anticlines of the "Continental intercalaire" of south Tunisia.

6. QUATERNARY OF THE HOGGAR

1. *Volcanic Activity*

Works on this subject include: Bourcart (1928), Butler (1925), Kilian (1934), Lacroix in Dalloni (1934), Bourcart and Denaeyer (1927), Bourcart and Perret (1935) and Bordet (1951, 1952, 1955).

The Hoggar has been the site of large volcanic eruptions in both the Tertiary and the Quaternary. Bordet has shown that the same deep-seated mechanism has produced an upwarping of the crystalline basement and the volcanism. He distinguishes: plateau basalt flows with intercalated laterites, and valley flows, all followed by an acid phase, predominantly phonolitic.

In the Ataqr there are numerous basalt flows, but the more chaotic flows are phonolitic. These are eruptions of the Mont Pelée type. The highest volcano is the Tahat (2,918 m.), followed by the Pic Ilaman (2,760 m.) and the Assekrem (2,728 m.). South of Ataqr the Tamanrasset region is characterised by tabular acid volcanics. Bordet has also described explosion craters in the Hoggar (Eheri, Tedjet Ilaman, Ouksem, Tesemt, Edjéré).

Monod has shown that the rhyolitic mountain of In Zize is not a volcanic crater but a hollow eroded in the Pre-Cambrian. This hollow contains a small lake, an *ag'elman*, 12 m. in diameter and 5 m. deep.

In the Tassilis des Ajjer, to the north-east, the Tin Taoussis volcano lies near the bottom of the wadi Djanet and would seem to be related to a large N.-S. fracture of Hercynian age (Kilian). The rocks include trachytes and basanites. In this group the magma is always deficient in silica and there are no recent rhyolites.

2. *Continental Molluscs*

A few Quaternary mollusc beds have been discovered in a terrace and in the ancient Titérine crater in the Silet area.

There Jodot (1958) has demonstrated that terrestrial molluscs are rare while fresh-water shells are abundant. There are few extinct species implying a Recent age. Most of the fossils from the Titérine crater are subtropical Ethiopian molluscs (but not from tropical Africa) with a few temperate Mediterranean species although these form 64 per cent. of the fauna of the wadi terrace. These faunas and the discovery of laterites give an indication of the Quaternary climatic variations in the Hoggar as in the rest of the Sahara (and the whole world).

3. *Various Aspects of the Flora* (Pons and Quezel 1956)

The Quaternary flora is unknown but palynological studies of various fossil soils date the last humid phase and show that the following trees were present during this epoch: Aleppo Pine, oak, olive, alder, jujube, cedar, juniper, cyprus and even lime. The lime has since completely disappeared from Africa. This occurrence has been confirmed by Loret (1892), who found it among the plant species of prehistoric Egypt.

REFERENCES

- BORDET, P., 1951. Présence des latérites fossiles dans l'Ataqor du Hoggar. *C.R. Soc. Géol. Fr.*, p. 97.
— 1952. Les appareils volcaniques récents de l'Ahaggar. *Mon. Rég. Algérie*. (1), No. 11, *XIX^e Congr. Géol. Intern.*, Algiers.
— 1955. Les cratères d'explosion de l'Ahaggar (Sahara central). *Bull. volcanol.*, 17, 127-134.

- La série de Sérrouenout (Continental intercalaire) et son substratum précambrien en Ahaggar oriental. *Bull. Serv. Carte Géol. Algérie*, **5**, 9-42.
- BOURCART, J., 1924. Un voyage au Sahara. *Publ. Com. Afr. fr.*
- 1928. Carte de reconnaissance du sommet de l'Ahaggar. *Rev. Géogr. Phys. et Géol. Dyn.*, **1**, 271.
- and M.-E. DENAEYER, 1927. Sur la composition lithologique des laves de l'Ahaggar. *C.R. Ac. Sc.*, **185**, 1492.
- and TH. MONOD, 1931. L'Adrar Ahnet. (Description géologique.) *Rev. Géogr. Phys. et Géol. Dyn.*, **4**, 223-346, and 1932, **5**, 245-297.
- and R. PERRET, 1935. Sur les laves de l'Adrar des Asjer. *C.R. Ac. Sc.*, **200**, 2025-2026.
- BOUREAU, E. and P. CAILLON, 1958. Sur la flore fossile et l'âge des couches de Taouratine dans le bassin de Fort-Polignac (Sahara). *C.R. Ac. Sc.*, **247**, 2173-2175.
- P. CLARACQ and F. NOUGARÈDE, 1957. Sur la paléobotanique et la stratigraphie du bassin de Fort-Polignac (Sahara). *C.R. Ac. Sc.*, **245**, 544-545.
- BUTLER, H., 1924. Observations sur le Cénomanien et le Turonien de la Hammada de Tinghert. *Eclogae Geol. Helvet.*, **18**, 519-521.
- 1925. Contribution à la géologie de l'Ahaggar. *C.R. Congrès intern. Géol.*, Liège, p. 819.
- CHANUT, C. and G. SIMANDOUX, 1958. Précisions sur la stratigraphie du Paléozoïque de Fort-Polignac. *C.R. Soc. Géol. Fr.* pp. 299-300.
- CHUDEAU, R., 1918. Recherches sur la tectonique de l'Afrique occidentale. *Bull. Soc. Géol. Fr.*, **18**, 61.
- COLLIGNON, M., 1957. Céphalopodes néocrétacés du Tinrhert. *Ann. Paléont.*, **43**, 113-136.
- CORNET, A., N. GOUSKOV and Cl. PINARD, 1959. Sur la présence d'une faune yprésienne dans certains forages du Bas-Sahara. *C.R. Soc. Géol. Fr.*, pp. 35-36.
- DALLONI, 1934. Mission au Tibesti. *Mém. Ac. Sc.*, **61**, 305.
- DEPERET, C. and J. SAVORNIN, 1927. La faune de Reptiles et de Poissons albiens de Timimoun. *Bull. Soc. Géol. Fr.* (5), **27**, 257-265.
- DESCHASEAUX, C., 1946. Le genre *Desertella* Mun. Ch. type d'une nouvelle famille de Lamellibranches: les *Desertellidae*. *C.R. Soc. Géol. Fr.*, pp. 307-309.
- DUBOIS, P., B. KERAUDREN and C. WILLM, 1959. Stratigraphie du Carbonifère marin du bassin de Fort-Polignac. *C.R. Ac. Sc.*, **248**, 3323-3324.
- FLAMAND, G. B. M., 1911. *Thesis* (1,001 pp., 22 maps, 16 pl.).
- FOLLAT, J., 1948. *C.R. Ac. Sc.*, **226**, 1997.
- 1952. Ahnet et Mouydir. Monogr. rég. Algérie, No. 1, *Publ. XIX^e Congr. Géol. Int. Algiers*.
- FREULON, J. M., 1955. Stratigraphie du Carbonifère du Tassili n'Ajjer et du Fezzan occidental. *C.R. Ac. Sc.*, **241**, 1478.
- GRAVELLE, M. and M. LELUBRE, 1957. Découverte de Stromatolithes du groupe des *Conophyton* dans le Pharusien de l'Ahaggar occidental. *Bull. Soc. Géol. Fr.*, **7**, 435-441.
- HAUG, E., 1905. Paléontologie. *Documents de la Mission Fourreau-Lamy*, pp. 751-832.

- JODOT, P., 1958. Classification et climatologie des Mollusques du Quaternaire dans l'Ahaggar (Sahara). *C.R. Soc. Géol. Fr.*, pp. 367-370.
- JOULIA, F., 1959. *C.R. Soc. Géol. Fr.*, p. 64.
- KARPOFF, R., 1946. Stratigraphie de l'Antécambrien au Sahara. Le Nigritien. *C.R. Ac. Sc.*, **223**, 428-429.
- KILIAN, C., 1922. Essai de synthèse de la géologie du Sahara sud-constantinois et du Sahara central. *C.R. XIII^e Congr. Géol. Intern.*, Brussels, **2**, 887-945.
- 1923. Sur la structure du Sahara sud-constantinois et central. *C.R. Soc. Géol. Fr.*, p. 71.
- 1932. Sur les conglomérats précambriens du Sahara central: le Pharusien et le Suggarien. *C.R. Soc. Géol. Fr.*, p. 87.
- 1933. D'une association de Graptolithes observée dans le Gothlandien de Tioukenin (Emmidir). *C.R. Soc. Géol. Fr.*, pp. 91-92.
- 1933. De l'Ordovicien et du Gothlandien du bouclier saharien. *C.R. Soc. Géol. Fr.*, pp. 25-26.
- 1935. De la coupe d'Amserha et des mouvements calédoniens au Sahara. *C.R. Soc. Géol. Fr.*, pp. 219-220.
- LAPPARENT, A.-F. DE, 1947. Stratigraphie et âge du Continental intercalaire dans le Gourara, le Touat et le Tidikelt (Sahara algérien). *C.R. Ac. Sc.*, **225**, 754-756.
- 1949. Première description géologique de l'Edjélé tan In Azoua (NE. de l'Ajjer). *Ann. Soc. Géol. Nord*, **69**, 86-94.
- 1949. Sur la stratigraphie et la paléontologie du Djoua (Sahara central). *C.R. Ac. Sc.*, **228**, 1040-1042.
- and E. BASSE, 1948. Précisions stratigraphiques sur le Crétacé de la Hamada de Tinrhert. *Bull. Soc. Hist. Nat. Afr. Nord*, **39**, 138-141.
- P. CLARACQ and F. NOUGARÈDE, 1958. Nouvelles découvertes de Vertébrés dans les séries continentales au Nord d'Edjeleh (Sahara central). *C.R. Ac. Sc.*, **247**, 2399-2402.
- and M. LELUBRE, 1948. Interprétation stratigraphique des séries continentales entre Ohanet et Bourarhet (Sahara central). *C.R. Ac. Sc.*, **227**, 1106.
- LEFRANC, J. P., 1952. Des couches à bois fossiles du Tinrhert occidental et de Bel Guebbour (Sahara central). *C.R. Soc. Géol. Fr.*, pp. 253-254.
- LEHMAN, J.-P., 1957. Les Stégocéphales sahariens. *Ann. Paléont.*, **43**.
- LELUBRE, M., 1942. Sur les divisions du socle ancien du Sahara central. *C.R. Ac. Sc.*, **215**, 367-369.
- 1951. Découverte de *Collenia* dans le Pharusien de l'Ahnnet. *C.R. Soc. Géol. Fr.*, pp. 88-89.
- 1952. Recherches sur la Géologie de l'Ahaggar central et occidental (Sahara central). *Bull. Serv. Carte Géol. Algérie*, **22**, 2 vol.
- 1952. *Thesis*, **2**, 285-288.
- 1955. Aperçu sur l'Antécambrien de l'Ahaggar. *Bull. sc. écon. B.R.M.A.*, Algiers, **3**, 1-31.
- 1957. La "série pourprée de l'Ahnnet" et le problème des "séries intermédiaires" au Sahara. *C.R. Colloque intern. C.N.R.S.*, Paris, pp. 173-190.
- LESSARD, L., 1959. Note préliminaire sur la géologie des Tassilis Oua-n-Ahagar (Sahara méridional). *C.R. Soc. Géol. Fr.*, pp. 151-152.

- LESARD, L. and J. P. BERTRAND, 1958. Sur l'existence d'une discordance dans le Cambro-Ordovicien du Sahara central. *C.R. Soc. Géol. Fr.*, pp. 72-75.
- MENCHIKOFF, N., 1939. Le Paléozoïque du Tidikelt occidental. *Rev. Géogr. Phys. et Géol. dynam.*, **12**, 339-342.
- MEYENDORFF, A., 1938. Note sur le Gourara. *Rev. Géogr. Phys. et Géol. dynam.*, **11**, 150-155.
- MUNIER-CHALMAS, 1903. Notice sur Travaux scientifiques. p. 94.
- PONS, A. and P. QUEZEL, 1956. Premiers résultats de l'analyse palynologique de quelques paléosols sahariens. *C.R. Ac. Sc.*, **243**, 1656-1658.
- POUEYTO, A., 1957. Contribution à l'étude des grès inférieurs au Sahara septentrional. *Colloque inter. C.N.R.S.*, Paris, pp. 191-197.
- RENAULT, P., 1953. Sur la présence du Crétacé marin et d'un gisement de plantes fossiles dans la région de Bilma (Niger). *C.R. Soc. Géol. Fr.*, pp. 52-53.
- TEMPÈRE, C., 1959. *C.R. Soc. Géol. Fr.*, pp. 194-195 and *Bulletin*.

CHAPTER XIV

WESTERN SAHARA

1. THE TINDOUF SYNCLINE

The Tindouf Syncline lies south of Morocco between the Anti-Atlas and the Eglab Anticline (or *Dorsale Reguibat*). A more or less complete Palaeozoic succession is found on its borders.

The Hamada. The Tindouf Plateau is formed by the Hamada. In the north the succession reaches 100 m. in thickness; it consists of sandstones with a calcareous cement and marly clays invariably capped by a band of cherty limestone. There are some intercalated conglomerates and gypsum deposits.

At Bou Akba in the Betana (right bank of the wadi Dra) the following succession overlies the Westphalian: marls (50 m.), conglomerate (4 m.), brown sandstones (20 m.), sandy marls (10 m.) and cherty limestone (10 m.). The thickness diminishes to the south and the conglomerates and gypsum disappear. The residual hills left by erosion bear the local name of *gour*. These formations are not accurately known and probably vary from place to place, and may represent the Cretaceous, the Palaeogene or the Neogene.

To the south Gevin has found silicified wood between Tindouf and Fort Trinquet: *Quercoxylon gevinii* Boureau and *Dombeyoxylon monodi* Boureau (Boureau 1949). The latter species is a sterculacean known also in the continental post-Eocene of the Azaouad (eastern Sudan).

1. Northern Border (from the Hamada to Bani)

Under the Hamada, Menchikoff (1930) has worked out the following section:

(a) *Silurian*: Silurian graptolitic shales and Ordovician Bani Quartzites.

(b) *Lower Devonian*: green Siegenian-Emsian shales of Bani.

(c) *Middle Devonian*: this includes the sandstones and limestones of Richs recognised by Gentil in 1923. They are underlain by the *Spirifer cultrijugatus* zone.

(d) *Upper Devonian*: shaly sandstones with fossiliferous limestone beds intruded by dolerites. The fauna includes: *Streptorhynchus crenistria* Phill., *Productus praelongus* Sow., *Productella productoides* Murch., *Spirifer verneuili* Murch., *Rhynchonella letiensis* Gosselet and *Bellerophon* cf. *hiulcus* Martin. It seems very probable that this is part of the uppermost Devonian, the Faménian, which in northern France is characterised by *Rhynchonella letiensis*.

(e) *D'Etroeungt or Strunian Zone* of Tazout (Choubert 1948; Termier 1948): sandstones with *Spirifer strunianus* var. *alata* Gosselet, *S. tornacensis* De K., and *S. verneuili* Murch. increasingly abundant as the undoubted Upper Devonian is approached.

On the right bank of the Dra, 2 km. from Tazout, and in an even lower horizon Menchikoff (1948) has found a goniatite horizon with *Spirifer tornacensis* De K., productids, and certain peculiar spirifers. The nearest Saharan beds with goniatites of this age occur in the south (Aouïnet Legra) and 800 km. further east, in the Gourara.

(f) *Tournaisian* of Ouarkziz: limestones with *Leptaena rhomboidalis* Wilck, *Productus vaughani* M. W., *Athyris lamellosa* L'Éveillé, *Spirifer tornacensis* De K., *Phacops bergicus* Drev.

(g) *Visean*:

1. Limestone with *Zaphrentis* cf. *enniskilleni* M. E. and H.
2. Shaly sandstones.
3. Limestones with *Productus auritus* Phill., *P. maximus* McCoy and *P. hemisphaericus* Sow.
4. Limestone with sections of large *Productus*.
5. Limestone with sections of *Productus giganteus* Mart.
6. Limestone with *Productus cora* d'Orb., *P. concinnus* Sow., *P. martini* Sow.
7. Limestone with cyathophyllids.
8. Limestone with sections of large *Productus*.
9. Limestone with *Productus giganteus* Martin, *Cyathophyllum regium* Phill., *C. murchisoni* M. E. and H., *Dibunophyllum muirheadi* Th.,
10. Sandstone and hard limestone with *Alveolites capillaris* Phill.
11. Shaly sandstones and limestone with large *Productus*.
12. Limestones with *Productus giganteus*.
13. Bed with *Productus longispinus* Sow., *P. latissimus* Sow., *Spirifer bisculcatus* Sow., *Cyathophyllum murchisoni* M. E. and H.
14. Limestones with *Lithostrotion irregulare*.

(h) *Westphalian*: alternating sandstones and shales resting conformably on the Visean. The beds in the middle of the succession contain plant impressions which are certainly Westphalian. No coal seams are known, but borings in the centre of the syncline, across the Hamada, should show whether the Middle Carboniferous is productive as it is in the neighbouring regions of Guir and Zousfana.

2. Southern Border

On the southern border of the Tindouf Syncline, Menchikoff and Gevin (1948) have described a section between the crystalline rocks of Yetti-Eglab and Aïn el Barka and passing by Aouinet Legra. Gevin has found successively the Coblencian (80 m.), Eifelian (45 m.), Givetian (50 m.), Frasnian (200 m.), Famennian (400 m.), Tournaisian (450 m.) and Visean (300 m.).

The section from bottom to top is as follows:

1. *Crystalline basement*.
2. *Cambrian?*: quartzites of the gara Djebilet (with indeterminate brachiopods).
3. *Silurian*: greenish grey shales and sandstones with dykes and lenses of dolerite (= Aouinet Legra Sandstone).
4. *Gedinnian*: unfossiliferous sandstones and shales.
5. *Coblencian*: pink sandstones with *Spirifer pellico* de Vern. and d'Arch., sandstone with *Favosites* of the *golfussi* group; thick sandstones with *Favosites* and *Spirifer primaevus*; calcareous sandstone with tentaculites, bryozoans and trilobites. Iron ore at the top (80 m.).
6. *Eifelian*: marly shales with *Schizophoria striatula* Schl., *Productella productoides* Murch., *Athyris concentrica* v. Buch., *Leptaena rhomboidalis* Wilck., *Calceola sandalina* Lmk.; sandstone and crinoidal limestones with *Atrypa reticularis* L., *Spirifer speciosus* Schl., *S. cultrijugatus* Roemer and small ferruginous goniatites (45 m.).
7. *Givetian*: yellowish limestone with *Schizophoria striatula*, *Spirifer mediotextus* d'Arch. and Vern., *Cyathophyllum helianthoides* Schl.
8. *Frasnian*: limestone with *Atrypa reticularis* L., *Spirifer verneuili* Murch., shales (4-5 m.); limestone with *Schizophoria striatula*, *Spirifer bouchardi*; shales with *Atrypa reticularis* L.,

Rhipidomella tetragona Murch., De Vern., Kais.; limestone with corals; shales with *Orthis orbicularis* Murch., *Spirifer verneuili* Murch.

9. *Devonian*, Famenian: consists of poorly fossiliferous sandstones with impressions of plants. Below, there are beds with *Spirifer verneuili* Murch. (400 m.).
10. *Tournaisian*: sandy limestone with goniatites (*Muensteroceras* cf. *subglobosum* Libr.), *Syringothyris cuspidata* Martin,

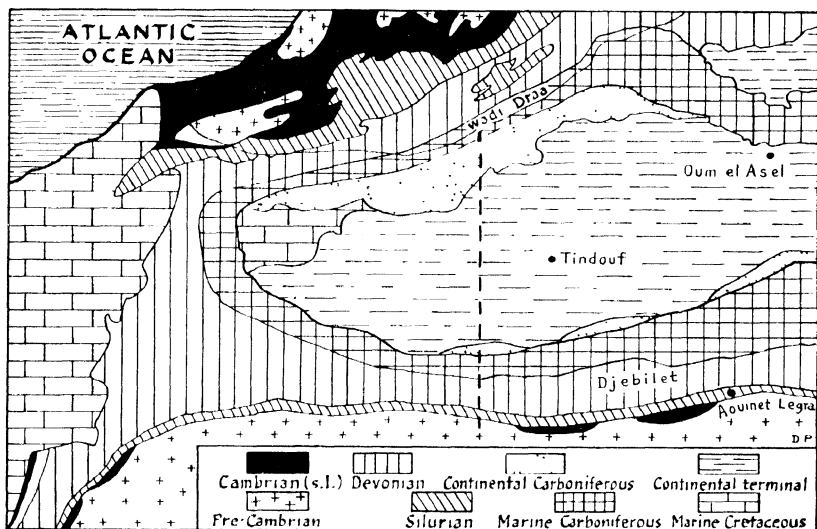


FIG. 6. Sketch map of the Tindouf Syncline.

Productus semireticulatus Martin; sandstone; calcareous flagstone with *Spirifer tornacensis* de K., *Productus vaughani* M. Wood, *Spirifer strunianus* Gosselet; sandstone with *Dielasma hastata* Sow.

11. *Passage zone between the Tournaisian and the Visean*: layered limestones with goniatites (*Muensteroceras* and *Beyrichoceras*).
12. *Visean*: pale sandstones with *Productus giganteus* Martin, ending with red barren sandstones which disappear beneath the Hamada; red sandstones; limestones with *Productus cora* d'Orb, *P. undatus* DeFr., blue limestone with

corals; limestone with *P. cora* d'Orb; limestone with *P. auritus* Phill., *P. fibriatus* Sow., *P. semireticulatus* Martin, *Michelinia favosa*, M. E. and H.

All this succession has a gentle 10° dip to the north and rests unconformably on the Eglab crystalline massif (Dorsale Reguibat).

Pays Mechems and Zemmour

In 1936 Jacquet found that the Tindouf Syncline continued to the south-east. The Mechems area is part of the southern limb of the syncline. A uniformly dipping succession is seen orientated ENE.-WSW. and dipping 10° towards the NNW. This area was likewise land in Cambrian times so that the crystalline basement is overlain by tens of metres of Ordovician conglomerates and sandstones. The overlying Silurian sandstones, shales and limestones with orthoceroids outcrop for 6 to 7 km. with dips of 5 to 8° .

Jacquet has described this overlying succession (Menchikoff and Nicklès 1942):

Lower Devonian: sandstone and limestone with *Spirifer rousseaui* Rouault, *S. trigeri* de Vern. and *S. paradoxus* Giebel (Coblenician).

Middle Devonian:

1. Zone of *Spirifer cultrijugatus* Roemer, *S. speciosus* Bronn. and *Pentamerus* cf. *hercyniae* Halpar.
 2. Zone of *S. elegans* Stein., *Leptaena rhomboidalis* Wilck., *Atrypa reticularis* L. and *Calceola sandalina* Lmk.
 3. A coral zone.
 4. Shales and limestones with corals and brachiopods.
- This succession represents the Eifelian.

Upper Devonian: shales and limestones with corals, *Spirifer verneuili*, *Schizophoria striatula* Schl., *Atrypa reticularis* L.

Lower Carboniferous: the sedimentation became sandy. The Hassi-el-Fokra fauna contains *Spirifer tornacensis*, *Schizophoria resuptionata* and *Productus pustulosus* Phil.

There is a different succession in the Zemmour, 300 km. to the south-east. Here the beds are orientated NNE.-SSW. instead of ENE.-WSW. and have been folded to dip at 25 to 30° , and even occasionally at 50° .

Subsequently the work of Jacquet and Sougy has established

the following succession in this difficult region (north of Fort-Trinquet):

Pre-Cambrian: granite.

Basal conglomerate or arkoses.

Infra-Cambrian: dolomitic limestones with stromatolites, which thin from 600 m. in the south to 8 m. in the north and finally wedge out completely.

Mottled arkoses (base of the *Cambrian*):

1. Sandstone with tigillites from Oumat el Ham.
2. Clays with *Obolus* and sandstones with lingulas (*Cambrian* according to Sougy).
3. Psammites with glauconitic horizons (50 to 70 m.).
4. Upper sandstones with tigillites (4 m.) and sandy shales (6 m.) sometimes removed by erosion.
5. Unconformity, ("*discordance de ravinement*").
6. Upper cross-bedded sandstones of Garat el Hamoueïd (20 to 150 m.).

It is very probable that horizons 3 to 6 are of Ordovician age as in the Tassilis.

Silurian: basal graptolitic shales overlain by orthoceroid limestones resting directly on granites (as at 167 km. on the road from Fort-Trinquet in the Tindouf direction).

Devonian: fairly complete and covered by sandy limestones of the Hamada.

Further west in Rio de Oro, Spanish geologists have described a long strip of marine Cretaceous, also recognised by Sougy in the Zemmour.

3. *South-eastern Extremity (east of the Dorsale Reguibat)* (Gevin 1957)

The Dorsale Reguibat is bounded on the north by the Tindouf Syncline whose beds bend to the east in a southerly direction, so enveloping the Pre-Cambrian.

Gevin has described the following succession:

1. Basal detrital beds overlying the *crystalline basement*.
2. *Infra-Cambrian*: stromatolite limestones.
3. *Cambrian*: Gara Djebilet Quartzites.
4. *Ordovician*: Aouinet Legra Sandstones.
5. *Silurian*: with graptolites.

2. SAOURA BASIN

The Ougarta Ranges. The Saoura. The Guir Basin

Water from the Atlas Mts. flows into the Sahara for 600 km. along the wadi Saoura, whose main tributaries are the Guir and Zousfana which join at Igli. Beyond there the wadi Saoura is overlooked in the west by the Ougarta Ranges and to the east by the Grand Erg occidental. A valley extends from Béni-Abbès and Gourara to the Touat Oasis where the river vanishes among the salt lakes.

The Ougarta Ranges and the Saoura

In the Ougarta Ranges, east of the Saoura, Menchikoff (1933) observed more than 200 m. of rhyolites and volcanic tuffs at the base of the Palaeozoic. The rhyolites are dark coloured—grey, red and violet—and are cut by small veins of milky quartz which may reach the base of the overlying sandstones. These recall the usual facies of the Infra-Cambrian.

Above the rhyolites is the Ougarta Sandstone with an arkose base, then more sandstone up to 1,000 m. thickness—and 2,000 m. in the Gourara. (Meyendorff 1938). The lower part of the sandstone is of Cambrian age while the upper marine part has been dated Ordovician by various fossils: lingulas and conularids, *Calymene tristani* at Kheng Tlaia and impressions of *Orthis* of the *alternata* group at Hassi Chambaa (Roch 1933; Poueyto 1957), conodonts and fish (Mutvei 1956).

At the beginning of the Silurian the sedimentation changed, and a thick series of graptolitic shales was deposited on the sandstones.

Llandovery: carbonaceous shales from El-Ksaïb with *Climacograptus scalaris* Hisinger and *Monograptus lobiferous* McCoy (Zones 19 to 21 of Elles and Wood).

Wenlock: Ougarta Shales with *Monograptus priodon* Bronn., *M. vomerinus* Nich., *Cyrtograptus murchisoni* Carr. and *flaccidus* Tull. (Zones 26 and 27).

Ludlow: 300 m. shales with four beds of blue orthoceroid limestone intercalated near the top. Fossils include: *Cardiola interrupta* Sow., *Isocardia insocialis* Barr., *Monograptus roemeri* Barr., *M. ultimus* Perner (ending with Zone 36).

The Silurian ends with pink shales with calcareous fossiliferous nodules yielding orthoceroids, gastropods, and lamellibranchs.

There is no apparent discontinuity between the Silurian and the Devonian. The latter begins with sandstones, shales and beds of limestone. The Geddinnian consists of sandstones and shales with *Spirifer digitatus* Barr.

Lower Coblencian (Siegenian): 100 m. shaly sandstones with three limestone horizons with *Spirifer rousseaui* Rouault, *S. trigeri* De Vern. and *Athyris undata* Deifr.

Upper Coblencian (Emsian): 250 m. of shaly sandstones with three beds of hard orthoceroid limestone.

The Middle Devonian is known at Marhouma (25 km. downstream from Béni-Abbès) and at the northern end of the Erg Djemel (6 km. south-east of Ougarta).

Eifelian: at Marhouma a reef, forming the base of the Middle Devonian, has yielded trilobites (*Phacops*), a goniatite (*Anarcestes lateseptatus* Bey.), and brachiopods (*Spirifer speciosus* Schl., *Athyris concentrica* Schn., *Atrypa reticularis* L., *Schizophoria striatula* Sch. and *Leptaena rhomboidalis*, etc.). A few metres higher there is a bed of blue limestone with *Pinacites jugleri* Roemer and several forms of *Anarcestes* and *Agoniatites*.

Givetian: at the end of the Erg Djemel the shales are capped by a limestone bed which, in turn, is covered by more shales with ferruginous goniatites including *Anarcestes rouvillei* v. Koenen, typical of the Lower Givetian. At Marhouma the Upper Givetian limestone contains *Maenioceras terebratum* Sandb., *Parodiceras brilonse* Kays., etc.

The Upper Devonian is well represented in the Saoura valley as a succession of shales with intercalated limestones. Using goniatites and clymenias, Menchikoff has distinguished all the western European zones.

Frasnian: subzone Ia: shales with ferruginous fossils: *Pharciceras* (*Prolecanites*) *lunulicosta* Sandb., *P. clavilobum* Sandb., *P. tridens* Sandb., *Timanites lamellosus* Sandb., *Tornoceras simplex* v. Buch.

Subzone Ib: limestone with *Manticoceras cordatum* Sandb.

Subzone Ic: pink shales and limestones with *Tornoceras simplex* v. Buch., *Crickites holzapfeli* Wedek., *Bactrites*, etc.

Famennian: zone II: shales with *Cheiloceras subpartitum* Munster.

Zone III: shales with limestone horizons with *Pseudoclymenia planidorsata* Munst., *Sporadoceras biferum* Phill., *Euomphalus loricatus* Schmidt.

Zone IV: reddish brown Ouararout Limestone (discovered by Gautier during his first expedition into the Sahara in 1913) from

which Menchikoff has collected: *Tornoceras bilobatum* Wedek., *Sporadoceras biferum* Phill., *Aganides discoidale* Schind., *Platyclymenia annulata* Munst., *P. intracostata* Frech., *Cyrtoclymenia enkebergensis* Wedek., *C. compressa* Sandb., *Cymaclymenia striata* Munst., *Oxyclymenia* cf. *undulata* Munst., etc.

Zone V: a little upstream from the Ouararout Oasis there are two beds of red massive limestone separated from Zone IV by 100 m. of pink shales which contain: *Aganides sulcatus* Munst., *Wedekindoceras cucullatum* v. Buch., *Cyrtoclymenia striata* Munst., *Oxyclymenia undulata* Munst., *Gonioclymenia speciosa* Munst., *G. subcarinata* Munst., *Phacops granulatus* Munst., etc.

Zone VI: pink shales with *Gonioclymenia wocklumensis*, *Cymaclymenia striata*, etc.

Petter (1954, 1955, 1958) has shown that among 96 goniatite species determined between the Eifelian and Famennian VI, 76 occur in the European Devonian. Their stratigraphical distribution parallels that of Germany. The *Clymenia* fauna is likewise very rich.

The Lower Carboniferous (Dinantian) of the Saoura valley is divided into two distinct parts; a lower shaly and sandy Tournaisian which passes into the Upper Devonian; and an upper Visean division of sandy limestones which reaches successively higher levels towards the northern Guir and Zousfana basins.

Tournaisian: the lowest beds are found half way between Béné-Abbès and Mazzer. In the middle of flagstones a small ferruginous bed contains abundant *Camarophoria isorhyncha* McCoy. The overlying sandstones are fossiliferous, with *Streptorhynchus crenistria* Phill., *Spirifer tornacensis* De Kon. and *Syringothyris cuspidata* Mart.

These are covered by 4 m. of red limestone with *Aganides rotatorius* De Kon., *Muensteroceras oweni* Hall., *M. sphaeroidalis* McCoy, *Prolecanites compressus* Sow., gastropods, pelecypods and corals. The goniatites indicate an upper Tournaisian age (C₁ horizon in the English classification).

Visean: the Visean is fossiliferous near Mazzer where Menchikoff has described the following section:

1. Sub-reef limestone with *Productus vaughani* M. Wood, *P. deshayesianus* De Kon., *Spirifer bisulcatus* Sow., *S. striatus* var. *fascicostatus* Mench., *Spiriferina laminosa* McCoy, *S. octoplicata* Sow., large corals.

2. Shaly sandstones and shales with five intercalated beds of limestone outcropping near Akacha:
 - (a) bluish limestone with *Lithostrotion irregulare* Phill.;
 - (b) limestone with *L. irregulare* and *Dibunophyllum*;
 - (c) limestone with *L. irregulare* and *Spirifer striatus* var. *fascicostatus* Mench.;
 - (d) limestone with *S. striatus* var. *fascicostatus*;
 - (e) limestone with *Orthoceras*.
3. Upper Visean limestones of Harrez-Igli with *Productus latissimus* Sow., *P. edelburgensis* Phill., *Cyathophyllum murchisoni* M. E. and H. and *Dibunophyllum*.

The marine Namurian was deposited on a continental platform which extended far to the north. There the subsidence is reflected in the accumulation of 450 m. of neritic Upper Namurian. The sea retreated twice during the Namurian so that coal forests formed on the exposed land.

Quaternary

Alimen (1955; Alimen, Chavaillon and Conrad 1959; Alimen and Chavaillon 1959) has studied the Quaternary deposits of the wadi Saoura and the wadis of the Ougarta Range where she revealed four successive alluvial complexes in the north-west Sahara corresponding to four pluvial phases. Between these alluvial complexes there are arid formations (dated by prehistoric industries) and fossil soils. So as not to prejudice the correlation of these Saharan phases with the rest of Africa, Alimen and co-workers have suggested a local terminology.

The Pleistocene begins with a humid *Villafranchian* whose deposits rest directly on a Pliocene sandstone. The Pebble-culture appears in this period.

Then follows, from the bottom:

1. Post-Villafranchian arid phase (red beds).
2. Red fossil soil covering the Post-Villafranchian Arid Phase.
3. 1st Post-Villafranchian Pluvial Phase: *Mazzerian* with Pebble Culture.
4. Post-Mazzerian Arid: pink sandstone and buff aeolian sands.
5. Brownish-red fossil soil.

6. 2nd Post-Villafranchian Pluvial: *Ougartian* with Acheulian.
7. Post-Ougartian Arid, with Acheulian and Aterian.
8. 3rd Post-Villafranchian Pluvial: *Saourian* with Aterian and black soils.
9. Post-Saourian Arid, lower screes (Neolithic).
10. Last humid episode, Neolithic: *Guirian*.
11. Return of Post-Saourian Arid which continues to the present Arid.

The black patinas, left by pedological processes of iron and manganese movement, require some humidity for their formation and must have been produced during a change from Pluvial to Arid.

3. THE COLOMB-BÉCHAR-KÉNADZA BASIN

Flamand (1911) discovered the Colomb-Béchar coal basin which has been more recently prospected by Deleau (1945, 1951).

The basal Carboniferous sediments are marine. Viséan and Namurian reef and dolomitic limestones form the anticlinal hills of the Antar and Béchar. Continental sandstone horizons occur in the Upper Namurian, which outcrops with the Westphalian in the plain south of Colomb-Béchar and Kénadza. The Moscovian (marine facies of the Westphalian) outcrops south of Colomb-Béchar and is 1,000 m. thick. Deleau has called this the *Kenadzian*:

Lower Kenadzian with *Anthracoceras aegiranum* and *Gastrioceras* (= Lower Westphalian of Europe (320 to 620 m.)).

Upper Kenadzian without *Gastrioceras* but with *Endothyra* and fusilinids (= Lower Westphalian C of Europe (260 to 440 m.)).

The terminal Kenadzian is represented by the uppermost bed with crinoids and *Anthracoceras*. Upper Westphalian C begins immediately above.

Continental Carboniferous

The sedimentation was lagoonal-lacustrine and lagoonal-continental with repeated deltaic facies, layers of coal or just soils with plants. There are 49 plant beds at Kenadza and 54 at Béchar, occupying a total thickness of 600 m.

The Upper Westphalian C flora is characterised by *Mariopteris latifolia*, *Alethopteris lonchifolia* and *Linopteris muensteri*. These pass imperceptibly into Westphalian D, which was continental and deposited after the formation of an erosional discontinuity in Upper Westphalian C times. The sediments become redder with thick sandstones containing a new freshwater fauna, including *Anthracomya prolifera* and *Candona elongata*. These are found in the Sahara in the uppermost horizon of Westphalian D (with *Neuropteris scheuchzeri* and *Pecopteris abbreviata*) at the junction with the Stephanian. In the Saar Basin, however, they occur in the Lower Stephanian. The continental Carboniferous ends with red gypsiferous beds deposited in salt lakes. Deleau maintains that all the rocks are Stephanian, but the Permian could be represented.

Guir Basin (Daguin 1929; Deleau 1945, 1950)

The Guir Basin is situated south of the Colomb-Béchar Basin. The continental sediments deposited during Westphalian A and B are sandstones with thin beds of coal, proving that a "coal" forest grew in the Sahara. There are five marine horizons. The total thickness is about 500 m.

Westphalian C begins with 10 cm. of marine limestone characterised by the abundance of *Anthracoceras aegiranum*. Other sediments (220 m.) are three shale beds and three coal seams overlain by a marine horizon with *Myalina lamellosa* De K. One hundred metres of red beds and sandstones with two coal beds overlie these. The Westphalian C flora resembles that of the Bruay Horizon in northern France. One hundred metres of unfossiliferous sandstones may represent Westphalian D.

250 m. of sandstones and blue coal shales lie above intercalated with four beds of red marl. The upper beds contain a freshwater Lower Stephanian flora: *Anthracomya prolifera* Waterlot, *Estheria limbata* Gold. The succession ends with 300 m. of sandstones and marls of Stephanian age and possibly Permian at the top.

Mézarif Basin (Jongmans and Deleau 1948)

70 km. east of Colomb-Béchar the Djebel Mézarif Anticline marks the western end of the Nekheila synclinal cuvette.

The flora and fauna of the coal outcrops so far examined suggest the occurrence of the Lower Stephanian (or Westphalian D), and this leads us to expect that the A, B and C horizons may

also be present. The coal measures are covered by 500 m. of marls, sandstones and red conglomerates of Middle-Upper Stephanian and perhaps even Autunian age.

The Tectonics of the Coal Basins

The Colomb-Béchar coal basin is a large synclinorium whose eastern border is marked by the Djebal Béchar Hercynian anticline where the Namurian dips at 50°. Traces of horizontal Cenomanian and Turonian limestones show that this area was unaffected by the post-Turonian folding. However, the northern border of the syncline includes Carboniferous anticlines, as at Djebel Antar, where the Cenomanian limestones have been folded. The productive coal seams are found in the southern part of the synclinorium as a NE.-SW. belt, 70 km. long and 4 km. wide. The southern boundary is marked by the marine limestone with *Anthracoceras aegiranum* while the northern is a Cretaceous cliff where the thickness exceeds 1,000 m. The coal outcrops on the plain only in restricted areas, being usually concealed by several metres of Recent formations.

The Guir Basin is bounded to the north by the anticline which separates it from the Colomb-Béchar Basin; it is subdivided into two cuvettes: Sfaia and Ghorassa. The productive coal measures outcrop in the north and north-east for an area of 600 sq. km.

Post-Carboniferous Sediments

Subsidence of the Guir Basin ceased after the deposition of the Stephanian, but 50 to 100 km. further north the subsidence continued for a longer period. After the Turonian sea retreated, an immense salt marsh formed in the downwarp north of Colomb-Béchar. Here, 700 to 800 m. of salt deposits accumulated; 500 m. of rock salt, anhydrite and mottled marls have been pierced in a boring of between 235 to 720 m. depth. These deposits would seem to mark the late Cretaceous and Eocene. They were folded when the Atlas Mts. were uplifted and then covered by red detrital deposits and pink and beige lacustrine limestones.

Some of the lacustrine limestones contain gastropods: *Clavator* (*Leucotaenius*) *soltanensis* Jodot, resembling *Clavator* (*Clavator*) *kantarensis* Jodot from the Aquitanian of the Aurès. This succession of limestones forms the Hamada and extends up to the Pliocene at the top.

4. THE HAMADA DU GUIR. CONTINENTAL CRETACEOUS
AND TERTIARY FORMATIONS

Several kilometres south of the Cenomanian and Turonian marine limestone outcrops is the Grand Hamada du Guir. The basement appears on the western border of this large plateau. Above the folded and eroded Palaeozoic there are 25 m. of reddish, cross-bedded sandstones of varying hardness. These estuarine sandstones have yielded fossils, in particular the rostral teeth of *Onchopristis numidus* Haug, teeth of *Ceratodus*, crenulated teeth of megalosaurid dinosaurs, dermal scales and teeth of large crocodiles which resemble the giant species described in the "Continental intercalaire" at Aoulef, and perhaps *Stomatosuchus inermis* of Egypt (Lavocat 1948). This horizon of the Lower Cretaceous is also known from southern Morocco to Egypt and Nigeria (Continental intercalaire).

The Cenomanian and Turonian seas seem not to have reached this area; but north of Colomb-Béchar the Senonian and possibly the early Eocene are represented by red lagoonal and saline deposits. Above the red series in the south-east of the trough there is a succession of coarse sandstones with basal conglomerates covered by pink and beige lacustrine limestones. Clariond has found *Ceratodes* in the limestones suggesting a Lower Eocene deposit (Menchikoff 1946).

After a slight unconformity new deposits accumulated: conglomerates, sandstones and sandy limestones. A very constant horizon contains a pulmonate: *Clavator* (*Leucotaenius*) *soltanensis* Jodot (Jodot 1938), which resembles the living pulmonate *Clavator* (*Leucotaenius*) *favannei* Lmk, found in the Quaternary and Recent of Madagascar. This discovery compares with that of *Clavator* (*Clavator*) *kantarensis* Jodot in the Aquitanian of the Aurès, a close relative of *Clavator* (*Clavator*) *grandidieri* Cr. and Fisch. from the Quaternary and Recent of Madagascar. The two subgenera *Clavator* and *Leucotaenius*, both Quaternary species from Madagascar, were also able to co-exist in north Africa before their migration. The lacustrine limestones with *Leucotaenius* of the Hamada are probably Aquitanian—like those containing *Limicolaria*.

The most recent continental series forms the top of the Hamada and should represent the Neogene succession. *Limnaea bouilleti* indicates a Pliocene age both here and further east under the Grand Erg, where it occurs in chalcedonous beds.

An important aquifer in this region is fed by rain water filtering through the sands of the Erg; it feeds numerous springs in the left bank of the Saoura Valley (Schoeller 1945).

Post-Pliocene of the Béni-Abbès Area

At Béni-Abbès the Pliocene is overlain by the Mazzer sands, sandstones and clays. These are sands with silicified roots. These unfossiliferous sediments underlie the Grand Erg, and are perhaps Upper Pliocene or Early Pleistocene in age.

Above the Mazzer formations come fine grey or white sands, more or less calcified, and containing *Limnaea palustris* Muller, *Planorbis metidjensis* Forbes, *Bulinus contortus* Michaud, *Succinea pfeifferi* Rossm.

Ancient dunes 10 to 15 m. thick and known as “sables à fulgurites” appear to be contemporaneous with the *Limnaea* beds. All these beds are covered by recent dunes in the Grand Erg occidental.

Recent Folds in the Hamada du Guir

Menchikoff (1946) has shown that Aquitanian beds with *Clavator* have been subjected to local movements, notably in the wadi Tafidjart. Recent movements affecting all the Neogene sediments, including the Upper Pliocene, have been described by Lavocat (1948, 1954). In the Glat-el-Hamman gorges, at the western source of the wadi Tafidjart, the Neogene sediments overlying the *Clavator* beds form a large E.-W. syncline with the limbs dipping at about 10°. 20 km. to the south-east, between Hacı Houia and Guelta el Ksob, the Hamada is wrinkled by an E.-W. synclinal system with the higher horizons dipping at 20° (presumably Pliocene). The Neogene sediments of the Hamada du Guir have therefore been affected by considerable movements as far as 50 km. south of the south-Atlas flexure.

5. PRE-CAMBRIAN OF THE DORSALE REGUIBAT

Pre-Cambrian outcrops in the western Sahara form an arc around the Taoudéni Basin; the NE.-SW. Dorsale Reguibat in the north (Algerian Sahara and Mauritania) and all western Mauritania from the north to the River Senegal.

The age of the uncovering of the Pre-Cambrian has been completely ignored. It is commonly assumed that the Dorsale Reguibat was covered by Palaeozoic sediments (including

the Infra-Cambrian) and that these have since been removed by erosion, but this is by no means certain. Monod (1937) and Menchikoff (1949) have demonstrated that the Tindouf Basin and the Taoudéni Basin may not have been joined so simply. Monod has confirmed that the Adrar sedimentary beds often thin out to the west as if a western massif had existed in the area of the present Tiris.

Lower Pre-Cambrian. In western Mauritania, Blanchot (1955) has shown that the oldest rocks are the Amsaga Series, first identified in the Amsaga (west of Adrar) and extending to Tiris. To the east they disappear beneath the sedimentary plateaux of the Adrar. The Amsaga Series consists predominantly of varieties of gneiss (cordierite gneiss, leptynites, biotite gneiss and hypersthene gneiss) with intercalated mica-schists, quartzites, marbles and amphibolites. The quartzites are more resistant to erosion and form the relief. They are often ferruginous, containing limonite and magnetite and sometimes form good iron ores (Fort-Gouraud). All the Amsaga Series has been folded, tilted vertical and intruded by granites. The general fold direction in the Amsaga is NE.-SW.; south of Tiris it veers NW.-SE. Blanchot compares the Amsaga Series to the Suggarian of the central Sahara.

The more northerly outcrops (Zemmour and Yetti in particular) have been studied by Rocci (1957) and Sougy (1956). These rocks are varied and difficult to interpret, but the Ghallaman Series of migmatites, gneiss and associated metamorphic rocks is incorporated into the Amsaga Series.

Further north-east Gevin also has recognised various successions in the crystalline rocks of the Yetti-Eglab Massif. The Chegga Series is the oldest, but may be younger than the Ghallaman.

Middle Pre-Cambrian. Blanchot named his second series the Akjoujt Series, after a locality in the Inchiri, south-west of Atar. This succession lies unconformably on the Amsaga Series and is less metamorphosed. It contains schists, marble and ferruginous quartzites—which resemble those of the Amsaga Series. It has been intruded by syn- and post-tectonic granites. The folds are gentle and regular. A large part of the Inchiri is covered by the Akjoujt Series, which also extends south-east to the Tankarkart Massif, while to the west the crystalline basement disappears beneath the Quaternary and Recent cover. Huot used electric logs in boreholes in the Coppolani-Nouakchott area but did not

reach the Pre-Cambrian basement at 2,000 m. depth. An important tectonic feature thus bounds the African basement in this area (as in others elsewhere).

In the north-east (according to Rocci and Sougy) an Aguelit Nebkha Series overlies the Ghallaman Series. In addition, Gevin has described a Yetti Series in the Eglab-Yetti Massif (schists, quartzites and volcanic rocks).

Upper Pre-Cambrian. In the Eglab-Yetti Massif Gevin has defined a Guelb el Hadid Series which is unconformable on the preceding groups, completely detrital, and formed of quartzites and conglomerates with extrusions of andesites and rhyolites. It is pierced by the Aftout Granites and covered unconformably by the Infra-Cambrian with stromatolites. To the south-east the Upper Pre-Cambrian could be represented by the Aïoun Abd el Malek Series intruded by the Yetti Granites.

The granite intrusions, with their associated microgranites and rhyolites, are younger than the Middle Pre-Cambrian (Relaïdian-Birrimian) and older than the Infra-Cambrian. Rocci (1957) has named them "*granites intermédiaires*". Their age is well known: younger than the Older Granites, contemporaneous with the Birrimian Orogeny and older than the "*granites ultimes*" or Younger Granites.

Terminal Pre-Cambrian or Lower Palaeozoic. Here may be cited the "Falemian" studied by Renaud (1958) in Mauritania. This unmetamorphosed series consists predominantly of pelites, jaspers and sandstones which appear to pass laterally to the east into the Infra-Cambrian of Tagant (Delpy 1959) and the Kiffa region (Bense). Furon, at the International Colloquium (1957) on the relations between the Pre-Cambrian and the Palaeozoic, considered that the Falemian appears to be a lateral extension of the Infra-Cambrian with stromatolites described in Mauritania, Mali, Nigeria and Guinea. This question is not yet completely resolved (Delpy 1959), but a similar problem occurs at the bend of the Niger.

6. TAOUDENI SYNCLINE

The Hercynian Taoudéni-Araouan Syncline, occupying the whole of the western part of the Sahara, is an immense cuvette—one of the largest synclines in the world (more than 1,200 km. in diameter). All the outcrops curve to the west in Mauritania and to

the north-east where the Palaeozoic succession is separated from that of southern Algeria by the Dorsale Reguibat. To the south the beds rise successively to emerge at the edge of the plateau overlooking the Aouker and also to the south-east on the right bank of the River Niger in the Bandiagara Plateau. The two ends, Tamga in the west and the region north of Timbuktu in the south-east, have been locally folded and inverted.

1. Geological Section from North to South

This is derived from the works of Menchikoff and Monod (1936) and Monod (1936).

Infra-Cambrian: the Hank Cliff is formed of sandstones overlain by 100 m. of dolomitic limestone with stromatolites.

Cambrian?: conglomerate with quartz pebbles and unfossiliferous bedded sandstones.

Ordovician: conglomerate with quartzite pebbles and 150 m. of coarse sandstones often cross-bedded.

Silurian: fossiliferous shales containing numerous *Monograptus* south of Tinioulig.

Devonian: Lower Eifelian found at the top of the cliff south of Teghazza contains: *Leptaena rhomboidalis* Wilck., *Atrypa reticularis* L., *Orthis* sp., *Spirifer* sp., cyathophyllids, bryozoans and crinoids.

The Upper Eifelian, discovered 10 m. south of Teghazza, contains ferruginous fossils in the shales: *Agoniatites* sp. (identical with a form from the *Pinacites jugleri* Zone of the Saoura), *Spirifer elegans* Stein., *Schizophoria* cf. *vulvaria* Schl., *Tropidoleptus* cf. *carinatus* Conr., gastropods, pelecypods, orthoceroids, corals and crinoids.

The Upper Devonian is probably present, but it has not yet been confirmed by the discovery of fossils.

Lower Carboniferous: the Lower Carboniferous, first recognised by Chudeau and Flamand, is now subdivided thus:

Tournaisian: *Muensteroceras* cf. *oweni* Hall, *Spirifer tornacensis* De K., *S. konincki* Dav., *Syringothyris cuspidata* Martin, *Athyris* sp., semireticulate *Productus*, *Rhynchonella*, *Orthoceras*, gastropods, *Zaphrentis*, *Michelinia* and crinoids (35-40 km. south of Agaraktem) and at Oum-el-Asel.

Lower Visean: *Spirifer striatus* Martin, *Syringothyris cuspidata* M., *Leptaena rhomboidalis* Wilck., *Productus cora* d'Orb., semireticulate *Productus*, *Pustula*, *Dielasma* (near Oum-el-Asel).

Upper Visean: *Productus hemisphaericus* Sow., *P. auritus* Phill., *P.*

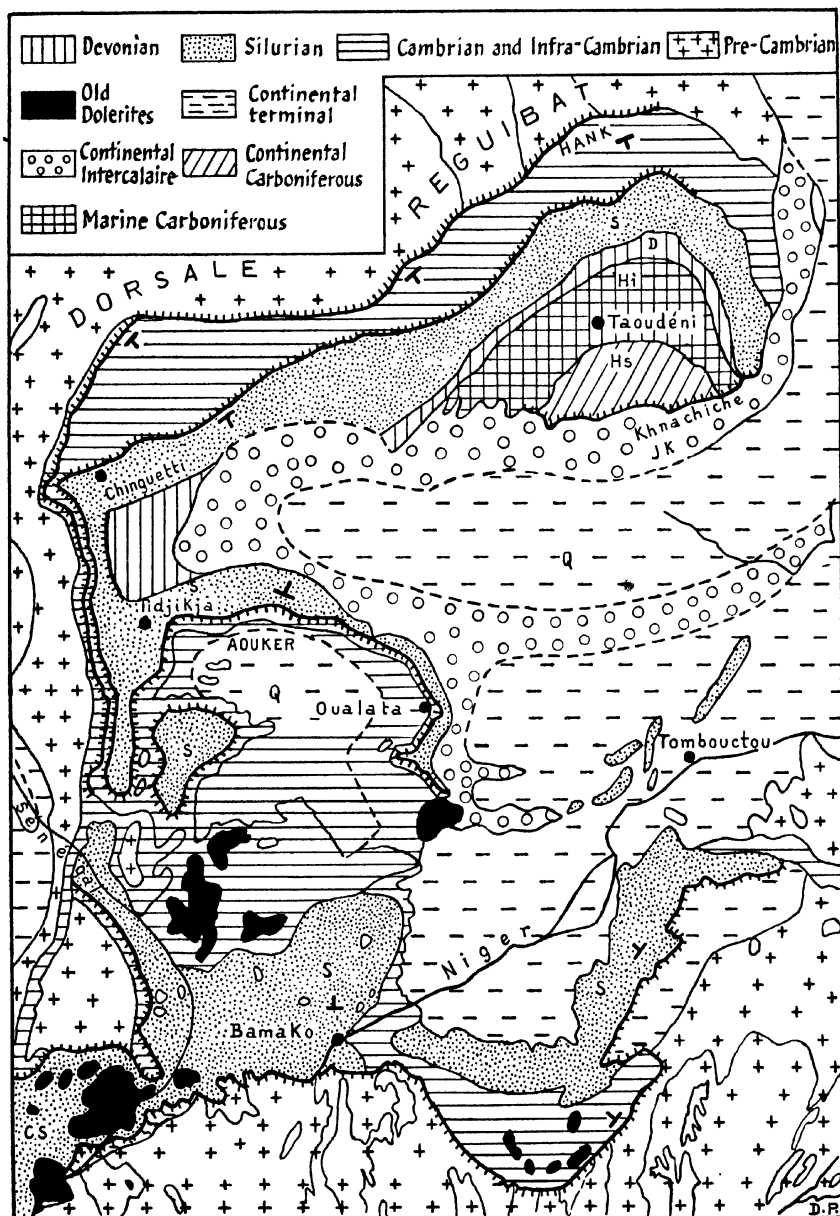


FIG. 7. The Taoudéni Basin.

striatus Fisch., *Cyathophyllum munchisoni* M. E. and H., *Lithostrotion irregulare* Phill. (from the limestones which form the Hamada-el-Haricha and Safia plateaux).

The Dinantian limestones on the north-eastern border, at Rezegallah (the boundary of the Erg Chech and Tanezrouft) contain numerous fusulinellas of forms intermediate between *Endothyra* and *Fusulina* (Pfender 1937). These are accompanied by *Archaeodiscus*, palaeoecchinoid spines and algae.

Namurian-Westphalian: the sea retreated from the central Sahara after the Hercynian movements. It seems that the emergence dates from the Namurian. Fabre and Villemur (1959) have completed the sections of Monod (and Meyendorff, unpublished).

The Visean marine limestones continue upwards into brecciodal limestones, sandstones and occasionally gypsiferous "lie de vin" clays which are probably lagoonal, lacustrine or perhaps locally of continental origin.

The overlying Post-Tassilian proper consists of about 150 m. of deposits: argilites and current-bedded sandstones of "lie de vin" colour. The argilites contain *Stigmaria*, *Asterocalamites*, *Bothrodden-dron*, *Neuropteris* Sp., freshwater pelecypods and phyllopods. These sediments outcrop on the Hamada-el-Haricha and disappear southwards beneath the "Continental intercalaire" of Khnachiche.

Dolerites. All the Palaeozoic, including the Westphalian, is cut by an extraordinary number of dolerite dykes. These, known as *agators*, cut each other and give rise to a typical "*paysage cloisonné*". Fabre and Villemur (1959) observed that the dykes are arranged as arcs or radii of a circle, which may be due to the collapse of a central zone. The rock is quartz labradorite dolerite with pigeonite (Denaeyer). The dykes cut the continental Carboniferous but not the "Continental intercalaire" so that they may be of Triassic or Liassic age as in other parts of Africa.

"*Continental Intercalaire*." A conglomerate overlies the "lie de vin" Westphalian clays and is covered by a much younger continental series: the "Continental intercalaire" (Lower Cretaceous). These sandstones with silicified wood form the Khnachiche Cliff and extend far to the south of Araouan and pass north-east under the Hamada du Tanezrouft. To the west the immense desert region of Djouf has been traversed by Monod (1958), who found a veneer of sandstones and clays with silicified wood.

Further south these formations extend to the Dahar Tichit-Oualata Néma region and join those of the Néma-Nara region, seen by Dars.

"*Continental Terminal.*" In the "Djouf", Monod found small patches of unfossiliferous but probably lacustrine flaggy sandstone. This bed resembles the Aquitanian deposits with *Limicolaria kemkemensis* Jodot found in a zone between the Hank and Erg Chech (Jodot and Rouaix 1957). The "Continental terminal" ends with about 100 m. of clayey sands and mottled clays which I put in Miocene-Pliocene.

Quaternary. Large *sebkhas* existed in the Taoudéni and Tegahza areas and left salt deposits which have been exploited for centuries. The Tegahza salt has been mined since the eleventh century and the town built out of salt. Taoudéni succeeded Tegahza at the beginning of the eighteenth century. Five workable salt beds, 10 to 15 cm. thick, are separated by clay horizons (Lt. Niéger). Elsewhere the presence of many freshwater shells, fish remains and fossil mammals indicate the humid phases in the Saharan Quaternary. Still in the Djouf, Monod was able to distinguish several horizons:

- I (SB): several tens of metres of white sands (with fulgurites), wind-affected but of alluvial origin, extending from Chinguetti to Lake Faguibine,
- II: red and orange sands (Trâb Hamrâ),
- III (G.B.I.): clayey sands and mottled clays with bones of elephants, hippopotami, crocodiles and fish,
- IV (CL): hard beige sands,
- V (GB 2): floury clays, occasionally red, with diatoms and *Limicolaria chudeaui*; a Neolithic and sub-recent horizon.

2. The Mauritanian Adrar

The Palaeozoic in Mauritania constitutes the large Adrar and Tagant Plateaux, forming the western part of the Taoudéni Basin. A complete description is due to Monod (1952), but it had been seen previously by Jacquet, re-examined by Bense, Dars, Delpy and Sougy and finally revisited by Monod (1960). Several problems of interpretation still remain to be resolved, but at least there is a complete section for the cliffs bordering the plateaux.

Monod's Adrar succession, with the sections from his recent publications, is as follows, from bottom to top:

1. *Folded and eroded Pre-Cambrian basement.*
2. *Major unconformity.*
3. *Basal shales and sandstones (nearly horizontal):*
 - C1. Aguéni Sandstones, "malachite" sandstones, conglomerates;
 - C2. Azougui Shales, multicoloured shales and sandstones with chert and jasper;
 - C3. Fom Chor Sandstones.
4. *Atar Limestone Group with stromatolites (horizontal):*
 - C4. Ksar Torchane Shales;
 - C5. brown or blue dolomitic limestones of Atar with bipyramidal quartz and stromatolites (*Conophyton ressoiti*);
 - C6. green shales (wadi Tarioufet, etc.);
 - C7. sandstones;
 - C8. Taouaz dolomitic limestones with *Conophyton*;
 - C9. red and green shales (Tarf Ndiérem, etc.);
 - C10. sandstones;
 - C11. blue dolomitic limestones with chert and small *Conophyton*;
 - C12. Jbeliat clays, shales and psammities.

This group varies from several metres to 150 m. in thickness; the thickness increases from south to north.

(The Atar stromatolite limestones could represent part or all of what I call the Infra-Cambrian.)

5. *Tillite of the Jbeliat and Aguinjob-Tingarédra:*

A tillite with a clayey calcareous cement follows without visible discordance. It was deposited by floating ice coming from the west, where the land was higher. This tillite sometimes reaches 40 m. in thickness. Although it is known as far off as Mali (Kayes area), it appears to lie mostly in lenses rather than in a continuous sheet. It is *possible* that there is a basal unconformity.

Since I have chosen a tillite to mark the base of the Cambrian, the sedimentary horizon immediately above can be considered as Cambrian.

6. *Sandstones, shales and limestones:*

- C13. dolomitic limestone of Agmeiminat with bipyramidal quartz (inconstant);
- C14. phtanites and multicoloured jaspers of Jraïf (*very constant horizon*);
- C15. paper shales and multicoloured sandstones;
- C16. dolomitic limestones with stromatolites of Amojjiar;
- C17. shaly sandstones and multicoloured shales of the Grand Dhar cliffs;
- C18. hard Serize Sandstone forming a cornice (Grand Dhar);
- C19. shaly sandstones, multicoloured shales and limestone lenses (Grand Dhar).

(This series of shales, jaspers and dolomitic limestones may perhaps be considered as Cambrian.)

7. *Dhar Sandstones (or Lower Sandstones):*

- O1. Chinguetti Sandstones (or Dhar Sandstones *sensu stricto*): thick hard quartzite bed forming the escarpment of the Grand Dhar. This sandstone bed rests conformably on horizon C19.
- O2. Mauve and green Oujeft Sandstones,
- O3. Zli Sandstones with lingulas and *Tigillites*.
- O4. Tamga Sandstones (or "*gres à corridors*") which splits up by jointing into giant parallelepipeds. These form the Tagant Plateau and the Dhar Tichit cornice overlooking the Aouker.

Monod (1952) includes the Dhar Sandstones in the Ordovician. Subsequently Dars and Sougy (1957) isolated Cambrian, beginning with horizon C17 (above the highest stromatolite limestones). The Zli Sandstones are separated from the Tamga Sandstones by an irregular unconformity (with channelling) similar to that found in the Zemmour. Bense and Delpy, on the contrary, have placed the Chinguetti Sandstones in the Ordovician. Thus the placing of the various boundaries is still disputed. Monod maintains a boundary at the base of the Chinguetti Sandstone. Elsewhere, geologists consider that all the older succession belong to the Palaeozoic *s. l.* with a major unconformity above the basement. Finally, Monod has remarked that below the tillite

between C₁₂ and C₁₃ there are *four other conglomerates* of doubtful origin.

8. *Silurian*:

This was discovered successively in 1934 and 1935 by Monod and Jacquet. It begins with the Aioun Lebgar Sandstones—also at El Amguid—in which Monod found a Wenlockian fauna with *Dalmanella elegantula*, *D. basilis*, *Homalonotus*, *Tentaculites* and crinoids.

Above comes the Ludlovian (grey paper shales with *Monograptus vulgaris*, *M. varians*, *M. flemingii*, *M. monodi*) (Nicklès).

The Silurian is 20 to 50 m. thick.

9. *Devonian*:

There is no unconformity in the passage beds between the Silurian and the Devonian; thus although the Gedinnian is unrecognised, it is impossible to find a gap in the succession. The following faunas have been precisely determined by Le Maitre (1952):

Siegenian with *Spirifer rousseaui*, *S. primaevus*, *S. hystericus* (Aouinet Zbel).

Emsian (?) sandy with *Pterinea costata*.

Eifelian limestone of Hassi el Motleh with *Spirifer parcefurcatus*, *S. cultrijugatus*, *S. speciosus*.

Givetian: bedded limestone with *Chonetes*.

Frasnian: sandstone with *Spirifer bouchardi* and *S. verneuili*.

The centre of the wadi el Abid syncline is filled with dunes, hence the upper horizons of the Frasnian are not exposed.

Carboniferous

Chudeau (1911) has described a small group of Lower Carboniferous beds in western Mauritania, in the wadi el Abid Basin between Aouinet Zebel and Hassi el Motleh. Its outcrop at the western end of the Taoudéni Syncline would seem to be logical. However, various geologists who have visited the area have never rediscovered it. Monod, in particular, has searched in vain and only found Upper Devonian sandstones. Nevertheless, on re-examining Chudeau's original samples with their original labels, I confirmed that they are remarkably similar to other samples of Carboniferous from other parts of the Sahara, which were collected in the same year. It is not impossible that the collection

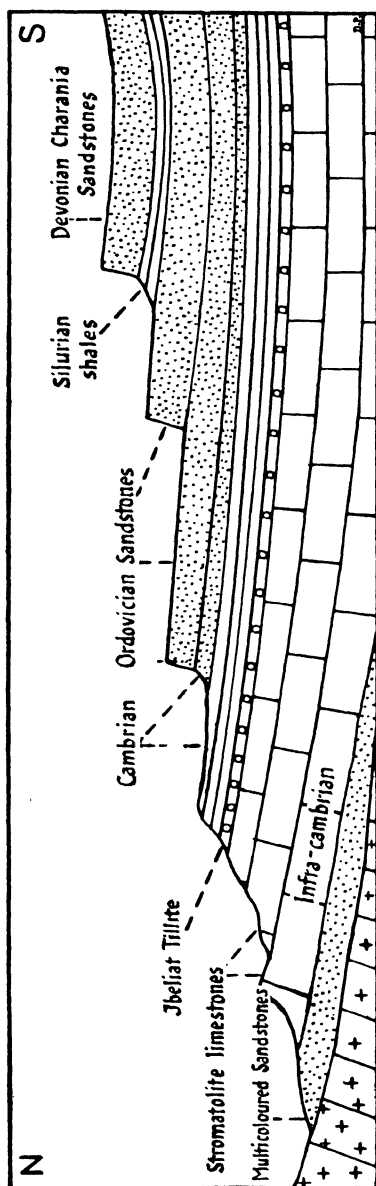


FIG. 8. Diagrammatic section of the Mauritanian Plateaux (after Monod).

formed *after Chudeau's death* consists of a mixture of specimens of various origins. Thus it is not possible to confirm that marine Carboniferous occurs in the wadi el Abid area.

Crater-like Structures

Monod has described five crater-like structures aligned NE.-SW. for 450 km. from Ouadane in Mauritania. Two parallel alignments can be distinguished. On the first and most westerly lies the Aouelloul Crater (50 km. SE. of Atar), 250 m. in diameter and 15 m. deep; showing Palaeozoic sandstones and yielding samples of glass comparable to that of tectites. Is this an explosion crater or the point of impact of a meteorite? 125 km. to the NE. there is the atoll-like Semsiyat Dome, hardly visible on the ground, which was apparently formed by the upward thrust of a laccolith (Monod 1952; Richard-Molard).

The second alignment includes from SW. to NE.: the eroded Richat Dome (50 km. in diameter) showing a section of stromatolitic Infra-Cambrian rocks, with a little rhyolitic material in the centre, suggesting that this may be of explosive, volcanic

origin; the Ténoumer Crater (1,800 m. in diameter) involving the Palaeozoic and the Hamada of "Continental terminal"; the Temimichat Ghallaman crater (500 m. in diameter) in the Pre-Cambrian. These lineaments studded with peculiar craters imply relatively recent volcanic activity, since they have not been effaced by erosion.

7. THE RECENT FORMATIONS OF WESTERN MAURITANIA

Blanchot (1957) has established a stratigraphical succession for the recent deposits in north-western Mauritania:

"Continental terminal" (s.s.): mottled Tirersioum Sandstones.
Villafranchian (?): ferruginous duricrust.

Tyrrhenian: shelly El Aïouj Limestone (beach deposit with *Heliophora rumphi* (Klein)).

Sandy limestone and sandstones of the Aguerguer with *Helix gruveli* and *Planorbis*.

Formation of yellow sand dunes (Wurmian?).

Flandrian: transgression and "raised" beaches (recorded by Dereims, Gruvel, Chudeau, Monod).

Formation of white dunes.

A 500 m. boring at Port-Etienne and geophysical prospecting around Nouakchott-Fort Coppolani have revealed a sharp flexure or fault in the crust. The crystalline basement must be at many thousands of metres of depth on the coast. The Port-Etienne boring was unfortunately not supervised by a geologist; and so the section is not usable. Nevertheless, we know that the marine Lower Miocene with *Bolivina costata* d'Orb var. *dissimilis* Cush. and Ellisor is found there at 67 to 68 m.

In southern Mauritania in the Lake Rkiz and Aftout de Boutilimit areas there is the following succession (Elouard and Michel 1958); from bottom to top:

1. "Continental terminal": clayey sandstones.
2. Lateritic hard-pan covered by clayey sandstones.
3. Gravels and lateritic conglomerates.
4. White lacustrine limestone with lateritic gravels.
5. New spread of lateritic gravels.
6. Red dune formation.

7. Terrace with *Arca senilis* (not further east than Lake Rkiz).
8. Clayey lacustrine limestone with a sub-Recent fauna in the interdunal spaces of red sands.

REFERENCES

- ALIMEN, H., 1955. Découverte de nouveaux dépôts et d'industries préhistoriques en couche dans les alluvions quaternaires de la Saoura. *C.R. Ac. Sc.*, **240**, 1652-1654.
- and J. CHAVAILLON, 1959. Découverte de la Pebble-Culture *in situ* au Sahara nord-occidental. *C.R. Soc. Géol. Fr.*, **248**, 2894-2896.
- and G. CONRAD, 1959. Formations arides et paléosols quaternaires au Sahara nord-occidental. *C.R. Soc. Géol. Fr.*, pp. 104-105.
- BLANCHOT, A., 1955. Le Précambrien de Mauritanie occidentale (Esquisse géologique). *Bull. Dir. Mi. Géol. A.O.F.*, **17**, 306.
- 1957. Les formations récentes de Mauritanie occidentale. *Bull. Dir. Mi. Géol. A.O.F.*, **20**, 9-92.
- BOUREAU, E., 1949. Étude paléoxylologique du Sahara (IV). *Bull. Mus. Nat. H. Nat.*, **21**, 414-418.
- CHOUBERT, G., 1948. Sur la géologie des plaines du Dra et le Tazout. *C.R. Soc. Géol. Fr.*, 99-101.
- DAGUIN, F., 1929. Étude stratigraphique et paléontologique du Carbonifère de la rive droite de l'oued Guir. *Notes et Mém. Serv. Mi. et Carte Géol. Maroc*.
- DARS, R. and J. SOUGY, 1957. La stratigraphie du "Cambro-Ordovicien" de l'Ouest africain et ses relations avec le Précambrien. *C.R. Colloque Précambrien-Cambrien C.N.R.S.*, pp. 223-237.
- DELEAU, P., 1945. Les bassins carbonifères du Sud oranais (Algérie). Le bassin de Colomb-Béchar et le bassin du Guir. *Bull. Soc. Géol. Fr.*, **15**, 625-632.
- 1950. Échelle stratigraphique du Carbonifère supérieur des bassins du Sud Oranais. *C.R. Soc. Géol. Fr.*, pp. 199-202.
- 1951. Les bassins houillers du Sud-oranais dans la région de Colomb-Béchar-Habadla. *Bull. Serv. Carte Géol. Algérie*, 275 pp.
- DELPY, J., 1959. Attribution au "Primaire" de formations métamorphiques estimées précambriennes en Mauritanie centrale. *C.R. Ac. Sc.*, **249**, 1374-1376.
- ELOUARD, P. and P. MICHEL, 1958. Le Quaternaire du lac Rkiz et de l'Aftout de Boutilimit (Mauritanie). *C.R. Soc. Géol. Fr.*, pp. 245-248.
- FABRE, J. and J. R. VILLEMUR, 1959. Le Carbonifère continental du Bassin de Taoudéni. *Ann. Soc. Géol. Nord*, **79**, 89-113.
- FLAMAND, G.-B.-M., 1911. Thesis, pp. 200 et *sqq.*
- GEVIN, P., 1948. Série paléozoïque d'Aouinet Legra. *Bull. Soc. Géol. Fr.*, **18**, 369-381.
- 1957. Le complexe sédimentaire de base à l'extrémité orientale de la dorsale Reguibat. *C.R. Coll. Précambrien-Cambrien, C.N.R.S.*, pp. 207-215.

- JODOT, P., 1938. Recherches sur les Mollusques continentaux. Un nouveau *Clavator* fossile dans les calcaires lacustres hammadiens des confins algéro-marocains du Sud. *Bull. Soc. Géol. Fr.*, **8**, pp. 185-191.
- and S. ROUAIX, 1957. Découverte de Mollusques continentaux de l'Aquitainien et du Villafranchien au Sahara mauritanien et soudanais. *C.R. Soc. Géol. Fr.*, pp. 375-377.
- JONGMANS, W. J. and P. DELEAU, 1948. Un nouveau bassin houiller dans le Sud Oranais (Algérie): le bassin du Mézarif. *C.R. Ac. Sc.*, **226**, 460.
- LAVOCAT, R., 1948a. Découverte du Crétacé à Vertébrés dans la soubassement de la Hammada du Guir (Sud marocain). *C.R. Ac. Sc.*, **226**, 1291-1292.
- 1948b. Sur l'existence de plissements affectent récents de la Hammada du Guir. *C.R. Soc. Géol. Fr.*, pp. 134-135.
- 1954. Reconnaissance géologique dans les Hammadas des confins algéro-marocains du Sud. *Notes et Mém. Serv. Carte Géol. Maroc*, **114**.
- MAITRE, D. LE, 1952. Contribution à l'étude des faunes paléozoïques de l'Adrar mauritanien. *Bull. Dir. Mi. A.O.F.*, **15**, 2, 301-383.
- MENCHIKOFF, N., 1930. Recherches géologiques et morphologiques dans le Nord du Sahara central. *Rev. Géogr. Phys. et Géol. dyn.*, **3**. (Thesis).
- 1933. La série primaire de la Saoura et des chaînes d'Ougarta. *Bull. Serv. Carte, Géol. Algérie*, **2**, 109-123.
- 1946. Sur les dépôts post-turonien des confins algéro-marocains du Sud. *C.R. Soc. Géol. Fr.*, p. 53.
- 1948. Sur la présence du tournaïen à Goniatites dans la vallée du Dra (Sahara marocain). *C.R. Soc. Géol. Fr.*, pp. 36-37.
- and TH. MONOD, 1936. Coupe géologique du Hank à Taoudéni (Sahara occidental). *C.R. Ac. Sc.*, **202**, 230-232.
- and M. NICKLÈS, 1942. La géologie des confins de la Mauritanie septentrionale, d'après les travaux de F. Jacquet. *Bull. Ser. Mi. A.O.F.*, **6**, 51-83.
- MEYENDORFF, A., 1938. Note sur le Gourara. *Rev. Géogr. Phys. et Géol. dyn.*, **2**, 150-155.
- MONOD, TH., 1936. Données nouvelles sur la structure du Sahara occidental. *C.R. Ac. Sc.*, **202**, 1797-1799.
- 1952. L'Adrar mauritanien (Sahara occidental). *Bull. Dir. Mi. A.O.F.*, **15**, 2 vol.
- 1958. Majâbat al-Koubrâ. Contribution à l'étude de l' "Empty Quarter" ouest-saharien. *Mém. Inst. Fr. Afrique Noire*, **52**, 406 pp.
- 1960. Remarques sur la stratigraphie de la falaise d'Hamdoun-Aginjob. (Adrar de Mauritanie). *Bull. I.F.A.N.*, **22**, 18.
- MUTVEI, H., 1956. *C.R. Ac. Sc.*, 19 Nov.
- NICKLÈS, M. Les faunes de Graptolithes récoltées par F. Jacquet dans le Gothlandien de Mauritanie. *C.R. Ac. Sc.*, **224**, 355-356.
- PETTER, G., 1954. Famenien terminal aux environs de Beni-Abbès. *Bull. Soc. Géol. Fr.*, **4**, 11-16.
- 1955. Note sur les gisements dévoniens à Ammonoidées de la vallée de la Saoura et des Mts d'Ougarta. *C.R. Soc. Géol. Fr.*, pp. 76-78.
- 1958. Goniatites dévoniennes du Sahara. (Thesis.) *Bull. Serv. Carte Géol. Algérie*.

- PFENDER, J., 1937. Sur la présence de Fusilinelles dans le Dinantien du Sahara. *C.R. Soc. Géol. Fr.*, **79**, 119-121.
- POUEYTO, A., 1957. Contribution à l'étude des grès inférieurs au Sahara septentrional. *C.R. Colloque Précambrien-Cambrien, C.N.R.S.* (1958), pp. 191-197.
- RENAUD, L., 1958. Le Précambrien du Sud-Ouest de la Mauritanie et du Sénégal oriental. Roneotyped thesis, Clermont-Ferrand.
- RICHARD-MOLARD, J., La pseudo-boutonnière du Richat. *Bull. Dir. Mi., A.O.F.*, **1**, 166-190.
- ROCCI, G., 1957. Formations métamorphiques et granitiques de la partie occidentale du pays Reguibt (Mauritanie du Nord). (Thesis.) *Bull. Dir. Min. A.O.F.*, **21**, 2 vol.
- 1959. Sur l'existence d'un complexe des granites intermédiaires et sa position dans l'ensemble des granitisations de l'Ouest africain. *C.R. Ac. Sc.*, **248**, p. 3588-3590.
- ROCH, E., 1933. Sur deux gisements fossilifères dans les grès d'Ougarta. *C.R. Soc. Géol. Fr.*, p. 30.
- SCHOELLER, H., 1945. L'hydrogéologie d'une partie de la vallée de la Saoura et du Grand-Erg occidental. *Bull. Soc. Géol. Fr.*, **15**, 563-586.
- SOUGY, J., 1956. La stratigraphie du "Cambro-Ordovicien" de Zemmour (Sahara occidental). *Bull. Soc. Géol. Fr.*, **6**, 99-113.
- TERMIER, H. and G., 1948. Sur la présence du Tournaisien à Goniaitites dans la vallée du Dra (Sahara marocain). *C.R. Soc. Géol. Fr.*, pp. 102-104.

EASTERN SAHARA

1. THE DEPRESSED REGION BETWEEN THE HOGGAR
AND THE TIBESTI

In the depressed region between the Hoggar and the Tibesti the Palaeozoic rocks of the Tassilis are partly covered by Cretaceous sediments. Suess conceived the hypothesis that there was a Cretaceous marine communication between the Mediterranean and the Gulf of Guinea. At first this region was known from isolated discoveries and then more information was acquired by the expeditions of Dalloni (1948), Freulon, Lefranc and others (Bizard *et al.* 1955.)

Palaeozoic. In the Hoggar, as in the Tibesti, the Cambro-Ordovician is represented by a thick succession of sandstones.

The Silurian of Djado (Orida Oasis) is not of the graptolitic shale facies, as in the Fezzan and the Hoggar, but has a sandstone facies with *Harlania*, which is also found in the Tibesti near Defirou and further south. *Spirophyton* also occurs (Silurian and Lower Devonian).

The Devonian is fossiliferous at Dadafi and Kamadia (200 km. to the NNE. of Bilma). This Coblencian, which consists of friable micaceous sandstones, contains *Spirifer* cf. *rousseai* Rouault, *Stropheodonta oriskania* Clarke, *Trigleria* cf. *adrieni* de Vern. and d'Arch., *Chonetes* cf. *sarcinulata* Schloth., etc.

West of the Tibesti the passage beds between the Devonian and the Carboniferous consist of the Defirou continental beds with *Archaeosigillaria*.

The marine Lower Carboniferous covered the area south of the Fezzan. Fossiliferous limestones are found at Yat (north of Bilma), south of Toummo and near Lebo (south of Lugri) and contain minute goniatites, *Orthoceras* sp., *Euomphalus pentagonatus* Sow., *Bellerophon hiulcus* Sow., *Productus cora* d'Orb., *Orthotetes crenistria* Phill., *Dielasma hastata* Sow. and *Spirifer bisulcatus* Sow. Freulon has also recorded stromatolitic limestones. The Lower Carboniferous marine succession reaches 300 m. in thickness.

The "*Continental post-tassilien*" is found between Mts. Doumergue

and the "mountain" of Djado, in the Enneri Chelemma, whose cliffs contain moulds of freshwater mytilids resembling *Naidaites carinata* Sow., of the European and North American Westphalian (Kilian and Langlois 1938).

"*Continental intercalaire*." The Djado, Manguéni and Toummo Plateaux are covered by beds with silicified gymnosperm wood: *Dadoxylon* (*Araucarioxylon*) *aegyptiacum* Unger, *D. lugriense* Boureau, *D. lagadaense* Boureau, *Protophyllocladoxylon madamaense* Boureau, *Podocarpoxylon aegyptiacum* Kraus., etc. (Boureau 1948).

The "Continental intercalaire" forms the summit of Emi Fezzan (840 m.) and is 280 m. thick. This succession represents the Jurassic and the Lower Cretaceous.

Marine Cretaceous. The transgressive marine Upper Cretaceous is detected by the discovery of *Ostrea olisiponensis* Sharpe in the Djado region between Tiffa and Chirfa (Upper Cenomanian-Lower Turonian) (Furon 1933) and *Hemiaster fourneli* Desh. in the Enneri Chelemma (Manguéni), at an altitude of 710 m. (Kilian and Langlois 1938; Furon and Kilian 1934). This latter discovery is of the greatest importance. Although the fossiliferous group has not been rediscovered, which is hardly surprising in such poorly frequented areas, its altitude corresponds remarkably with that of Amguid in the Hoggar to the north; this is evidence of marine Cretaceous in the sunken area between the Hoggar and the Tibesti. In spite of the very pertinent opinions of many of my colleagues I continue to believe that the Cretaceous and Eocene Saharan sea extended from Kaouar to Fezzan, locally covering the crystalline border of the Hoggar. The Eocene is indicated by moulds of lucinas found north of Bilma.

2. THE TIBESTI, BORKOU AND ENNEDI

The Tibesti and its surrounding areas are plateaux of Palaeozoic sandstones resting on a Pre-Cambrian basement. The Tibesti Massif is dominated by a large volcano, the Emi-Koussi, whose summit reaches 3,415 m. in altitude. It has been studied by Tilho (1910-1914), Dalloni (1934), Lelubre (1946) and Gèze.

Pre-Cambrian. The Pre-Cambrian basement outcrops over a wide area in the northern part of the Tibesti Massif. In the north-west there is a monotonous succession dominated by greenish schists, sericite schists and fine-grained sandstones. The beds have been tilted nearly vertical along a NNE. strike and

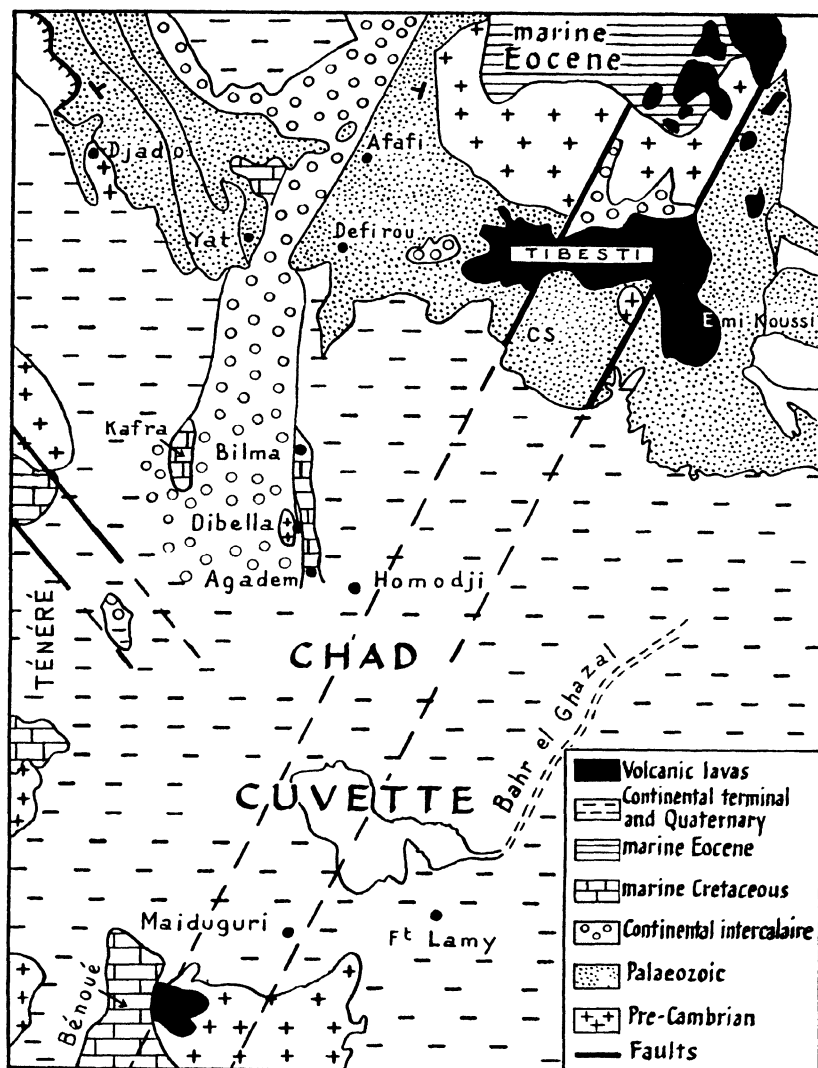


FIG. 9. Geological sketch map of the Tibesti and the neighbouring areas.

extend eastwards to beyond Yébigué. A few conglomerate lenses are found in the Taanoa region together with marbles, between the Domous and the Sanaka.

Further to the east in the Kahbor Valley the schists pass into beds of marble, micaceous quartzites, carbonaceous schists, quartzites, amphibole schists and mica-schists which disappear beneath the sandy Dohone Cliff. This group extends north of Enneri-Eguei, where it disappears beneath the continental Eocene formations.

Numerous granites occur. The oldest outcrop near Edeba and west of Bardai and have been crushed in the folds of the metamorphic rocks. Other syntectonic granites were crushed contemporaneously with the rocks which they had metamorphosed.

Finally, there are some post-tectonic granites which have intruded the folded crystalline schists and formed contact aureoles. Good examples of these are seen in the Domous.

Lelubre has described rhyolitic formations belonging to the Upper Pre-Cambrian, which have been crushed and unconformably overlain by Palaeozoic sandstones in the higher ground of the Enneri-Kemmé. This author considers that the northern Tibesti metamorphic formations are a homogenous group formed from a sedimentary succession, metamorphosed before the orogenic movements. These are lithologically and tectonically analogous to the Pharusian of Emmidir and Ahnet, north-west of the Hoggar, or to those of the wadi Sersouf to the south-east of the same massif. The granites belong to several successive intrusions and the volcanic activity took place at the end of the Pre-Cambrian cycle, with rhyolitic flows.

Continental Post-Huronian: feldspathic sandstones.

Cambro-Ordovician: the 500 m. of sandstones have a basal conglomerate containing quartz pebbles. The sandstones, sometimes ripple-marked, are more or less hardened, sometimes quartzitic, sometimes soft and friable. Cayeux, who has studied the petrography of these sandstones, stated that they are typical shallow marine deposits. Therefore the transgression certainly reached the Tibesti.

Silurian: the Silurian, which forms the major part of the Borkou, is not shaly as in the Hoggar and does not contain graptolites. It is a facies of mottled and micaceous shaly sandstones with problematical trace-fossils: *Harlania* (= *Arthrophyucus*) *harlani* and *Cruziana* (= *Bilobites*).

Devonian: this poorly defined unit could be represented by the youngest hard sandstones with *Harlania* and *Spirophyton* and by the sandstones and conglomerates which separate the Silurian from the plant-bearing Carboniferous. The marine Devonian, however, extended to the Ennedi, since in the Mourdi depression, in particular, the sandstones with *Harlania* are overlain by limestones.

Terminal Devonian and Lower Carboniferous. The best succession is that of Defirou in the west of the Tibesti. Corsin (1934) has determined arborescent lycopods: *Archaeosigillaria vanuxemi*, *Dictyodendron kidstoni*, *Cyclostigma* sp. and *Knorria* sp. which are all plants comparable with those described by Nathorst in the Lower Carboniferous of Spitzbergen. The Defirou succession contains no shales but only very fine sandstones. To the south-east near the Egyptian-Sudan frontier the large sandy Ennedi Plateaux extend to the Borkou (Fritel 1925).

Above the sandstones with *Harlania*, *Cruziana* and *Spirophyton* and the Devonian limestones there are Lower Carboniferous sandstones with *Archaeosigillaria vanuxemi* Kidston, *Lepidodendron veltheimianum* Sternb., *L.* sp. and *Ulodendron majus* L. and H. This is the same flora as at Defirou and Djebel Ouenat where the beds rest directly on the basement.

Marine Lower Carboniferous. The marine Lower Carboniferous extended to the Tibesti proper and even the Mourdi Depression, whose pink and blue limestones seem to mark the extreme eastward limit of the Dinantian transgression (Bonnet *et al.* 1955).

"Continental intercalaire." The silicified wood on the surface of the Mourdi indicates the proximity of the Nubian Sandstone. These form all the relief north of the Mourdi Depression. The Erdi Dji Plateau of *"Continental intercalaire"* sandstone rises some 200 m. above the surrounding beds. It is the same as the Erdi Ma.

Marine Eocene. Marine Cretaceous is unknown immediately north of the Tibesti; however, Lelubre (1949) has described marine Eocene in the Sérir Tibesti, at the foot of the Dohone Cliff. This Lutetian occurs at an altitude of 500 m. Its surface forms a vast north-south trough stretching from the north of the Tibesti to the Syrte.

"Continental terminal." A veneer of *"Continental terminal"* is known north and south of the Tibesti, especially on the Angamma Plateau where a ferruginous duricrust is present.

Volcanic Activity

Works on this subject include: Gèze *et al.* (1957), Gèze, Hudeley and Vincent (1957) and Gèze and Vincent (1957).

The Tibesti Massif was the site of intense volcanic activity, which perhaps began in the Oligocene. The major eruptions are of Quaternary age. The NE.-SW. volcanic alignments of the northern Tibesti are an extension of those of the Cameroun Trough.

The Emi Koussi (3,415 m.) has a very broad-based cone resting on Palaeozoic sandstones at a height of 1,200 m. A basaltic phase was followed by a trachytic. Along some fractures the rhyolitic volcanoes were contemporaneous with the trachytic phase of the Emi Koussi. The Toussidé (3,265 m.), built up on Palaeozoic sandstones, was first a great rhyolitic and trachytic pile. It formed a caldera, on the margin of which appeared two explosion craters and the present one. The recent lavas are basalts and there are still fumaroles.

In the central Tibesti the volcanoes of Tarso Yéga, Tarso Toon, Tarso Voon and Soborom are complex structures where ignimbrites are very important. Strong fumarolic activity persists at Soborom.

This Tertiary and Quaternary volcanic group covers 60,000 sq. km. All the original summits have disappeared due to the formation of subsidence calderas, which are associated with explosion calderas or volcano-tectonic domes. The volcanic activity has not yet ended. To account for the origin of this volcanic activity Gèze has suggested an explanation similar to that of Bordet for the Hoggar: an upwarping of the basement due to the intrusion of a laccolith.

Quaternary Sedimentary Deposits

In the Tibesti Quaternary deposits were laid in lakes into which fell volcanic ash (tuffs and vitric tuffs) and where diatoms flourished (e.g. the Bardagué lake). Other lakes have left behind calcareous deposits with *Limnaea africana*, *L. natalensis*, *Planorbis stanleyi*, *Bullinus (Isodora) strigosus*, *Melania tuberculata*, *Pisidium landeroini* and ostracods.

From Borkou, Kanem and Eguei, Arambourg has determined silurids of the genera *Synodontis* and *Clarias*, a percoid genus, *Lates niloticus*, and a tortoise—witness of a humid phase.

At Ounianga-el-Kébir, south-east of the Tibesti, and north of

the Mourdi Depression, a fossil fauna is found which includes: *Hippopotamus amphibius* L. of smaller than normal size, *Elephas* sp., smaller than the present African Elephant, and a large wild boar (Joleaud and Lombard 1933).

REFERENCES

- BIZARD, C., A. BONNET, J.-M. FREULON, G. GÉRARD, A.-F. DE LAPPARENT, P. VINCENT and P. WACRENIER, 1955. La série géologique entre le Djado et le Tibesti. *C.R. Ac. Sc.*, **241**, 1320-1323.
- BONNET, A., J.-M. FREULON, A.-F. DE LAPPARENT and P. VINCENT, 1955. Observations géologiques sur l'Ennedi, le Mourdi et les Erdi (Territoire du Tchad, A.E.F.). *C.R. Ac. Sc.*, **241**, 1403-1405.
- BOUREAU, E., 1948. Considérations sur une flore ligneuse fossile récoltée dans le Sahara central. *C.R. Soc. Géol. Fr.*, pp. 312-313.
- CORSIN, P., 1934. Flore dinantienne de Defirou. *Arch. Muséum Nat. Hist. Nat.*, **11**, 147-155.
- DALLONI, M., 1934. Mission au Tibesti (1930-1931). *Mém. Ac. Sc.* **61**, 1.
- 1948. Matériaux pour l'étude du Sahara oriental. Région entre la Libye, le Tibesti et le Kaouar (niger). Géologie et Préhistoire. *Inst. Rech. sahariennes Univ. Alger*, **6**, 120 pp.
- FRITEL, P.-H., 1925. Végétaux paléozoïques et organismes problématiques de l'Ouadai. *Bull. Soc. Géol. Fr.*, **25**, 33-48.
- FURON, R., 1933. Nouvelles observations sur l'extension du Crétacé et de l'Eocene dans la colonie du Niger. *C.R. Ac. Sc.*, **196**, 1033.
- and C. KILIAN, 1934. Primaire et Crétacé entre Tibesti et l'Air. *C.R. Ac. Sc.*, **198**, 1798.
- GÈZE, B., H. HUDELEY, P. VINCENT and P. WACRENIER, 1957. Morphologie et dynamisme des grands volcans du Tibesti. *C.R. Soc. Géol. Fr.*, pp. 117-120, 1815-1818, 2328-2331.
- H. HUDELEY and P. VINCENT, 1957. Le volcan de l'Emi Koussi, dans le Tibesti oriental. *C.R. Ac. Sc.*, **245**, 2064-2067.
- and P. VINCENT, 1957. Les volcans du Tarso Yéga, du Tarso Toon, du Tarso Voon et de Soborom, dans le Tibesti central. *C.R. Ac. Sc.*, **245**, 1938-1940.
- JOLEAUD, J. and J. LOMBARD, 1933. Mammifères quaternaires d'Ouniangael-Kébir (Tibesti sud-oriental). *C.R. Ac. Sc.*, **196**, 497.
- KILIAN, C. and X. LANGLOIS, 1938. Sur la découverte de Moules d'eau douce d'âge carbonifère moyen près des aiguades N. de Chelemma . . . *C.R. Ac. Sc.*, **207**, 368.
- LELUBRE, M., 1946. Sur les séries antécambriennes du Tibesti septentrional. *C.R. Ac. Sc.*, **223**.
- 1949. Géologie du Fezzan oriental. *Bull. Soc. Géol. Fr.*, **19**, 251-262.
- TILHO, J., 1910-1914. *Documents scientifiques de la mission Tilho (1906-09)*. 3 vols., Paris.

CHAPTER XIV

LIBYA

1. TRIPOLITANIA AND CYRENAICA

References on this area include: *Annali del Museo libico de storia naturale* (1940 and 1941), Desio (1943), Coggi (1940), Brichant (1952) and de Lapparent (1952).

Permo-Trias and Jurassic

These systems are continuous with those of Tunisia and outcrop in the region south of Tripoli, at El Azizia, in the Djeffara Plain.

The succession begins with Permian sandstones and ends with Jurassic cherty limestones. The Lower Trias sandstones which overlie the Permian at Djebel Tebaga, in Tunisia, are unknown in Tripolitania between Azizia and Tripoli. However, the Muschelkalk is represented by 100 m. of limestones near Azizia and Gharian with *Spiriferina lipoldi* Bittner, *Nucula strigillata* Goldf., *Modiola pygmaea* Munst., *Pecten saccoi* Parona and *Myophoria inaequicostata* Klipst. Above (Upper Trias and Lias) there is a 200 to 300 m. gypsiferous succession overlain by grey dolomites with *Avicula costata* and a small Bajocian fauna.

"Continental Intercalaire"

From the neighbourhood of Homs to near the Tunisian frontier the "Continental intercalaire" outcrops at the foot of the cliff bounding the Cretaceous plateau. There are sandstones and clays with plant remains. Near Nalout the Scek-Sciuk lignites contain a Wealdian flora: *Cladophlebis albertsi* Brong., *C. zaccagnai* Princ., *Yuccites* sp., *Dioonites buchianus* Bornm., *Sphenolepidium kurrianum* Heer and *Bechlesia anomala* Seward. In other places silicified wood has been identified: *Araucarioxylon zuffardi*, *Cupressinoxylon* sp., *Protocedroxylon paronai*. The "Continental intercalaire" extends south to the margins of the Tibesti but it is overlain by Cretaceous marine limestones.

Marine Cretaceous

The Cenomanian marine transgression invaded Tripolitania and Cyrenaica. The most important deposits are those of the

Hamada el Homra which joins the Hamada de Tingert and the Tademaït of the Algerian Sahara. The marine Cretaceous is complete from the Cenomanian to the Danian:

Cenomanian: *Neolobites peroni*, *Exogyra flabellata*, *Hemiaster batnensis*,
Beds with Rudists: *Radiolites lefebvrei*, *R. peroni*, *R. trigeri*, *Sphoerulites foliaceus* and *Praeradiolites biskraensis*, passing into the Turonian.

Turonian: *Biradiolites arnaudi*, *Radiolites choffati*, *R. lusitanicus*, corals, nerineas and *Inoceramus*.

Senonian: *Libycoceras ismaeli*, *Hemiaster thomasi*, *Alectryonia nicaisei*, *Venericardia beaumonti*, *Turritella forgemoli* (?), *Voluta stromboides*, etc.

Danian: *Hercoglossa danica*.

In the south the Cretaceous extends to near Ghadamès and the cliff overlooking the Fezzan Cuvette. To the east it disappears beneath the Tertiary beyond the meridian of Homs.

Tertiary

The Eocene outcrops widely to the north and east of Djebel

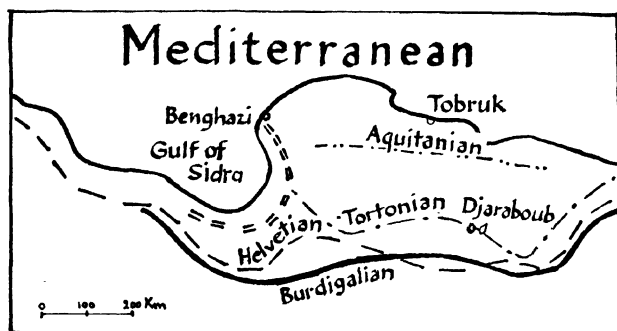


FIG. 10. The extent of the Neogene seas in Libya (after Desio).

Soda as well as on the coast in the Djebel el Akhad to the east of Benghazi. It extends to near Djebel Nero in the Sérir Tibesti (Rossi 1941): Eocene of Fezzan (Desio, Lelubre).

At El Fogha the succession is complete:

Lower Eocene with *Operculina hardiei*, *Linthia desioi*, *Schizaster mokattamensis*, *Vulsella eymari* and *Lucina thebaica*.

Middle Eocene with *Nummulites gizehensis*, *Echinocyamus luciani* and *Psammechinus desioi*.

Upper Eocene with *Anisaster gibberulus*, *Plicatula indigena*, *Ostrea elegans* and *Cassidaria desori*. To these should be added (among others) *Raetomya schweinfurthi* from Syrtica, a species known in Egypt (Upper Mokattam) and Nigeria (Ameki).

Near Derna (Djebel el Akhdar) Stefanini noted:

Montian with *Nummulites deserti*.

Lower Eocene with *Nummulites planutalus* and *Operculina pyramidum*.

Middle Eocene with *Nummulites atacicus*, *N. gizehensis*, *Porocidaris schmideli*, *Chlamys subtripartita*, *Lucina pharaonis*, *L. thebiaca*, *L. mokattamensis*, *Cassidaria nodosa* and *Volutilithes depaupereta*.

Upper Eocene with *Nummulites fabianii*.

The Oligocene sediments suggest that there was a deep gulf south of the Gulf of Sidra but it did not extend as far as that of the Eocene.

Several horizons have been distinguished there:

Sannoisian with *Nummulites intermedius-fichteli* and *N. boucheri*.

Stampian with *Natica crassatina*.

Chattian with *Chlamys gravesi* and *Lepidocyclina dilatata*.

The Miocene sea extended over part of Cyrenaica. The first deposits are Aquitanian with *Eulepidina elephantina*. Then followed:

Burdigalian with *Operculina complanata*, *Scutella forumjuliensis*, *Pecten zizinae*, *P. josslingi*, *Flabellipecten burdigalensis*, *Gryphea gingensis*, *Placuna miocenica* and *Anomia epihippium*.

Helvetian with *Alveolina bradyi*, *Clypeaster subplacunarius*, *Amphiope arcuata*, *Echinolampas hemisphaericus*, *Pectunculus pilosus*, *Pecten scabriusculus*, *Ostrea virleti*, *Cardium multicostatum* and *Turritella archimedis*.

Regressive Tortonian with *Alveolina bradyi*, *Ostrea plicatula*, *Mytilus galloprovincialis*, *Tellina nitida*, *Flabellipecten galloprovincialis* and *Turritella turris*.

The youngest beds (Lower Pliocene with *Modiola adriatica*) are found at Agedabia at the end of the Gulf of Sirte.

Volcanic Activity

Volcanic activity occurred in two regions: the Djebel Gharian south of Tripoli and the important Djebel es Soda and Djebel

Haroudj el Soued Massifs east of the Hamada el Homra. The volcanic eruptions appeared to begin in the Oligocene and continued until recent times if one may judge by the state of preservation of the basaltic country and its flows.

The rocks are essentially β and β^1 basalts, ankaratrites, basanites and phonolites. Nephelenitic types are abundant. This is a series in which soda predominates, very different from that known in Tunisia, Algeria and Morocco where the Tertiary volcanoes are fed by a sub-alkaline magma giving more rhyolites than basalts (Lacroix, 1927 and in Dalloni, 1934).

2. THE FEZZAN

The Fezzan marks a large cuvette of Nubian Sandstone resting on the Palaeozoic. It has been studied by Desio, Cornet, Lelubre and Menchikoff, Bellair, Freulon and Lefranc. The general structure is relatively simple. Two large divisions can be distinguished: a southern synclinal zone (extending from the covering of the Hoggar and the Tibesti) and a northern zone formed by the Cretaceous Hamada de Tinghert in the west and the Eocene in the east. On these rest immense volcanic massifs stretching from Tripolitania to the Dohone.

Western Fezzan

Works on this area include: Lelubre (1946, 1952), Freulon (1951, 1959), Freulon and Lefranc (1952) and Lefranc (1959).

The western Fezzan is bounded to the north by a Cretaceous plateau, the Hamada el Homra, and to the south by the Tassilis des Ajjer and the plateaux bordering the Hoggar.

South of the Hamada el Homra, in the Chati area, Lelubre discovered a large ENE.-WSW. anticline which is connected in the south-west to the Ghat anticlinal zone. This structure determines the morphology. On both sides of the anticlinal crest sandstone and limestone strata form a series of south-facing escarpments between Dembaba and El Hassi and north-facing escarpments in the southern Chati.

On the northern flank, which disappears below the Hamada, there is this succession, from below:

1. Brown sandstones with *Spirifer verneuili* Murch. (Upper Devonian).

2. Carboniferous limestones with *Productus* and *Bellerophon*.
3. Carboniferous sandstones with *Lepidodendron*.
4. Clay and dolomite rocks (Trias = Zarzäitine).
5. Continental sandstones with silicified wood and *Ceratodus* teeth (Jurassic = Taouratine).
6. Green and red marls with fish remains (Upper "Continental intercalaire" (Lower Cretaceous));

The eroded centre of the anticline is formed of Silurian shales with graptolites (*Monograptus*), outcropping in the El Gasr Wells 20 km. north-west of Edri; there is a core of Middle Pre-Cambrian.

On the southern flank the same succession occurs, but with a well marked continental facies:

Non-fossiliferous sandstones.

Thick sandstones with *Spirophyton* (Devonian).

Yellowish ferruginous sandstones.

Ferruginous sandstones with *Lepidodendron* (basal Carboniferous?).

Thin-bedded sandstones with ferruginous beds rich in brachiopods (*Spirifer tornacensis*), well represented towards Gorda, Maharouga and Brak (marine Lower Carboniferous).

Further to the south this succession is concealed beneath the sands of the Erg d'Oubari which extends up to the foot of the Messak Cliffs.

The southern extension of the anticline was seen in the south-west by Cornet. Near the Timenocaline Wells (490 m.) the section shows from the bottom to the top:

Crinoidal limestones and greyish purple limestones (2 m.).

Conglomerate with *Productus semireticulatus* and *Athyris* limestones belonging to the Visean.

Purple sandstones with silicified wood (8 to 10 m.) and greyish-purple limestones representing the Visean (Cornet 1948).

This ENE.-WSW. anticline stretches from north of Serdelès to west of Edri; it closes to the north-west as the Fezzan synclinal cuvette, which forms an artesian basin. In the Serdelès area Menchikoff (1945, 1946) observed the "Continental post-tassilien" (Upper Carboniferous) resting on marine Lower Carboniferous.

The Visean is defined by *Productus semireticulatus* Mart., *P. vaughani* M.-W., *P. undatus* Deifr., *P. cora* d'Orb., *Streptorhynchus*

crenistria Phil., *Syringothyris cuspidata* Mart., *Bellerophon carinatus*, etc. Freulon has described limestones with *Collenia* in the Dinantian.

Below the Dinantian a succession of Devonian sandstones is found; also the Silurian graptolitic shales described by Desio (1940), between Serdèles and Ghat on the border of the Tassili des Ajjer. These shales contain: *Monograptus nilssoni* Barr., *M. dubius* Suess, *Climacograptus libycus* Desio and *Diplograptus modestus* Lapw. (Ludlow and Llandovery).

The Messak Cliffs provide a section of the Nubian Sandstone: clays and sandstones containing silicified wood and some plants. Above the first horizon of silicified trees of the Ikaraf Cliff, Lelubre (1946) has described, from the bottom:

Alternation of sandstones and white and red clays.

Second horizon with silicified wood near Tenis.

10 to 15 cm. ferruginous horizon with plant remains at the aguelman de Tissit where Corsin has determined *Weichselia reticulata* Stokes and Webb.

Third horizon of sandstones with silicified wood.

Fine sandstones at the top of the cliff.

Fourth and last horizon of sandstones with silicified wood.

Fine sandstones.

The Nubian Sandstone complex of Messak covers the Mourzouk Cuvette whose raised margin forms the Messak, Djebel Ati and Djebel Ben Guénéma. This complex, studied by Freulon, has enabled Boureau (1959) to determine a Jurassic age for the lower zone with *Weichselia reticulata*, accompanied by *Cladophlebis* and *Phlebopteris* (= *Lacopteris*). The Messak flora also contains *Tuccites*, some species of which resemble many of the forms known from the Upper Bathonian.

Thus three fossiliferous horizons are confirmed in the "Continental intercalaire": Trias, Jurassic and Lower Cretaceous, clearly established by Lefranc (1959).

Eastern Fezzan (Lelubre 1948)

The eastern Fezzan is limited to the north by the eastern end of the Hamada el Homra, composed of Cretaceous rocks, which disappears beneath Tertiary deposits; and to the south by an area of Palaeozoic rocks, a northerly extension of the Tibesti.

In the north-west of the area are the Palaeozoic sediments of

Chati, which disappear to the east of Brak. Towards the south they vanish beneath sands near the wadi Lajal. On the southern side the Cretaceous Nubian Sandstone outcrops, forming the Mourzouk Cuvette and extending far to the south. It contains *Dadoxylon aegyptiacum* Unger, cited by Chiarugi and Fantoli.

Towards the east the track from Temissa to Ouaou-el-Kébir crosses the northern Meherchema. There Lelubre has seen a succession of Carboniferous sandstones, undated sandstones and lower sandstones cut by quartz veins.

A little further to the south, on the track from Gatroun to Ouaou-el-Kébir, in the southern Meherchema, the succession is as follows:

1. *Silurian*: upper cross-bedded sandstones overlying lower sandstones crossed by quartz veins (eastern Meherchema).
2. *Devonian*: sandstones forming the western Meherchema.
3. *Marine Lower Carboniferous*: limestones with *Productus undatus* Defr., crinoids, *Bellerophon* and bryozoans.
4. Unconformity, *Lower Nubian Sandstone* (Upper Carboniferous?).
5. *Nubian Sandstone* with silicified wood of Djebel ben Guénéma (Cretaceous).

The succession dips to the west. In the east the lower sandstones are separated by an unconformity from the overlying Eocene limestones at Ouaou-el-Kébir.

Further south, this succession occurs near the track from Ouaou-el-Kébir to Kourizo and the Tibesti, from north to south:

1. Pre-Cambrian basement, outcropping at Fokiouré.
2. Lower sandstones with quartz veins, which occur in the Mouri-Idié Plateau where they join those of the Tibesti.
3. *Silurian*: upper thick red sandstones with cross-bedding, containing *Harlania harlani* at Djebel Kibei-Maiokma (400 m.).
4. *Devonian*: psammites with *Arthropycus* south of Lebo (150 m.).
5. *Marine Lower Carboniferous*: limestones with *Bellerophon* and *Productus vauhani* Muir-Wood (200 m.).
6. *Lower Nubian Sandstone* (Post-Dinantian).

7. *Nubian Sandstone* with silicified wood (Infra-Cretaceous), forming the Tiera-Madoa Cliff.

The eastern Fezzan appears to be the eastern limit of the graptolitic Silurian.

Marine Eocene

During the Middle Eocene the marine transgression advanced to the Tibesti. Lelubre has found sediments on the western slope of the Dohone, west of the enneri Mouzorké. These comprise 200 m. of limestones dipping north-west and overlying the Palaeozoic sandstones or resting directly on the Pre-Cambrian. This is the eastern end of the Syrta Trough whose shorelines are found today at a height of 600 m.

"Continental Terminal"

The "Mourzouk Limestones" form a series of limestone plateaux locally sandy and of lacustrine origin, containing only small gastropods and *Chara* oogonia. They have been deeply eroded (50 m.) and the gullies filled by Quaternary deposits with *Cardium edule*. Lelubre attributes this succession to the "Continental terminal".

Elsewhere to the east of the basaltic Haroudj el Assoued Massif the marine Eocene is covered by the "Continental terminal" containing remains of *Palaeophys*, saurians, tortoises, fish and silicified wood (Bellair *et al.* 1954). 120 km. south of Oua en Namous, Lelubre has collected silicified wood including *Sterculi-oxylon* (*Nicolia*) *aegyptiacum* known from Rio de Oro to Somalia. Freulon has found a related species (*S. freulonii* Boureau) near Oua en Namous (Boureau 1957).

Volcanic Activity of the Harouj el Hassoued (Bellair *et al.* 1952)

The enormous volcanic eruptions of the Harouj el Hassoued at the boundary of the Fezzan and the Libyan Cuvettes cover an area of 25,000 sq. km. Two main basaltic divisions have been distinguished. The older was erupted from fissures and inundated the nearby Eocene plateau and now forms an immense lava field.

Towards the centre of the massif are more recent plateaux with a surface of scoriaceous basalt from which arise complete volcanic cones whose basaltic flows are superimposed on the deposits of the two preceding episodes. These small cones do not exceed

200 m. in height. There is no longer any active volcanism although solfataric activity occurs at El Kebrit.

3. THE DJEBEL OUEMAT

References to this area include Menchikoff (1926, 1927).

The Djebel Ouenat is the most important feature of a small mountainous massif situated at the junction of the Libyan-Egyptian-Sudanese borders.

The basement is formed of Middle Pre-Cambrian crystalline schists folded in a ENE.-WSW. direction. These schists have been intruded by granites. The granite, which forms the greater part of the Djebel Ouenat, is a hyperalkaline granite with riebeckite and aegyrine, accompanied by microgranites, pegmatites and grorudite. This is the usual composition of the Pre-Cambrian "recent granites" in the Hoggar, the Aïr and the Zinder region. The magmatic activity ended after the deposition of the first continental sandstones with a flow of alkaline aegyrine rhyolite.

The Nubian Sandstone was deposited above the altered rhyolites and extends widely into the Libyan desert to the north and south of Djebel Ouenat.

It should be emphasised that there are here no Cambro-Silurian nor Devonian sandstones as in the regions further south in the Tibesti and Ennedi. Above 3 m. of sandstones is a 15 to 20 cm. bed of argillaceous sandstone containing impressions of *Archaeosigillaria* cf. *vanuxemi* Kidston and corresponding to the extreme base of the Carboniferous. Above this basal Carboniferous lies a thick series of continental sandstones with cross-bedding and ripple-marks, and pink or purple clay bands. The only organic remains are pieces of silicified wood.

By analogy with the neighbouring regions these upper sandstones may be of "Continental intercalaire" age.

REFERENCES

- BELLAIR, P., J. M. FREULON and J. P. LEFRANC, 1952. Les éruptions volcaniques de l'Harouj el Assoued (Sahara oriental). *C.R. Ac. Sc.*, **234**, 2460.
— — — — — 1954. Découverte d'une formation à Vertébrés et Végétaux d'âge tertiaire au bord occidental du Désert libyque (Sahara oriental). *C.R. Ac. Sc.*, **239**, 1822.

- BOUREAU, E. and J. M. FREULON, 1959. Sur les flores jurassiques du Continental intercalaire saharien. *C.R. Soc. Géol. Fr.*, pp. 53-54.
- BRICHANT, A., 1952. Sur la découverte du Trias au pied du Djebel Garian (Tripolitaine). *C.R. Ac. Sc.*, **234**, 1456.
- COGGI, L., 1940. Fossili triassici della Gefara tripolina. *Ann. Museo. Libico* (2), p. 139.
- CORNET, A., 1948. Constitution géologique du Zegher (Fezzan). *C.R. Ac. Sc.*, **226**, 2162.
- DALLONI, 1934. Mission au Tibesti. *Mém. Ac. Sc.*, **61**, 324.
- DESIO, A., 1940. Fossili neosilurici del Fezzan occidentale. *Ann. Mus. Libico*, St. Nat., **2**, 13-45.
- 1942. *Geol. Rundschau*, **33**, 415-421.
- 1943. L'esplorazione mineraria della Libia. Publ. *Ints. Politica intern.*, *Geogr. Univ. Milano*, series G, No. 27.
- FREULON, J. M., 1951. Sur la série primaire nord-occidental. *C.R. Soc. Géol. Fr.*, pp. 216-217.
- 1959. Thesis.
- and J. P. LEFRANC, 1952. Structure et stratigraphie du Nord du Fezzan. *C.R. Congrès Géol. Intern., Algiers*, **14**, 109-148.
- KILIAN, C. and M. LELUBRE, 1946. De l'âge des Grès de Nubie à l'Orient de l'Ajjer (Sahara central). *C.R. Ac. Sc.*, **222**, 233.
- LACROIX, A., 1927. Les caractères chimico-minéralogiques des roches intrusives et volcaniques tertiaires de l'Afrique du Nord. *C.R. Ac. Sc.*, **185**, 573.
- LAPPARENT, A. F. DE, 1952. Stratigraphie du Trias de la Jeffara (Tunisie et Tripolitaine). *C.R. XIX^e Congr. Géol. Intern., Algiers*, **21**, 129.
- LEFRANC, J. P., 1959. Les séries continentales intercalaires du Fezzan nord-occidental (Libye). *C.R. Ac. Sc.*, 249-1685.
- LELUBRE, M., 1946. Sur le Paléozoïque du Fezzan. *C.R. Ac. Sc.*, **222**, 1403.
- 1948. Le Paléozoïque du Fezzan sud oriental. *C.R. Soc. Géol. Fr.*, p. 79.
- 1952. Aperçu sur la géologie du Fezzan. *Bull. Serv. Carte. Géol. Algérie* fasc. 3, 109-148.
- MENCHIKOFF, N., 1926. Observations géologiques faites au cours de l'expédition de S.A.S. le Prince Kenal-el-Dine Hussein dans le désert de Libye (1925-1926). *C.R. Ac. Sc.*, **183**, 1047.
- 1927. Les roches cristallines et volcaniques du centre du désert de Libye. *C.R. Ac. Sc.*, **184**, 215.
- 1945. Les grès de Serdelès (Fezzan). *C.R. Ac. Sc.*, **220**, 292.
- 1946. A propos de la faune de l'ouadi Oubarrakat (Fezzan occidental). *C.R. Soc. Géol. Fr.*, p. 346.
- ROSSI, 1941. *Ann. Mu. Libico*, **3**, 97-193.

EGYPT AND THE SUDAN

1. EGYPT

1. *Pre-Cambrian*

The Geological Survey of Egypt has not been able to provide a text for the *Lexique stratigraphique international*, nor for the Structural Map of Africa.

The Pre-Cambrian basement outcrops widely in eastern Egypt in the Arabian Range. It has been studied by Barthoux (1922), Hume (1934) and Schürmann (1942-1957). Numerous successions have been distinguished and described, but their stratigraphic and structural relationships are not always sufficiently clear for it to be possible to interpret the succession and correlations. The following is a summary of Schürmann's (1957) succession.

Lower Pre-Cambrian (or Proto-Archaeon): it is represented by orthogneiss (Fundamental Gneiss) intruded by numerous granites and particularly by the *Shaitian* Granite.

Middle Pre-Cambrian (or Meso-Archaeon): discordant on the Proto-Archaeon, it is divisible into three series, from bottom to top:

Atala and Mitiq Series, including gneiss and strongly metamorphosed rocks (which could belong to the Lower Pre-Cambrian).

Shadli Series, beginning with a conglomerate containing pebbles of Shaitian Granite and volcanic rocks, and followed by schists, quartzites and marbles.

Dokhan Series with serpentines, gabbros and lava flows, invaded by "Gatterian" Granites.

Upper Pre-Cambrian (or Epi-Archaeon): unconformable on the Dokhan Series and termed the Hammamat Series. The rocks include conglomerates, schists, greywackes, dacitic and andesitic flows, intruded by the young Gatterian riebeckite granites, dated at approximately 480 m.y. (from the isotopic analysis of a feldspar).

It is difficult to compare this succession with that of the central

Sahara. But it seems reasonable to suppose, with Schürmann, that the Proto-Archaeon corresponds to the Suggarian, the Meso-Archaeon to the Pharusian (Relaidinian) and the Epi-Archaeon to the Nigritian.

2. Nubian Sandstone

Owing to the absence of a marine transgression at the base of the Palaeozoic the Pre-Cambrian basement is covered by continental sandstones known as the Nubian Sandstone. Described for the first time by de Rozière in 1826 as "monumental sandstones" they were given the name of Nubian Sandstone by Rüsseger in 1839. The term was adopted by Lartet and it has remained in use to describe a succession of continental deposits whose oldest beds are Lower Palaeozoic and youngest are Upper Cretaceous. It has been possible to establish a number of sections in this enormous succession due to the numerous intercalated marine transgressions.

First and Lowest Series: Carboniferous. The oldest fossiliferous succession is overlain by Carboniferous marine sediments of Dinantian age. In Sināi Barthoux recorded *Lepidodendron mosaicum* Salter and *Calamites* sp. in the Oum-Bogma Sandstones, which are covered by Dinantian limestones with *Streptorhynchus crenistria* Phill.

Since then, Lower Carboniferous has been recognised in Egypt on the shores of the Red Sea (Gebel Gharib, Ayum Musa). Jongmans described the Egyptian flora from various borings; it contains *Lepidendropsis fenestrata* Jongmans, *Sublepidodendron fasciatum* Jongmans, *Cyclostigma aegyptiaca* Jongmans, *Stigmara ficoides* Br. and *Sphenopteris whitei* (Berry) Jongmans. This is the basal Carboniferous *Lepidodendropsis* flora (Jongmans *et al.* 1955).

Marine Visean. The Lower Carboniferous transgression has been recognised in north-east Egypt on the western shores of the Gulf of Suez, in the wadi Araba and in the wadi Abou Darag 20 km. further north.

The wadi Araba Beds contain *Productus semireticulatus* Martin and *Productus longispinus* de Kön. The wadi Abou Darag Beds include black crinoidal limestones, marls, glauconitic sandstones and ochreous sandstones with *Spirifer* aff. *fasciger* Keys., *Productus* sp., *Edmondia oblonga* McCoy, *Aviculopecten aegyptiacus* Walt., *Bellerophon* cf. *tenuifasciata* de Kön. and *Orthoceras* sp. (Cuvillier 1937). These deposits belong to the Visean.

The sea then retreated and the deposition of continental sandstones continued during the Westphalian.

Second Series (Liassic). West of the Gulf of Suez and north of the wadi Araba in the Gebel El Galala El Bahariya, a complex of multicoloured sandstones has yielded a small flora: *Phlebopteris* aff. *muensteri* Schenk, *Todites williamsoni* Brong., and *Zamites* cf. *schmeideli* Stern. considered as Infra-Lias (Carpentier and Farag 1948).

Bajocian-Bathonian Marine Transgression. The eroded surface of the Infra-Liassic plant beds is covered by 100 m. of limestones, marls, shales and gypsiferous sandstones, containing fossils at Khasm el Galala (Sadek 1926) and Ras el Abd (Farag 1948).

At Ras el Abd, Farag has collected *Pholadomya orientalis* Douv. of the Bajocian; *Rhynchonella obsoleta* Sow., *R. concinna* Sow., *Trigonia pullus* Sow., *Astarte pisiformis* Sow., *Amphitrochus mogharensis* Douv., etc., of the Bathonian and *Eudesia cardium* Lmk. of the Upper Bathonian. This is the Sinai fauna, found in a gulf of transgressive Bajocian-Bathonian.

Third Series, Lower Cretaceous. The marine Jurassic of Gebel el Galala is covered by 150 m. of sandstones and mottled clays which are in turn overlain by the transgressive marine Upper Cenomanian. The main break in the succession is above this third series of sandstones.

They have been studied in detail in the west of the Nile Valley, in the Libyan Desert, in the Baharia Oasis and especially in the Djebel Dist.

There the Nubian Sandstone contains various fossilised plants: *Nelumbites schweinfurthi* Fritel, *Dadoxylon aegyptiacum* Ung. and *Weichselia reticulata* St. and W., a species from the "Continental intercalaire" of the southern Fezzan and Djoua. These beds are renowned for the fish and reptile fauna studied by Stromer (1914, 1917-1936):

Fish: *Ceratodus africanus* Haug., *Scapanorhynchus subulatus* Ag., *Onchopristis numidus* Haug., *Platyspondylus foureaui* Haug., *Lepidotus* cf. *pustulatus* Woods, *Lamna appendicularia* Ag. and *Enchodus* sp.

Reptiles: crocodiles (*Libycosuchus brevirostris* Stromer, *Stomatosuchus inermis* Str., and *Aegyptosuchus peyeri* Str.); dinosaurs (sauropods-titanosaurs: *Aegyptosaurus baharijensis* Str. whose femurs are 1.3 m. long) and theropods: *Spinosaurus aegyptiacus*

Str. and *Carcharodontosaurus saharicus* Dep. and Sav. (whose femurs reach 1.26 m.).

The faunas and rock facies show that this is an estuarine and lagoonal deposit with a warm and dry climate. The age is older than the marine transgressive Upper Cenomanian. It can be considered as Lower Cretaceous *sensu lato*.

Another rich flora has been discovered by Barthoux in the Nubian Sandstone near Aswan on the right bank of the Nile where the sandstones rest directly on granite and gneiss.

Fritel has determined: *Weichselia* sp. and *Cycadeomyelon fourtaui* Fritel; together with dicotyledons: *Laurus caillaudi* Fritel, *Cinnamomum humei* Fr., *Anona assouaniana* Fr., *Magnolia barthouxi* Fr., *Nelumbium schweinfurthi* Fr. and *Liriodendropsis angustifolia* Newberry. All these species are allied or identical to types abundantly represented in the Lower Cretaceous and the earliest Middle Cretaceous, up to the Lower Cenomanian inclusive, in Europe and America (Barthoux and Fritel 1925). Fritel's conclusions confirm those concerning the deposits in the Baharia oasis and are found to be locally confirmed by the fresh-water fauna of Jowikal, south of Aswan (W. F. Hume).

Thickness of the Nubian Sandstone. The thickness of the sandstones increases from 50 m. close to Aswan in the south-west to 600 m. at Sinai in the north-east. The greater part is of Lower Cretaceous age and has been deposited directly on the crystalline basement. The large extent of these sandstones has given Egypt a tabulated character which was not modified by the Cretaceous transgression.

3. The Mesozoic of Sinai

In the Sinai peninsula the lower sandstones, about 100 m. thick, contain *Lepidodendron mosaicum* Salt., and *Calamites* sp. They are covered by 50 m. of manganiferous beds and two intercalated beds of sandstone and turquoise marls. Above is a purple limestone with *Orthis michelini* Phill., *Productus pustulosus* Phill. and *Spirifer striatus* Martin of uncertain age (Viscan?).

Later the Carboniferous sea retreated and the Nubian Sandstone continued to accumulate. The upper limit varies in different places depending on the age of the overlying marine transgression.

North-east of Sinai, at Djebel Araif el Naga near the Israel border, are 200 m. of marine Middle Trias, with *Myophoria laevigata* Alberg, conodonts (Awad 1945; Eicher 1946) and ceratites.

At Djebel Moghara (Sinaï) the transgression is of Bajocian age while in Egypt it was Cenomanian or later. The Djebel Moghara (802 m.) is found 80 km. east of the Suez Canal (Douville 1916; Cossmann and Douville 1925; Farag 1949). It is an anticline whose eroded crest is formed of Nubian Sandstone of unknown age. Barthoux gives the following section from the Djebel Moghara:

1. Nubian Sandstone with silicified wood (*Araucarites*) (60 m.).

2. *Bajocian*:

Limestone with *Rhynchonella edwardsi* Chap. and Dew. (80 m.).

Limestone with *Coeloceras humphriesi* Sow. (50 m.).

Marls with *Holactypus depressus* (50 m.).

Limestone with *Oppelia subradiata* (12 m.).

Marly limestone with rhynchonellas (10 m.).

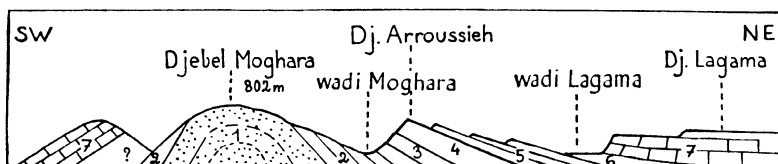


FIG. 11. Section of the Djebel Moghara (Sinaï) (after Barthoux).

3. *Bathonian-Callovian*:

Limestone with *Eudesia cardioides* Douv. (230 m.).

Compact limestone (150 m.).

Limestone with *Rhynchonella orbigny* Oppel (50 m.).

Marly limestones (70 m.).

4. *Oxfordian*:

Limestones (90 m.);

Limestone with *Perisphinctes martelli* Oppel (80 m.);

Coral limestone (60 m.).

The upper zones of the Jurassic do not seem to be represented and the Djebel Moghara succession continues into the Lower Cretaceous.

Barremian: this contains *Holaster syriacus* de Lor., *Lytoceras liebigeri* Oppel., *Phylloceras semistriatus* d'Orb. and *Desmoceras hemiptychum* Kilian.

Aptian: yellow limestone with *Puzosia matheroni* d'Orb., *Douvilleiceras meyendorffi* Sinzow., *Knemiceras priscum* Douv., *Trigonia picteti* Coq. and *Orbitolina conoidea-discoides* Gras.

Albian-Vraconian: yellow impure limestone with *Latidorsella latidorsata* Michelin, *Desmoceras beudanti* Brong., *Douvilleiceras mamillare* Schloth., *Knemiceras uhligi* Choffat and *Glauconia deserti* Douv.

Cenomanian: white limestone with *Exogyra flabellata* Goldf., *E. mermeti* Coq. and *E. olisiponensis* Sharpe.

Turonian: grey limestone with *Acanthoceras deveriae* d'Orb. and *Hippurites grossouvrei* Douv.

Senonian: with *Alectryonia nicaisei* Coq., *Ostrea vesicularis* Lmk., *Pecten farafrensis* Zittel and *Hemiasterourneli* Desh.

Danian: chalk with *Venericardia beaumonti* d'Arch. and H. and shaly marls.

An unconformity separates the terminal Cretaceous from the Lower Eocene with *Operculina libyca* Schwag.

4. The Cretaceous Transgression in Egypt

References to this area include Fourtau (1914, 1917) and Greco (1915, 1916, 1917).

The Jurassic sea did not invade Egypt but in contrast the Cretaceous sea extended very far, up to Wadi Haifa on the Sudanese border.

The Cretaceous transgression began in the Cenomanian or more precisely in the Upper Cenomanian, as clearly shown by the strata of the Baharia Oasis overlying the Infra-Cretaceous Nubian Sandstone.

Upper Cenomanian: limestones and marls with *Heterodiadema libycum*, *Salenia batnensis* Coq., *Exogyra olisiponensis* Sharpe, *E. mermeti* Coq., *E. flabellata* Gold., *Sphaerulites schweinfurthi* Zittel and *Neolobites vibrayeanus* d'Orb.

Turonian: limestones with rudists (*Sauvagesia*, *Bournonia* and *Durania*) and upper limestones with nerineas (*Nerinea requieniana* d'Orb.). The Turonian of Abou Roach exceeds 100 m. in thickness. In the wadi Quéna (north of Louqsor) the Turonian contains an ammonite fauna. The Cenomanian and Turonian do not extend further south than Louqsor.

Lower Senonian: the Coniacian of Abou Roach is represented by impure limestones with *Echinobrissia waltheri* Gauth., *Leiocidariscrameri* de Lor., *Plicatula ferryi*, *Ostrea costei* Coq. and *Tissotia tissoti*

Peron. The Coniacian reappears further to the south in a more siliceous facies in the wadi Quéna.

The *Santonian* (*sensu stricto*), difficult to separate from the Coniacian, is represented at Abou Roach by upper limestones with *Phyllocoenia roachensis* and *Kingena blanckenhorni*.

Upper Senonian: the true Campanian is difficult to separate from the Maestrichtian and its existence has not been proved. The transgressive Maestrichtian extends further and often rests directly on the Nubian Sandstone and ends with phosphatic beds.

In all the Arabian Desert (east of the Nile) the cephalopod facies is widespread, with *Bostrychoceras polyplacum* Rom., *Baculites syriacus* Conrad, *Ptychoceras*, *Scaphites*, etc., and pelecypods such as *Trigonoarca multidentata* B. Newton, *O. lyonsi* Newton, etc. Generally speaking, this fauna corresponds with that of the Upper Cretaceous of India in the Pondicherry region. The upper beds contain *Libycoceras ismaeli* Zittel, *Baculites*, *Gryphea vesicularis* Lmk., *Exogyra overwegi*, *Roudaireia auressensis* Coq., etc.

Danian: the Danian extends still further to the south as it is found near the Kourkour and DOUNGOL Oases south-west of Aswan and north of Wadi Haifa. It is represented by chalky limestones and paper marls. The Danian chalk is characterised by *Hercoglossa danica* Schl., *Voluta aegyptiaca* Wann., *Natica farafrensis* Wann. and *Echinocorys fakhryi* Fourtau.

In the Louqsor region, particularly at Esna, the stage consists of paper shales with the same fauna. These shales are very well developed from Esna until north of Thèbes. The lower zone of these paper shales is Danian (Cuvillier 1934); at the top they pass into the Montian with *Aturia preziczac* Opp.

5. *The Palaeogene*

Cuvillier (1930, 1933, 1935, 1949) has described the Palaeogene sediments, of which the Eocene is very well developed in Egypt. In the Arabian Desert their most southerly outcrop is at 26° N. whence they form a widening belt which in the latitude of Cairo unites the Nile Valley with the Gulf of Suez. In the Libyan Desert their southern limit is near the Tropic of Cancer.

The passage from the Cretaceous to the Tertiary differs in each of the regions studied. Sedimentation was variably continuous from the Cretaceous to the Eocene or interrupted by a Ypresian, Lutetian or Bartonian transgression.

Montian: the Farafra Oasis is one of the rare regions where one

can see an uninterrupted succession of Cretaceous and Tertiary sediments. The Montian, intercalated between the Danian paper shales and the Ypresian marls, is characterised by very small nummulites: *Nummulites deserti* de la Harpe and *N. fraasi* de la Harpe.

Lower Eocene: Cuvillier dates the Ypresian as the first important marine transgression. This is represented by 400 m. of limestones particularly studied at the Hill of Thèbes (Gebel Gournah) near Louqsor. The tombs in the "Valley of the Kings" have been excavated in Ypresian limestones.

The upper limit of the Ypresian is defined by the appearance of *Orbitolites complanatus* indicating the first Lutetian beds.

The section at Gebel Gournah is as follows, from the bottom to the top:

1. Grey paper marls with *Aturia preziczac* (Montian).
2. White limestone with chert nodules and small foraminifera; 120 m. thick and of indefinite age.
3. Marly limestone (75 m.) with *Lucina thebaica* Zittel and *Ostrea multicostata* Desh.
4. Limestone with operculinas, rare *Nummulites atacicus* Leym and *Linthia delanouei* Desh.
5. Kneaded limestone with *Nummulites globulus* Leym. (30 m.).

In the Farafra Oasis the succession is a little more complicated and it may be that earlier horizons, intermediate in age between the Montian and Ypresian, are present.

1. Paper shales with *Nummulites deserti* and *N. fraasi* (100 m., Montian).
2. Marly limestones with *Nummulites deserti*, *N. fraasi*, *Linthia caerosa* de Lor., *Vulsella zitteli* M.-E., *Lucina edita* Opp., etc. (100 m., indefinite age).
3. Greenish marly limestone with *Alveolina decipiens* Schwag., *N. deserti*, *Velates schmiedelanus* Chemn. (base of the Ypresian?).
4. Greenish marly limestone with *Nummulites deserti* and *N. atacicus* (25 m., definitely Ypresian).
5. Lutetian marly limestone.

Middle Eocene: the beginning of the Lutetian is marked by *Orbitolites complanatus* Lmk., which survived up to the beginning

of the Bartonian. The other characteristic foraminiferan of the Egyptian Lutetian is *Nummulites gizehensis* Forskal, represented by a small form in the Lower Lutetian of the Arabian Desert (Cuvillier 1933b; Doncieux and Cuvillier 1935) and by its large form in the Upper Lutetian, where it is accompanied by *Nummulites curvispira*, *N. uroniensis*, *N. laevigatus* and *N. lucasi*. This Lutetian, as currently understood, represents the old Upper Libyan of Zittel and the Lower Mokattam, except for the terminal beds.

The Lutetian transgression is hardly marked in the south of Egypt where the sea extended the same distance as in the Ypresian.

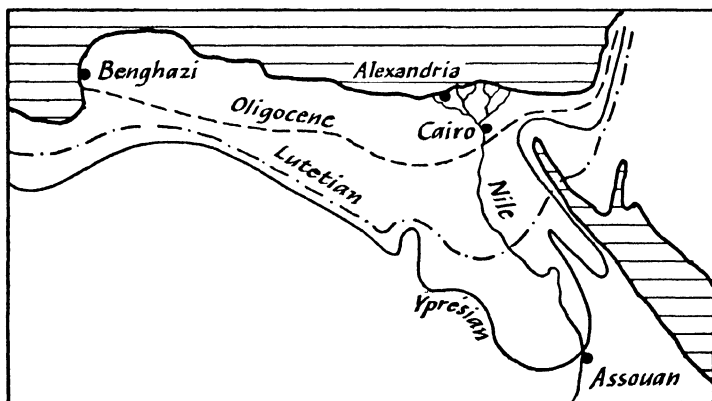


FIG. 12. The extent of the Palaeogene seas in Egypt (after Cuvillier).

However, the Lutetian sea extended much further to the east and west, compensating for the other abandoned areas. The local transgressions were not contemporaneous.

The Middle Eocene outcrops in the Nile Valley from Assiout to Cairo; the different units appear successively from the south to the north; beds with alveolinas and orbitolites at the base, then Upper Lutetian with large nummulites, used as building stones.

At Gebel Drounka, near the Lycopolis cemetery (Upper Egypt) the succession is as follows, from bottom to top:

1. White limestones with echinoids (*Conoclypeus delanouei* de Lor., *Linthia cavernosa* de Lor., etc.) (probably representing the top of the Lower Eocene).

2. Yellowish porous limestone with *Nummulites ataticus* Leym. and *Aveolina* cf. *subpyrenaica* Leym. (base of the Lower Lutetian).
3. Limestone used for building (40 m.), with *N. ataticus* Leym., *Orbitolites complanatus* Lmk. and *Cerithium giganteum* Lmk.
4. White shaly limestone with *Ostrea multicosata* Desh., *Cardita aegyptiaca* Fraas, *Thersitea cossmanni* Opp., *Rimella aegytiaca* Opp. and the same foraminifera.
5. Limestone with *Sismondia logotheti* Fraas.
6. Friable limestone with *Alveolina* cf. *subpyrenaica* Leym.
7. Clays with *N. ataticus* Leym.
8. Limestone with *Ostrea multicosata* Desh. and *Sismondia logotheti* Fraas.

The Lower Lutetian succession is 300 m. thick. Much further north, in the Cairo region, is the classic area for studying the Upper Lutetian, which is there transgressive on the Upper Cretaceous. The sphinx has been carved in this Lutetian, which provided stone for building the pyramids of Gizeh.

The type locality is Gebel Mokattam, east of Cairo. The Middle Eocene is 130 to 140 m. thick:

1. Upper Cretaceous.
2. Sandstones and conglomerates (3 m.) with shell fragments and silicified wood.
3. Yellowish Limestone with *Nummulites globulus* Leym., *N. guettardi* d'Arch, *N. gizehensis* Forskal (small size), *Velates schmiedeliani* Chem., etc. (this horizon represents the top of the Middle Lutetian or the base of the Upper Lutetian).
4. White limestone with the same nummulites and molluscs.
5. White limestone with *N. globulus* Leym., and *N. ataticus* Leym.
6. White limestone with *N. ataticus* Leym.; *N. lucasi* d'Arch. and *N. uroeniensis* Heim.
7. Limestone with *N. gizehensis* Forskal (maximum size) and *N. lucasi* d'Arch.
8. Limestone with *N. curvispira* S. and M. and *Schizaster mokattamensis* de Lor.

9. Limestone (exploited as a building stone) with pectens, echinoids and nautiloids.
10. White limestone with *N. atacicus* and numerous internal moulds of molluscs.

Upper Eocene. The base of the Upper Eocene is marked by the appearance of a new nummulite fauna: *N. contortus* Desh. and the megaspheric form: *N. striatus* Brug., in the white limestones which lie directly above those of the Upper Lutetian.

The upper boundary is indeterminable as the fluvio-marine beds pass into the Oligocene without a very noticeable change in the fauna. Generally the Lower Bartonian corresponds to the upper layers of the Lower Mokattam and the Upper Mokattam, the Upper Bartonian to the "Qasr el Sagha Series" of Fayoum. The extent of the Upper Eocene sediments is much less than those of the Middle Eocene.

In the Fayoum Depression, behind the Qasr el Sagha Temple, the Upper Eocene reaches 150 m. in thickness.

At the base of the section come:

1. Gypsiferous clays with *Ostrea clot-beyi* Bell.
2. Siliceous limestone with *Anisaster gibberulus* Mich.
3. Clays and friable limestone with *Ostrea fraasi* M.-E., *Carolia placunoides* Cantr. and *Turritella imbricataria* Lmk.
4. Shelly limestone.
5. Gypsiferous clays with *Ostrea elegans* Desh.
6. Siliceous shelly limestone with *Ostrea clot-beyi*.
7. Argillaceous sands with the same fauna and also abundant vertebrates: *Podocnemis antiqua* Andr., *Tomistoma africanum* Andr., *Moeritherium lyonsi* Andr., *M. gracile* Andr., *Barytherium grave* Andr., *Eosiren libyca* Andr. and *Zeuglodon osiris* Dames.
8. Limestones and clay with *Ostrea clot-beyi* Bell., etc.
9. Clay and sands with *Moeritherium lyonsi* Andr., and *Tomistoma africanum* Andr.
10. Sands and limestones containing the same fauna of molluscs and vertebrate remains.

Near Cairo, at Gebel Mokattam, the Lower Bartonian is indicated by *Nummulites contortus* and *N. striatus* and a rich mollusc

fauna. Fish are abundant, but other vertebrates are absent from the Upper Bartonian.

Oligocene. The Oligocene is represented by the fluvio-marine series of Fayoum deposited above the Qasr-el-Sagha Series and forming the final zone of sedimentation in this depression. The maximum thickness is 250 m., near Ouidan Faras. There are relatively few molluscs: *Lucina pharaonis* Bell., *Tellina lepsiusi* M.-E., *Natica crassatina* Desh., *Turritella pharaonica* Cossm. and *Ficula mayer-eymari* Blanck. By contrast the vertebrate fauna is very rich and well-known (Andrews 1906):

Chelonians: *Podocnemis fayumensis* Andr., *Testudo isis* Andr., etc.
Crocodiles: *Tomistoma gavialoides* Andr., *Crocodylus megarhinus* Andr.

Birds: *Eremopezus eocoenus* Andr. (a ratite).

Mammals: *Provampyrus orientalis* Schloss., *Sagatherium magnum* Andr., *Moeritherium lyonsi* Andr., *M. beadnelli* Andr., *Palaeomastodon wentoni* Andr., *P. parvus* Andr., *P. minor* Andr., *Tetrabelodon* sp., *Arsinoitherium zitteli* Bead., *A. andrewsi* Lank., *Brachyodus andrewsi* Schmidt, *Parapithecus fraasi* Schloss., *Moeripithecus markgrafi* Schloss., *Propliopithecus haeckeli* Schloss.

Undoubted marine facies are rare. One can mention the siliceous deposits from Gebel Khasbab, west of the Gizeh Pyramids and especially those at Borg-el-Arab, south of the western end of Lake Mariout, in the north of the Libyan Desert. There, the limestones are fossiliferous and contain *Nummulites* cf. *intermedius* d'Arch. and lepidocyclines (*L.* cf. *dilatata* Mich.) (Cuvillier 1938a). This is the classic fauna of the neighbouring regions, Libya in the west and Syria in the east.

6. The Neogene

Lower Miocene. The Lower Miocene is found in the whole of the Mediterranean region. It reaches 200 m. in thickness in the Moghara Oasis (150 km. west of Cairo).

Marine fossils are not very numerous. Cuvillier (1938b) has described two good groups of beds: Gebel Chebrouet and Gebel Aouébed (Cairo and Suez).

The first includes a limestone with *Miogypsina irregularis* Mich., amphistegines, lithothamnions, *Pseudarbacina fraasi* Fourtau, *Pericosmus latus* Ag., *Clypeaster* cf. *intermedius* Desm. and pectens of

the Burdigalian. The Gebel Aouébed limestones also contain miogypsinas, *Ostrea plicatula* Gm., *O. frondosa* Serr. var. *rohlfsi* Fuchs.

The fluvio-marine deposits of the Moghara Oasis contain vertebrate bones: chelonians and crocodiles, various mammals including an *Aceratherium* and a *Brachyodus* (essentially Aquitanian genera).

West of Cairo, in the Fayoum Depression, there is a basalt flow younger than the Burdigalian and older than the Vindobonian.

Middle Miocene (Vindobonian). The Vindobonian follows directly on the Burdigalian in many places. It contains a certain number of fossils, *Ostrea gingensis* Schloth., *Aturia aturi* and *Pecten submalvinæ* Bl.

In the eastern region around Suez and along the coast of the Red Sea, the Vindobonian extends as far as Ras Banas and the Tropic of Cancer. The facies changes to 600 m. of oil-bearing dolomites and gypsiferous marls. The exact age of this formation is disputed and it is possible that it extends up into the Upper Miocene (Deperet and Fourtau 1900; Macfadyen 1930).

South of Suez, in the Gebel el Galala, Sadek (1926) found a classical Vindobonian fauna: *Pecten submalvinæ* Blanck., *P. cristatocostatus* Sacco, *Phacoides columbella* Lmk., *Corbula carinata* Duj., *Turritella terebralis* Lmk., *Cerithium bronni* Part. and *Ostrea crassissima* Lmk.

Upper Miocene. The marine Upper Miocene, the Sahelian, is regressive.

Pliocene. The transgressive Pliocene is marked by beds containing *Ostrea cucullata* Born. It is recognised on the margin of the Nile delta and formed a narrow gulf in the present valley of the Nile little further than Biba and El Facher (Cuvillier 1926, 1935-1936).

The Plaisancian includes the wadi Natron Sandstones containing *Gastrana fragilis*, *Cerithium conicum* and also the sands at Gebel Chelloul (south of the pyramids) with *Clypeaster aegyptiacus*, *Pecten scabrellus* and *P. benedictus*.

Near El Saff the Astian contains a very similar fauna with *Ostrea cucullata* in addition. Is this perhaps only a different facies?

In the Upper Pliocene new epeirogenic movements caused an uplift. In the Gulf of Suez area this is marked by the uplift of horsts between E.-W. and N.-S. fractures, sometimes along ancient NW.-SE. faults.

7. *The Quaternary*

The Egyptian Quaternary, studied in the Nile terraces, includes the lacustrine deposits of Kharga (south-west of Abydos) and Fayoum and is identical to that of East Africa (Arambourg 1947; Bovier-Lapierre 1925; Sandford and Arkell 1934, Caton-Thompson and Gardener 1932; Gardener 1935; Huzayyin 1941; Alimen 1955).

Fluviatile deposits around Cairo are attributed to the Villafranchian (Kaguerian Pluvial); these have yielded a very primitive stone industry and the remains of a brevirostrate mastodon: *Anancus osiris* Arambourg.

The 30 m. terrace of the Nile Valley contains a Chellian Industry *in situ* with an Old Acheulian. The 15 m. terrace contains Old and Middle Acheulian while the 9 m. terrace has Upper Acheulian on the surface. The Fayoum and Kharga Lakes have been subjected to some curious variations in level so that a succession of pluvial and interpluvial or arid phases is found.

2. SUDAN

The Republic of the Sudan is situated south of Egypt and extends to Ethiopia in the south and Chad to the west. References include Andrew (1948) and Delany (1952, 1955). The first geological surveys were undertaken by Rüsseger and then by Schweinfurth. A Geological Survey was created in 1905 by the British.

1. *Pre-Cambrian*

An important reference is Ruxton (1956).

The Pre-Cambrian basement outcrops over a very wide area in the Sudan, extending from the northern zone known in Egypt. Workers have distinguished three phases whose relationships are not always very clear nor comparable from north to south.

Lower Pre-Cambrian or Primitive System: this includes the oldest and most metamorphosed rocks, essentially the granite-gneiss of the north, mica-schists and schists which have all been intruded by granites and dolerite dykes. This should be equivalent to the Dahomeyan-Suggarian. It passes into the Western Nile System, west of the Nile.

Middle Pre-Cambrian or Nafirdeib Series: this is unconformable on the Primitive System and metamorphosed. It includes gneisses,

quartzites, marbles, schists and green andesite flows. The series is traversed by granites, gabbros, norites and auriferous quartz veins. The thickness exceeds 3,000 m. in the type region between Khor Nafirdeib and To-Olak ($36^{\circ} 24' - 20^{\circ} 30'$).

Upper Pre-Cambrian or Awat Series: 1,600 m. of lavas (from andesites to rhyolites), argillites and conglomerates, intruded by two different granites. This succession is comparable to that of Hammamat in Egypt; it is neither folded nor metamorphosed but cut by granites and syenites with sodic minerals, frequently in ring structures.

2. Nubian Sandstone

In all the northern zone and throughout the north-west the Pre-Cambrian basement is covered by the Nubian Sandstone. This has been particularly studied by Sandford, Andrew and Delany.

There are lower unfossiliferous sandstones of Palaeozoic age (except at Djebel Ouenat, treated with Libya, and which, following the 1 : 5,000,000 International Geological Map, seems to be divided between Libya, Egypt and the Sudan). Delany (1952) discovered a marine intercalation at Kh. Langeb in the north-east. This *could* be Jurassic, of unknown origin, since the system is not known in this region but only in Sinaï, in the northern part of the Red Sea zone and in Ethiopia.

The upper fossiliferous succession contains a quantity of silicified wood usually determined as *Dadoxylon* and attributed to the Lower Cretaceous.

The Djebel Dirra Sandstones near El Fasher (in the Darfour) have yielded a flora with *Weichselia reticulata*, *Frenelopsis hoheneggeri* and *Dadoxylon aegyptiacum* (Edwards 1926). South of the 10° latitude the Nubian Sandstone is called the Yrol Beds.

The Nubian Sandstone does not end with the Cretaceous; it continues into the Eocene as shown by the discovery of annonacean wood at Djebel Sheba in the western Darfour.

3. Hudi Cherts and Laterites

The north-east of the Sudan was covered by a large lake which deposited siliceous muds on the Nubian Sandstone. These "Hudi Cherts" contain gastropods which Cox (1933) considered as Oligocene: *Pseudoceratodes irregularis* Blankenhorn, *P. rex* Cox, *Lanistes grabhami* Cox, *Achatina hudiensis* Cox and *Planorbis siliceus*

Cox. They are often overlain by 12 to 15 m. of sands, then by an important ferruginous duricrust which seems to mark a topographic surface probably of end Oligocene age.

4. Volcanic Activity

From place to place the lateritic duricrust is covered by basalt flows. Some fossiliferous horizons have been discovered between the basalt flows; these contain gastropods, freshwater fish and fragments of tortoises of indefinite age. In this group are basalt flows which are contemporaneous with those of Ethiopia: Miocene, Pliocene and Pleistocene. Certain craters such as that of the Jebel Marra are very well preserved; this one is 5 km. in diameter and contains two lakes.

5. Quaternary Deposits

Borings have shown that in certain places the depressions in the ancient basement have been covered by 250 m. of alluvium. A varied fauna has been discovered there: *Hippopotamus amnectens* Morton, *Hylochoerus grabhami* Hopwood, *Elephas meridionalis* (?) (reported by Joleaud, 1933, in the Villafranchian of Khartoum), *Thyromys arkei* Bate and *Hemioiceras singae* Bate.

Study of the Nile Valley has shown that the second cataract did not exist at the end of the Acheulian, which agrees well with what is known of the fractures of the Rift Valleys.

REFERENCES

- ALIMEN, H., 1955. *Préhistoire de l'Afrique*. Paris.
 ANDREW, G., 1948. Geology of the Sudan in *Agriculture in the Sudan*, pp. 84-128.
 ANDREWS, C. W., 1906. *A descriptive catalogue of the Tertiary Vertebrata of the Fayum (Egypt)*. 1 vol.
 ARAMBOURG, C., 1947. Sur le gisement d'*Anancus osiris*. *C.R. Soc. Géol. Fr.*, pp. 165-166.
 AWAD, G. H., 1945. *Bull. Inst. Egypt*, **28**.
 BARTHOUX, J. and P.-H. FRITEL, 1925. Flore crétacée des Grès de Nubie. *Mém. Inst. Egypte*, **7**, 2, 73-119.
 BOVIER-LAPIERRE, P., 1925. Le Paléolithique stratifié des environs du Caire. *L'Anthropologie*, **35**, 37-46.
 CARPENTIER, A. and I. FARAG, 1948a. Sur une flore probablement rhétienne à El Galala El Bahariya (rive occidentale du Golfe de Suez, Egypte). *C.R. Ac. Sc.*, **226**, 686-688.
 ——— 1948b. *Bull. Soc. Géol. Fr.*, **18**, 551-563.

- CATON-THOMPSON, G. and E. W. GARDENER, 1932. The prehistoric geography of Kharga Oasis. *Geog. J.*, **80**, 369-409.
- COSSMANN, H. and H. DOUVILLÉ, 1925. Le Callovien dans le massif du Moghara. *Bull. Soc. Géol. Fr.*, **25**, 302-328.
- COX, L. R., 1933. A lower Tertiary siliceous rock from the Anglo-Egyptian Sudan. *Bull. Inst. Egypt*, **15**, 315-348.
- CUVILLIER, J., 1926. Le Pliocène au Nord des Pyramides de Guizeh. *Bull. Inst. Egypt*, **8**, 255-256.
- 1930. Revision du Nummulitique égyptien. *Mem. Inst. Egypt*, **16**.
- 1933a. Sur la présence de l'*Orbitolites complanatus* Lmk. dans les couches de passage de l'Éocène moyen à l'Éocène supérieur en Égypte. *C.R. Ac. Sc.*, **197**, 931.
- 1933b. Nouvelle contribution à la paléontologie du Nummulitique égyptien. *Bull. Inst. Egypt*, **22**.
- 1934. Les "Esna Shales" et leur véritable signification stratigraphique. *Bull. Inst. Egypt*, **16**, 133-137.
- 1935. Étude complémentaire. *Bull. Inst. Egypt*, **28**.
- 1935-1936. Sur la présence du Pliocène marin à l'Est d'El Saff (Haute-Égypte). *Bull. Inst. Egypt*, **18**, 151-155.
- 1937. Présence du Carbonifère marin dans l'ouadi Abou Darag (désert arabe). *C.R. Ac. Sc.*, **204**, 1834.
- 1938a. Découverte de Lépidocyclines dans l'Oligocène d'Égypte. *C.R. Ac. Sc.*, **206**, 685.
- 1938b. Présence de Miogypsines dans le Miocène d'Égypte. *C.R. Ac. Sc.*, **206**, 1035.
- 1949. Présence du Paléocène en Haute-Égypte. *C.R. Soc. Géol. Fr.*, 268-270.
- DELANY, F., 1952. Recent contributions to the geology of Anglo-Egyptian Sudan. *C.R. 19th Int. Geol. Congr.*, Algiers, **20**, 11-18.
- 1955. Ring Structures in the Northern Sudan. *Eologiae Geol. Helv.*, **48**, 133-148.
- *Lexique stratigraphique international*. Vol. Afrique. Fasc. Sudan. (In the press.)
- DEPERET, C. and R. FOURTAU, 1900. Sur les terrains néogènes de la Basse-Égypte et de l'isthme de Suez. *C.R. Ac. Sc.*, **131**, 401-403.
- DONCIEUX, L. and J. CUVILLIER, 1935. Les foraminifères du Lutétien inférieur dans le Sud du désert arabe. *C.R. Ac. Sc.*, **200**, 1873.
- DOUVILLÉ, H., 1916. Les terrains secondaires dans le massif du Moghara, à l'Est de l'isthme de Suez, d'après les explorations de M. C. Barthoux. *Mém. Ac. Sc.*, **54**.
- EDWARDS, W. N., 1926. Fossil plants from the Nubian Sandstones of Eastern Darfur. *Q.J.G.S.*, **82**, 94-100.
- EICHER, D. B., 1946. Conodonts from the Triassic of Sinaï. *Bull. Am. Ass. Pet. Geol.*, **30**, 613-616.
- FARAG, I., 1948. Deux nouveaux gisements de Bathonien fossilifère sur la rive occidentale du golfe de Suez en Égypte. *C.R. Soc. Géol. Fr.*, pp. 109-111.
- 1949. Un nouveau gisement de Jurassique au Gebel El Barqua (massif de Moghara). *C.R. Soc. Géol. Fr.*, pp. 30-32.

- FOURTAU, R., 1914 and 1917. Catalogue des Invertébrés fossiles. Terrains crétacés. I Echinoids, II Lamellibranchs. *Geol. Surv. Egypt, Paleont.* 2 & 3.
- GARDNER, E. W., 1935. The Pleistocene Fauna and Flora of Kharga Oasis. *Q.J.G.S.*, **91**, 479-515.
- GRECO, B., 1915. Fauna cretacea dell'Egitto. *Palaeontogr. Italica*, **21**, 189-231.
- 1916. *Ibid.*, **22**, 103-169.
- 1917. *Ibid.*, **23**, 93-161.
- HUME, W. F., 1925-1939. *Geology of Egypt*. 4 vols.
- HUZAYYIN, S. A. S., 1941. The place of Egypt in Prehistory. *Mém. Inst. Egypte*, **43**, 474.
- JONGMANS, W. J. and S. VAN DER HEIDE, 1955. Flore et faune du Carbonifère inférieur de l'Egypte. *Meddel. Geol. Stichting*, **8**, 59-75.
- MACFADYEN, W. A., 1930. Miocene foraminifera from the clysmic area of Egypt and Sinai. *Mem. Geol. Surv. Egypt*.
- RUXTON, B. P., 1956. The major Rock Groups of the Northern Red Sea Hills, Sudan. *Geol. Mag.*, **93**, 314-330.
- SADEK, H., 1926. The geography and geology of the district between Gebel Ataq and El Galala El Bahariya (Gulf of Suez). *Geol. Surv. Egypt*, **40**.
- SANDFORD, K. S. and W. J. ARKELL, 1934. Palaeolithic Man and the Nile Valley in Upper and Middle Egypt. *Publ. Univ. Chicago Oriental Inst.*, **18**.
- SCHÜRMANN, H. M. E., 1957. The Precambrian of Egypt, East of the River Nile. *Geol. en Mijnbouw*, **19**, 165-171.
- STROMER, E., 1914. Die Topographie und Geologie der Strecke Gharag. Baharije nebst Ausführungen über die geologische Geschichte Aegyptens. *Abh. k. bayer. Akad. Wiss.*, **26**, 3-78.
- 1917-1936. Ergebnisse der Forschungsreisen Prof. Stromer in den Wüsten Aegyptens. Wirbeltier-Reste des Baharije-Stufe (Unterstes Cenoman). *Ibid.*

CHAPTER XVIII

ARABIA

Geographically and geologically the Arabian peninsula belongs to Africa and not to Asia. It forms exactly the north-eastern part of Africa and is separated from Africa by the Persian Gulf and all the sedimentary zone which extends from the foot of the Zagros mountains to Turkey. There existed in fact a Pre-Cambrian Arabo-Nubian shield which is visible in eastern Egypt, the Sudan and Saudi Arabia. It formed the promontory of Africa bounded by the Tethys Sea and it was only recently, in the Tertiary and the Quaternary, that this shield was uplifted, fractured and broken in two by the Red Sea Trough.

Although the geology of the Near Eastern states is hardly part of a book dedicated to the study of Africa it is necessary to mention Saudi Arabia to show how Africa is bounded to the north-east (Lamare 1936; Karpoff 1957).

1. PRE-CAMBRIAN

The Pre-Cambrian outcrops over nearly 800,000 sq. km. in the west of Arabia on the borders of the Red Sea. This is the eastern part of the Arabo-Nubian Shield. Karpoff (1957) has distinguished two successions separated by an important unconformity: the Medina Series and the Wadi Fatima Series.

Medina Series. Nearly all the rocks of the Medina Series show a metamorphism from chlorite schists to gneiss and migmatites. The base of the succession is unknown. It begins with dark lavas generally andesitic, which are 7,000 m. thick east of Ruwaydah. Above lie 13,000 m. of mica-schists, quartzites and some marbles, gneiss and migmatites. The succession, folded and intruded by granites, is more than 20,000 m. thick and resembles the Pharusian of the Sahara and the Birrimian of West Africa.

Wadi Fatima Series. The type succession outcrops for 35 km. on the right bank of the Wadi Fatima between the Bahrah and Jumoum Oases. It is strongly unconformable on the preceding succession with a conglomerate and red arkoses at the base. These are overlain by green lavas, shales and numerous beds of stromato-

lite limestones and finally by further lava flows. This succession has not been metamorphosed. Karpoff compares the Wadi Fatima Series to that of the Hammamat in Egypt, the Awat Series in the Sudan and the Nigritian of the Sahara.

2. THE SEDIMENTARY COVER

That part of the sedimentary cover which has not been removed by erosion forms a succession of arcuate areoles around the shield.

Cambro-Ordovician Sandstones

The eroded Pre-Cambrian basement is covered by a succession of sandstones. The basal lower sandstones, probably continental, pass towards the north into the marine Cambrian of Jordan. Above lie sandstones with *Tigillites* and *Bilobites* which are probably Ordovician and of marine origin.

Silurian Shales with Graptolites

The *Tigillites* sandstones are overlain by graptolitic shales, occasionally bituminous. First discovered about 60 km. ENE. of Hail, they have since been found by Blanckenhorn at Sahr el Ghul and by the geologists of ARAMCO.

Devonian, Carboniferous and Permian

The Lower Devonian is represented by brachiopod limestones in the region of Al Djauf. The Carboniferous is unknown. The Permian should be represented by the impure limestones with gypsum beds of Rhein, SW. of Riyadh.

Trias

A succession of 600 m. of shales and sandstones overlies the Permian and is exposed on the ancient basement. At first the Trias is represented by continental beds with silicified wood and reptiles. Above follows the Muschelkalk with *Protachyceras* (Arkell 1956), exposed near Buraida.

Lias

The continental Lias includes lignite beds containing the debris of conifers, especially *Brachyphyllum multistemum* Boureau and

B. karpoffi Boureau, found in the deep boring at Riyadh. This is the equivalent of the Liassic flora of the Yemen discovered by Lamare. A new marine transgression took place in the Lower Toarcian, with dolomites and limestones containing *Bouleiceras* sp., *Protogrammoceras madagascariense* Thév., *Spiriferina* sp., etc. This transgression came from the east and occupied a large gulf spread over part of eastern Arabia. The Upper Toarcian includes limestones with *Hildaites sanderi* Ark., *Nejdia bramkampfi* Ark., and *Shakraceras loeve* Basse. The succession ends with red continental sandstones.

Middle and Upper Jurassic

This marine Jurassic succession is predominately marly in the lower part and calcareous in the upper part, which underlies the town of Riyadh. A Callovian horizon with *Erymnoceras* is found at the foot of the Djebel Tuwaiq Cliff, 200 m. high and 900 km. long. A zone with *Perisphinctes* leads into the Lower Kimmeridgian. The calcareous Portlandian with *Terebratula subsella* Leym. ends with gypsiferous marls, 80 m. of anhydrite and another bed of marine limestone with oysters and corals, forming the Hith Cliff.

Cretaceous

The "Continental intercalaire" or the "Wasia Formation" is 300 m. thick. It extends a great distance, into Iraq and Jordan in the north and into the Dhofar and Hadramaout in the east and south-east. It is found in the Yemen together with the Taouilah Series (Lamare).

The Upper Cretaceous, the Maestrichtian, deposited from seas coming from the Mediterranean, is transgressive on the basement and further to the south. Karpoff has discovered limestones with *Venericardia ameliae* Person and *Corbula striatuloides* Forbes at the Asfan Col not far from Djeddah and Mecca, i.e. at the latitude of Wadi Haifa (northern Sudan). The Maestrichtian Aruma Formation is found east of Riyadh and disappears beneath the Tertiary of the Persian gulf. Clearly the Maestrichtian transgression invaded the Arabo-Nubian Shield over a wide area.

Tertiary

To the east of the Aruma Plateau extends an aureole of Eocene limestones and marls (Sander 1952) covered by marine Miocene.

The marine Neogene poses problems because it has been des-

cribed in the islands of Kamaran and Farsan of the southern Red Sea. Here there is rather doubtful Miocene (with *Operculina complanata* Deufr. and *Amphistegina lessonii* d'Orb) covered by Plio-Pleistocene gypsum beds (Macfadyen, Cox and Brighton 1930). Perhaps there are salt domes here? Marine Miocene has likewise been described from the Eritrean coast and in the Dahlac Islands, but Dainelli considers this to be Plio-Pleistocene. However, Montanaro Gallitelli confirms the presence of Miocene north of Massaouah. This would imply that the Red Sea Trough dates from the Miocene—an age recognised for the grabens of the Rift Valley. Nevertheless, and as far as is known, it was in the Upper Pliocene that the Red Sea took shape. The Suez isthmus persisted, allowing the passage of the asiatic land faunas. In the Pliocene numerous volcanoes were active in Saudi Arabia, erupting basalts which have developed a grey patina.

Quaternary

During the Pleistocene the faults were rejuvenated and the Red Sea Graben took on its present form. The Quaternary beaches, rich in corals, have been deformed, faulted and uplifted. Nesteroff (1955) has been able to follow an abrupt submarine cliff of 500 m. for 40 km. from the west of Abulat Island to the coast, where it continues as a large fault visible for 140 km. to the south of Djeddah, fracturing and upturning the Quaternary of the coastal plain. From isotopic analyses of carbon from the uplifted coral reefs of the Arabian coast the last important movements are dated at about 35,000 years ago, which closely corresponds to what we know of the latest movements of North, East and Central Africa.

It was also at some time in the Pleistocene that the last volcanoes and basaltic flows appeared. There are no longer any active volcanoes there but there are small fresh craters grouped on the faults (near Medina for example). According to tradition there was an eruption in the year 1256 near Medina. Also Karpoff has recorded thermal springs south of Djeddah.

REFERENCES

- ARKELL, W. J., 1956. *Jurassic geology of the world*. Edinburgh (Oliver and Boyd).
KARPOFF, R., 1957. Esquisse générale de l'Arabie séoudite. *Bull. Soc. Géol. Fr.*, 7, 653-697.

LAMARE, P., 1936. *Structure géologique de l'Arabie*. Paris.

MACFADYEN, W. A., L. R. COX and A. G. BRIGHTON, 1930. The Geology of the Farsan Islands, Red Sea. *Geol. Mag.*, **67**, 310-315.

—— ——— 1931. *Ibid.*, **68**, 1 and 323.

NESTEROFF, W. D., 1955. Résultats scientifiques de la campagne de la "Calypso" en Mer Rouge (1951-1952) Paris, (Masson ed.).

SANDER, R., 1952. La stratigraphie de l'Éocène. *Thesis, Paris*.

CHAPTER XIX

SENEGAL

1. PRE-CAMBRIAN

The Pre-Cambrian is represented in the east of Senegal at the foot of the Palaeozoic cliffs. It disappears rapidly to the west beneath the Cretaceous, Tertiary and Quaternary sediments.

Lower Pre-Cambrian or Dahomeyan. This seems to be represented by the Thiagnaf Mica-schists on the right bank of Senegal River. There mica-schists and gneisses appear in a window in the Bakel Quartzites.

Middle Pre-Cambrian or Birrimian. Light-coloured Bakel muscovitic quartzites are unconformable on the Thiagnaf Mica-schists. This is the opinion of Nicklès (1946), Roques (1948) and Renaud (1958). On the other hand, Bense and Delpy believe that the quartzites are considerably more recent and probably Palaeozoic.

2. INFRA-CAMBRIAN (OR FALEMIAN)

The Falemian, the type of which is found in the Falémé Valley, was defined in eastern Senegal by Jacquet and Nicklès (1943). The position of this group of shales, sandstones and jaspers has been long disputed. Renaud (1958), in a memoir on the group, insisted that the name Falemian should be reserved for the formations in the Falémé Valley and their extension into Mauritania. The relevant rocks are sandstones, shales and phthanites situated immediately below the Cambrian tillite. The succession thickens and becomes folded westwards. Many geologists think now that the Falemian represents the base of the Palaeozoic cycle and which includes the Infra-Cambrian, Cambrian and probably also the Ordovician sandstones.

3. PALAEOZOIC

The Palaeozoic of Senegal is still little known. However, above the basal Cambrian tillite come shales, pelites and limestones followed by Ordovician sandstones which continue into the Mali

Plateaux. The Palaeozoic outcrop ends in a west facing cliff dominating the lower ground which was covered by the Cretaceous and Tertiary seas of the Gulf of Senegal.

4. CRETACEOUS

The Cretaceous sea invaded the Senegalese and Mauritanian coasts, forming a gulf bounded to the east by the Palaeozoic cliffs. This sedimentary basin has been folded and fractured. The only outcrops are found in the Dakar region. The total thickness of the Cretaceous and Tertiary sediments is unknown.

The Tiénaba borehole, in the Thiès region, descended to 3,000 m. without reaching the crystalline basement. From 1,530 to 2,900 m. it traversed clays, sandstones and dolomitic limestones. From 1,530 to 1,330 m. buff sandstones contained a small fauna considered to be Turonian (?). Therefore there are locally 1,500 m. of sediments older than the Senonian (Maugis 1955).

The Lower Senonian has been defined by an ostracod fauna found in plastic clay deposits between 870 and 1,330 m. in the Tiénaba boring.

Above comes the Maestrichtian, well known from the outcrop at the base of the Popenguine Cliff (Tessier 1946; Sornay and Tessier 1949; Collignon 1949; Tessier 1950) and from boreholes. The succession from below is as follows:

1. Grey marls with sandy layers containing *Siphogenerinoides* cf. *ewaldi* (160 m.).
2. Grey clays and marls with *Gümbelina globosa* and *G. costulata*.
3. Red sandstones or sands of Popenguine and Cap de Naze with *Roudaireia drui* M. Ch., *Cardita* (*Venericardia*) *ameliae* Peron, *Tessieria senegalensis* Collignon, *Sphenodiscus corroyi* Sornay and Tessier, *Daradiceras gignouxii* S. and T. (2 to 25 m.).
4. Multicoloured papery, sandy shales of Cap de Naze with *Haplophragmoides excavata* (6 m.).

The upper beds, the impure N'Dayane Limestones, are attributed to the terminal Cretaceous by Tessier. This succession, which contains traces of oil, becomes more sandy to the east and reaches 450 m. in thickness in the Tiénaba borehole (from 405 to

870 m.). Also at Dakar is the outcrop of the Madelaine Marls, Hospital Clays and perhaps the Prison Marls. Many years ago, two echinoids were found here: *Physaster inflatus* Desor and *Stegaster mairei* Lambert.

At the end of the Cretaceous uplift took place in the N'Dias region, sedimentation was generally sandy and enriched with lignite deposits. This final emergence was accompanied by volcanic activity with deposits of tuff and ash intercalated in the Maestrichtian marls of the Anse Bernard Cliff as at Dakar.

5. EOCENE

Known since 1905 through the publications of Chautard, St. Meunier, Chudeau and Douvillé, the Eocene of Senegal has been more recently studied by Jacquet, Nicklès, Gorodiski and Tessier. The Eocene extends over a wide area in Senegal, penetrating deeply into the interior where the sea formed a large gulf.

Palaeocene. Near Popenguine Tessier discovered a Palaeocene horizon, very probably Montian, inserted between the Upper Cretaceous (which it covers with a slight unconformity) and the fossiliferous Ypresian. The Montian fauna of Popenguine includes a certain number of Palaeocene species found in Togo (*Rostellaria* (*Cyclomolops*) *subhumerosa* Opp., etc., and *Clinuropsis diderrichi* Vincent of the Palaeocene of Dahomey, Landana and Trinidad. It also includes certain new species resembling those of Mons and the Antilles (*Turritella* (*Torquesia*) *herminae* B. and C. nov. var., *Pseudoliva canaliculata* B. and C. and *Eocypraea bartlettiana* Maury, nov. var.).

This is an important discovery for interpreting the Eocene succession of West Africa. The Montian extends quite far to the east; it is found at the foot of the Thiès Cliff.

Passage from the Palaeocene to the Ypresian (Cizancourt and Cuvillier 1954; Abrard and Gorodiski 1955). In a low horizon of the Lower Eocene, which is still a little imprecisely defined (Lower Ypresian?), corded nummulites are found: *Nummulites* (*Operculinoides*) *bermudezi* Palmer and *N.* (*Ranikhotalia*) *sahnii-savitriæ* Davies, together with operculinas.

Ypresian. The Ypresian is formed of marls, clays and phosphatic limestones. It is clearly shown in the Thiès Cliff and the Popenguine area. It is found in wells in the Djolof, Baol and Sine-Saloum and is very fossiliferous with fine echinoids (*Echinopsis*

friryi Lamb., *Schizaster douvillei* *Echinolampas anceps* Lambert, *E. macrostoma* Lamb., *E. cuvillieri* Lamb., *E. jacqueti* Lamb., *Amblypygus dilatatus*), pelecypods (*Cardita sererina*, *Lucina thebaica*, *Ostrea multicostata*, *Meretrix nitidula* etc.), gastropods (*Eovasum senegalense* Tessier, *Gisortia brevis* Douv., *Heligmotenia molli* Douv., etc.) and nautiloids.

According to Tessier the distinction of several zones and the boundary between the Ypresian and the Lutetian are still uncertain. The Ypresian contains phosphatic beds. The sea retreated at the end of the Lower Eocene.

Middle Eocene. The Lutetian was recognised for the first time by Vasseur in 1902 in the limestones of the Saint-Louis-du-Senegal wells, the first section of which St. Meunier gave in 1904. The Lower Lutetian is characterised by numerous *Echinolampas* and phosphatic beds in the region of Thiès. A part of the phosphates has been lateritised (phosphatic lateroids = aluminous phosphates) (Tessier 1950; Latrilhe 1959; Abrard 1956a; Abrard and Gorodiski 1959; Roman and Gorodiski 1959).

The Upper Lutetian is characterised by a transgression and an abundance of nummulites: *Nummulites heeri* de la Harpe, *N. murchisoni* Brunner, *N. gizehensis* var. *vasseuri* Douvillé, *N. curvispira* var. *vasseuri* Douvillé. There also are discocyclinas with a central umbilical pustule: *Discocyclina senegalensis* Abrard, and a rich fauna of molluscs.

Towards the north the Lutetian is found at 200 m. depth at Saint-Louis-du-Senegal and must extend as far as Port-Etienne. In the west the Lutetian has clearly been let down by faulting. After the Lutetian the sea retreated. There are no marine sediments belonging to the Upper Eocene and Oligocene.

6. MIOCENE

The Miocene has been long known at Dakar, at the end of the Cape Verde peninsula. Hubert (1922) described white limestones with lepidocyclinas, particularly *Lepidocyclina marginata*, of Aquitanian age (Hubert and Lenoble 1927). Other, red, limestones likewise contain foraminifera which could also be Miocene in age. In addition the Ziguinchor borehole has revealed Burdigalian with lepidocyclinas and Vindobonian with *Heterostegina costata* d'Orb at 350 m. (Gorodiski 1958; Abrard and Gorodiski 1959).

7. DAKAR LAVA FLOWS

Basaltic lava, 40 m. thick and defined by Chautard and Lacroix as an ankaratrite, forms Cape Manuel. The same rock is also found in Gorée Island. The Cape Manuel flow appears to have come from the WNW., as did the volcanic tuffs which enclose blocks of Miocene limestones. There are well-developed polygonal columns. The associated tuffs contain Miocene foraminifera (Lys, *in* Tessier 1952).

The volcanic activity is more recent than that of the Mamelles Volcano, 10 km. north of Dakar. This volcano has been bisected by marine erosion so that its structure is revealed. Seven successive flows of basanites and doleritic basalts have been counted. The flows, being younger than a Lower Pleistocene laterite and some sand dunes, must be geologically very recent (Gorodiski 1952).

REFERENCES

- ABRARD, R., 1956. *Discocyclina senegalensis* nov. sp. du Lutetien du Sénégal. *Bull. Soc. Géol. Fr.*, **6**, 237-241.
- and A. GORODISKI, 1955. Précisions sur l'Éocène inférieur et moyen du Sénégal d'après des sondages récents. *C.R. Soc. Géol. Fr.*, pp. 162-165.
- — 1959a. Données stratigraphiques récentes sur l'Éocène du Sénégal. *C.R. Soc. Géol. Fr.*, pp. 148-149.
- — 1959b. Présence d'une importante série miocène à Ziguinchor. (Sénégal). *C.R. Ac. Sc.*, **248**, 3458-3459.
- CIZANCOURT, DE M. and J. CUVILLIER, 1954. Les Nummulites cordelées du Sénégal. *C.R. Soc. Géol. Fr.*, pp. 130-133.
- COLLIGNON, M., 1949. *Tessieria*, nouveau genre d'Echinides du Maestrichtien du Sénégal. *Bull. Soc. Géol. Fr.*, **19**.
- GORODISKI, A., 1952. Notice explicative de la carte géologique de la presqu'île du Cap Vert.
- 1958. Miocène et indices phosphatés de Casamance (Sénégal). *C.R. Soc. Géol. Fr.*, pp. 293-297.
- HUBERT, H., 1922. Notes et géophysique sur Dakar. *Bull. Com. Et. hist. sc. A.O.F.*, pp. 8-26.
- and A. LENOBLE, 1927. Notes de géologie sur Dakar. *Ibid.*, pp. 185-224.
- JACQUET, F. and M. NICKLÈS, 1943. Notice explicative sur le Feuille Dakar-Est au 1:1,000,000. Dakar.
- LATRILHE, E., 1959. Phosphates alumineux de la région de Thiès. *Bull. Serv. Géol. Mi., Dakar*, No. 25.
- MAUGIS, P., 1955. Études de préreconnaissance pétrolière dans le bassin sédimentaire du Sénégal. *Bull. Dir. Mi. Géol., A.O.F.*, **19**, 99-128.
- NICKLÈS, M. and M. ROQUES, 1946. Sur la situation stratigraphique des quartzites de Bakel (Sénégal). *C.R. Ac. Sc.*, **222**, 1452-1454.

- RENAUD, L., 1958. Le Précambrien du Sud-Ouest de la Mauritanie et du Sénégal oriental. (Unpublished thesis, Clermont-Ferrand.)
- ROMAN, J. and A. GORODISKI, 1959. Echinides éocènes du Sénégal. *Notes Serv. Géol. Prosp. Mi., Dakar*, **3**, 91.
- ROQUES, M., 1948. Le Précambrien de l'Afrique occidentale française. *Bull. Soc. Géol. Fr.*, **18**, 589-628.
- SORNAY, J. and F. TESSIER, 1949. Ammonites nouvelles du Maestrichtien du Sénégal. *Bull. Soc. Géol. Fr.*, **19**.
- TESSIER, F., 1946. Sur l'existence d'un niveau maestrichtien au Sénégal. *C.R. Ac. Sc.*, **222**, 505-506.
- 1950a. Contribution à la stratigraphie et à la paléontologie de la partie Ouest du Sénégal (Crétacée et Tertiaire). *Bull. Dir. Mi. A.O.F.*, **14**.
- 1950b. Thesis.

ATLANTIC ISLANDS

1. THE CANARY ISLANDS

Studies in Madeira and the Canary Islands have allowed J. Bourcart (1946) to establish a succession of geological events, partly hypothetical but which tally very well with events on the continent. The succession was established for the main island in the Canaries but is valid for the others as well.

The first question, as to whether an ancient basement is present, is answered in the negative. The oldest rocks known are doleritic basalts, erupted from the sea bed. They are probably Cretaceous in age.

The islands must have emerged towards the end of the Cretaceous.

Palaeogene. Layers of aegyrine rhyolites, alternating with trachytes, rest on an eroded surface of the old basalts. Tectonic movements have folded these layers.

Lower Miocene. Resting discordantly on the Lower Tertiary volcanics comes a series of trachytes, phonolites and white tuffs.

Upper Miocene. The higher tuffs contain a marine fauna of Vindobonian age, including *Clypeaster altus*. There is evidence of an important marine transgression and submergence of the islands.

Lower Pliocene. New volcanic eruptions, submarine at first but later subaerial, gave rise to the "plateau basalts", whose different layers are separated by beds of "terra rossa", formed by the weathering of basalts between successive periods of eruption.

Upper Pliocene. Period of diastrophism. Faults and collapse structures. New volcanic eruptions.

Pleistocene. G. Denizot has recorded the presence of Tyrrhenian, with *Strombus babonius*, in sandstones overlying the plateau basalts. Above these sediments come further basaltic lava flows containing intercalations of marine sands and red earths. In the interior occur lacustrine limestones older than some Acheulo-Mousterian movements.

This succession is valid for all the islands. Among the special features of some of them, however, we note the existence of

nepheline syenites, gabbros and diorites in the succession regarded as of Lower Tertiary age, in Lanzarote and Fuertaventura. These nepheline syenites are comparable in all respects to those of the Isles de Los in Guinea. At Teneriffe, the phonolites contain enclaves of nepheline syenite.

The latest eruptions were those of Teneriffe, in 1909.

Madeira. Although Madeira is a long distance away from the Canaries, the same scheme holds good: whitish tuffs and submarine lavas, Vindobonian limestone, Pliocene basalts (with a lignite horizon), Quaternary basalts and lacustrine limestones.

2. THE CAPE VERDE ISLANDS

The Cape Verde Archipelago consists of fifteen principal islands situated 400 km. from the African coast.

Exploration began with the visits of Charles Darwin in 1844 and Charles Sainte-Claire-Deville in 1848. The geology is known through the publications of Bebiano (1932), Bourcart (1946), Friedlander (1913), Sousa Torres and Pires Soares (1946), Pires Soares (1948, 1953) and Stahlecker (1935).

In several islands travellers have described deep-seated igneous rock types, giving rise to a belief in the existence of a Pre-Cambrian basement. They can only be ballast or volcanic enclaves or, more simply, the "granites" might belong to the suite of syenites and others rocks known amongst the igneous series of end-Cretaceous or Tertiary age of the Canaries (or the Isles de Los?). L. Berthois (1950) has likewise noted the petrographic similarity of all the nepheline syenites which could be relatively recent in age. One knows that the metamorphosed limestones of Maio are regarded as Cretaceous. It is therefore almost certain that no visible Pre-Cambrian basement exists in the Cape Verde Islands, which represent a volcanic archipelago situated along the line of the large fault near the Liberian coast.

Upper Jurassic. The oldest sediments are siliceous limestones with *Aptychus* (*Lamellaptychus*) *rectecostatus* (Peters) Tranth, considered as belonging to the youngest Jurassic.

Cretaceous. The Cretaceous of Maio Island begins with the Valanginian-Hauterivian. There are 250 m. of metamorphosed limestones with a basaltic layer at the top, under the Barremian. Fossils include *Aptychus*, *Leptoceras sabaudianum* P. and de L. and *Ancyloceras*.

The Barremian is represented by bituminous marls with *Crioceras emerici* Lev., *Lytoceras subfimbriatum* d'Orb., *Heteroceras giraudi* Kilian, *Inoceramus* spp. and fish. The overlying Aptian contains *Phylloceras* cf. *guettardi* Rasp., *Parahoplites* cf. *hitzel*: Jacob, *Costidiscus reticostatus* d'Orb., etc.

The succession continues with the Post-Aptian: multi-coloured clays and beds of metamorphosed limestone (and basalts). Some of these limestones have been attributed to the Senonian because they are found in a position similar to that of the São Nicolau Marls which contain *Venericardia* aff. *libyca* Zittel and *Turritella bonei* Baily. São Nicolau also contains some Lower Cretaceous-Upper Jurassic with *Iberina* (Maync 1959).

This fine Cretaceous series indicates that the Atlantic was opened in this period. On the Mediterranean side there exist faunas similar to those in Morocco and Portugal. Towards the west one finds affinities with Central America. Marine Lower Cretaceous rocks are known to the south, in Ghana, Cameroun, Gabon and Angola.

Eocene. The Eocene is represented by marls, presumed Lutetian, in São Nicolau. These contain *Cardita catalaunensis* de Laub., *Fissurella fenauxi* Desh., *Conus dujardini* Lmk., *Ranella marginata* Gmelin and *Cardita trapezia* L.

Neogene. Between this Eocene and beds of Miocene age comes a group of volcanic beds: phonolites, trachytes and basalts (Lower Miocene).

A transgression brought deposits of the Vindobonian Sea: limestones containing foraminifera (*Amphistegina lessorii* d'Orb. and *Elphidium crispus* L.), calcareous algae (*Lithothamnium isthmi* How, *L. vauhani* How, *Lithophyllum decussatum* Ellis and Sol.). In São Nicolau the same sediments contain in addition *Clypeaster altus* Klein and *Clypeaster martini* Desmoulins.

The *Crassostrea gingenesis* Marls of San Thiago and Maio might belong to the same horizon.

Pliocene and Quaternary. The Neogene sediments are covered by a new group of basaltic flows. A series of Quaternary beaches girdles the islands up to a height of 100 metres above sea-level.

Between the basalt flows are found red fossil soils containing phragmites, tamarisks, palms, crab claws and turtle eggs (*Testudo calcarata*).

A Tyrrhenian horizon contains *Strombus babonius*, *Cerithium atratum*, *C. guinaicum*, *Columbella rustica*, *Purpura neritoides*, *Conus*

papilionaceus, *C. mercator*, *Senilia senilis*, *Ostrea cucullata* etc. Two calcareous algae of this horizon, *Lithophyllum aninae* and *Mesophyllum erubescens* do not occur at the present day in the waters of the archipelago.

The most recent deposits have been lithified and conglomerates containing fragments of brick and iron occur.

REFERENCES

- BEBIANO, B., 1932. Geologia do Arquipelago do Cabo Verde. *Comm. Serv. Géol. Portugal*, **18**, 275 pp. (Bibliography).
- BERTHOIS, L., 1950. Contribution à la connaissance lithologique de l'archipel du Cap Vert. *Publ. Junta Invest. Col.*, vol. 7.
- BOURCART, J., 1946. Géologie des Iles Atlantides. *Mem. Soc. Biogéographie*, **8**, 9-40.
- CHEVALIER, A. and R. FURON, 1935. Sur quelques dépôts tertiaires et quaternaires des îles du Cap Vert. *C.R. Ac. Sc.*, **201**, 226-227.
- FRIEDLANDER, I., 1913. *Beitrag zur Kenntniss der Kapverdischen Inseln*. 1 vol., 109 pp. (Berlin).
- MAYNC, M. W., 1959. The Foraminiferal genera *Spirocyclina* and *Iberina*. *Micropaleontology*, **5**, 66.
- PIRES SOARES, J. M., 1948. Observations géologiques sur les îles du Cap Vert. *Bull. Soc. Géol. Fr.*, **18**, 383-390.
- 1953. A proposito dos "Aptychi" da Ilha de Maio (Arquipelago de Cabo Verde). *Publ. Junta Invest. Ultramar*, 111 pp., 12 figs., 2 pl.
- SOUSA TORRES, A. and J. M. PIRES SOARES, 1946. Formacoes sedimentares do Arquipelago de Cabo Verde. *Minist. Colonias, Mem. ser. geol.*, **3**, 397 pp.
- STAHLCKER, R., 1935. Neokom auf der Kapverden-Insel Maio. *N. Jb. Miner. Geol. Pal. abt., B.*, **73**, 302-311.

CHAPTER XXI

SOUTHERN MAURITANIA AND WESTERN MALI

1. THE AOUKER

The Aouker is a large cuvette 500 km. in diameter, bordered in the north by the Tichit-Oualata-Néma Escarpment; in the west by the cliffs of Tagant and Assaba; in the south by the small hills of the Nioro region and by the Manding Plateau. Westwards (in the Hodh region) the Aouker connects with the Macina by the Nara Gap. The Aouker is a large erosion "window".

The Hodh Cliff. The cliff bounding the Hodh in the east bears the name dahar: dahar Néma, dahar Oualata. The height of this cliff is from about 100 to 150 m. with the summit reaching 350. At Néma and Oualata the "dahar" consists of 85 m. of "Cambrian" (or Infra-Cambrian) shales, pelites and jaspers overlain by 60 m. of sandstone.

In the north, from the Enji Ravine as far as Tichit, Th. Monod and F. Jacquet record Silurian graptolitic shales and Devonian sandstones, completing the Palaeozoic succession, set back a little from the Ordovician sandstones.

The Baten. The Moors give the name *baten* to the depressed zone which follows the foot of the cliffs. Heights are negligible, between 150 and 200 m. The rocks which outcrop there locally belong to the base of the Palaeozoic (shales and pelites, dolerites). Elsewhere is a cover of Quaternary fluvial and lacustrine clays.

The Central Hodh. The whole of the central zone of the Hodh is covered by clayey-sandy sediments and fossil and recent dunes which may or may not be fixed. Such dunes do not cover the Baten. The thickness of these recent formations exceeds 30 m., the usual depth of wells which never reach the rocky basement.

In the neighbourhood of Oualata (latitude 19° 22' N.), the fluvial, forest and lacustrine fauna comprises: *Limicolaria chudeaui* Germain, *Planorbis bridouxii* Bourguignat, *Bullinus (Isidora) strigosa* Marthens, *Melania tuberculata* Müller, *Caelatura lacoini* Germain and *Corbicula andoini* Germain (Germain 1931).

Limicolaria chudeaui Germain is only known in the subfossil state, very much to the north of the present habitat of limicolarias,

and in regions which are desert at the present day. It has been found as far north as 21° N., from the Borkou in the east to Tagant in the west.

Melania tuberculata Müller, abundant in the waters of tropical regions, is found subfossil by the thousand from the Aouker to beyond Chad.

All these species signify a humid period and a hydrographic system which has completely disappeared.

The Tagant Cliff. In the north-west the Aouker is bordered by the cliff of the Tagant Plateau uninterruptedly from the Mauritanian Adrar.

The Tagant has been studied by F. Jacquet and Th. Monod, and more recently by J. Delpy (1958, 1959). The cliff measures 200 m. in mean height and the edge of the plateau reaches 500 m. Delpy gives the following section, from bottom to top:

Cambrian: shales, pelites, dolomite rocks, phtanites, mauve sandstones (over 100 m.).

Ordovician:

Quartzitic sandstone (up to 100 m.), corresponding to the Chinguetti Sandstone.

Sandstone with *Tigillites* (50 m.), quartzitic sandstones (50 m.)

Silurian: Charaniya sandy argillites and graptolitic paper shales (30 m.).

Devonian: sandstone with tubular structures and *Tigillites* (20 to 30 m.), constituting the largest part of the Charaniya Plateau.

Age unknown: traces of white quartzitic sandstone with lateritised intercalations.

The Tagant Plateau has a group of north-south striking anticlines and synclines; the intensity of the folding increases westwards. One passes gradually from very gentle dips of 20° to subvertical dips and faulted structures in the west.

The Assaba Cliff, the Kiffa Plain and the Affolé Plateau. The Assaba Plateau follows that of the Tagant southwards and thus forms the western limit of the Aouker.

Cl. Bense, R. Dars and J. Sougy have established the following complete section from the low Kiffa Plain up to the summit of the Assaba Cliff (Bense 1959a):

Infra-Cambrian: Nagara psammities, visible in the south and the Kiffa Plain and constituting all the base of the Affolé Plateau in the east.

Tillite: argilo-calcareous conglomerate, visible 25 km. south of the village of Nagara, and containing numerous striated pebbles, which confirms L. Baud's opinion on its glacial origin. It is well represented in the Kankossa region, where it is about 10 m. thick.

Cambrian:

- Lower dolomite horizon (15 m.).
- Bouly jaspers and pelites (70 m.).
- Feldspathic sandstones (100 m. near Kankossa).
- Upper dolomite horizon (20 m.).
- Pelites and mauve sandstones (70 m.).
- Mauve sandstones (100 m.).

Ordovician: white sandstones, forming the top of the Assaba cliffs (from 10 to 100 m.) (equivalent of the Chinguetti Sandstone of the Adrar).

The Western Assaba Cliff and the Guidimaka. At the western foot of the Assaba Plateau lies the Guidimaka and the Sélibaby region. The Sélibaby formations are considered to be "Faleman" by L. Renaud (thesis, 1958). Cl. Bense, R. Dars and J. Sougy have established the correlation between the Palaeozoic of Kiffa-Bouly and Sélibaby (Bense 1959b). The conclusion is to be drawn that the "Faleman" formations of Sélibaby include Cambrian and Ordovician besides Infra-Cambrian. Folding becomes progressively more intense westwards, with a slight metamorphism transforming shales and pelites into sericite schists. The section is continuous and supports the comparable observation due to Bense and Delpy on the similarity of the Palaeozoic formations of Tagant and the Lefdotar succession (Faleman of Renaud) (Bense and Delpy 1958).

2. FROM NIORO TO FALÉMÉ

In the region north of Nioro (210 m.) the Cambrian emerges from the sands of the Aouker. It is composed of shales, pelites and magnesian limestones, all traversed by doleritic bodies. The contact with the Pre-Cambrian is not visible.

The limestones are particularly abundant in the neighbourhood of Sirakora (35 km. east of Nioro). Here, the visible Cambrian section is, from bottom to top, as follows: pelites and black shales, purple sandstones, hard limestones, dolerite. Important accumulations of titaniferous magnetite occur at the contact of the lime-

stones and dolerites. The limestones have locally been mineralised by copper-bearing solutions. In many localities the Cambrian is terminated by mauve sandstones.

In the neighbourhood of Néma, 30 km. ESE. of Nioro (not to be confused with the little village of Néma in the eastern Hodh), the limestones outcrop over a large area in a variety of forms: saccharoidal limestones, limestones largely recrystallised, black and fetid limestones with zoned siliceous nodules.

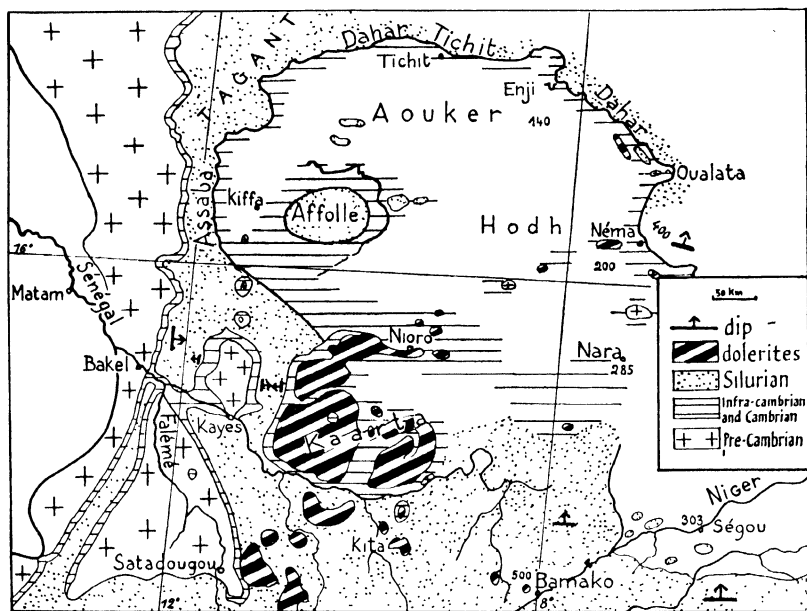


FIG. 13. Geological sketch-map of western Mali (the Cambrian and Infra-Cambrian are grouped together).

The Nioro region is separated from the valley of the Senegal and Baoulé by the Sarakollé Massif and the Kaarta, a zone of rugged relief ranging in altitude from about 200 m. in the valley depths up to 300 m. This is largely a doleritic massif where numerous sills give the impression of an enormous laccolith. The dolerites have penetrated between shaly Cambrian beds, raising them sometimes to form domes. Lower Cambrian outcrops on the border of the Kaarta and on both sides of the Baoulé Valley.

East of the village of Faréna and on Dioumi mountain appears

the Infra-Cambrian basement, represented by quartzites. Overlying this unconformably comes the "fluvio-glacial" conglomerate, greenish, dark grey or brown in colour, consisting of pebbles of quartz, quartzites and gneiss enveloped in a slightly calcareous, silico-argillaceous cement. It was here that R. Furon (in 1928) discovered for the first time this "tillite", which is recognisable over most of West Africa (Furon 1932). This glacial episode was followed by the Cambrian transgression, with deposits of shales, black phthanites, pelites or greenish cherts, red jaspers and sometimes dolomitic limestones. The latter are well seen near the railway in the neighbourhood of Toukoto, immediately south of Baoulé. Location of the Infra-Cambrian-Cambrian boundary is still the subject of dispute.

The cover of Ordovician sandstones has been removed by erosion over the whole area of this large massif. It is found again south of Baoulé, where it constitutes the western part of the Manding Plateau. Dolerites have intruded the Ordovician sandstones near Kita.

Further west, in the Senegal valley, is the classic section near Kayes, where the shaly-calcareous Cambrian directly succeeds the tillite (Baud 1933). From what I have seen and from specimens from other localities I am inclined to believe in the existence of two tillite horizons.

The Palaeozoic succession was established by R. Dars, J. Sougy and F. Tessier (Dars *et al.* 1957; Dars and Sougy 1957 (1958)). It comprises from bottom to top:

Infra-Cambrian and Cambrian (?): Koniakari Series, with tillite (containing striated pebbles), shales, jaspers, pelites and dolomitic limestones with stromatolites;

Cambrian (?): Médine Series, with glauconitic sandstones and *Tigillites*.

Ordovician: Fellou Series, with barren, cross-bedded sandstones.

3. FROM NÉMA TO BAMAKO

The post of Néma (254 m.) is built on the Cambrian shales at the foot of the Dahar, which rises above it about 100 m. and is capped by a steep cliff of sandstone.

The nearest sandstones southward are 200 km. away, north of Mourdiah, at nearly 300 m. above sea-level.

Between Néma and Mourdiah, via Nara, one crosses a depressed

zone, below 300 m., connecting the Hodh Basin with that of the Macina. At the bottom of this erosion depression the Cambrian-Infra-Cambrian shales (and dolerites) outcrop from place to place from beneath the Recent sands. Near Mourdiah the sandstones reappear, locally covered by sands of the erg du Ouagadou.

From Mourdiah to Bamako (240 km. to the south) the sandstones constitute the eastern half of the Manding Plateau, covered by laterites. The altitude rises again southwards to reach about 450 m. at Koulouba, where the plateau ends with a cliff over 100 m. high overlooking the Niger and the town of Bamako (340 m.). The sandstones extend further south, dissected only by the valley of the Niger; at a distance of 20 km. or so they come to an end and the Pre-Cambrian basement is exposed.

Dars (1957, 1960) and Dars and Sougy (1957 (1958)) have determined the stratigraphical succession of this zone, from bottom to top as follows:

1. Major unconformity on the Pre-Cambrian basement.
2. Basal Series: feldspathic sandstones (Infra-Cambrian?).
3. Tillite.
4. Nara Series: up to 1,000 m. of shales, phthanites, jaspers and dolomitic limestones with stromatolites (Cambrian? or Infra-Cambrian?).
5. Sotuba Series: up to 300 m. of purplish glauconitic sandstones with *Problematica* (Furon 1950) (Ordovician? or Cambrian?).
6. Koulouba Series: sandstones and shales placed in the Silurian.

The succession is closely comparable with those in Mali and Mauritania, with the same uncertainty about the placing of the stromatolitic limestones in the Cambrian or the Infra-Cambrian, the limit between the two being located by the tillite (which, as I have indicated above, could be taken to occur within the Infra-Cambrian (?)).¹

R. Dars has discovered north-east of Nara the "Continental

¹ After the publication of the French edition of this work, M. Zimmermann published a very interesting new interpretation. He considers that the Kayes and Nara Series represent the Cambrian resting on a tillite and that the Affolé, Koulouba, Sotuba, Koutiala and Bandiagara sandstones belong to the Infra-Cambrian (*Rep. XXI Int. Geol. Congr.*, Copenhagen 1960, part 8, pp. 26-36). (Author's note, translated.)

intercalaire" containing Jurassic *Brachyoxylon*, making up a small 20 m. cliff extending in the direction of Lake Faguibine.

4. THE MACINA

The Macina is the region north of the Niger, in the Ségou-Sansanding district. It is bordered on the north by the Palaeozoic uplands of Maharadates, near Bacikounou, dependency of Dahar Néma. The surface deposits of the Macina are laterites, sandy-clayey formations with calcareous concretions and fixed dunes.

Examination of numerous wells has confirmed that the Macina is a basin filled with sandy, clayey and sandstone formations belonging to the "Continental terminal". The thickness of these formations increases northwards to reach 75 m. at Famembougou, near Sokolo.

The sum of observations made in the Sansanding region allows the establishment of a theoretical type succession, from bottom to top as follows:

1. Recent sandy alluvium of the Niger, dune sands.
2. Laterites (over 20 m.).
3. Multi-coloured clays and diatomites (0 to 5 m.).
4. Yellow clayey sands with calcareous nodules (20 to 30 m.).
5. Yellow calcareous clay (2 m.).

These horizons are more or less incomplete in various places but constant.

The laterites assume great importance south of the Niger, between this river and the Bari. The Niger has cut its present course through them, leaving little material on its bed and in many places removing it completely. These laterites are hard and breccoid or conglomeratic, with a colour varying from beige to deep red and purple. Because of their origin they are really lateritites (Jodot 1933), having been formed from the detritus of laterites transported by the Niger and deposited in the Ségou Basin.

Two groups of altered rocks form the bulk of these lateritites: micaceous schists and dolerites, in fragments, for the schists, of several tens of millimetres.

These laterites show several varieties:

1. Uniquely formed from isolated fragments of the mother rock, cemented by a bauxitic and iron oxide gangue.
2. Composed of jumbled fragments of laterites.
3. Comprising in addition nodules of remanié lateritic material.

The whole assemblage is covered by a ferruginous crust, giving lateritites of Kirango type.

Detailed analyses by P. Jodot have revealed that the lateritites contain neither fragments of sandstone nor quartz grains. The origin of their constituents remains a mystery. Dolerites are common upstream, but the micaceous schists can only have come from the Pre-Cambrian basement. Whether the constituents of the lateritites come from the confines of Guinea and Mali or only from the region immediately upstream from Bamako, the river that transported them must have crossed the sandstones of the Manding Plateau between Bamako and Koulikoro. Perhaps the wind has been involved.

From the river to Sokolo, 120 km. to the north, the Macina Plain is composed everywhere of alluvial deposits.

North of Sokolo (293 m.) begins a large dune massif, the erg du Ouagadou. This erg, 100 km. wide and 250 km. long, extends in a NE.-SW. direction, from the outcrops of Palaeozoic sandstones north of Niafunké to the edge of the Manding Plateau at Mourdiah. It rests on ferruginous sandstones, which belong to an old erg fixed and encrusted by iron oxide at a period perhaps contemporaneous with the consolidation of the lateritites of the Ségou-Sansanding region. The maximum thickness of the erg du Ouagadou is of the order of 10 m. (altitude 300).

5. THE FOSSIL DELTA OF THE MIDDLE NIGER

In 1909 René Chudeau propounded the hypothesis that the present Niger was formed by the union of two rivers: the upper Niger or Djoliba from its sources in the Fouta Djallon to the Timbuktu region and the lower Niger from Tosaye to the sea. The upper Niger flowed into an enclosed lacustrine basin. The lower Niger, which had its source in the Adrar des Iforas, would have captured the upper Niger at the Tosaye Sill.

The Timbuktu Basin has itself posed the long-debated problem of a Quaternary sea. There are no marine sediments, but subfossil marine shells have been collected, in particular marginellas. The

problem arose whether these marginellas and other shells which accompanied them in lesser abundance came from a geological deposit or had been brought in from elsewhere. It is now certain that these shells were brought from the coast by caravans several centuries ago and that they served as currency before the introduction of cowries (*Cypraea moneta*) (Monod 1938). There has therefore never been a Quaternary sea in the Timbuktu region but only a lacustrine zone whose existence is revealed by the presence of numerous subfossil molluscs.

In contrast, the existence of an old hydrographic system, very different from that at the present day, is now proven. The middle Niger spread out widely from Ségou in a deltaic zone, well upstream from Timbuktu in the Macina Cuvette. Its effluents probably penetrated into the Hodh. The essential points of the studies and hypotheses of R. Furon (1929) have been confirmed by the topographic survey of Commandant Urvoy (1942) and by subsequent aerial photographs.

The Fossil Delta of the Macina. In the Macina the old Niger eroded the lateritite cover partly or completely in various places.

Its flow is extremely slow due to a very gentle slope: 15 m. per 250 km. downstream from Ségou.

The height of the Niger at Ségou is 300 m. Before Niafunké the river subdivides into numerous branches which rejoin at Lake Débo. One of the most important branches of the Niger is the Diaka side-channel (Marigot), which begins at Diafarabé, at 291 m. altitude, and flows towards the Débo, passing through the flood plain at 282 m. The contour lines are always convex downstream, indicating that the water currents flow a little above the general level of the plain, as is always the case in deltaic regions at the present day.

Upstream from the Diaka Marigot, between Sansanding and Ségou, one finds traces of two fossil effluents, obstructed by sands but which flowed from the Niger towards the north and north-east in a historic and proto-historic period and also have piles of ruins along the banks. Their beds are both marked by strings of pools and a notable vegetation.

The more interesting of these branches is that of Sokolo, known by the natives as the "fala de Molodo". This effluent leaves the Niger at a height of 300 m. and reaches Sokolo, 120 km. to the north, at 290 m. Near Sokolo the effluent turns eastwards, follows the southern boundary of the erg du Ouagadou, running

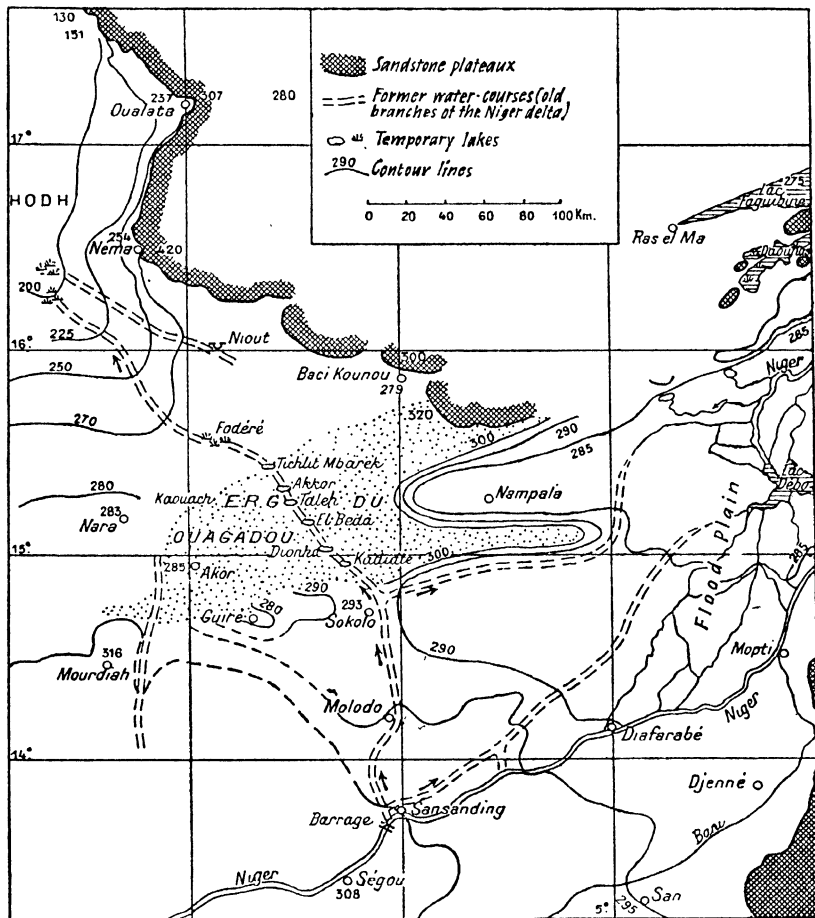


FIG. 14. The Macina and the fossil delta of the Niger.

along its raised bed, passes through Toulebambi and Boulel, diverges around the sandstone of the fossil erg and rejoins the zone of pools which reaches to the neighbourhood of Niafunké. One of these channels must have gone directly to Lake Débo.

In the neighbourhood of Sokolo, near Diébal, begins a channel which disappears rapidly northwards under the sands of the erg du Ouagadou. As all the region north and north-west of the erg is at a lower altitude than Sokolo, one is led to believe that an effluent at least of the Quaternary Niger continued into the Hodh.

The Way leading to the Hodh. North-west of Sokolo lie the dunes of the erg du Ouagadou, about 10 m. high, with hollows 5 m. deep, at the bottom of which occur a certain number of temporary pools. Further on comes the Nara Gap, in particular the large pool of Fodéré, at 274 m. above sea-level.

From the Fodéré Pool to the large Mahmoudé Pool, 150 km. to the north-west between Néma and Timbedra, one follows a depression, a true dry valley, made conspicuous by lines of pools. Urvoy's topographic survey showed successive altitudes of 270, 250, 225 and then 200 (at the Mahmoudé Pool). This large valley corresponds exactly to the Fodéré Channel, considered by Furon as an effluent of the fossil Niger.

Beyond this area topographic data are still inadequate, but they indicate very low altitudes in the north-eastern part of the Hodh: 160 and 150 in the Baten, west of Oualata.

This story of the Niger has more than just palaeogeographic interest. The effluents of the fossil Macina Delta have already been restored to life by the construction of the Diamarabougou Barrage, near Sansanding. According to Urvoy, re-excavation of the other effluents would enable water to be discharged into Lake Faguibine and allow the re-establishment of a lake in the Daounas region; a canal cut across the erg du Ouagadou, using a line of pools as much as possible, would serve to convey Niger water from Sokolo into the plains of the northern Hodh (Urvoy 1942). In addition, the "Sonni Ali Canal" has been rediscovered west of Lake Faguibine (Palausi 1958).

6. VOLCANIC ACTIVITY IN THE DAOUNAS

One of the most extraordinary discoveries has been that of recent and present-day volcanism in the Daounas (near Lake Faguibine) by Th. Monod (1958) and G. Palausi. There are basaltic lavas and microdykes injecting the fissures in lacustrine clays. That volcanism is still active is confirmed by the fire and smoke which escape through the desiccation cracks in the muds during the dry season.

REFERENCES

- BAUD, L., 1933. Le conglomérat argilo-calcaireux dans la région de Kayes et de Bafoulabé (Soudan occidental) et sa position stratigraphique. *C.R. Ac. Sc.*, 197, 172-173.

- BENSE, C., 1959a. La série stratigraphique de la région de Kiffa (Mauritanie orientale). *Bull. Soc. Géol. Fr.* (7) **1**, 128-131.
- 1959b. Sur l'identité des formations sédimentaires de la région de Kiffa et du Falémien de Sélibabi (Mauritanie). *Ibid.*, 183-186.
- and J. DELPY, 1958. A propos de la position stratigraphique du Falémien de Mauritanie. Nouvelles observations sur la coupe de Touéïjigigt. *C.R. Ac. Sc.*, **247**, 2388-2391.
- DARS, R., 1957. Découverte d'une discordance dans le Cambro-Ordovicien du Soudan occidental. *C.R. Soc. Géol. Fr.*
- 1960. Étude géologique des séries primaires et des dolérites du Soudan occidental. (Thesis, Paris.)
- and J. SOUGY, 1957 (1958). La stratigraphie du "Cambro-Ordovicien" de l'Ouest africain et ses relations avec le Précambrien. *Colloque international C.N.R.S. (Précambrien-Cambrien)*, Paris, pp. 223-237.
- J. SOUGY and F. TESSIER, 1957. Nouvelle stratigraphie des séries paléozoïques de la région de Kayes (Soudan français). *C.R. Ac. Sc.*, **244**, 2312-2314.
- DELPY, J., 1958. Esquisse structurale du bassin hercynien du Tagant (Mauritanie). *Ibid.*, **247**, 1756-1758.
- 1959. Observations sur le "Primaire" du Tagant (Mauritanie). *Bull. Soc. Géol. Fr.* (7), **1**, 123-127.
- FURON, R., 1929. L'ancien delta du Niger. *Rev. Géogr. Phys. et Géol. dynam.*, **2**, 265-274.
- 1930. Carte géologique du Soudan occidental (1/2,000,000^e). 1930. Étude géologique du Sahel soudanais. *Ibid.*, **3**, 263-292.
- 1932. La série schisto-calcaire du Soudan, son conglomérat de base et sa position stratigraphique. *C.R. Ac. Sc.*, **195**, 55-58.
- 1933a. Présentation d'une échelle stratigraphique pour les terrains paléozoïques de l'Afrique occidentale. *Ibid.*, **197**, 1055-1057.
- 1933b. Essai sur l'évolution structurale de l'Afrique occidentale. *Bull. Agence gen. Colonies*, No. 293, 1037-1066.
- GERMAIN, L., 1931. Mollusques terrestres et fluviatiles recueillis par le Lieutenant Boery à Oualata (Sahara soudanais). *Bull. Com. Et. hist. et sc. A.O.F.*, 205-217.
- JODOT, P., 1932. Remarques sur la présence de grès glauconieux aux rapides de Sotuba sur le Niger, près de Bamako (Soudan français). *Bull. Soc. Géol. Fr.* (5), **2**, 93-107.
- 1933. Étude de quelques roches latéritiques de la vallée du Niger (Soudan occ. fr.). *Ibid.* (5), **3**, 619-656.
- MONOD, Th., 1938. Sur quelques coquilles marines du Sahara et du Soudan. *Mem. Soc. Biogéogr.*, **6**, 154-178.
- 1958. Majabat al-Koubra. *Mem. Inst. Fr. Afr. Noire*, No. 52.
- PALAUZ, G., 1958. Un projet d'hydraulique fluviale soudanaise au XV^e siècle : le canal de Sonni-Ali. *Notes africaines, Dakar*, No. 78, pp. 47-49.
- URVOY, Y., 1942. Les bassins du Niger. *Mem. Inst. Afr. Noire*, No. 4.

EASTERN MALI, NIGER AND CHAD

1. THE ADRAR DES IFORAS

The Adrar des Iforas is a highly eroded crystalline massif which forms the south-western prolongation of the Hoggar. Its altitude has a mean value of 600 m. and approaches 1,000 m. at the highest point (Timaldejelen Massif). Pre-Cambrian formations of the Hoggar are exposed. They have been studied by R. Karpoff and M. Lelubre (Karpoff 1954; Lelubre 1952); also by H. Radier in the south.

The Pre-Cambrian

The *Suggarian* appears in a rectilinear, north-south horst with submeridional ranges of quartzites, marbles and amphibolites associated with foliated gneisses. The two successions of the Hoggar, of the Arechchoum and the Egéré, are found here. The most southerly outcrops of the Suggarian occur in the valley of the Iracher Sadiden ($16^{\circ} 50'$ lat. N., $1^{\circ} 20'$ long. E.).

The structure exhibits folds of Appalachian style, NNE.-SSW. in the west, N.-S. in the centre and NNW.-SSE. in the east. The folds are symmetrical and rarely overturned.

The Suggarian is cut across by several granites.

It was in the north of the Adrar des Iforas that Lelubre defined the "In Ouzal" Series, which follows that of the Hoggar, thins towards the Mali frontier and then reappears and expands as far as 60 km. south of In Tabezass. Hypersthene is common in this facies, recalling the charnockite series of India. The rocks occur in a 600 km. long N.-S. band, extending from Tanezrouft, which suggested to Lelubre "*l'existence d'accidents cassants en profondeur qui auraient pu favoriser des phénomènes de recristallisation particuliers dont le mécanisme nous échappe encore.*"

The *Pharusian* appears east and west of the Adrar des Iforas, on each side of the Suggarian horst.

The unconformity of the Lower Pharussian (Relaïdinian) on the Suggarian has been clearly observed: it marks the southerly prolongation of the large trough of the western Hoggar. One sees at

the base about 1,000 m. of andesitic volcanics, followed by schist, conglomerates, more lavas and a few calcareous lenticles. The same series of green lavas is well seen in the west, at Tessalit (Karpoff 1949), and can be followed as far as 80 km. north of Aféfi. Thus the Relaidinian of the Adrar is characterised by slightly metamorphosed rocks (schists, mica-schists, quartzites, marbles) and an abundance of green lavas.

Granitic batholiths with migmatites are seen in the Pharusian; syntectonic batholiths with calc-alkaline granites passing into granodiorites on the borders of the massif. Some post-tectonic granites form massifs cutting discordantly across the country rock (= *granites intermédiaires* of G. Rocci).

According to Karpoff (1948b) the fracture that borders the Relaidinian in the east belongs to a long line of dislocation extending 2,400 km. from the Gulf of Guinea to the gorges which separate the Mouydir from the Ahnet. M. Lelubre has discussed the question (*C.R. Ac. Sc.*, January 1949).

The *Nigritian*, the third stratigraphical unit of the Pre-Cambrian, was defined by R. Karpoff in the small massif of Timétrine, west of the Adrar des Iforas, and is found again west of Tessalit (Karpoff 1946).

The Nigritian, unconformable on the Relaidinian, comprises 2,000 m. of sandstones and conglomerates, associated with a phase of rhyolitic extrusions. C. Kilian and M. Lelubre include the Nigritian in the Pharusian *sensu lato* because, outcropping over only a few square kilometres, it does not compare with large groups outcropping over immense areas. They treat the Nigritian as Upper Pharusian. In 1954, R. Karpoff precisely stated his point of view: "*Le Nigritien est le terme le plus récent de l'Ante-cambrien du Sahara central, il s'apparente à l'Infracambrien défini par P. Pruvost. Il n'offre aucune parenté avec le Pharusien, sur lequel il est discordant et dont il renferme les granites sous forme de galets*".

The difference in interpretation is not negligible. At any rate we know that the Nigritian is represented in the western Adrar by vast rhyolitic flows unconformable on the folded Relaidinian and its granites, and by arkoses and conglomerates sometimes very thick, rich in pebbles of granite and rhyolite (Adrars Oumessa, Izelilène, Tirirar and Kidal district). The Nigritian is not metamorphic in the Timétrine, but it is slightly so in the north-west of the Adrar.

Extension towards the South-West. The Adrar des Iforas Massif

is separated from the Pre-Cambrian of the Bend of the Niger by only about 100 km. of sedimentary deposits. This is the region of the Gao Trough.

The Palaeozoic. No Palaeozoic cover is known to the north, west or south of the Adrar. In the east, in contrast, is the Tassili oua n'Ahaggar with its Cambro-Silurian sandstones, known from Timissao to 6 km. east of Tin Essako; also at Assegueffi, 12 km. east of Timeras.

2. THE BEND OF THE NIGER

The Pre-Cambrian Basement. The Lower Pre-Cambrian (Dahomeyan) is poorly defined. M. Roques (1945) would readily include in it the granitic gneiss of Bourré, which appears in a structural window underneath younger rock groups.

The Middle Pre-Cambrian (Birrimian) would be represented by the "Yatakala" Series, comprising schists, quartzites and greenstones.

The Upper Pre-Cambrian (Tarkwaian) is not known.

Palaeozoic Succession and "Nigerian". The Palaeozoic succession in the west (Koutiala-Sikasso-Bandiagara) has been perfectly worked out by G. Palausi, who distinguished, from bottom to top:

1. "Basal Sandstone", "Sikasso Sandstone" and "Tondigaria Sandstone".
2. "Bobo-Dioulasso Sandstones and Dolomitic Limestones Group", containing stromatolites, with beds of fine sandstones and jaspers (thickness about 300 m.).
3. "Toun Shales": shales and jaspers (100 m. thick in the south and 3,000 m. in the north).

These three horizons seem to correspond well with the Infra-Cambrian and Cambrian of western Mali and Mauritania.

4. "Koutiala Sandstones", often conglomeratic (150 m.) (Cambrian?).
5. "Bandiagara Sandstones", silicified, massive (600 m.) (Ordovician?).

The "Hombori-Douentza Series" appears to be only a lateral facies of this fine succession.

To the north-east, in the Gourma, the facies is much different,

and M. Defosse, G. Palausi and H. Radier (1957) had to make a long study to analyse a very complicated group which they called the "Nigerian".

At the base comes the "Ansongo Series" on the Niger, with sandstones, quartzites, conglomerates, shales and a few interstratified dolomite rocks. Elsewhere come the "Firgoun Sandstones", whose lower position with respect to the "Yassane-Labbezenga Series" has been fixed with the aid of a series of pits and trenches (Aicard, Blanchot and Sougy 1958).

The "Yassane-Labbezenga-Ydouban Series", with 10,000 m. of little metamorphosed shales and quartzites, represents a flysch facies.

The authors have given this assemblage the name "Nigerian" and consider it the equivalent of the "Horizontal Sandstones" of the Palaeozoic further to the west, including in it naturally the Infra-Cambrian or terminal Pre-Cambrian (?). This compares with the opinion of N. R. Junner, for whom the Akwapimian-Buém-Voltaian assemblage of Ghana constitutes one unit, a cycle later than the Tarkwaian-Birimian, and recalls the case of the Falmian of Mauritania and Senegal.

3. THE TILEMSI VALLEY, THE ASSELAR PLATEAU AND THE ADRAR TIGUIRIRT. THE GAO TROUGH

The Tilemsi is a large dry valley bordering the Adrar des Iforas on the west, oriented north-south and extending to the Niger at Gao. It is an old Quaternary valley, probably the upper valley of the lower Niger.

In the west the Tilemsi is overlooked by a group of cliffs showing a complete succession from the "Continental intercalaire" to the clayey sands of the "Continental terminal".

Further east, to the south of the Adrar des Iforas, is the Adrar Tiguirirt, studied by V. Pérébasine (1933) and H. Radier (1959). The general structure is the same as that of the plateaux of Asselar.

"*Continental Intercalaire.*" The clays and sandstones of the "Continental intercalaire" directly overlie the crystalline rocks on the periphery of the Adrar des Iforas (in the absence of Palaeozoic). They contain silicified wood and R. Karpoff has recorded trunks 30 m. long and 1 m. 50 wide between Tin Essako and Guelchiet.

Cenomanian-Turonian. The marine limestones of the Cenomanian-Turonian have not been described in the Adrar Tiguirirt, but they have been found in borings in the Gao Trough, in the "Sudanese Strait". In addition, lagoonal deposits often occur between the "Continental intercalaire" and the marine Maestrichtian.

Maestrichtian-Danian. The Maestrichtian transgression is marked by glauconitic sands, then by 10 m. of limestone with *Libycoceras ismaelis* Zittel, *L. ismaelis* var. *sudanese* Péréb., *Nautilus duboisi* Péréb., *Rondaireia auressensis* Coq., *Pseudoheligmus douvillei* Péréb., *Alectryonia nicaisei* Coq., *Venericardia ameliae* Peron, *Echino-tiara perebaskinei* Lambert, etc. A foraminiferan should also be mentioned: *Laffitteina monodi* Marie.

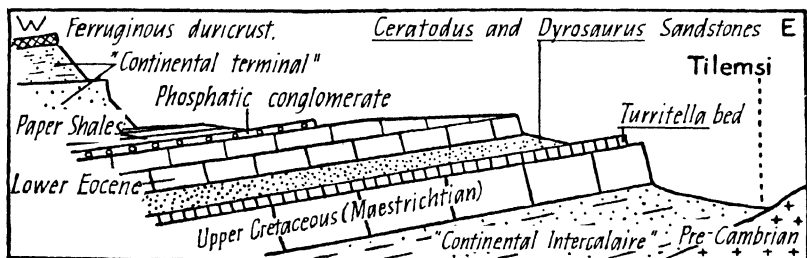


FIG. 15. Diagrammatic section of the Tilemsi Cliffs (after Monod, Pérébasquine and Radier), valid for all the plateaux surrounding the Adrar des Iforas.

It seems that the Danian cannot be separated from the Maestrichtian. The marine succession ends with a layer containing turritellas (*T. trempina* Gareze and *T. forgemoli* Coq.), put into the Danian by V. Pérébasquine and into the Palaeocene by H. Radier.

Continental Maestrichtian ("Continental hamadien"). The borders of the crystalline massif were not invaded by the sea and Senonian rocks of continental facies rest directly on the "Continental intercalaire". A few fragments of dinosaurs have been found. V. Pérébasquine has found a bone of a titanosaur and J. Greigert a tooth of *Megalosaurus*. Still within the terminal Cretaceous, Greigert found *Pseudoceratodes niameyensis* (at Elleba, 57 km. south-east of Zakak, Niger).

Palaeocene. The Palaeocene is represented by a few metres of sands and argilites containing crocodiles (*Dyrosaurus*), *Ceratodus* teeth and *Myliobathys* as well as plants (*Ficoxylon cretaceum* Schenk

and *Myristicoxylon princeps* Boureau). There are marine horizons and separation from the Danian seems very difficult. Their flora and fauna suggest that these horizons fall into the beginning of the Tertiary.

Ypresian. The Lower Eocene, which is transgressive, is represented by 15 m. of limestones with *Nautilus chudeaui* Douv., *N. molli* Douv., *N. labechei* d'Arch. and H., *Heligmoteria molli* Douv., *Gisortia brevis* Douv., *Alectryonia nicaisei* Coq. var. *elongata* Péréb., *Plesiolampas saharae* Bather var. *paquieri* Lambert, *Linthia sudanensis* Bather and *Operculina canalifera* d'Arch. This horizon is always well represented by the two echinoids, which are very abundant.

The marine succession ends with limestones and marls attributed to the Lower Eocene, with *Nautilus labechei* d'Arch. and H. *N.*, *jacobi* Péréb., *Chenopus dimorphospira* Cossm., *Velates schmideli* Chemn., *Lucina* cf. *pharaonis* Bell., *Pseudoheligmus nigeriensis* Newton, *Ostrea multcostata* Desh. and *Operculina canalifera* d'Arch. According to H. Radier, one always finds *Laffiteina monodi* Marie, together with *Raetomya schweinfurthi* M. E. and *Operculinoides bermudezi* etc.

Phosphatic Beds. One passes upwards into phosphatic beds containing *Carolia placunoides* Cantraine (of the Ypresian-Lutetian of Senegal), *Ostrea multcostata* Desh. (of the Ypresian-Lutetian of North Africa), fish (*Phosphictys thomasi* Arambourg and *Paleophys maghrebianus* Arambourg, of the Moroccan Ypresian and *Trichiurus plicidens* Aramb. of the Moroccan Ypresian-Lutetian). H. Radier would have these beds Lutetian, but their fauna could very well be Upper Ypresian.

"Continental Terminal." The continental beds deposited after the retreat of the phosphate-rich sea have a maximum thickness of about 50 m. They include argilites, ferruginous oolites, sandstones and sands, all covered by a ferruginous duricrust. A few fossils are known: a *Moeritherium* in the Gao region (Arambourg, Kikoine and Lavocat 1951) and *Pseudoceratodes iforasensis* Jodot in the lacustrine limestones of the In Abser Valley.

The plants include *Ficoxylon cretaceum* Schenk, *Dombeyoxylon monodi*, *Myrtoxylon secretans*, *Leguminoxylon ersanense*, *Annonoxylon striatum*, *A. edengense*, *Terminalioxylon edengense* *Rutoxylon corneti* Boureau etc. (Boureau 1958).

The Sudanese Strait and the Gao Trough. R. Furon has given the name "Sudanese Strait" to the zone between the Pre-Cambrian of the Bend of the Niger and that of the Adrar des Iforas, judging

that it was through this region that the Mediterranean and the Gulf of Guinea connected.

This hypothesis has been verified by H. Radier (thesis, 1957) who also demonstrated the existence of an important tectonic trough (Gao Trough), oriented SE.-NW. and bordered on its two sides by faults with a minimum throw of 300 m. Boreholes have shown that the depth of the trough everywhere exceeds 1,000 m. Its width varies from 35 km. in the Bourem region to 100 km. south-west of Ménaka. It has been recognised over a length of 400 km.

According to Radier there is no "Continental intercalaire" in the bottom of the trough. This region must have been a sill which collapsed at some time in the Cretaceous, probably in the Cenomanian. The transgression spread over very diverse terraines. The filling of the trough indicates a continuous subsidence.

4. THE ADAR DOUTCHI

The Adar Doutchi is a region of irregular topography, a succession of dissected limestone plateaux reaching 100 m. in height, on the frontier of Niger and Nigeria (Furon 1935).

The lower horizons of the Adar Doutchi, visible in the Tigart ravines, 14 km. north of Tahoua, have yielded a Cenomanian fauna: *Exogyra columba minor* Lmk., *Strombus incertus* d'Orb., and *Ostrea biauriculata* var. *hippopodium* Furon.

Following these come:

Lower Turonian with *Exogyra olisiponensis* Sharpe, *Vascoceras* (*Paravascoceras*) *cauvini* Chudeau, *Vascoceras* (*Paracanthoceras*) *chevalieri* Furon.

Sandy-shaly Upper Turonian.

Calcareous Maestrichtian with *Rondaireia aurensensis* Coq., *Ostrea overvegi* Buch, var. *tamalleni* Perv., *Liostrea thevestensis* Coq., *Pseudoheligmus douvillei* Péréb., *Venericardia* sp., Danian certainly present, but not separable.

Montian-Lower Eocene, not separated; limestone with *Operculina*, *Linthia sudanensis* Bather, *Plesiolampas saharae* Bather, *Pseudoheligmus nigeriensis* Newton, *Spondylus quadricostatus* Douv., *Ostrea multicostata* Desh., *Panopea sahariensis* Newton, *Velates schmiedeli* Chemn., *Eovasum soudanense* Douv., *Chenopus dimorphospira* Cossm., *Gisortia brevis* Douv., *Calyptraea nigeriensis* Newton.

A certain number of crushed fossils in the marls recall forms different from those of the true Lower Eocene and suggest a Montian fauna (Garde collection, Natural History Museum, Paris).

The continental post-Eocene beds are shaly sands and ferruginous sandstone ("Niger Sandstone"), capped by a ferruginous lateritic layer.

5. THE DAMERGOU AND THE TEGAMA

The region between the Air to the north and the Nigerian frontier to the south is a large plain varying from 400 to 500 m. above sea-level. It is bounded on the north by the Tidjeddi Cliff. It is overlooked in the north by an area of higher ground, the Damergou. The Damergou, oriented NE.-SW., is 80 km. long and 40 km. in average width. Its relative height is on average about 50 m.

Geological references include Chudeau (1909), Furon (1935), Lambert (1943), Arambourg and Joleand (1943), Schneegans (1943), Joleaud and Hsu (1943) and Greigert *et al.* (1954).

The Tegama. The plateau of the Tegama is bounded on the north by the Tidjeddi Cliff, which describes an arc of a circle around the Air from In-Gall to the Tazolé district.

The "Continental intercalaire" is to be seen here with, at the base, the "Agadès Sandstones", which contain only silicified wood. Then come the "Irazer Clays" containing *Estheria*, *Unio*, *Ceratodus* teeth and fragments of sauropods and theropods; finally, at the top, the "Tegama Sandstones" with the same fauna. Sandstones and clays of the Tegama outcrop as far as the Nigerian frontier.

The Damergou. The Damergou is an outlier 100 m. in height, situated between the Air and Zinder.

At the base is seen the "Continental intercalaire" of Tegama type, with *Ceratodus* teeth. The hills are formed mainly of Cenomanian and Turonian limestones.

Cenomanian. The first calcareous lenticles contain a fauna belonging to the transgressive marine Upper Cenomanian, including *Neolobites vibrayanus* d'Orb., *Exogyra columba minor* Lmk., *E. africana* Lmk., *Plicatula fourneli* Coq., *P. auresensis* Coq. and *Micropedina olisiponensis* Forbes, forms known both in North Africa and Nigeria.

Turonian. The facies changes to yellow, sandy, dolomitic

limestones containing a very rich fauna of Lower Turonian age: *Exogyra olisiponensis* Sharpe, *Astarte nigeriensis* Schneegans, *Cardium productum* Sow., *Pholadomya pedernalis* Roemar, *Natica bulbiformis* Sow., *Turritella fittoni* Münster, *Fasciolaria saharica* Schn., *Hopli-toides nigeriensis* Woods, *Metengonoceras dumbli* Cragin, *M. nigeriensis* Furon, *Paravascoceras chevalieri* Furon, *P. cauvini* Chudeau, *P. chudeaui* Furon, *P. nigeriensis* Woods, *Nigericeras jacqueti* Schn., *N. lamberti* Schn., *N. gignouxii* Schn.

The Upper Turonian appears to be regressive and is represented by unfossiliferous sandstones.

According to A.-F. de Lapparent the fish fauna known from the Damergou is of Turonian age (*Ceratodus africanus*, *C. humei*, *Coelodus plethodon*, *Enchodus lamôerti*, *Onchosaurus pharao* etc.). They are freshwater forms that lived in pools and estuaries.

Senonian and Eocene. A.-F. de Lapparent considers that there is no longer any marine Senonian or marine Eocene in the Damergou.

Zinder, Koutous and Mounio Regions. East of the Damergou, the Koutous Plain is composed of Tegama sandstones and clays, with a few signs of marine Cretaceous.

To the south of the Koutous, the Zinder region is known for its outcrops of Pre-Cambrian (quartzites and igneous rocks), which are the only ones between the Niger and western Chad.

Granites emerge from the Recent sands beneath the town of Zinder and for about 25 km. to the west. They are alkaline granites with riebeckite and aegyrine, passing at the margins into microgranites. They recall the *granites recents* of the Air. Other granitic outcrops occur to the east of Zinder. They are varied calc-alkaline granites similar to those of Borkou and the Ouadai. These granites belong to a large area of old rocks, the major part of which is covered by fixed dunes.

East of Zinder, in the direction of Kissambana, a few residual hills show quartzites, metamorphic conglomerates and marbles. This ancient group is cut by a grey or pink granite, containing microcline and orthoclase, passing marginally into amphibolitic orthogneisses with quartzite enclaves. Dips are westward and the metamorphic conglomerates appear to occupy the axis of a syncline, where they succeed the quartzites.

A little to the east of Kissambana R. Karpoff (1948c) discovered a group of fine, cross-bedded quartzites exhibiting little to no sign of metamorphism and of eastward dip. This is the "Amzara

Series", younger than the previously mentioned rocks and not, apparently, reached by the granites.

125 km. east of Zinder is another old massif emerging from the sands; the Mounio (Freydenberg 1908; Garde 1911; Chudeau 1909; Karpoff 1948c).

Near Gouré outcrop mica-schists, quartzites and amphibolites, comparable to the Kissambana succession, attributed to the Middle Pre-Cambrian. The higher land is composed of rhyolites, microgranites and riebeckite and aegyrine granites. Another granite of the same age, which is granulitic, outcrops east of Gabana. These granites are the "Young Granites", prospected for tin and wolfram.

6. THE WADI AZAOUAK BASIN AND THE TAMESNA

The wadi Azaouak is an immense Quaternary valley over 1,000 km. long, whose numerous tributaries cut deeply into the mountainous massifs of the Hoggar and the Air. The lower course of this dry valley, the dallol Bosso, joins the Niger south of Niamey.

The various segments of this long valley bear different names: wadi Tesellaman in the catchment area, wadi Assakarî further west, wadi Azaouak from the Niger-Mali frontier and then dallol Bosso. This wadi describes a large arc of a circle. In a general way the right bank is made up of old rocks and the "Continental intercalaire" while the left bank is overlooked by plateaux of Cretaceous and Eocene rocks. It is only near a longitude of 5° E. that the wadi succeeds in cutting into the plateau in a south-west direction in a relatively narrow valley flanked by cliffs. The general dip is towards the south.

The immense plain in the north is known by the Tuaregs as the Tamesna. This country lies between the Adrar Tiguirit in the west and the Tegama in the east. A.-F. de Lapparent has discovered dinosaur beds there (Furon 1935; de Lapparent 1953a, b).

The following beds are seen there successively from north to south:

"*Continental Intercalaire*": sandstones and clays with silicified wood, *Ceratodus* teeth, crocodiles and dinosaurs. On Mont Iguella, in particular, there are numerous bones of sauropods and theropods together with shells of *Unio*.

Upper Cenomanian: marine and transgressive, as indicated by

calcareous lenticles with *Neolobites vibrayeanus*, *Exogyra columba minor*, *E. africana* and *E. flabellata*, visible from the Tamaia region to within the Adar Doutchi.

Marine *Turonian* with vascoceratids and *Exogyra olisiponensis*, in addition to the fish fauna known since the Infra-Cretaceous. Marine *Maestrichtian*, with *Roudaireia auressensis*, *Ostrea overwegi* and *Plicatula ferryi*. 80 km. north of Tahoua (Adar Doutchi) the *Senonian* of Mont Igdaman consists of a phosphatic bone-bed with the bones of fish, crocodiles and dinosaurs (including *Titanosaurus*).

The Cretaceous-Eocene boundary is marked by the small *Turritella* bed of the Adrar Moisey (Danian or Montian).

Lower Eocene: limestones with *Linthia sudanensis* and *Plesiolampas saharae*.

Quaternary: In the north is a zone of marshy low ground which was inhabited by the rich Quaternary fauna of the Tesellaman Basin. *Hippopotamus amphibius*, *Phacochoerus aethiopicus*, *Elephas africanus*, *Camelopardalis giraffa*, *Bos* sp., *Crocodilus niloticus* and antelopes have been found there. The hippopotamus seems to have disappeared from the area in the Neolithic and the others a little later, except the *Phacochoerus* which lives there still.

7. THE AÏR

The Aïr Massif is a south-eastern apophysis of the Hoggar and is a counterpart of the Adrar des Iforas in the west. It is a prolongation of the crystalline massif of the Hoggar in the direction of Mounio and Nigeria. The crystalline zone of the Aïr is separated from the Hoggar by the wadi Azaouak and for the most part is enveloped by a sedimentary cover. It is a horst, exposed by erosion, rising up between the Tamesna and the Ténéré. According to Faure, the uplift of the Aïr took place in the Tertiary and Quaternary.

The Pre-Cambrian

M. Raulais has distinguished two series in the metamorphic Pre-Cambrian (Raulais 1946, 1948, 1952, 1957).

The Lower Pre-Cambrian is represented by the "Tazizilet Series" (= Suggarian of the Hoggar), composed of gneisses, mica-schists, quartzites, marbles and amphibolites. The whole assem-

blage is folded, cut by granitic bodies and migmatized. It constitutes the major part of the massif.

The Middle Pre-Cambrian is known as the "Proche-Ténéré Series". It is seen on the borders of the Ténéré, to the east of a large N.-S. fault visible for 330 km. This series (= Pharusian of the Hoggar) begins, according to Raulais, with a tillite and consists of rocks less metamorphosed than the Lower Pre-Cambrian.

In the absence of Upper Pre-Cambrian the latest group of granites can be treated as terminal Pre-Cambrian. These are hyperalkaline riebeckite granites, rich in soda and potash and poor in lime and alumina. Cassiterite is not present. They form the highest ground in the Aïr, reaching 1,900 m. and constitute batholiths cutting the surrounding rocks. They exhibit an alkaline facies with biotite, which contains cassiterite, wolfram and columbite. Some rhyolitic outpourings are associated with the latest granites.

The first specimens of these hyperalkaline granites were recorded by L. Gentil from material collected at Iférouane by the Foureau-Lamy Expedition. Raulais has pointed out their economic importance.

The Damaragam and the Baguezans Mountains are composed of these riebeckite and aegyrine granites, which are found further south in the Mounio, at Zinder and in Nigeria. The microgranites pass into rhyolites (which are comendites).

The Sedimentary Envelope

North. Outside a few plateaux of Palaeozoic sandstones Raulais has recognised the "Continental intercalaire" with silicified wood, up to 1,200 m. above sea-level (Raulais 1952).

North-west. Southerly portions of the Tassili oua n'Aghagar border the north-north-western part of the Aïr. Going southwards one finds Cambro-Ordovician, Silurian, Devonian and marine Lower Carboniferous of the In Tedreft (known since 1913) with *Spirifer*, *Productus* and fish. Further south, on the borders of the Aïr, is some continental Lower Carboniferous with *Rhacopteris ovata* Walkan, *R. elegans* Schimper and *Triphyllopteris lescuriana* (Meek) Jongmans (Joulia and de Lapparent 1956; Boureau 1958; Joulia 1959). This continental Dinantian disappears westwards under the "Continental intercalaire" of the Tamesna.

South. The Pre-Cambrian formations of the Aïr are directly overlain by the "Continental intercalaire" of the Tegama.

East. Sedimentary rocks, dipping gently eastwards, form a belt 200 km. long and 40 km. wide, resting in the west on the Precambrian of the Air and disappearing in the east under the sands of the Ténéré. H. Faure (1959a and b) distinguishes, from bottom to top:

1. *The Tefidet Group* ("Continental intercalaire") subdivided into: Angornakouer Sandstone with silicified tree trunks (200 m.); Tagrezou Sandstone with silicified wood, crocodiles and dinosaurs (100 m.); Tanguerat Sandstone (200 m.) corresponding to the Dibella Formation further to the east. The contact with the basement is always at a fault or faulted flexure. There is a NW.-SE. "Tefidet Trough" directed towards Lake Chad.
2. *Lower Cenomanian*: Alanlara Formation (sandstones with *Ceratodus* and dinosaurs, with several marine beds containing oysters and gastropods (200 m.)).
3. *Upper Cenomanian and Lower Turonian*: about 10 m. of limestones beginning with a bed containing *Neolobites vibraeyanus* d'Orb., continuing with a limestone containing *Micro-pedina olisiponensis* Forbes and ending with limestones with *Exogyra olisiponensis* Sharpe and *Nigericeras*.

Volcanism

R. Lambert was indicated the existence of a series of volcanoes in the Air which underwent two periods of activity. One of these resulted in large flows of plateau basalts older than the present valleys; the other, more recent, has left well-preserved craters in the Baguezan Mountains and flows following the valleys. This resembles the Pliocene-Quaternary volcanism of the Hoggar.

There exist elsewhere basaltic necks (Mont Greboun, Pic Ourteguide) which appear to M. Raulais to be older than the Cretaceous sandstones that surround them (?).

M. E. Denaeyer has distinguished two types of basalts in the Air: basalts β : doleritic, with andesine, and basalts β' : holocrystalline, with labradorite, with ophitic texture, enclosing a few flakes of mica.

8. THE CHAD BASIN

The Chad Basin is a large enclosed basin, the knowledge of whose geography we owe to the explorations of General Tilho.

Lake Chad, fed essentially by the Chari, is a shallow, marshy sheet of fresh water whose form and dimensions vary annually. Observations over a sufficiently long period of time have shown that the variations of the lake surface are related to climatic cycles of eleven and thirty-six years' periodicity.

Lake Chad does not occupy the most depressed area of the cuvette. Its mean height above sea-level is 243 m. General Tilho has shown that the lowest region, the "Pays-Bas du Tchad", is 700 km. north-east of the lake, 100 m. lower and connected with the lake by a canal, the Bahr-el-Ghazal.

The Bahr-el-Ghazal is an effluent of Lake Chad which is obstructed by the Chari alluvium. The Quaternary Lake Chad was immense (Freydenberg 1908; Garde 1911; Tilho 1910-1914).

The Pre-Cambrian basement is known on the distant borders of the basin: at Zinder and in the Mounio in the west, in the Air in the north-west, in Nigeria and Ubangi in the south and in Ouadai in the east.

The rhyolitic rocks of Hadjer-el-Hamis, immediately south-east of the lake, 85 km. NNW. of Fort-Lamy, belong to the Pre-Cambrian (?) (Barbeau and Gèze 1957). The bluish or greenish rock has phenocrysts of corroded quartz, alkaline feldspars, amphibole and pyroxene in a fine-grained matrix that was originally vitreous. It includes enclaves of rocks unknown in local outcrop, in particular an aegyrine microgranite. They are the same rock-types as those of the Mounio. Several domes of these peculiar granites emerge between Lake Chad and Lake Fitri (Ngoura, Kalkalé, Gamsous, etc.).

In the north-east the plateaux of Palaeozoic sandstones of the Ennedi and Borkou continue to the Tibesti.

Later, the whole of the bottom of the Chad Cuvette was covered by deposits of the "Continental intercalaire" which outcrop over a broad area on the western margin. These are the "Achegour Sandstones" and the "Dibella Sandstones", the latter containing impressions of plants: gymnosperms (*Podocarpites saharianum* Boureau) and dicotyledons belonging to the genera *Laurophyllum* and *Cinnamomoides* (probably Albian-Lower Cenomanian) (Renault 1953; Faure 1954; Boureau 1955).

The Cenomanian transgression invaded the Chad Basin, as proved by the discovery of a *Neolobites* in the Ténéré du Tafasasset.

The marine Turonian with *Hoplitoides nigeriensis*, *H. munieri* and

Metengonoceras sp. outcrops at Zoo-Baba, between Agadem and Bilma (Furon 1942), also in the Agadem district and as far as the northern part of the Ténéré, where *Exogyra olisiponensis* has been discovered between Chirfa and Tiffa.

The marine Senonian outcrops near Bilma, where an echinoid has been collected (*Noetlingia monteili* Gauthier) (Gauthier 1901; A. de Lapparent 1901) and the marine Eocene is indicated by moulds of a large *Lucina*.

However, at certain localities the "Galhama Series" (east of Agadem) constitutes the base of the Kaouar Cliff; it is of continental origin and marked by 20 m. of pisolitic bauxite. H. Faure readily assigned it to the terminal Cretaceous or Lower Eocene.

Finally, the "Continental terminal" is represented by the "Homodji Series", 50 m. thick, formed of ferruginous and oolitic sandstones. These formations are found east and west of the Kaouar Valley. The succession ends with alternating lacustrine and dune deposits.

In the south, the Chad Cuvette is of unknown depth, especially in the west. Reference must be made to the Maiduguri Borehole (in Nigeria), at the same latitude as Fort-Lamy. Here the "Continental terminal" (Chad Group) is 700 m. thick and the marine Cretaceous over 400 m. The boring stopped at 1,103 m. without reaching the basement. At Fort-Lamy a borehole reached 356 m., again without reaching the basement.

We find ourselves here on the line of the NE.-SW. axis which links the fractures and volcanoes of the Tibesti with those of Cameroun.

Though dunes cover most of the Chad Basin the region knew humid periods in the Quaternary like the rest of the Sahara.

The large fossil fauna includes elephants, hippopotamuses, giraffes and large wild boars. The commonest fish is *Lates niloticus*, recorded over a wide area extending into the Borkou, the Eguei and the south-western Tibesti, accompanied by fragments of tortoises. J. Barbeau has discovered a mammal fauna in the Lower Villafranchian, including *Elephas* (*Archidiskon*) *africanavus* and *Hippopotamus* cf. *protamphibius* (Barbeau 1959; Abadie, Barbeau and Coppens 1959).

L. Germain has described a multitude of subfossil molluscs: *Planorbis bridouxi* Bourguignat, *P. chudeaui* Germain, *P. gardei* Germain, *P. sudanicus* Martens, *Physa* (*Isidora*) *strigosa* Martens,

P. tchadiensis Germain, *P. dantzenbergi* Germain, *Limnaea tchadiensis* Germain, *L. africana* Ruppel, *Viviparus unicolor* Olivier, *Bythinia neothomaeformis* Germain, *Melania tuberculata* Müller, *Valvata tilhoi* Germain, *Unio lacoini* Germain, *Spatha bourguignati* Ancey, *Corbicula lacoini* Germain, and *C. audoini* Germain (Germain 1909; Garde 1911).

Germain has often insisted on the special character of this fauna, which includes several subfossil species found from Mauritania to the Nile Valley.

REFERENCES

- ABADIE, J., J. BARBEAU and Y. COPPENS, 1959. Une faune de vertébrés villafranchiens au Tchad. *C.R. Ac. Sc.*, **248**, 3328-3330.
- AICARD, P., A. BLANCHOT and J. SOUGY, 1958. Sur la position stratigraphique des grès de Firgoun (Niger). *C.R. Soc. Géol. Fr.*, 297-299.
- ARAMBOURG, C. and L. JOLEAUD, 1943. Vertébrés fossiles du bassin du Niger. *Bull. Dir. Mines A.O.F.*, No. 7.
- J. KIKOINE and R. LAVOCAT, 1951. Découverte du genre *Moeritherium* dans le Tertiaire continental du Soudan. *C.R. Ac. Sc.*, **233**, 68-70.
- BARBEAU, J., 1959. Quaternaire des abords orientaux du lac Tchad. *C.R. Soc. Géol. Fr.*, p. 110.
- and B. GÈZE, 1957. Les coupoles granitiques et rhyolithiques de la région de Fort-Lamy (Tchad). *Bull. Soc. Géol. Fr.* (6), **7**, 341-351.
- BOUREAU, E., 1955. Sur les empreintes végétales du Continental intercalaire de Dibella (Niger). *Ibid.* (6), **5**, 3-9.
- 1958. Paléobotanique africaine. *Bull. sc. Com. Trav. hist. sc.*, **2**, 1-64.
- CHUDEAU, R., 1909. Sahara soudanais.
- DEFOSSEZ, M., G. PALAUSI and H. RADIER, 1957. Données nouvelles sur les séries anciennes de la Bouche du Niger (Soudan). *Bull. Dir. Mines Géol. A.O.F.*, No. 20, 148-191.
- FAURE, H., 1954. Géologie des régions au Nord du Tchad. *C.R. Soc. Géol. Fr.*, pp. 309-312.
- 1959a. Géologie des formations sédimentaires à l'E. de l'Aïr (Niger). *Bull. Soc. Géol. Fr.* (7), **1**, 143-149.
- 1959b. Une hypothèse sur la structure du Ténéré (Niger). *C.R. Ac. Sc.*, **249**, 2591-2593.
- FREYDENBERG, H., 1908. Le Tchad et le bassin du Chari. (Thesis.)
- FURON, R., 1935. Le Crétacé et le Tertiaire du Sahara soudanais. *Arch. Mus. Nat. Hist. Nat.* (6), **13**, 1-100.
- 1942. Le Crétacé moyen du Sahara oriental. *C.R. Soc. Géol. Fr.*, p. 184.
- 1945. Sur l'existence du Cambrien marin au Sud du Niger. *Ibid.*, p. 181.
- GARDE, G., 1911. Description géologique des régions situées entre le Niger et le Tchad et à l'Est et au Nord-Est du Tchad. (Thesis.)

- GAUTHIER, V., 1901. Description d'un Echinide du Sahara. *Bull. Soc. Géol. Fr.* (4), **1**, 189-192.
- GERMAIN, L., 1909. Recherches sur la faune malacologique de l'Afrique équatoriale. *Arch. Zool. expér. et gén.*, **1**, 1-195.
- GREIGERT, J., F. JOULIA and A.-F. DE LAPPARENT, 1954. Répartition stratigraphique des gisements de vertébrés dans le Crétacé du Niger. *C.R. Ac. Sc.*, **239**, 433-435.
- JOLEAUD, L. and T. Y. HSU, 1943. Crustacés décapodes du Crétacé de Tanout (Damergou). *Bull. Dir. Mines A.O.F.*, No. 7.
- JOULIA, F., 1959. Les séries primaires au N de l'Aïr (Sahara central): discordances observées. *C.R. Soc. Géol. Fr.*, p. 64.
- and A.-F. DE LAPPARENT, 1956. Découverte de la série paléozoïque sur la bordure occidentale du massif de l'Aïr (Sahara méridional). *C.R. Ac. Sc.*, **238**, 2545-2547.
- KARPOFF, R., 1946. Stratigraphie de l'Antécambrien au Sahara. Le Nigritien *Ibid.*, **223**, 428-429.
- 1948a. Observations géologiques dans le Mounio. *C.R. Soc. Géol. Fr.*, 349-351.
- 1948b. Sur un ligne de dislocation majeure en Afrique occidentale et saharienne. *Ibid.*, **227**, 857-858.
- 1948c. Observations géologiques à l'Est de Zinder. *C.R. Soc. Géol. Fr.*, 339-340.
- 1949. Sur quelques laves interstratifiées dans le Pharusien de l'Adrar des Iforas (Sahara soudanais). *Ibid.*, 302-303.
- 1954. Stratigraphie de l'Antécambrien dans la partie occidentale de l'Adrar des Iforas. *C.R. Ac. Sc.*, **238**, 129-130.
- 1958. Étude géologique de l'Adrar des Iforas. (Unpublished thesis.)
- LAMBERT, R., 1943. Note stratigraphique sur le Crétacé supérieur du Damergou. *Bull. Dir. Mines A.O.F.*, No. 7.
- DE LAPPARENT, A., 1901. Sur la découverte d'un Oursin crétacé dans le Sahara oriental. *C.R. Ac. Sc.*, **132**, 388.
- DE LAPPARENT, A.-F., 1953a. Sur la stratigraphie du Tamesna. *Ibid.*, **236**, 2255-2257.
- A.-F., 1953b. Reconnaissance des gisements à Dinosauiens du Tamesna. *Trav. Inst. Rech. sahariennes*, **19**, 7-18.
- LELUBRE, M., 1952. Recherches sur la géologie de l'Ahaggar central et occidental. *Bull. Serv. Carte Géol. Algérie* (2), No. 22; 2 vols.
- PÉRÉBASKINE, V. 1933. Contribution à l'étude géologique du Soudan oriental. *Bull. Ag. Gen. Col.*, pp. 124, pl. 9.
- RADIER, H., 1959. Contribution à l'étude géologique du Soudan oriental. *Strasbourg thesis. Bull. Dir. Mines A.O.F.*, No. 26.
- RAULAIS, M., 1946. Le série granitique ultime de l'Aïr, au Niger, et sa mineralisation. *C.R. Ac. Sc.*, **233**, 96.
- 1948. Sur la découverte de wolfram dans le jeune granite à biotite de l'Aïr. *C.R. Soc. Géol. Fr.*, 113-114.
- 1952. Sur la découverte d'une discordance dans le Précambrien du SW. de l'Aïr. *Ibid.*, 93-94.
- 1957. Sur la mineralisation de l'Aïr et sa relations probables avec la tectonique. *C.R. Ac. Sc.*, **244**, 913-916.

- RENAULT, P., 1953. Sur la présence du Crétacé marin et d'un gisement de plantes fossiles dans la région de Bilma (Niger). *C.R. Soc. Géol. Fr.*, 52-53.
- ROQUES, M., 1945. Les séries anciennes de la Boucle du Niger au Soudan. *Bull. Soc. Géol. Fr.*, (5), 15, 528-546.
- SCHNEEGANS, D., 1943. Invertébrés du Crétacé supérieur du Damergou. *Bull. Dir. Mines A.O.F.*, No. 7.
- TILHO, J., 1910-1914. Documents scientifiques de la Mission Tilho (1906-1909), 3 vols.

GUINEA AND SIERRA LEONE

1. PRE-CAMBRIAN

After the works of H. Hubert and A. Lenoble, our knowledge of the Pre-Cambrian of Guinea is due essentially to G. Goloubinow for the north-east (Goloubinow 1936, 1938) and to A. Obermuller for the forested region (Obermuller 1939; Obermuller and Roques 1946). The Pre-Cambrian of Sierra Leone has been studied by J. D. Pollett (1951, 1956).

The *Lower Pre-Cambrian* is represented in Guinea by the granitogneissic complex of the Dahomeyan; in Sierra Leone by the "Kasila System" and by the Kambui and Sula Schists, which are cut by pegmatites dated at 2,900 million years.

The *Middle Pre-Cambrian* corresponds to the *anciens schistes et quartzites redressés* of Hubert, with, in addition, much more metamorphosed rocks, including a varied assemblage of argillaceous, siliceous, arkosic, sericitic, amphibolitic and graphitic schists. One also finds micaceous or non-micaceous quartzites, which may play an important role in the relief as is the case in the Pays de Macenta. Limestones transformed into marbles have been recorded in several places as enclaves in the granites. The whole assemblage has, together with ancient volcanics, been violently folded and then eroded and the visible outcrops usually show dips close to the vertical.

Besides the large granitic massifs in which the Birrimian sediments have been progressively assimilated there are a number of clearly circumscribed massifs which have been intruded discordantly.

The Middle Pre-Cambrian of Guinea is divided into three series by M. Roques (1948): Atacorian (Simandou and Nimba Quartzites); Lower Birrimian (schists, quartzites and arkoses of the Siguiri Basin); Upper Birrimian (schists, quartzites and greenstones).

Rocks of this age in Sierra Leone are known as the "Marampa Schists".

The Middle Pre-Cambrian is particularly interesting because of its gold, iron and diamond resources.

The fold directions are generally N.-S., but virgations are discernible, revealing the existence of the Guinean or Liberian "Shield".

On the borders of Guinea, Liberia and the Ivory Coast, on Mont Nimba, is an assemblage of rocks little affected by granitisation (Lamotte and Routhier 1943). Mont Nimba belongs to a NW.-SE. dome which extends to Man, in the Ivory Coast. Magnetitic and muscovitic quartzites have a mean thickness of 3,000 m. The group also contains graphitic mica-schists with garnet and staurolite, and 500 m. of amphibolites and amphibolitic schists. The complete succession seems to have a thickness of about 5,000 m.

The *Upper Pre-Cambrian* would be represented by a few shreds of conglomerates, which could belong to the Tarkwaian.

The *Terminal Pre-Cambrian* (?) always presents the problem as to whether it is better placed in the true Pre-Cambrian or the Infra-Cambrian. It is *certain*, anyhow, that everything above the Birrimian (and eventually the Tarkwaian) rests with major unconformity upon the folded basement.

Near Gaoual, in the Tominé Valley, and at Youkounkoun, E. de Chételat has seen a conglomerate passing into red feldspathic sandstones. The same feldspathic sandstones have been found by R. Furon north-east of Kindia, south of Mont Souti as far as the Kolenté, where they reach a thickness of 200 m.

There is an important series of shales, jaspers and cherts usually occurring above the continental feldspathic sandstones and covered by a dolerite (Furon 1943). This assemblage passes northwards into the "Falemian" and southwards into the Rokell Series of Sierra Leone. This is the *série intermédiaire* of P. Legoux, but his interpretation is not unanimously accepted: true Pre-Cambrian or (according to us) Infra-Cambrian and unconformable base of Palaeozoic. The beds are sometimes horizontal, sometimes undulating, and folded only locally.

2. PALAEOZOIC

Continental Episode. Between the folded Pre-Cambrian and the first marine transgression (Infra-Cambrian, Cambrian or even Ordovician) one finds traces of a continental episode. In the

Santa Valley, at Tabouna, near Kindia, there is a consolidated eluvial formation between the Birrimian and Ordovician.

Infra-Cambrian. This was defined by M. Arnould, J.-M. Aymé and R. Guillaume (1959). It begins with sandstones of the "Ségou Series" (Guinea), resting with major unconformity on the folded Birrimian. It continues with over 1500 m. of red *Collenia* limestones, lower argilites, quartzites and upper argilites, composing the "Madina Kouta Series". This is the old "Falemian".

Cambrian. The Cambrian begins with a *tillite* situated at the base of the "Walidiala Series" which is formed of 200 m. of shales, dolomitic limestones and jaspers. It ends with the "Mali

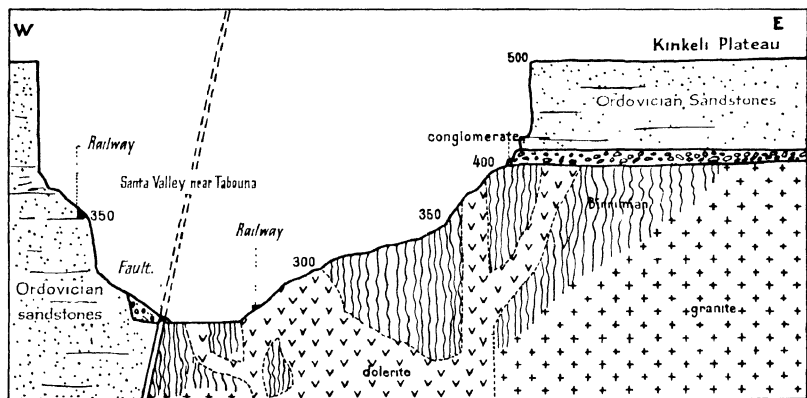


FIG. 16. Section in the Santa Valley near Kindia (Guinea).

Shales", reaching 1,000 m. in thickness and containing numerous doleritic sills.

Ordovician. The Ordovician begins with a basal conglomerate with quartz pebbles. It consists of white and pink sandstones, variously cross-bedded, fine- and coarse-grained, often with a black patina especially towards the top. The thickness of these sandstones is several hundreds of metres, 500 m. at least.

Silurian. The Silurian, discovered near Téli-mélé by H. Sinclair in 1918, is usually composed of a few metres of black, pyritic, graptolitic shales, and by thin-bedded sandstones (de Chételat 1938; Pobeguín 1947). The main fossiliferous beds are found: near Téli-mélé; near Médina-Bové (75 km. NNW. of Téli-mélé), on the frontier of Portuguese Guinea, 60 km. west of Gaoul; at

Ouassadou (cercle de Boké); at Sogoulou (cercle de Boffa); at the Konkouré-Ouonkoulou confluence (cercle de Dubréka); at Guémé Saint-Jean (mouth of the Rio-Nunez).

Two palaeontological zones are distinguishable: Lower zone of *Monograptus sedgwicki*, *Petalograptus altissimus*, *Gladiograptus perlatus*, *Climacograptus hughesi*, *C. scalaris*, *Glyptograptus tamariscus* var. *incertus* (= Zone 21 of Elles=Valentian); Upper zone of *Monograptus priodon* and *Gladiograptus geinitzianus* (= Zones 23 to 26 of Elles).

Towards the top graptolites disappear and give place to specifically indeterminable *Orthoceras*.

At Guémé Saint-Jean, at the mouth of the Rio Nunez, are some fine-grained sandstones containing *Clarkeia antisiensis* d'Orb., known from the Silurian of South America.

Devonian. The Lower Devonian was discovered by E. de Chélat (1939) who found a few brachiopods (*Trigleria* cf. *gueran-geri*, *Meganteris* (?) and *Amphigenia* (?)). *Pleurodictium problematicum* has since been found in the Rio Corubal Valley. The average thickness of the Lower Devonian is 100 m.

The Upper Devonian is represented by 200 m. of grey shales containing *Spirifer verneuili*, at Chaqui, on the Rio Colufi. The Upper Devonian is the youngest Palaeozoic unit in Guinea, where no trace of Carboniferous is known.

Hercynian and more recent movements. The Palaeozoic succession of Guinea occurs in a syncline bordered on the south by the large Léo Anticline. One may locally still distinguish a "Falémé Anticline", eroded almost to the Pre-Cambrian basement. Erosion has served to separate the Palaeozoic of Guinea almost completely from that of western Mali, leaving only Infra-Cambrian rocks behind.

In the west, the uplands of Fouta-Djalou do not seem to be directly related to Hercynian folding but are associated with a series of fractures more or less parallel to the coast, which have effected appreciable displacements of the terrain. Two of these tectonic displacements, measured in the Kindia region, have the same sense and are both of the order of 250 m.

In the Téli-mélé region the Silurian is found at an altitude of 750 m. On the Atlantic coast, at Tomboya, it is found at only a few tens of metres above sea-level. This may be explained either by the movement of still undetected faults or by a syncline whose axis lies somewhere off the coast.

P. Legoux suspects the existence of another, parallel, intermediate synclinal zone between the coast and the Fouta-Djalon. E. de Chételat reports a SW.-NE. syncline in the probable Silurian of Cape Verga.

The whole assemblage seems to have the general form of a cuvette, surrounded almost completely by outcrops of the Pre-Cambrian basement.

Dolerites. Dolerites are very important in the geology of Guinea. They form, as in Mali, an enormous laccolith. They are met with over a distance of 600 km., from the Conakry district, on Mont Kakoulima, to the Mali frontier, going through the Fouta-Djalon. They are found at all altitudes, 50 m. in the bed of the Kolenté, 1,100 m. on Mont Gangan, 1,450 m. at the summit of Mont Linsan. Sills reach 200 m. in thickness and sometimes split up into prisms like at the falls of the Santa (at Tabouna) and Bougourou. The beds can be very numerous. From Upper Gambia (360 m. above sea level) to the Mali Post (1,450 m.) H. Hubert counted twelve layers of dolerite intercalated in sandstones.

They are grey-green to dark green rocks with an ophitic texture. They are rich in quartz and orthoclase micropegmatites and often have the grey colour of granites. While being ophitic they often show large crystals of plagioclase (labradorite with 68 per cent. of anorthite at the centre and oligoclase with 18 per cent. at the margins), partly enveloped by pigeonite. The micropegmatites are found in the interstices of feldspars and pyroxenes. Certain hypersthene-rich varieties, like those of Mont Kakoulima, pass into gabbros and even dunites right at the visible base of the laccolith. The Kakoulima intrusion shows the following differentiation from bottom to top: dunites, wehrlites (glittering with augite), troctolites and finally 800 m. of gabbros. Associated with them are a few Filonian rocks: euphotides, granophyres and lamprophyres. Superficial alteration of these basic rocks has produced the iron ores of the Kaloum Peninsula (Millot and Dars 1959a). Other types are black, compact and fine-grained, composed of plagioclase and augite, plus a little magnetite, biotite and olivine. Others, finally, are medium-grained and progressively richer in such minerals as quartz, orthoclase, biotite and apatite. They grade into rocks resembling granites while retaining a doleritic composition (A. Lacroix, E. Jérémie). Contact alteration is inconsiderable.

These dolerites are found throughout the Palaeozoic succession. As in the other regions of West Africa their exact age is unknown.

3. THE NEPHELINE SYENITES OF THE ISLES DE LOS

The nepheline syenites of the Isles de Los are well known through the petrographic analyses undertaken by A. Lacroix (1911). They are certainly much later in age than Pre-Cambrian, dating from the end of the Cretaceous or the Palaeogene. The circular archipelago of the Isles de Los readily suggests an "annular structure", a ring-dyke. It is situated on the line of the NW.-SW. fractures of the West African coast (Millot and Dars 1959b). Lateritic alteration reaches a depth of 10 m. and allows the important exploitation of bauxite.

4. THE UPPER CRETACEOUS AND PALAEOGENE OF PORTUGUESE GUINEA

The coastal sediments comprise Upper Cretaceous and Palaeogene (Sousa Torres, Pires Soares and O'Donnell 1947).

Radioles of *Cidaris* (*Cyathocidaris*) aff. *pseudo-pistillum* Cotteau, collected in fairly large numbers from a littoral platform of the Ilheu do Rei, indicate the immediate proximity of the Upper Cretaceous.

Three kilometres north of the town of Bissao, at Ponta Colonia in the Ilheu do Rei, are some altered marly limestones containing moulds of foraminifera, corals, echinoids, molluscs and crustaceans. The main elements of the fauna include *Orbitolites* aff. *complanatus* Lamarck, *Lucina saxorum* Lamarck, *Pecten plebeius* Lamarck, *Chama calcarata* Lamarck, *Nucula* cf. *packardi* Clarck, *Ostrea crassicostata* Lamarck, *Turritella mitis* Desh and *Fissurella frenauxi* Cossman. This would be Middle Eocene.

Near Bissao a small cliff shows 12 m. of shaly sands, weathered at the top, passing into 6 m. of much-reddened sandstone with a ferruginous crust. The higher beds contain moulds of *Nucula* aff. *nelsoni* Clarck, *Cardita* aff. *cor avium* Lamarck and *Cardium* (*Loxocardium*) aff. *brewerii* Gabb. and could be Oligocene.

REFERENCES

- ARNOULD, M., J.-M. AYMÉ and R. GUILLAUME, 1959. Nouvelle stratigraphie des grès primaires du Nord du Fouta-Djalon (Guinée, Sénégal). *C.R. Soc. Géol. Fr.*, p. 66 and *Bulletin*.

- DE CHÉTELAT, E., 1938. Sur l'extension du Gothlandien en Guinée française. *C.R. Ac. Sc.*, **207**, 371-372.
- 1939. Sur l'existence du Dévonien inférieur en Guinée française. *Ibid.*, **209**, 446-447.
- FURON, R., 1943. Géologie de la Guinée française. *Publ. Bureau d'Ét. Géol. et Min. col.*, p. 47.
- GOLOUBINOW, R., 1936. Géologie et ressources en or du Nord-Est de la Guinée. *Thesis, Nancy. Publ. Serv. Géol. A.O.F.*
- 1938. Relations des terrains métamorphiques redressés et des granites dans la région guinéo-soudanaise. *Bull. Serv. Mines A.O.F.*, No. 1, 3-88.
- LACROIX, A., 1911. Les syénites néphéliniques de l'Archipel de Los et leurs minéraux. *Nlles. Arch. Mus. Nat. Hist. Nat.* (5), **3**, 1-162.
- LAMOTTE, M. and P. ROUTHIER, 1943. Monographie géologique du Mont Nimba. *Bull. Soc. Géol. Fr.* (5), **13**, 113-124.
- MILLOT, G. and R. DARS, 1959a. La presqu'île du Kaloum et le massif du Kakoulima (République de Guinée). *Notes du Serv. Géol. Prospect. mi., Dakar*, No. 2, 1-44.
- 1959b. L'archipel des Iles de Los. Une structure annulaire sub-volcanique en Guinée (Afrique occidentale). *C.R. Soc. Géol. Fr.*, p. 8, and *Notes du Serv. Géol. Prospect. mi., Dakar*, No. 2, 47-56.
- OBERMULLER, A., 1939. Description pétrographique et étude géologique de la région forestière de la Guinée française (thesis). *Bull. Serv. Mines A.O.F.*, No. 4, p. 207.
- and M. ROQUES, 1946. *C.R. Ac. Sc.*, **223**, 1163-1164.
- POBEGUIN, T., 1947. Sur quelques schistes à Graptolithes de la Guinée française. *Ibid.*, **224**, 137-138.
- POLLETT, J. D., 1951. The geology and mineral resources of Sierra Leone. *Colon. Geol. Min. Res.*, **2**, 3-28.
- 1956. Sierra Leone and Gambia, in *Lexique stratigraphique international*, vol. 4. Africa; **3a**, 5-10.
- ROQUES, M., 1948. Le Précambrien de l'Afrique occidentale française. *Bull. Soc. Géol. Fr.* (5), **18**, 589-628.
- SOUSA TORRES, A., J. M. PIRES SOARES and H. O'DONNELL, 1947. Alguns testemunhos geologicos da Guiné portuguesa. Contribuições paleontologicas. *Bull. Soc. Port. sc. nat.*, **15**, 105-108.

THE IVORY COAST AND UPPER VOLTA

The Ivory Coast consists essentially of a large peneplain gently inclined southwards towards the sea. It is most irregular in the west, where the mountains of the Massif de Man range up to about 1,000 m. in altitude. Almost the whole area of the country is composed of Pre-Cambrian formations which continue into Upper Volta until they disappear in the north under the Palaeozoic plateaux of the Bobo-Dioulasso region. In the south there is a thin coastal strip of Cretaceous and Tertiary sediments.

1. PRE-CAMBRIAN

References for the Pre-Cambrian include Bolgarsky (1950), Bodin (1951), Sagatzky (1954) and Soule de Lafont (1956).

Lower Pre-Cambrian or Dahomeyan. Distinction of a granitic gneiss basement older than the Birrimian cannot be established in the Ivory Coast. In Upper Volta J. Sagatzky (1954) thought he could recognise this Dahomeyan in the form of bands of granitic gneiss at the foot of the Palaeozoic cliff of Bobo-Dioulasso and on the road from Gaoua to Banfora.

In any case the Dahomeyan in these areas has become indecipherable because of its assimilation by Birrimian and post-Birrimian granitic batholiths.

Middle Pre-Cambrian (Atacorian and Birrimian). The magnetiferous or garnetiferous quartzites of the Atacorian have survived only as isolated remnants described from the west of the Ivory Coast.

The Lower Birrimian, with its schists and quartzites, covers immense areas in the basins of the Bagoé, Volta, Yaouré, Comoé, etc. The Upper Birrimian comprises greenstones, schists and manganiferous quartzites. In the Haute-Comoé, M. Arnould has observed ovoid sections which are perhaps foraminifera. All the rocks have been folded NNE.-SSW. and invaded by granitic bodies.

L. Bodin (1951) has given the name "granites Baoulés" to large concordant batholiths, whose type is taken in the Bouaké region, which occupy the major part of the Ivory Coast and Upper

Volta. They exhibit several phases of intrusion and considerable variations in texture. In addition there are discordant batholiths of Bondoukou type, which are post-tectonic. They correspond to the Dixcove Granite in Ghana.

The Charnockites of the Massif de Man. The Ivory Coast has been famed for a long time amongst petrographers for the presence of a calc-magnesian province, with granites containing a special pyroxene, hypersthene. These granites are known by the name "charnockite", which was given them by H. Holland (Holland 1900; Rama Rao 1945) for the series in India. The charnockite series was discovered in the Ivory Coast, in the Massif de Man, by H. Hubert and A. Lacroix (1910) and its detailed study undertaken by P. Legoux (1939).

The Massif de Man, in the west of the Ivory Coast, lies at the eastern extremity of a range of mountains extending west-north-westwards as far as Kissidougou in Guinea. The mountainous massif rises up to 1,000 m. above sea-level, clearly commanding the peneplain whose mean altitude is 250 to 300 m.

Petrographically there is a continuous series from granites to norites. The ordinary granites are calc-alkaline, with biotite, microcline, plagioclase and quartz. The microcline is constant and there is no hypersthene. Garnet, zircon and magnetite are common accessories. Next come leucogranites, which are very light-coloured monzonitic calc-alkaline granites whose essential components are quartz and a potash feldspar, sometimes microcline as in the ordinary granite and sometimes a perthitic orthoclase. The perthite granites grade into hypersthene granites characterised by the co-existence of hypersthene and fusiform perthite. Quartz is abundant, biotite and apatite common.

The noritic series begins with leucocratic norites. These contain quartz and the plagioclases have antiperthitic inclusions of orthoclase, but the potash feldspar never occurs separately, which marks the division between the hypersthene granites and the norites. The series comprises: plagioclases with quartz and a little hypersthene, biotite and magnetite; very leucocratic norites in which pyroxenes are more common; mesocratic norites (containing andesine and labradorite) with hypersthene, augite and amphibole; melanocratic norites, hypersthene with olivine and pyroxene. Beyond this the series passes into metamorphics, pyroxenites and amphibolites. Quartzites with magnetite and garnets also occur.

The pyroxenites and amphibolites are interpreted as metamorphosed old basic igneous rocks (basalts, dolerites and gabbros) such as occur in the Birrimian of the Ivory Coast and Ghana.

Upper Pre-Cambrian or Tarkwaian. Systematic research on the Tarkwaian has revealed some important exposures (Bouige and Bonnault 1938; Sagatzky 1954; Soule de Lafont 1956).

In the centre of the Ivory Coast the Tarkwaian occurs in the Fettekro region and the Yaouré. One sees slightly metamorphosed beds of conglomerate containing large pebbles of rhyolites, basic rocks, granites, etc., derived from the Middle Pre-Cambrian. There are in addition sandstones, more or less quartzitic, showing high dips.

In the east the principal outcrops are between Agnibilékrou and Bondoukou. Coarse arkoses and beds of conglomerate with small pebbles occur west of Transua. In the Zanzan region the slightly metamorphosed conglomerates form hills 200 m. high. Here the beds are subhorizontal and lenticular in form. East of Transua, on Mount Taakroum, the quartzo-phyllitic conglomerates are accompanied by 200 m. of white quartzitic sandstones.

The rocks which correspond to the "Huni Sandstones" in Ghana have been found in the Gnyeurié, Baya d'Amafi and Baya de Méré Valleys. The sandstones contain veinlets and thin lenticles of quartz. Dips are to the WSW.

The whole assemblage gives the impression of a syncline where the youngest rocks have survived, while the Bouyé-Zanzan region would correspond to the top of a highly eroded anticline.

The unconformity on the Birrimian schists and quartzites cannot yet be recognised in the centre of the country but is visible in the east.

2. PALAEOZOIC

Palaeozoic rocks form the southern extremity of the large "Sudanese" plateaux which extend into the north of the Ivory Coast, in Upper Volta, in the Bobo-Dioulasso region.

South of Sikasso (Mali) the base of the cliffs which form the southern boundary of the Palaeozoic plateau shows only conglomerates and sandstones. A little further east, in the Bobo-Dioulasso region, the contact between the Pre-Cambrian and Palaeozoic can be seen. J. Sagatzky (1954) has given details of it. Resting with major unconformity upon the folded basement

comes first of all a group of "Lower Sandstones" with beds of conglomerate. The only fossils are indeterminate trails (Furon 1951). Then comes a horizon of shales and dolomitic limestone with stromatolites of *Collenia* type (Furon 1945; Furon and Prunet 1945), which is put in the Cambrian. In the absence of tillite it is impossible to know what may be assigned to the Cambrian or Infra-Cambrian, but it is apparent anyhow that we are dealing with the horizontal and transgressive base of the Palaeozoic. It is the same horizon that is found further north, in Mali at the foot of the Bandiagara Cliffs, under the "Kontiala Sandstone".

The type locality is Tiéra, 31 km. along the road from Bobo-Dioulasso to Sikasso.

Then follows a third horizon, the "Upper Sandstones", which are attributed to the Ordovician: the "Bandiagara Sandstones".

3. CRETACEOUS AND TERTIARY

References include Maugis (1955) and Abrard (1955).

The Cretaceous and Tertiary seas invaded the lower Ivory Coast. The sedimentary basin extends 320 km. from Fresco in the west to the Ghanian frontier in the east. Its maximum width is 35 km., between Abidjan and Aboisso.

Geophysical researches have revealed the existence of a major collapse parallel to the coast. In the depressed zone the depth of the basement could reach 3,000 m. It is recognised that movement began in the Cretaceous and continued into the Quaternary.

The sedimentary succession is known from the outcrops at Fresco and Eboïnda and from the borings at Abidjan-Locodjo (172 m., with basement at 170 m.), Nzida (107 m. 50), Boroba and Adiaké (120 m.).

Lower Cretaceous: lignitic clays resting on the basement.

Upper Cenomanian: lower limestones of Locodjo (10 m.) with *Plicatulaourneli* Coq.

Lower Turonian: upper limestones of Locodjo (17 m.) with *Exogyraolisiponensis* Sharpe.

Senonian: upper sands of Locodjo, Eboïnda bituminous sands.

Palaeocene: "Ebocco Formation" with *Macrocallista adabionensis* Oppenh., *Corbula atlantica* Furon; "Fresco Formation" with *Nautilus* (J. Malavoy 1935).

Lower Eocene: marine Upper Fresco Formation with disco-cyclines and *Operculina (Nummulitoides) tessieri* Abrard.

"Continental terminal": Fresco shaly sands, Eboinda shaly sands, Ebocco shaly sands, covered by laterites.

REFERENCES

- ABRARD, R., 1955. Une Operculine cordelée de l'Éocène inférieur de la Côte d'Ivoire: *Operculina (Nummulitoides) Tessieri* n. subgen., n. sp. *Bull. Soc. Géol. Fr.* (6), 5, 489-493.
- BODIN, L., 1951. Contribution à l'étude des granites birrimiens dans le Précambrien de l'Afrique occidentale française. *Bull. Dir. Mi., A.O.F.*, No. 12.
- BOUIGE, L. and D. BONNAULT, 1938. La série arénacée dans le centre et dans l'Est de la Côte d'Ivoire. *Bull. Serv. Mines A.O.F.*, No. 2, 57-69.
- BOLGARSKY, M., 1950. Étude géologique et description pétrographique du Sud-Ouest de la Côte d'Ivoire. *Bull. Dir. Mi. A.O.F.*, No. 9.
- FURON, R., 1945. Sur l'extension du Cambrien marin au Sud du Niger. *C.R. Soc. Géol. Fr.*, 181-182.
- 1951. Quelques Problematica du Cambrien de l'A.O.F. *Notes africaines*, Dakar, No. 49, 14-16.
- and J. PRUNET, 1945. Sur la présence du Cambrien marin dans le Nord de la Côte d'Ivoire. *Bull. Mus. Nat. Hist. Nat.*, 452-453.
- HOLLAND, H., 1900. The Charnockite Series. *Mem. Geol. Surv. India*, 28, 2.
- LACROIX, A., Sur l'existence à la Côte d'Ivoire d'une série pétrographique comparable à celle de la charnockite. *C.R. Ac. Sc.*, 150, 18.
- LEGOUX, P., 1939. Le Massif de Man (Côte d'Ivoire). Essai de géologie pétrographique. *Bull. Serv. Mines A.O.F.*, No. 3.
- MAUGIS, P., 1955. Reconnaissance pétrolière (géologique et géophysique) du bassin sédimentaire de la Côte d'Ivoire. *Bull. Dir. Mi. Géol. A.O.F.*, No. 19, 7-95.
- RAMA RAO, B., 1945. The Charnockite Rocks of Mysore (Southern India). *Bull. Mysore Geol. Dept.*, No. 18, 199.
- SAGATZKY, J., 1954. La géologie et les ressources minières de la Haute-Volta méridionale. *Bull. Dir. Mi. A.O.F.*, No. 13.
- SOULE DE LAFONT, D., 1956. Le Précambrien moyen et supérieur de Bondoukou (Côte d'Ivoire). *Ibid.*, No. 18.

CHAPTER XXV

GHANA

1. PRE-CAMBRIAN

The Pre-Cambrian of Ghana is subdivided into four series: Old Pre-Cambrian (Archaean), Middle Pre-Cambrian (Birrimian), Upper Pre-Cambrian (Tarkwaian), Terminal Pre-Cambrian (Buem). Each of these series is separated from the preceding one by a fold phase and unconformity. Igneous bodies have metamorphosed them at various times, contemporaneously or immediately after folding (Junner 1940; Bates 1956, 1957).

1. *Lower Pre-Cambrian.* The Dahomeyan is represented by the granite gneiss of the south-eastern zone. The rocks include ortho- and paragneiss, granites with two micas, quartzites and mica-schists. Garnetiferous gneisses are abundant. The whole assemblage, which is highly folded, has been cut by later granites.

2. *Middle Pre-Cambrian (Birrimian).* The Middle Pre-Cambrian is represented by the Birrimian, named after the formations of the river Birrim, tributary of the Pra. The Birrimian outcrops over a sixth of the surface of Ghana. It is economically the most important of all the geological systems, since it contains gold, manganese and diamonds. The Lower Birrimian consists of schists, slates, phyllites and greywackes. The Upper Birrimian consists of sandstones and schists with an abundance of metamorphosed lavas ("greenstones").

Dips are of the order of 30° to 90°; strikes are usually NE.-SW., underlining the direction of old folds.

The most curious rocks are the "gondites", quartzites with manganiferous garnets, which grade into manganese ores. The manganese oxides of these ores, exploited at Nsuta, are not derived entirely from the weathering of the garnets (spessartites) because the latter are little altered. It seems that originally there was a deposit fairly rich in manganese, part of which was utilised during the formation of the garnets. Manganiferous shales are associated with the gondites. The exploited ores are oxides: psilomelane and pyrolusite.

The Birrimian rocks have been folded, metamorphosed and partly assimilated by granitic bodies. Two post-Birrimian, pre-

Tarkwaian granites are distinguishable, an older granite (G₁) of Cape Coast and Winneba type and a younger granite (G₂) of Dixcove type. The older granite occurs in concordant batholiths, accompanied by pegmatites and quartz veins. The Dixcove Granite, less widespread, contains veins of auriferous quartz.

3. *Upper Pre-Cambrian (Tarkwaian)*. The Upper Pre-Cambrian was defined in the south-west of Ghana, at Tarkwa (Junner, Hirst and Service 1942). Much less folded than the Birrimian, the Tarkwaian occurs in two NE.-SW. synclines; one extending from the region east of Kumasi to Tarkwa, the other, further north-west, from the bend of the Black Volta to the Ivory Coast.

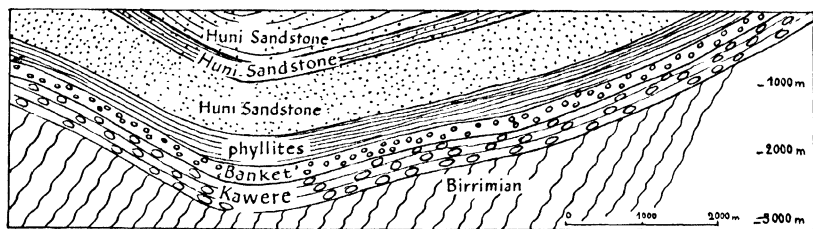


FIG. 17. Section in the Tarkwa Syncline (after Whitelaw).

The Tarkwaian reaches a thickness of 3,000 m. and is subdivided into several units.

At the very base, resting unconformably upon the Birrimian, is the Kawere Group (conglomerates, feldspathic quartzites and shales), well developed in the Bonsa Valley and reaching 500 to 700 m. in thickness near Aboso. Above this group comes the Banket Series, 700 m. thick, well known for its richness in auriferous conglomerates. The conglomeratic horizons are separated by beds of quartzite and sandstone. Certain beds are very rich in haematite. The Tarkwa Syncline has furnished more than 100 tons of gold since the beginning of this century. The third series is known as the Tarkwa Phyllites. It consists of 300 m. of shales and green chloritic phyllites. The highest beds are the Huni Sandstones, which reach 1,500 m. in thickness. These are essentially feldspathic sandstones with lenticular pelitic intercalations known as the Dompim Phyllites.

Numerous igneous bodies cut the Tarkwaian, known as pink dykes and green dykes according to whether they are acid or

basic respectively. The most important is the epidiorite sill, 200 m. thick, in the Huni Sandstones.

4. *Terminal Pre-Cambrian (Buem Series)*. In the east of Ghana the Palaeozoic (Voltaian) rests upon a succession of conglomerates, feldspathic sandstones, limestones, jasper rocks and dolerites, known as the Buem Series. This series is best displayed in Togo (see next chapter).

2. PALAEOZOIC

1. *Voltaian* (Junner and Hirst 1946). The Voltaian covers half the surface of Ghana. Its limits are determined by erosion and as a whole it forms a very large plateau, bordered by cliffs and dissected by the Volta and its tributaries.

The Voltaian corresponds mainly with the Cambrian and Silurian. It is unconformable on the Tarkwaian and other Pre-Cambrian series, excepting the Buem.

British authors subdivide it thus:

Upper Voltaian:

Upper, coarse sandstones (200 m.).

Finely-bedded sandstones (125 m.).

Lower Voltaian:

Obosum Beds (150 m.).

Oti Beds (250 m.).

Basal Sandstones (60 m.).

One can make satisfactory comparisons with the successions in "French West Africa", which are now well known.

The Basal Sandstones, well developed at Bord and west of the Volta Basin, are of continental origin. They often include a conglomerate which is not a basal marine conglomerate but a continental formation with large boulders reaching 50 or 60 cm. in diameter in the Akroso region. Faceted pebbles have been found in it. The matrix is very fine grained and brown and reddish in colour. These are the characteristics of a fluvio-glacial conglomerate, of the "tillite" known at the base of the Palaeozoic from South Africa to Mali.

The Oti Beds are well developed in the Oti Valley and in Lower Volta. They include feldspathic sandstones, shales, siliceous beds (cherts and jaspers) and important lenses of limestone up to 30 m. in thickness, near Okraji and Asuboni. These

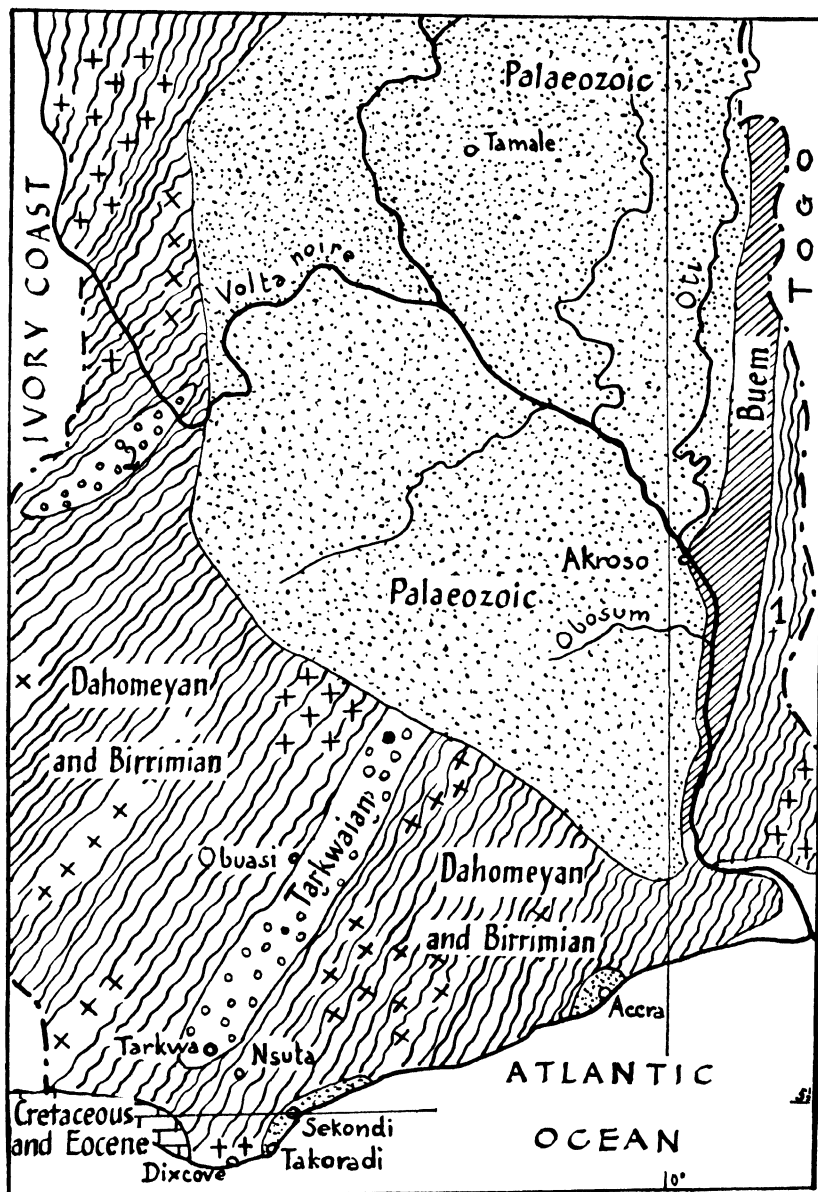


FIG. 18. Geological sketch-map of Ghana.

limestones are rich in silica and magnesia, containing up to 25 per cent. of the former and 15 per cent. of the latter.

The Oti limestones contain sponge spicules and many stromatolites north-east of Yendi and north of Oprida. The Yendi stromatolites recall *Collenia*, forms known in the Sahara and Upper Volta (near Bobo-Dioulasso). The Oti Beds may similarly be regarded as Cambrian or Infra-Cambrian.

The Obosum Beds, defined on the banks of the river of this name, are composed of sandstones and conglomerates in the east and of brown, red and purple shaly beds in the west and north-west. They are about 150 m. in thickness and contain a second "tillite", grey-greenish in colour. The pebbles suggests an origin east of the area of deposition. This tillite bears the name "Sang Conglomerate". It occurs towards the top of the Obosum beds and has been observed over a distance of 250 km. True tillite and fluvio-glacial conglomerates appear to indicate the existence of mountain glaciers in the Atacora Range. The age of this formation remains unknown.

The non-fossiliferous Upper Voltaian consists of 125 m. of finely bedded sandstones at the base and 200 m. of coarse cross-bedded sandstones at the top. The top of the Voltaian may be Devonian, like the top of the Guinea Sandstones.

All the Voltaian has been gently folded. It forms a basin, a syncline south-east of the Leo Anticline. The shales of the Oti Beds are visibly folded more than the conglomerates and sandstones. In the east, all of the Voltaian has been more strongly folded.

2. *Coastal Palaeozoic (Devonian)*. There are two Palaeozoic outcrops on the coast, completely isolated from the large outcrops of the Voltaian.

The first of these exposures is around Accra, where one finds sandstones and sandy shales containing trilobites (*Dipleura (Homalonotus) dekayi* Green), pelecypods (*Nuculites*, *Palaeoneilo*, *Leptodesma*, *Lunulicardium*, *Conocardium*), brachiopods (*Lingula*) pteropods (*Hyolithes*) and gastropods (*Pleurotomaria?*) (Kitson and Davies 1922).

Dipleura dekayi is a species occurring in the American Hamilton Group and indicates a Middle Devonian (Givetian) age.

The second exposure, well to the west, extends from Cape Coast to Sekondi and Takoradi.

The complete succession measures several hundreds of metres in thickness. It is divided, from bottom to top, as follows:

1. Crenulated argilo-calcareous shales and micaceous sands containing pebbles of granite, gneiss, quartz, Birrimian greenstones and Tarkwaian quartzites (Adjua Shales). It may be glacial in origin. At Amanful the succession is seen to lie unconformably on the Dixcove Granite.
2. Chocolate-coloured arkose (Elmina Sandstone, 300 m.).
3. Pyritic and bituminous shales, with beds of ripple-marked sandstone (Takoradi Shales).
4. Sandstones and shales (Efia Nkwanta Beds).

The Takoradi Shales yielded a first group of fossils attributed without doubt to the Carboniferous, but a new group, in better condition of preservation, has enabled L. R. Cox to determine new forms with much stronger affinities to the Devonian than to the Carboniferous. They include gastropods (*Pleurotomaria batesi* Cox) pelecypods (*Palaeoneilo junneri* Cox, *Nuculana* cf. *diversa* Hall, *Sphenotus sekondiensis* Cox) and a brachiopod (*Lingulodiscina guineensis* Cox) (Cox 1946; Crow 1952).

3. CRETACEOUS AND TERTIARY OF THE COAST

“*Continental Intercalaire*”. Continental sediments have been discovered at the mouth of the river Amisa, between Accra and Sekondi. They contain the remains of unidentified plants, ostracods and *Bairdestheria*, known in the Upper Jurassic and Lower Cretaceous. These sediments bear the local name “Amisian System”.

Marine Cretaceous. The Cretaceous and Tertiary formations of the Ivory Coast continue into Ghana. They are of considerable importance on the western part of the coast, since the Takinta Borehole went through 1,300 m. of sediment without reaching the Pre-Cambrian.

One finds at the base 800 m. of sandstones and clays of diverse origin (lacustrine, lagoonal and marine) containing several oil-bearing horizons.

The first genuine marine horizon is that of the Anwiafutu Limestone with *Plicatula aurensensis* and *Exogyra olisiponensis* (Upper Cenomanian-Turonian).

The Nauli Limestones contain a Senonian (more particularly Campanian) fauna with *Trigonarca curvatodonta*, *T. camerunensis*,

Plicutala renniei, *Venericardia nauliensis* (formerly confused with *V. beaumonti*), *Calyptrophorus africanus*, etc. (Cox 1952).

The whole Cretaceous is known as the Apollonian.

Eocene. The Tertiary begins with fossiliferous Palaeocene, described by Cox (1952), comparable to that in Senegal, Togo and Dahomey.

From the Apatuema Well (near the Togo frontier) Cox cites: *Fibularia (Eoscutum) seefriedi* Oppenheim, *Callianassa seefriedi* von Ammon, *Venericardia junneri* Cox, *Fimbria furoni* Cox, *Calyptraea aperta* Sol., *Calyptrophorus subhumerosus* (Opp.), *Pseudaulicina simplex* Furon, etc.

Among the other material, L. M. Davies has recorded disco-cyclines and nummulites; F. Oates has noted *Ficus (Pirula)* sp.

At some time in the Middle or Upper Eocene the sea withdrew and the present coastline has beds of the "Continental terminal".

4. QUATERNARY VOLCANISM AND EARTHQUAKES

The lateritic plateau of the coastal region has an elevation of 60 to 70 m. above sea-level. Along the coast are a series of marine terraces, at 1, 7, 12, 25 and 30 to 40 m.

Traces of a Pleistocene volcano survive in the Bosumtwi Caldera, occupied today by a lake. The lake level is 100 m. above sea-level, and is overlooked by the walls of the caldera which rise up to 500 m. The volcanic products include breccias, bombs and dacitic pumice (Junner and McGregor 1937).

The study of earthquakes confirms that a fault borders the coast and explains the unforeseen thickness of the Mesozoic and Tertiary sediments.

REFERENCES

- BATES, D. A., 1956. Gold Coast and Togoland. *Lexique stratigraphique international*, vol. 4. Afrique, Fasc. 3, Paris.
- 1957. The geological evolution of the Gold Coast. *C.R. 2nd meeting of the C.C.T.A.*, Accra, 13-22.
- COX, L. R., 1946. The fossils and age of the Sekondi Series (Upper Palaeozoic) of the Gold Coast. *Ann. Mag. Nat. Hist.* (II), 13, 602-624.
- 1952. Cretaceous and Eocene fossils from the Gold Coast. *Bull. Gold Coast Geol. Survey*, No. 17, p. 68.
- CROW, A. T., 1952. The rocks of the Sekondi Series. *Ibid.*, No. 18, p. 68.
- JUNNER, N. R., 1940. Geology of the Gold Coast and western Togoland, with revised Geological Map (1:1,000,000). *Ibid.*, No. 11.

- and D. P. MCGREGOR, 1937. The geology of the Bosumtwi Caldera and surrounding country. *Ibid.*, No. 8.
- T. HIRST and H. SERVICE, 1942. The Tarkwa Coalfield. *Mem. Geol. Survey Gold Coast*, No. 5.
- and T. HIRST, 1946. The Geology and Hydrology of Voltaian Basin. *Ibid.*, No. 8.
- KITSON, A. E. and A. M. DAVIES, 1922. Devonian rocks at Accra, Gold Coast. *C.R. XIII Intern. Geol. Congr.*, Brussels, 945-947.

TOGO AND DAHOMEY

Togo and Dahomey belong essentially to a Pre-Cambrian domain, and geological studies are concerned with solution of the problems posed by the Atacora Range. A little Palaeozoic is present in the west of Togo and some Cretaceous and Eocene in the coastal zone of both Dahomey and Togo.

References include Hubert (1908), Roques (1948, 1951-2), Junner (1940), Pougnet (1959) and Aicard (1959).

1. PRE-CAMBRIAN OF THE ATACORA

The Atacora Range extends more than 1,000 km. in a SSW.-NNE. direction from the Accra region in Ghana into western Nigeria, through Togo and the north-west of Dahomey. Beyond the Niger the system disappears under Recent deposits. This range is about 50 km. wide. It forms a remarkable relief feature in this region of Pre-Cambrian peneplains. Its mean altitude is 500 m. with highest points at about 1,000 m. (e.g. the Atilaousé, Togo, 990 m.).

Lower Pre-Cambrian. The Lower Pre-Cambrian (Dahomeyan of M. Roques, 1948) is composed of granites, gneisses and mica-schists spread over a wide area in the centre and east. The gneisses are affected by NNE.-SSW. folds. There are also diorites, gabbros and peridotites, which have given rise to serpentines. One must note, because of its rarity, a magnificent eclogite, with garnets disseminated in a mass of grass-green omphazite. This rock is associated with the garnetiferous orthoamphibolites of Mont Lato (Togo).

Middle Pre-Cambrian. The Middle Pre-Cambrian is given different names in different regions: "Akwapimian" in Ghana and the old British Togoland, *série du Togo* in Togo proper and *série de l'Atacora* (or Atacorian) in Dahomey.

It is characterised by thick beds of quartzites separated by pelitic beds. These quartzites, which are often micaceous, are accompanied by itacolumites and itabirites. Generally speaking

they exist as relief features forming the main part of the Atacora Range.

The stratigraphic position of this succession is much disputed. No unconformity on the granite-gneiss complex has actually been observed but is generally admitted by geologists. In Dahomey, in particular, folded quartzites describe an arc which cuts the NNE.-SSW. striking granite-gneiss complex (Pognet 1948).

The Atacora quartzites have locally been invaded and assimilated by granites containing biotite and often muscovite. Traces of manganese have been found.

Discussions on stratigraphical relationships took place in 1948 at the International Geological Congress in London between English and French geologists. No agreement was reached, since the former place the Akwapimian above the Birrimian.

The stratigraphical position and lithological character enabled M. Roques to include the Irikouakou Sericitic Schists, in Dahomey, in the Lower Birrimian. The Upper Birrimian appears to be missing entirely.

Terminal Pre-Cambrian. The question of the Terminal Pre-Cambrian is also a delicate one. The relevant rocks are the "Buem Series", defined by Koert in 1910, which occupy a band of ground, 30 km. wide, immediately to the west of the Atacora Quartzites.

When the succession is complete, it comprises, from bottom to top:

1. Shales and arkose at the base.
2. White feldspathic sandstones, with quartz veinlets, and conglomerates at the top, sometimes containing a little gold.
3. Calcareous shales, limestones and tillite.
4. Volcanic group (mostly basalts and dolerites, together with some rhyolites).

In Dahomey the Buem rests on the Atacora, according to Chermette. The sandstones pass there into jaspers.

Comparisons can be made with other West African types, notably with the "Falemian" or Infra-Cambrian (e.g. the presence of limestones and tillite).

In the west the Buem Series disappears under the Oti Series, which we regard as Cambrian. The contact is visible at at least

one place, Akroso, on the Lower Volta on the Togo-Ghana frontier. Here the Oti Series begins with a conglomerate containing pebbles of Atacora-Akwapimian greenstones and Buem jaspers.

According to Roques, the Terminal Pre-Cambrian is intruded by chromite-bearing serpentines. These serpentines are of considerable economic interest since exploitable bodies of chromite occur both in Togo (Mont Djéti, Mont Ahito, etc.) and Dahomey (Cercle de Natitingou) (Arsандаux 1935; Chermette 1938; Koert 1909; Roques 1949).

Tectonics. The Atacoran range is folded like the rest of the Pre-Cambrian but is preserved in abnormal relief. The most violent folding occurred in the west, *where it has affected the Palaeozoic sediments of the Voltaian*, which are upturned on the border of the range. Generally it is impossible to recognise the connection between the Pre-Cambrian and Palaeozoic because the contacts are abnormal, the whole of the western border of the Atacoran Range being faulted. It must therefore be recognised that the Atacoran Range was produced by movements at two different times, the first in the terminal Pre-Cambrian as in the neighbouring regions and the second later than the Palaeozoic deposits, perhaps at the time of the Hercynian orogeny.

There would seem to be an important line of dislocation which was rejuvenated on several occasions, as is the case in many other areas.

2. "CONTINENTAL INTERCALAIRE"

The Pre-Cambrian in the north of Dahomey is covered by the "Kandy Sandstones" whose lower part (120 m.) contains trunks of silicified wood and passes into the "Illo Group" and "Gundumi" sandstones of Nigeria (Pougnet 1949).

3. CRETACEOUS AND EOCENE OF THE COAST

The Cretaceous and Eocene seas invaded the coastal region of Togo and Dahomey. Deposits of this age are covered by more recent ones, red in colour, known as the *terre de barre*, which are in part aeolian sand accumulations.

A little back from the coast, erosion has removed this cover and exposed Eocene sediments seen in Dahomey at the bottom of the

Hollis-Lama Depression, extending E.-W. from the Nigerian to the Togo frontier.

The limestones of the Lama, discovered by H. Hubert, have a much greater importance than was thought. They reach 300 m. in thickness.

Elsewhere, seismic prospecting has revealed a very sharp flexure of the margins of the old basement, which is found at a depth of about 1,800 m. at Cotonou.

In the west outcrops are found in the Mono Valley at Missini-kondji (Dahomey) and between Torkpli and Adabion (Togo). It was in this region that Koert discovered a group of Eocene fossils (Stromer von Reichenbach 1910, Oppenheim 1915).

Where the Eocene and Cretaceous beds are hidden by younger deposits they are known through wells and boreholes. The most interesting well in Togo is that of Togblékové, 17 km. north of Lomé, which goes down 41 m., where N. Kouriatchy noted a bluish marl with foraminifera at 26 m., a bed of phosphatic limestone at 38 m. and a fossiliferous limestone at 38 m. 50 to 41 m. 50. The fossiliferous limestone yielded quite an important fauna (some fifty species). A few species are like those of Adabion, described by Oppenheim (1915), but the others are new. The assemblage is of Palaeocene age (Furon and Kouriatchy 1948): *Meretrix grüneri* Opp., *M. (Callista) proxima* Desh. var *montensis* Cossm., *Corbis sub-davidsoni* Furon, *Venericardia koerti* Opp., *Plicatula huberti* Furon, *Rostellaria (Cyclomolops) subhumerosa* Opp., *Galeodea (Cassidaria) kouriatchyi* Furon, *Lapparia (Pseudaulicina) simplex* Furon, *Clinuropsis togoensis* Opp., *Tornatella africana* Furon, etc. Fish: *Pycnodus variabilis* Stromer, *Myliobatis dixonii* Ag., *Hypolophites myliobatoides* Stromer, *Odontaspis macrotis* Ag. mut. *striata* Winkler and *Ginglymostoma* sp. have been discovered in the well at Adabion, described by Stromer and compared by M. Leriche to the fauna of Landana, by White to that of Nigeria. The discoveries made in Senegal confirm the Montian age of the molluscan fauna.

Numerous boreholes for water, phosphate and oil have allowed the establishment of a detailed stratigraphical column for the coastal basin from Montian upwards.

M. Slansky (1958) gives the following composite section (from bottom to top):

Maestrichtian: about 200 m. thick, beginning with unfossiliferous sands, continuing with a group of coals (like the Upper Coal

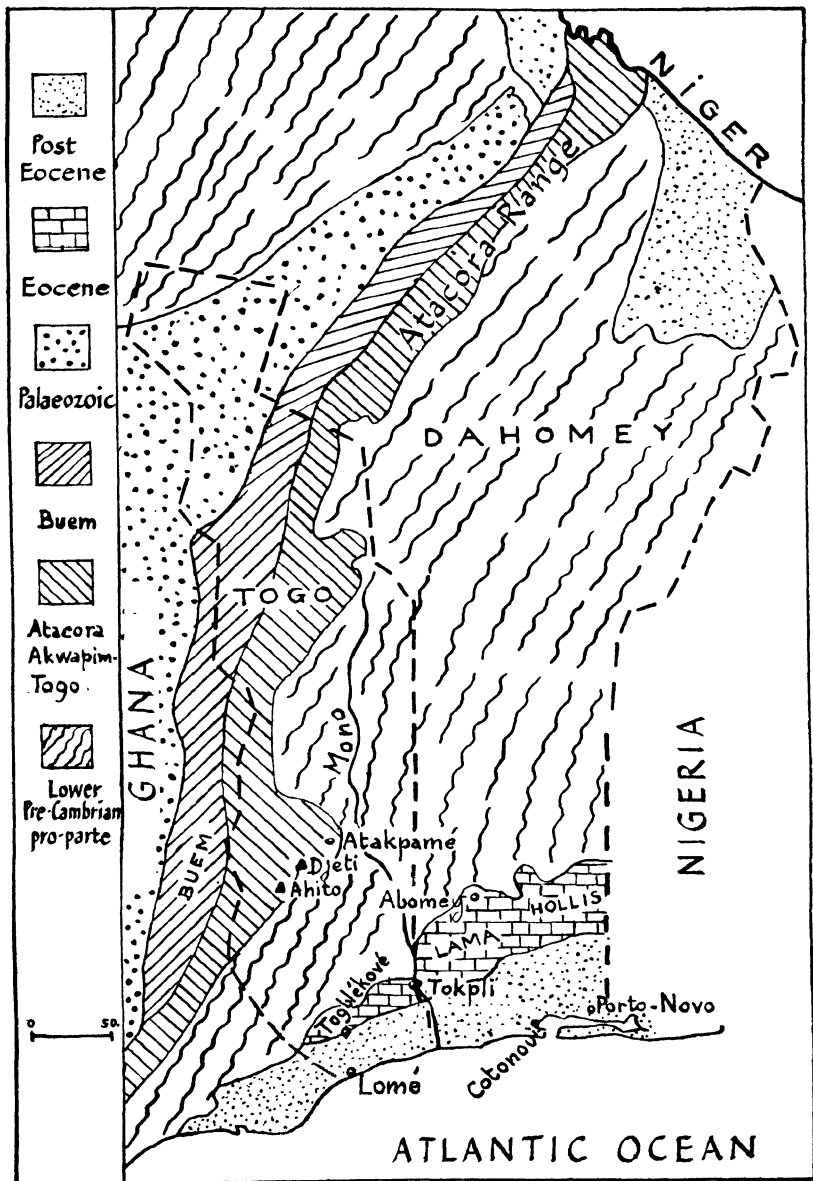


FIG. 19. Geological sketch-map of Dahomey and Togo.

Measures of Nigeria²), clays and marls, and topped by a fossiliferous horizon with *Roudaireia drui* and microforaminifera.

Palaeocene (*Montian-Thanetian*): about 50 m. thick, concordant on the Upper Cretaceous, with a horizon of sandy limestones containing *Togocyamus seefriedi* and all the macrofauna described by Furon from Togo.

Ypresian: this begins with marls and limestones with corded nummulites and in particular *Ranikothalia sahnii-savatriae* Davies.

One must here lay stress on a merely verbal argument which has retarded understanding of the stratigraphical position of these corded nummulites, some speaking of the Sparnacian and others of the Ypresian, while it has been known for years that the Sparnacian is only a continental facies of the Lower Ypresian. *Thus we are concerned simply with the base of the Ypresian*, that must be carefully isolated from the Palaeocene, which can only include the Montian and Thanetian. It goes without saying that the boundary between the true Palaeocene and Ypresian is very difficult to determine in Africa.

Lutetian: this begins with a phosphatic facies; it is dated by microforaminifera (*Nonion*, etc.) and by *Raeta schweinfurthi* Mäyer-Eymar and *Plicatula polymorpha* Bellardi. Slansky records also an unidentified corded nummulite which is *not N. nuttali* Davies (recorded earlier in error).

"*Continental terminal*": sandy and clayey beds at the base; *terre de barre* at the top. The total thickness ranges up to 100 m.

REFERENCES

- AICARD, P., 1959. Le Précambrien du Togo et du Nord-Ouest du Dahomey. *Bull. Serv. Mi. Géol.*, Dakar, No. 23.
- ARSANDAUX, H., 1935. Sur la chromite du Mont Djéti, Cercle d'Atakpamé, Togo. *Bull. Soc. Fr. Miner.*, **48**, 70-76.
- CHERMETTE, A., 1938. Le gisement de chromite de Bontomo (Haut-Dahomey) *Bull. Serv. Mi. A.O.F.*, No. 1, 67-73.
- FURON, R. and N. KOURIATCHY, 1948. L'Éocène du Togo. *Mém. Muséum Nat. Hist. Nat.*, **27**, 95-114.
- HUBERT, H., 1908. Mission scientifique au Dahomey. (Thesis.) Larose ed., 568 pp., 1 geol. map.
- JUNNER, N. R., 1940. Geology of the Gold Coast and Western Togoland. *Bull. Gold Coast Geol. Surv.*, No. 11.
- KOERT, W., 1909. Zur Chromeneisenstein Vorkommen in Atakpamebezirk. *Amst. Schutzgeb. Togo*, p. 379.

- OPPENHEIM, P., 1915. Die eocäne Invertebraten-Fauna des Kalksteines in Togo. *Beitr. Geol. Erf. Deutsche Schutzgebiete*, 12.
- POUGNET, R., 1948. Sur les relations de l'Archéen et des quartzites de l'Atacora au Dahomey. *C.R. Ac. Sc.*, **226**, 2161.
- 1949. Stratigraphie et identification des formations continentales du Moyen-Niger et du Haut-Dahomey. *Bull. Soc. Géol. Fr.* (5), **19**, 493-498.
- 1959. Le Précambrien du Dahomey. *Bull. Serv. Mi. Géol.*, Dakar, No. 22.
- ROQUES, M., 1948 (1949). Le Précambrien de l'Afrique occidentale française. *Bull. Soc. Géol. Fr.* (5), **18**, 589-628.
- 1949. Géologie de l'Afrique occidentale. In *Encyclop. marit. et coloniale*, vol. A.O.F., p. 201.
- 1951-1952. Observations nouvelles sur le Précambrien de l'A.O.F. et du Togo-Dahomey. *Rapp. ann. Serv. Géol. A.O.F.*, 22-26.
- SLANSKY, M., 1958. Vue d'ensemble sur le bassin sédimentaire côtier du Dahomey-Togo. *Bull. Soc. Géol. Fr.* (6), **8**, 555-580.
- STROMER VON REICHENBACH, E., 1910. Reptilien und Fischreste aus dem marinen Alttertiär von Sud-Togo (Westafrika). *Z.D. Geol. Ges.*, **62**, 478-507.

NIGERIA

Nigeria presents several points of interest: tin-bearing granites and fine fossiliferous Cretaceous and Eocene beds indicating the gulf link between the Guinea region and the Mediterranean, with faunas showing similarities with both Niger and the Elobi Islands (Tattam 1943, 1956).

1. PRE-CAMBRIAN

References include Mackay, Greenwood and Rockingham (1949) and Jacobson, Macleod and Black (1958).

The whole of the Pre-Cambrian has been grouped together by British authors as the "Basement Complex". It is ordinarily described as a large zone of gneisses, mica-schists, schists and amphibolites invaded by batholiths of the "Older Granites". Certain stanniferous pegmatites are associated with these granites (Jacobson and Webb 1946). It is impossible at present to establish subdivisions in the Pre-Cambrian of Nigeria, or to know how many bodies of Older Granite there are.

These granites, dark in colour, quite often form isolated peaks and hummocks in typical inselberg terrain. Thus the Shau Inselberg, in the Solli Mountains, reaches 1,600 m. in altitude, overlooking the granite-gneiss complex of the Bauchi Plateau by 300 m. Solution produces singular erosion features. There is even a grotto in the granite of the Gokar Inselberg, 8 m. deep and 7 m. high at the entrance. It has been formed by solution and water erosion along a horizontal joint.

Younger Granites. The Bauchi Plateau, on the left bank of the Niger, is well known because of the exploitation of cassiterite, wolfram and columbo-tantalite. These minerals are associated essentially with bodies of these granites, which are younger than the Older Granites and probably end-Pre-Cambrian or Cambrian in age. They are "young" because of this and because they have not been crushed by later tectonic movements. They were profoundly eroded before the deposition of the "Continental intercalaire". Several types of rock are distinguishable. The com-

monest type is biotite granite, accompanied by a few rhyolites; no cassiterite is found. Nor do the riebeckite granites, less abundant, contain this mineral. One also meets with porphyritic granites, microgranites and rhyolites, occurring marginally. It is accepted that tin and tungsten were concentrated in residual fluids near the end of consolidation of the biotite granite and they are found in greisen and small mineralised veins (in cassiterite, wolfram and columbo-tantalite). These younger granites are

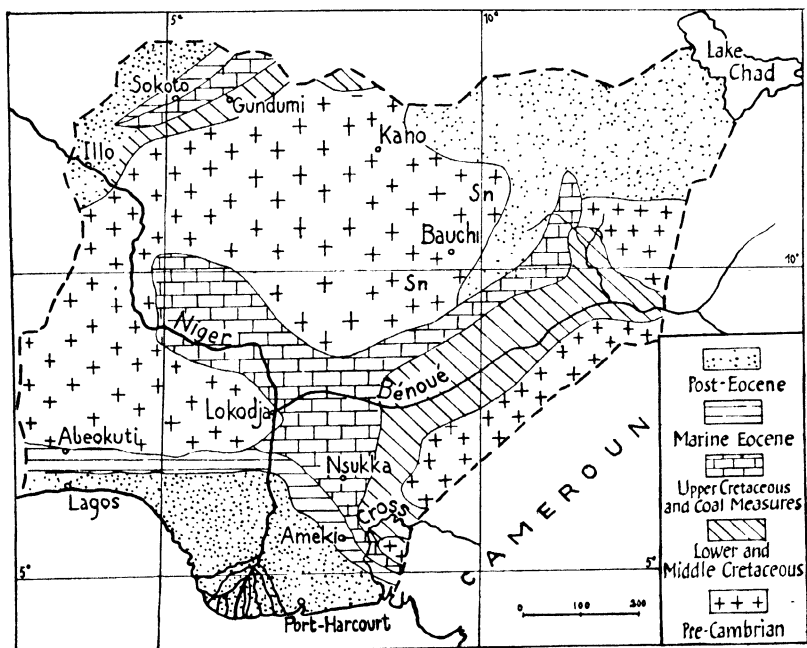


FIG. 20. Geological sketch-map of Nigeria.

generally of light colour and exhibit ring structures (Jacobson, Macleod and Black 1958).

2. "CONTINENTAL INTERCALAIRE"

In the Benue Valley and the Bornou the "Continental intercalaire" is represented by 500 m. of sandstones, marls and variegated shales, which are sometimes saliferous (Lower Grits and Sandstones, Bima Sandstones, etc.).

In the west, in Sokoto Province near the Niger-Dahomey frontier, the "Continental intercalaire" is represented by the Illo Group, whose shaly sandstones contain silicified wood, and by the Gundumi Group (Upper Sandstones).

These continental formations are covered in certain places by the transgressive marine Upper Cretaceous and sometimes by the "Continental terminal" (shaly sandstones of the Giwandu Group).

3. MARINE CRETACEOUS

Albian. Evidence of marine transgression in Upper Albian times is found in the south-east of Nigeria in the Benue Valley. Several fossiliferous localities (Ishiago, Enjiba, Arofu) have yielded an ammonite fauna: *Pervinquiera depressa* Spath, *P. quadrata* Spath, *Elobiceras newtoni* Spath (a species found in the Albian of Mozambique), *E. cf. lobitoense* Spath, *Stoliczkaia* sp., *Anisoceras cf. perarmatum* Pictet and Camp. (Spath 1928).

Cenomanian and Turonian. In the valleys of the Benue and its tributary the Gongola, slightly magnesian, sandy, yellowish limestones occur containing a fauna attributed to the Lower Turoñian, but which could embrace the Upper Cenomanian, including *Micropedina olisiponensis* Forbes, *Ostrea praelonga* Sharpe, *Exogyra olisiponensis* Sharpe, *Hoplitoides nigeriensis* Wood, *Thomasites jordani* Perv. and numerous *Vascoceras*. This is the same horizon as at Damergou in Niger.

The Turonian fauna, studied by R. A. Reyment (1954, 1955a and b, 1956) and W. Barber (1957), is extremely rich. I shall only mention here the cephalopods: *Coilopoceras discoideum* Barber, *Epengonoceras dumbli* Cragin, *Eotissotia simplex* Barber, *Vascoceras nigeriense* Woods, *V. polygonum* Barber, *V. bulbosum* Reyment, *V. globosum* Reyment, *Fagesia simplex* Barber, *Nigericeras gongilense* Woods, *Pseudotissotia nigeriensis* Woods, etc.

Upper Cretaceous. In the south the Upper Cretaceous comprises the Awgu Ndeaboh shales with *Venericardia nauliensis* Cox and the Nkporo shales with *Libycoceras ismaelis* (Zittel) and *Didymoceras cf. hornbyense* Haughton, of the Maestrichtian.

In the north-west (Sokoto Province) the Upper Cretaceous is represented by limestones with *Veniella undata* Conrad, fish (*Lamna biauriculata* Wanner, *L. libyca* Quaas, *Schizorhina stromeri* Weiber, *Stephanodus libycus* Dames) and reptiles (*Mosasaurus nigeriensis* Swinton).

In the north-east, fossiliferous marine Cretaceous has been found at 700 m. depth in the Maiduguri Borehole (Chad Province).

4. THE COAL MEASURES

In the south-east of Nigeria, in the region south of the Benue, is the Nsukka-Enugu Coal Basin. There are there some 1,000 m. of sandstones and black shales containing five beds of coal, of which the most important one reaches 1 m. 50 in thickness.

The first traces of coal are found close to the base in the Enugu Shales. A few plant impressions have been found which suggest an end-Cretaceous or Lower Eocene age (*Salvinia formosa*, *Thyphacites kitsoni* Stopes, *T. latissimus* Brown). The problem of the age has been more or less resolved since geologists of the d'Arcy Shell Company discovered *Libycoceras angolense*, of the Maestrichtian, right at the base of the Enugu Shales (Simpson 1954).

The Enugu Shales are overlain successively by the Lower Coal Measures, the White Sandstones, the Cross-bedded Sandstones and Upper Coal Measures.

South-west of Okigui the Coal Measures are overlain by the Imo Shales, which contain Palaeocene foraminifera. The Coal Measures are therefore end-Cretaceous in age.

5. EOCENE

Southern Nigeria. Southern Nigeria was invaded by the Palaeocene Sea, which left 1,000 m. of foraminiferal shales in the Onitsha and Owerri districts. These are the Imo Shales with *Globorotalia compressa*, *Globigerina pseudobulloides*, *G. triloculinoides* etc.

In south-west Nigeria there occur shaly sandstones, soft sandstones and shales containing phosphatic beds. These are the Oshosun Phosphatic Beds, in Abeokuta Province (north of Lagos), which rest directly on the crystalline basement not far from the coast. The fauna includes moulds of molluscs, vertebrae of a sea snake, *Palaeophis africanus* Andrews, fish teeth (*Ginglymostoma serra* Leidy, *Odontaspis koerti* Stromer, *Carcharinus nigeriensis* White, *Myliobatis toliapicus* Ag., *Trichiurus oshosunensis* White and *Cylindracanthus rectus* Ag.) and orthophragmines.

These lagoonal and estuarine deposits range up to 100 m. in thickness. They pass eastwards into other Eocene beds with a

better molluscan fauna accompanied by the same species of fish. The Oshosun Beds are Lutetian in age (Bather 1904; Newton 1905; White 1934; Swinton 1930).

The molluscan fauna, studied by R. B. Newton, is very rich. The principal species are: *Rostellaria unidigitata* Newton, *R. bidigitata* Newton, *Surcula ingens* M. Eymar (Bartonian), *S. africana* Newton, *Athleta lugardi* Newton, *Volutospina multispinosa* Newton, *Strepsidura spirata* Newton, *Cornulina minax* Sol. (Bartonian), *Bulbifusus nigeriensis* Newton (close to *B. inauratus* of the Lutetian of Alabama), *Turritella mauryana* Newton, *T. cf. sulcifera* Desh. (Lutetian-Bartonian), *Neverita cf. calvimontana* Desh. (Lutetian), *Calyptrea crepidularis* Lamarck, *Plicatula polymorpha* Bell. (Upper Mokattam), *Fossularia africana* Newton, *Glycimeris nigeriensis* Newton, *Divaricella oppenheimi* Newton, *Cardita cf. planicosta* Lamarck, *Callista kitsoni* Newton, *Mactra semisulcata* Lamarck (Lut.-Bart.), *Raetomya schweinfurthi* M. Eymar (Upper Mokattam and Libya), *Corbula rugosa* Lamarck and *Belosepia sepioidea* Blainv. (Newton 1922).

There are in addition numerous foraminifera and a few fish: *Trichiurus oshosunensis* White, *Cylindracanthus rectus* Ag. *Eaglesomia eaglesomei* White, *Odontaspis koerti* Stromer, *Carcharinus nigeriensis* White, *Myliobatis dixonii* etc. (White 1926).

Northern Nigeria. Marine Eocene has been recognised in the north-west of Nigeria, in Sokoto Province. It is the local continuation of the Adar Doutchi succession. Like the latter it succeeds the Upper Cretaceous without recognisable unconformity. The age is Lower Eocene (Montian-Ypresian) (Russ 1924; White 1926; Newton 1911).

Besides two classic echinoids (*Plesiolampas saharæ* Bather and *Linthia sudanensis* Bather) and a few molluscs (*Panopea sahariensis* Newton, etc.) there is a fine group of fish and reptiles coming from four beds at Wurno, Gada, Ruampeli and Sokoto.

The fish, determined by E. I. White, include *Squatina nigeriensis* White, *Hypolophites myliobatoides* Stromer (known from the Palaeocene of Togo, Cameroun and Landana), *Myliobatis wurnoensis* White, *Eotorpedo hilgendorfi* Jaekel (first discovered in Cameroun), *Pycnodus variabilis* var. *togoensis* Stromer (known from the Palaeocene of Togo).

The reptiles are four in number: *Wurnosaurus wilsoni* Swinton, *Rhabdognathus rarus* Swinton, *Sokotosaurus nopsai* Swinton and *Dyrosaurus minor* Swinton, very close at least to *D. phosphaticus*

Thomas, of the Palaeocene of north Africa, Senegal, Soudan and Togoland.

In Sokoto Province the sea retreated and the Lower Eocene is covered only by continental sandy and shaly sediments.

6. "CONTINENTAL TERMINAL"

In the south of Nigeria is an undated post-Eocene continental succession, the Lignite Group. This consists of about 25 m. of sandstones and shales containing two beds of lignite, one of which is nearly 3 m. thick. This group is known over a distance of 80 km., between the river Imo and Oba, near the Niger. It is covered unconformably by the Benin Sands. These are honey-coloured shaly sands, which are consolidated in the east. They range locally up to 250 m. in thickness and are regarded as Plio-Pleistocene in age.

In north-eastern Nigerian the post-Eocene continental succession is widely represented by the Chad Sands comprising up to 700 m. of shaly sands, sandstones and diatomites. Besides the surface subfossil fauna the Chad Sands have yielded *Hippopotamus imagunculus* Hopwood, of the Lower Pleistocene, which was found in a well at 63 m. depth.

Recent Volcanism. In Bauchi Province (Sura district) J. D. Falconer (1926) has studied a group of volcanoes whose cones, partly composed of ash, are aligned for 15 km. along a N.-S. fracture. Emerging from the granite-gneiss complex are five main volcanoes, which have erupted blue-black basaltic lavas containing crystals of augite and olivine. They cannot be old as the craters are well preserved.

In contrast, other, older basalts occur a little to the south-west of the recent volcanoes, in the Baron and Mounkar Basins. These are evidence of old lava flows, remains of basaltic volcanoes with no crater preserved and a deposit of fluvio-volcanic sediments with basaltic detritus. The whole assemblage ranges in thickness up to 250 m. and is dissected by valleys. Originally these rocks must have extended much more widely over the Bauchi Plateau.

REFERENCES

- BARBER, W., 1957. Lower Turonian ammonites from north-eastern Nigeria. *Bull. Geol. Surv. Nigeria*, **26**, pp. 68, pl. 34.

- BATHER, F. A., 1904. Eocene echinoids from Sokoto. *Geol. Mag.* **1**, 292-304.
- JACOBSON, R. R. E., W. N. MACLEOD and R. BLACK, 1958. Ring Complexes in the Younger Granite Province of Northern Nigeria. *Mem. Geol. Soc. London*.
- MACKAY, R. A., R. GREENWOOD and J. E. ROCKINGHAM, 1949. The geology of the Plateau Tinfields-Resurvey 1945-48. *Bull. Geol. Surv. Nigeria*, No. 19.
- NEWTON, R. B., 1905. Eocene shells from Nigeria. *Ann. Mag. Nat. Hist.* (7), **15**, 83-90.
- 1911. Fossil Mollusca from Southern Nigeria. *Ibid.* (8), **8**, 202-206.
- 1922. Eocene Mollusks from Nigeria. *Bull. Geol. Surv. Nigeria*, No. 3.
- REYMENT, R. A., 1954. New Turonian ammonite genera from Nigeria. *Col. Geol. Min. Res.*, **4**, 149-164.
- 1955a. Upper Cretaceous Mollusca from Nigeria. *Ibid.*, **5**, No. 2.
- 1955b. Cretaceous Ammonoidea of Southern Nigeria and the Southern Cameroons. *Bull. Geol. Surv. Nigeria*, No. 25, pp. 112.
- 1956. On the stratigraphy and palaeontology of Nigeria and the Cameroons. *Geol. Fören. Stockh. Förh.*, **78**, 17-96.
- RUSS, W., 1924. The Phosphate Deposits of Abeokuta Province, with a Note by C. W. Andrews. *Bull. Geol. Surv. Nigeria*, No. 7.
- SIMPSON, A., 1954. The Nigerian Coalfield. *Ibid.*, No. 24.
- SPATH, L. F., 1928. The Albian Ammonoidea of Nigeria. *Ibid.*, No. 12, 51-54.
- SWINTON, W. C., 1930. On fossil Reptilia from Sokoto Province. *Ibid.*, No. 13.
- TATTAM, C. M. 1943 (?). A review of Nigerian Stratigraphy. *Ann. Rep. Geol. Surv. Nigeria* for 1943.
- 1956. In *Lexique stratigraphique international Vol. Afrique, fasc. Nigeria*.
- WHITE, E. I., 1926. Eocene Fishes from Nigeria. *Bull. Geol. Surv. Nigeria*, No. 10.
- 1934. Fossil Fishes of Sokoto Province. *Ibid.*, No. 13.

CHAPTER XXVIII

CAMEROUN AND RIO MUNI ISLANDS OF THE GULF OF GUINEA

The Pre-Cambrian basement outcrops over most of Cameroun. The Cretaceous and Tertiary seas invaded a wide area in the coastal region. A large NE.-SW. tectonic trough is marked out by volcanoes, the most important of which, Mont Cameroun (4,000 m.), is still active.

Systematic exploration began in the 1860s. The first ascent of Mont Cameroun was undertaken in 1861 by a party including Calva, the English explorer Burton and the German botanist Mann. The fundamental geological publications are those of Passarge and Stromer von Reichenbach (1895-1896), Esch (1900-1904), Guillemain (1908-1909) and Hassert (1909-1912), augmented by contributions from petrographers and palaeontologists.

Since the 1914-1918 war the British Cameroons has been studied by Wilson. In 1939 B. Gèze studied Mont Cameroun and the Franco-British frontier zone. The former French zone was mapped by the *Service des Mines et de la Géologie* (Gazel, Hourcq and Nicklès 1956; Koch 1959; Lasserre 1958).

1. PRE-CAMBRIAN

The *Lower Pre-Cambrian*, still called the Basal Complex, is composed of crystalline schists (ectinites and migmatites) and older granites. Tectonically it is very disturbed.

The *Middle Pre-Cambrian* appears to be represented by a number of rock groups (Lom, Poli, Ayes and Mbalmayo-Bengbis) which form an important folded complex consisting of amphibolitic schists, lavas and quartzites cut by granitic bodies.

The *Upper Pre-Cambrian* seems to be represented by the Lower Dja and Mangbeï successions. Both of these begin with quartzites, sandstones and shales, but whereas the Lower Dja ends with a tillite, the shales of the Mangbeï are followed by arkosic sandstones, andesites and rhyolites.

Finally there are a few "younger granites" with pegmatitic veins containing cassiterite, wolfram, tourmaline and molybdenite.

These stanniferous riebeckite granites are of unknown age. They always occur as ring dykes, are associated with rhyolites and locally have been broken up into prismatic blocks (Koch 1959).

Koch shows clearly that these late granites are associated with major tectonic events and those that he studied in Cameroun fall exactly along the Cameroun-Chad line. Unfortunately the true age of these events is not known, since the present structural form is due without doubt to the rejuvenation of very old faults. It can be recalled that similar developments in Africa and Madagascar are of post-Triassic, pre-Cretaceous age, but there is nothing to prove that all these late granites are of similar age. I leave them, as does Koch, in the Pre-Cambrian, while stressing their singular character.

2. "CONTINENTAL INTERCALAIRE"

No Palaeozoic rocks are known in Cameroun. The basement is directly overlain by the "Continental intercalaire".

In the coastal region this includes the "Sublittoral Sandstones" which extend from Nigeria to Rio Muni and Gabon. P. Dusen (1894) described a succession of sandstones and lignitic shales with fish debris near Kita. The beds are gently folded, with dips ranging from 17 to 30°. The poorly preserved fauna was confidently attributed by Dames to the Lower Cretaceous (Dusen 1894).

In the Mamfe region, at the source of the Cross River, both Guillemain and Wilson have observed lignitic and bituminous shales, mottled clays and sandstones with silicified wood and limestone nodules. The bituminous shales contain *Estheria* and a Wealdian fish: *Proportheus kameruni* Jaekel.

At Seraouel, in the north-east near Chad, O. Mann and S. Passarge discovered shales and sandstones containing molluscs, plants and fish: *Lepidotus manni* Hennig and *L. giganteus*, known from the terminal Jurassic of Bavaria.

Other outcrops were recorded before the whole problem was looked into by E. Roch (1953) who discovered the "Continental intercalaire" in three E.-W. synclines in the Fali country; the Amakousou, Léré-Mayo Boulo and Figuil-Mayo Tafal Synclines (Guillemain 1909; Mann and Hennig 1913).

In the Mayo Tafal the marls are crowded with *Estheria* (*E. mawsoni* Jones, *Estheriella kameruni* Defretin, *E. tricostata* Defretin).

Ostracods occur which are related to *Cypris* cf. *purbeckensis* Jones, and among the plants E. Boureau has determined *Pagiophyllum* cf. *crassifolium* and *Frenelopsis hoheneggeri* (Defretin 1953; Boureau 1953). In the Pala Region, Roch found *Protopodocarpoxylon rochii* Boureau, a species very similar to infra-Cretaceous forms in Morocco and Portugal.

The "Continental intercalaire" is also preserved in the tectonic trough of the Mbéré, which measures 100 km. in length, 15 to 20 km. in width and 500 m. in depth. A long time ago P. H. Fritel and R. Chudeau recorded from there some coniferous wood, recalling that found in the Sahara. This could belong to *Protopodocarpoxylon* (?).

Post-Wealdian, Pre-Cenomanian tectonic movements

E. Roch (1953) described post-Wealdian, pre-Cenomanian movements which produced not only the synclines mentioned above and the Mbéré Trough but also a mountain range—the Benue Range. This extended in a SW.-NE. direction, for 800 km. (width 200 km.) from the Cross River to Léré.

3. MARINE CRETACEOUS

The marine Cretaceous outcrop forms a belt behind Douala and is found in the Upper Bénoué. The succession begins in the Vraconnian at the earliest, almost in the Cenomanian, with the Lamé Formation, containing *Venilicardia cuneata* (Roch 1953).

The best palaeontological discoveries were made by Esch (1897-1899) and Guillemain (1905-1907); study of the material is due to von Koenen, Solger, Harbort and Riedel (Esch *et al.* 1904; Guillemain 1908, 1909; von Koenen 1897; Riedel 1932) and subsequently to petroleum geologists (Reyment 1954; Freneix 1959).

The Douala Basin forms the eastern part of the sedimentary basin of Nigeria. The thickness of the sedimentary successions is of the order of 2,000 m., over 1,000 m. of which belong to the Upper Cretaceous. The finest exposures are in the Mungo Valley. The basal sandstones (600 m.), put in the Cenomanian, are overlain by limestones which are divided into three series: Mungo Series (Turonian-Campanian), Logbatjeck Series (Campanian) and Bomé Series (Maestrichtian).

The Mungo Series begins with the Turonian and contains a very good fauna: *Hoplitoides ingens* Koenen, *H. koeni* Solger, *Neoptychites telingaeformis* Solger, *Inoceramus camerunensis* Riedel, *Plicatula flattersi* Coquand, *Fragum perobliquum* Koenen, *Pholadomya incurvata* Koenen, *Plicatula auressensis* Coquand, *Turritella nodosa* Roemer, *T. harboti* Riedel.

The Coniacian is defined by *Barroisiceras* sp., *Tissotia latelobata* Solger and *Pholadomya adversa* Riedel; the Santonian by *Venericardia nauliensis* Cox and *Plicatula ferryi* Coquand; the Santonian-Campanian by *Trigonarca curvatodonta* Riedel, *T. camerunensis* Riedel, *Plicatula hirsuta* Coq., *Venericardia nauliensis* Cox, var. *doualensis* Freneix and *Inoceramus* cf. *bantu* Heinz.

The Logbatjeck Series is Campanian, with *Eupachydiscus* sp., *Menabites* sp., *Karapatides* sp., *Trigonarca curvatodonta* Riedel, *T. camerunensis* Riedel, *T. furoni* Freneix and Dart., *Liostrea rowillei* Coq., *Venericardia nauliensis* Cox, var. *doualensis* Fr., *Parmicorbula incurvata* Koenen, *Turritella nodosa* Roemer, *T. forge-molli* Coq., etc.

The Bomé Series represents the Maestrichtian, with *Venericardia ameliae* Peron, *Trigonoarca furoni* Fr. and Dart., *Volutilithes* cf. *pseudocostata* Noetling and *Pachydiscus* sp., *Didymoceras* sp. The characteristic species is *Venericardia ameliae* Peron.

4. TERTIARY

Boreholes put down in the Douala region have proved that no break exists between the Upper Cretaceous and the Eocene. The Danian is regressive, however.

The Dizangué Series, probably continental in origin and of uncertain age, is followed by the Bongué Series (250 m.) containing a Palaeocene fauna including *Rostellaria costellata* Leymerie, *Campanile claytonense* and foraminifera. Above this, the Middle Eocene is represented by the Bonangando Series, discovered by Esch in the Wouri Valley. Its fauna was first described by Oppenheim and includes *Leda substriata* Opp., *Cardita camerunensis* Opp., *Cytheria nitidula* Lamarck, *C. elegans* Lamarck, *Tellina subrotunda* Desh., *Corbula pregibba* Opp., *Buccinum choffati* Opp., *Murex camerunensis* Opp., *Pleurotoma wuriana* Opp., *P. camerunensis* Opp. (Hourcq 1956).

The Bomono and Souelleba boreholes have shown that there is also some Upper Eocene with *Bolivina* (1,000 m. thick) and

Oligocene with operculinas and miogypsinas. The Neogene may also be present.

5. DSCHANG LIGNITES AND BALANGI TUFFS

Lignite beds have been recorded between the Vouri and the Dibamba (south-east of Boko) and on the basement, 5 km. south-east of Dschang.

The Dschang beds consist of about 30 m. of conglomerates, sandstones and shales with lignites (Buisson and Depape 1931). They rest directly on the basement and are protected from erosion by a basaltic flow, lateritised at the surface. The flora is a present-day one.

Below Balangi, on the left bank of the Mungo, Guillemain discovered a shaly bed with plant remains above the marine Upper Cretaceous. This is 2 m. 50 thick and overlain by volcanic tuffs still containing plants, sandstone with basalt pebbles and finally micaceous sandstone. Although the plants are very numerous they cannot serve to date the rock since they are new species (Menzel, in Guillemain 1909). In addition to this, Esch found fish remains in the Balangi Tuffs. These include myliobatid teeth and *Eotorpedo hilgendorfi* Jackel, which belong to the Tertiary. *Eotorpedo hilgendorfi* has been found in the Lower Eocene of Sokoto, in Nigeria, and in younger rocks.

Another horizon of plant-bearing tuffs is found south-west of Mont Cameroun, at Cape Debuncha. Menzel identified two hundred and thirty-four plant species (belonging to forty-eight families), the majority of which are still living. Because of this the age of the tuffs (Tertiary or Quaternary) is still unknown. It is a matter to be investigated further, because it would enable us to learn much about the evolution of the tropical forest.

6. CRETACEOUS AND TERTIARY OF RIO MUNI AND THE ISLANDS

The coast of Rio Muni is covered by Cretaceous deposits in continuity with those of Cameroun in the north and Gabon in the south (Denaeyer 1929; d'Almonte 1902).

Lower Cretaceous of Bata. The oldest beds are multi-coloured sandstones and bituminous shales, resting on the basement. D'Almonte records dips of from 10 to 25° S. and SW. and a thick-

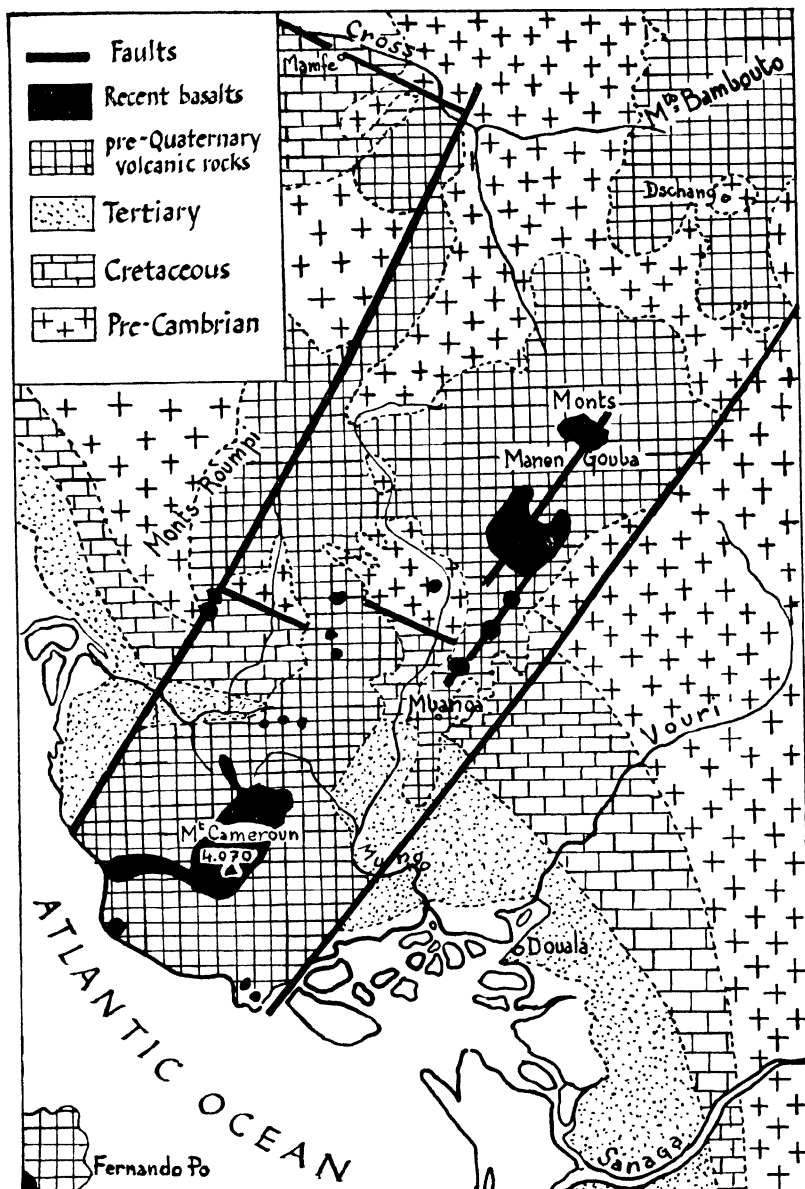


FIG. 21. Geological sketch-map of western Cameroun.

ness of about 1,000 m. These are the "areniscas sublittorales" (sub-littoral sandstones) of Lower Cretaceous age.

The oldest fossiliferous beds belong to the Lower Cretaceous. They are known at Ibando, in the neighbourhood of Bata, where they contain fish: *Parachanos aethiopicus*, *Diplomystus goodi* E., *Chirocentrites* (?) *guineensis* W. and *Enchodus* sp. (Weiller 1923, 1935). This is a fauna comparable with that of Gabon and the Bahia region in Brazil.

Vraconnian of Elobi. The Vraconnian is known on the banks of the Rio Muni and more especially on Elobi Island, where it was discovered by Lenz and studied by Szainocha (1884). It contains a fine ammonite fauna, with *Mortonicerias inflatum* Sow., *M. lenzi* Sz., *M. inflatiformis* Sz., *M. elobiensis* Sz., *M. (Elobicerias) szainochai* Spath.

The same horizons (Infra-Cretaceous and Vraconnian) appear to exist in Corisco Island, according to d'Almonte.

Cenomanian. At Bata, beds of glauconitic sandstone with plant debris contain *Acanthoceras rothomagense* Br. (?).

Turonian. This is represented by beds with *Prionotropis woolgari* Mantell, in Corisco.

7. LARGE FRACTURES AND VOLCANISM

Towards the end of the Cretaceous, a period of diastrophism was manifested by faulting, uplifts and depressions.

Guillemain and Passage had recognised an orthogonal system, with a SW.-NE. Cameroun Trend and a NW.-SE. Bénoué Trend. Hassert speaks of grabens in the Moungo Valley, but does not develop this idea. It is to B. Gèze that we owe a complete study and tectonic explanation of the volcanic region (Gèze 1943; Jérémie 1943).

There is in Cameroun a genuine trough of Rift Valley type extending north-eastwards from the Gulf of Guinea towards Chad. It is bordered on both sides by large subvertical faults whose throw reaches 1,000 m. These two faults defined by Gèze are, on the east, the Nlonake Fault, marked out by small volcanoes, and, on the west, the Roumpi Mountains Fault, that extends some 280 km. from the coast to the Nda-Ali Mountains.

The NW.-SE. Bénoué Trend has less importance except locally in the Cross River Basin, where Guillemain recorded five faults with this trend, three of which are marked out by saline springs

coming from the Lower Cretaceous. A tectonic line, composed of several parallel fractures, occurs within the large Cameroun Trough. The large volcanic massifs of Cameroun, Manengouba and Bambouto were built up along this line. This axis extends south-westwards into the Atlantic towards St. Helena; it is marked out by a set of volcanic islands: Fernando Po, Principe, São Thomé and Annobon. North-eastwards the trough passes into the Chad Basin, in the direction of Tibesti.

Mont Cameroun

Mont Cameroun is a typical strato-volcano reaching 4,000 m. in altitude. Despite its height it makes little impression because of its breadth at the base (50 by 35 km.). The total volume of lavas erupted is estimated at 1,400 cu. km. The actual summit, the Fako (Manga-ma-Loba = cavern of the gods) is a part of the northern edge of an old, eroded crater which is in the process of being filled in. Immediately to the west, near the highest point, at 4,060 m., there is a small vent floored by sulphur and discharging sulphurous gas. To the south is the large subactive crater, 100 m. wide and 50 m. deep, with vertical walls and fissures discharging burning vapours. 1 km. to the south-west is the recent cone of Mateer.

The volcanic activity of Mont Cameroun began in the Cretaceous. According to Guillemain, the basaltic tuffs at the base contain plants attributed to the Upper Cretaceous. Activity continued in the Lower Tertiary with large emissions of basaltic lavas (sometimes tending towards an andesitic composition), which are weathered very considerably.

A second active phase occurred in the Miocene, with the eruption of trachytes and phonolites. This is a group rich in nepheline, which is found up to an altitude of 3,000 m. Then follows an upper basaltic group of Plio-Pleistocene age. This group, 1,000 m. thick, forms the summits and covers the slopes. It marks several eruptive phases.

Activity has not ended. On 26th April 1909 a large eruption began with subterranean rumblings and shaking of the ground. Small volcanic cones were built up near 2,400 m. above sea level in the Okali crater. From this flowed a river of lava which reached 800 m. in width, 20 m. in thickness and 6 km. in length. In 1922 another period of activity lasted from 2nd February to 24th August. Lavas erupted from six craters descended the slopes,

setting fire to the forest, filled the small valleys and joined together in a single flow 9 m. thick and 300 to 400 m. wide, which reached the sea on 11th March. After a period of calm at the end of May, new lavas flowed to the sea. The eruption ended on 24th August. The formation of the Mateer cone at 3,600 m. altitude shows that the pressure was sufficient to carry magma to the summit of Mont Cameroun and that the axial vent was not obstructed. The lava emissions of 1922 were of the order of 10 million cubic metres. Another period of activity began in February 1959.

The lavas forming the recent flows represent all the classic types; blocky, scoriaceous, ropy, etc. The most curious features are lava tunnels of which the most important is the Gaskin Grotto, which reaches 180 m. in length and 5 m. in diameter and opens at an altitude of 2,850 m. south of Mont Isabelle.

Other Volcanic Regions

A series of volcanic massifs occurs to the north.

On the line of the western fault, east of the Roumpi Mountains, several volcanic outpourings on the old basement reveal the same three groups as on Mont Cameroun: older basalts, trachytes-phonolites and younger basalts.

In the same trough, 90 km. north-east of Fako, the Koupé Massif rises sharply from the plain, at 300 m., to a height of 2,050 m. Esch gave a very complete description of it and it was looked at again by Gèze. A peculiarity of the Koupé Massif is that it has a syenitic basement. These syenites belong not to the Pre-Cambrian but to the Lower Tertiary volcanic series. They are covered by younger basalts.

Further to the north-east is the Manengouba Massif, 25 km. wide and rising to 2,420 m. One can distinguish the remnants of an old caldera 8 km. in diameter and a second one, in good condition, preserved within it. The granitic basement is here at about 1,500 m. Above this come older basalts, andesites, trachytes and younger basalts. Despite the freshness of some of these volcanics, activity has ceased completely. The only posthumous manifestation is the mineral spring of Baré, which contains gas together with bicarbonates of calcium and iron.

Beyond this massif are the Bambouto Mountains, part of the Bamenda Mountains, a volcanic range extending along 180 km. of the old Franco-British frontier. The summit, at 2,679 m., is the highest point in the former French territory. Above the old

basement only two volcanic groups are found, the older basalts and the trachytes and phonolites.

Still further to the north-east are the large massifs in the Adamaoua.

The Character of the Eruptive Products

The volcanic rocks of Cameroun are alkaline or calc-alkaline, characterised by a tendency towards saturation. Variations exist between quartziferous and nephelinitic types, with a predominance of soda over potash. Generally speaking they are rocks without quartz and rich in nepheline.

In the alkaline series, E. Jérémie has distinguished hyper-alkaline rocks (rhyolites, trachytes and phonolites) and basic alkaline rocks (nephelinites, leucitites). The calc-alkaline lavas vary between andesinic hornblende andesites and andesinic basalts grading into basanites and ankaramites.

8. THE VOLCANIC ISLANDS

References include Boese (1912), Chevalier (1906) and Tyrrell (1934).

Fernando Po, the largest of the islands in the Gulf of Guinea, lies on the continental shelf and is separated from the continent by a stretch of water never deeper than 100 m. There are two large massifs: in the north, the peak of Santa Isabel, an extinct volcano 3,000 m. high; in the south the Cordillera of Fernando Po, rising up to 2,600 m. Phonolites and basalts have been collected.

Prince's Island (Ilha do Principe) (948 m.) is volcanic, for the most part basaltic. Miocene limestones with *Lithothamnium*, *Amphistegina* and a molluscan fauna are known.

Annobon, still further south-west, is likewise volcanic. These islands are situated along the same axis as the large volcanoes of Cameroun.

São Thomé is mainly basaltic, with well-preserved craters and flows in the northern half. Petrographers have described basalts, hornblende andesites, trachytes and phonolites, quite comparable with the rocks in Cameroun. The highest point is at 2,024 m.

In 1949 Teixeira recorded the presence of lignitic and bituminous sandstones with an argillaceous cement outcropping at Ubabudo (São Thomé) and manifested by bituminous seepages in Prince's Island. These would appear to be Lower Cretaceous

sediments analogous to those known on the margins of the continent (Teixera 1948-1949; da Silva 1956, 1958).

Following the same direction St. Helena is reached 2,000 km. to the south-west. St. Helena is also a volcanic island, essentially basaltic but with trachytes and phonolites (Daly 1927). It is impossible to decide whether the formation of St. Helena is related to the same system of fractures as in the case of the other islands. It lies on the edge of the Mid-Atlantic Ridge and the line that joins it with Cameroun crosses large oceanic troughs over 5,000 m. deep.

REFERENCES

- D'ALMONTE, E., 1902. Someras notas para contribuir a la descripcion geologica de la zona NW de la isla de F. Po y de la Guinea continental espanola. *Bull. R. Soc. Geogr. Madrid*, **44**, 223.
- BOESE, W., 1912. Petrographische Untersuchungen an jungvulkanischen Ergusgesteinen von São Thomé und Fernando Po. *N. Jb. Miner. Geol. Pal.*, abt. B, **34**, 253-320.
- BOUREAU, E., 1953. Sur quelques plantes fossiles du Territoire du Tchad et du Nord-Cameroun. *Bull. Serv. Mi. Cameroun*, No. 1, 1-110.
- BUISSON, E. and G. DEPAPE, 1931. Le gisement de lignite de Dschang (Cameroun occidental). *Ann. Soc. Géol. Nord*, **56**, 204-207.
- CARTE GÉOLOGIQUE du Cameroun au 1:1,000,000 et Notice explicative par J. GAZEL, V. HOURCQ et M. NICKLÈS. *Bull. Dir. Mi. Géol. Cameroun*, 1956; 1 map and 62 pp.
- CHEVALIER, A., 1906. L'île de San Thomé (notes petrographiques par A. Lacroix). *La Géographie*, **13**, 257-274.
- DALY, R. A., 1927. The Geology of Saint Helena Island. *Proc. Amer. Ac. Arts and Sc.*, **62**, 31-92.
- DEFRETIN, S., 1953. Quelques Conchostraces du Nord-Cameroun. *Bull. Serv. Mi. Cameroun*, No. 1, 111-120.
- DENAAYER, M. E., 1929. Los terrenos secundarios y terciarios de la Guinea espanola y del Territorio portugues de Cabinda. *Mem. R. Soc. Esp. Hist. Nat.*, **15**, 699-724.
- DUSEN, P., 1894. Om nordvästra Kamerunområdets Geologie. *Geol. För. Föhrandl.*, **16**, 29-63.
- ESCH, E., F. SOLGER, O. OPPENHEIM and O. JAEKEL, 1904. *Beiträge zur Geologie von Kamerun*. Stuttgart.
- FRENEIX, S., 1959. Mollusques fossiles du Crétacé de la Côte occidentale d'Afrique, du Cameroun a l'Angola. *Ann. Musée R. Congo belge*, **24**.
- GAZEL, J., V. HOURCQ and M. NICKLÈS, 1956. See Carte Geol. du Cameroun.
- GÈZE, B., 1943. Géographie physique et géologie du Cameroun occidental. *Mém. Mus. Nat. Hist. Nat.*, **17**.
- GUILLEMAIN, C., 1908. Ergebnisse geologischer Forschung im deutschen Schutzgebiet Kamerun. *Mitt. aus den D. Schutzgebieten*, **21**, 15-33.

- 1909. Beiträge zur Geologie von Kamerun, mit Beiträge von Harbort, Jaekel, Klautsch, Merkel. *Abh. k. preuss. Geol. Landesanstalt*, **62**, 466 pp.
- HOUCQ, V., 1956. Bassins sédimentaires du Cameroun. *20th Int. Geol. Congr., Mexico. Petrol. Sympos.*, **1**, 45-68.
- JÉRÉMINE, E., 1943. Contribution a l'étude pétrographique du Cameroun occidental. *Mem. Mus. Nat. Hist. Nat.*, **17**.
- VON KOENEN, A., 1897. Ueber Fossilien der unteren Kreide am Ufer des Mungo in Kamerun. *Abh. k. Ges. Wiss. Göttingen*, **1**, 65 pp.
- KOCH, P., 1959. Le Précambrien de la frontière occidentale du Cameroun central. *Bull. Dir. Mi. Géol. Cameroun*, No. 3, 300 pp.
- LESSERRE, M., 1958. Étude géologique de la partie orientale de l'Adamaoua (Cameroun central). *Unpublished thesis*, Clermont.
- MANN, O. and E. HENNIG, 1913. Mesozoische Ablagerungen in Adamaoua Kamerun. *Beitr. Geol. Erf. d. Schutzgebiet*, **7**.
- MENZEL, P., 1920. Ueber Pflanzenreste aus Basalttufen des Kamerungebietes. *Ibid.*, **18**.
- REYMENT, R. A., 1954. The stratigraphy of the southern Cameroons. *Geol. Fören. Förhandl. Stockholm*, **76**.
- RIEDEL, L., 1932. Die Oberkreide von Mungofluss in Kamerun und ihre Fauna. *Beitr. Geol. Erf. d. Schutzgebiet*, **6**, 155 pp.
- ROCH, E., 1953. Itinéraires géologiques dans le Nord du Cameroun et le Sud-Ouest du Territoire du Tchad. *Bull. Serv. Mi. Cameroun*, No. 1, 1-110.
- DA SILVA, G. H., 1956. La faune miocène de l'île du Prince. *Mem. lab. Min. Géol. Univ. Coimbra*, No. 42.
- 1958. Contribucao para o conhecimento da microfauna di Mioceno marinho da ilha do Principe. *Garcia de Orta*, **6**, 507-510.
- SZAINOCHA, L., 1884. Zur Kenntnis des mittelkretaz. Cephalopodenfauna der Insel Elobi. *Denkschr. m.-nat. Kl. Ak. Wiss. Wien*, **49**, pp. 231 et seq.
- TEIXERA, C., 1948-9. Notas sobre a Geologia das Ilhas de Sao Tomé e do Principe. *Estudos coloniais*, **1**, 12 pp.
- TYRRELL, G. W., 1934. Petrographical notes on rocks from the Gulf of Guinea. *Geol. Mag.*, **81**, 16-23.
- WEILLER, W., 1923. Die Fischreste aus den bituminösen Schieferen von Ibando bei Bata (Sp. Guinea). *Paläont.* **2**, **5**, 148-160.
- 1935. Neue Untersuchungen aus den Fischresten. *Abh. k. Bayer. Ak. Wiss.*, **32**, 1-57.

CHAPTER XXIX

GABON, CONGO REPUBLIC AND CENTRAL AFRICAN REPUBLIC (UBANGI)

Gérard (1958) should be consulted for explanatory notes on the map of the former French Equatorial Africa and references to work on the geology.

1. GABON AND MIDDLE CONGO

Gabon and the Middle Congo may be subdivided into several natural regions corresponding to geological units: the Mayombe Range and its continuation north of the Ogooué, the Batéké Plateau and the Cretaceous gulfs of the Ogooué and Pointe-Noire.

(a) *The Mayombe and the Nyanga Syncline*

The Mayombe Range forms the western border of the Congo Basin. It extends in a general NW. direction parallel to the Atlantic coast, from which it is separated by a narrow zone of Cretaceous sediments. The highest points do not exceed 800 m., while the maximum width of the range is 60 km. In the north the Mayombe bends eastwards and connects with the northern peneplain and the Monts de Cristal via the Koumouna Bouali Mountains and Lower N'Gounié. It is also through Lower N'Gounié that one reaches the granitic massif of Chaillu, which borders the folded zone in the east.

The Mayombe Range is crossed by several rivers which flow into the Atlantic: the Congo, Shiloango, Kouilou, Nyanga and Ogooué. The ground is very hilly and covered by the equatorial forest, which makes surface observations difficult.

The Congolese zone has been studied mainly by V. Babet (1929) and A. Amstutz, later by J. Cosson (1955) and P. Nicolini; the Gabonese zone by Furon *et al.* (1930), B. Choubert and subsequently by V. Babet and J.-P. Dévigne.

Lower Pre-Cambrian: Pre-Mayombe System

The old crystalline basement is visible over a wide area in the western border of the Mayombe, where it occupies a belt 30 km.

in average width. Near M'Boulou, in the Middle Congo, A. Amstutz discovered in 1929 a conglomerate containing pebbles of granite and interpreted it as the basal conglomerate of a group of rocks younger than the basal "granite-gneiss" complex, which he henceforth called the "substratum primordial". The M'Boulou conglomerate appeared to be very local in extent and authors were not able to distinguish two groups in the basement. Subsequently Belgian geologists gave the name "Mayombe System" to the crystalline and "cristallophyllian" assemblage in the Lower Congo, and the geologists of "French Equatorial Africa" set about joining up their maps. Then J.-P. Dévigne (1958) showed that there are indeed two groups separated by a conglomerate, an unconformity and a considerable difference in the orientation of tectonic axes. He distinguished therefore a lower Pre-Mayombe System and an upper Mayombe System.

The Pre-Mayombe System is subdivided into three series:

(a) At the base, the "Doussa Series", composed of fine-grained gneisses in strips within a migmatitic and granitic assemblage.

(b) The "Kouboula Mountains Series", composed mainly of micaceous and non-micaceous quartzites, always in strips within the migmatitic substratum (base of the Pre-Mayombe visible in Congo).

(c) The "Douigni Series", comprising mica-schists, amphibolites, talc-schists, epidotites and a few porphyritic lavas.

This assemblage was involved in the formation of a Pre-Mayombeian pluton with three metasomatic phases staggered in time (calc-sodic, potassic and sodic). The intrusive rocks are localised geographically. The Pre-Mayombeian System is folded in a WSW.-ENE. direction.

Middle Pre-Cambrian: Mayombe System

The Mayombe System as defined by Dévigne does not correspond with the Mayombe System of J. Cosson and Belgian authors. It is based upon a stratigraphic, tectonic and petrological discontinuity. The system is divided into two series, the Loukoula and the Sounda.

At the base, the Loulouka Series begins with conglomerates and thick beds of arkoses, continues with black schists and micaceous quartzites and ends with chlorite schists with a silky green patina and pelites. At the top, the Sounda Series rests on the Loulouka, the separation being marked by a period of erosion,

but no tectonic discordance is visible. It contains volcanics, chloritic schists and quartzites of very fine grain.

The whole of the Mayombe System comprises a pluton showing evidence of two metasomatic phases (sodic and potassic). It occupies a belt of ground oriented SE.-NW., with SE.-NW. axes, normal to the tectonic axes of the Pre-Mayombe System.

Upper Pre-Cambrian: Bamba Mountains System

This system is widely transgressive over the eroded basement. It begins with a basal conglomerate with pebbles of granite. The following groups are distinguished, from bottom to top:

“Banza Series”: conglomerates and feldspathic quartzites, schists and rare marbles (detrital deposits in the west, much more fine-grained in the east: M’Vouti Series).

“M’Beia Series”: quartzitic sandstones and pelitic facies with lustrous schists.

The rocks are folded SE.-NW. in a Mayombeian direction.

In the south of the Middle Congo, the Bamba Mountains System is subdivided by J. Cosson into the “M’Vouti Series” at the base and the “Mossouva Series” at the top. This would correspond to the Sansikwa System in the Congo, tending towards the western facies.

Terminal-Pre-Cambrian: Western Congo System

This system is seen in the Nyanga Syncline (between the Mayombe and the Chaillu Massif) and in the Middle Congo.

J. Cosson (1955) established the stratigraphical positions of the different groups from his own observations and the conclusions of the African geologists who met at Leopoldville in 1955. In 1958 Dévigne expounded them in detail; the succession is, from bottom to top:

(a) The “Bamba Glacial Series”, which only appears on the western flank and corresponds to the Lower Tillite of the Lower Congo (former Belgian Congo). Its stratigraphical position was established in “French Equatorial Africa” by P. Nicolini, J. Cosson and J.-P. Dévigne. It consists of conglomerates with a shaly matrix and shaly intercalations, whose average thickness is of the order of 300 m.

(b) The “Louila Series” (western flank of the Nyanga Syncline) and “Bouenza Series” (on the eastern flank). This corresponds for the most part to the old *système quartzo-schisteux* of Babet

and the Upper Shiloango System of the Congo. The Louila Series is composed predominantly of lustrous green, more or less calcareous schists and dolomitic beds. In the bend of the Niari, P. Nicolini (1959) recognised 23 horizons in the series, which reaches 1,000 m. in thickness and contains dolomitic limestones with stromatolites.

On the north-eastern flank of the syncline, that is on the western border of the Chaillu Massif, the crystalline substratum is covered unconformably by a group of feldspathic sandstones and argillites that V. Babet called the "complexe de Leboulou-Sibiti". L. Baud (1950) gave it the name "étage Bouenzien", distinguishing three horizons on the river Bouenza. Cosson correlated it with the Louila Series, but whereas the latter is situated between two

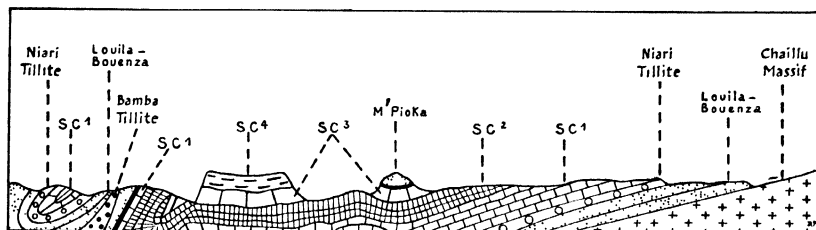


FIG. 22. Section across the Nyanga Syncline (after Nicolini).

tillites the "Bouenza Series" rests directly on the basement without the Bamba Tillite.

(c) The "Niari Glacial Series", known for a long time on the eastern flank of the Nyanga Syncline and reaching 150 m. in thickness. It consists of a reddish, purplish, blue or greenish tillite. It is found on the western flank and passes southwards into the Upper Tillite of the Lower Congo, of Belgian authors.

(d) The *série schisto-calcaire*. This was mentioned by E. Pechuel-Loesche and E. Dupont at the end of the nineteenth century, in the Niari Basin. In 1917 F. Delhay and M. Sluys briefly noted the subdivisions and gave an original and detailed description a little later (Delhay and Sluys 1921). Fuller descriptions have been given by Babet (1929, 1932), Lagotala (1929), Furon *et al* (1930), Furon (1950), Legoux (1943), Nicklès (1952), Nicolai (1954), Cosson and Nicolini (1954), Dévigne (1958) and Nicolini (1959).

The *série schisto-calcaire* rests on the Niari Tillite and is covered

by the *série schisto-gréseuse*. When complete, it comprises four subdivisions:

- SC¹: thin grey or pink dolomitic horizon (5 to 10 m.); thin-bedded dark red and green marl horizon (300 m.), followed by horizon of limestones, often oolitic and silicified;
- SC²: often begins with a dark wine-coloured ("lie de vin") shale horizon and continues with grey dolomitic marls with beds of light grey chert. At N'Dendé, this horizon is completely silicified;
- SC³: dolomitic limestones with stromatolites, dolomite rocks with silica concretions and quartz veins, dark grey fetid, compact dolomite rocks;
- SC⁴: multicoloured shales concordantly overlying SC³ and covered by conglomerates passing into the Niari Breccia.

This excellent succession, up to 500 m. thick, is well seen in the Niari Syncline (Middle Congo) and in the Nyanga Syncline (Gabon).

The *série schisto-calcaire* was folded and eroded before deposition of the next series. The contact between the two series is generally marked by a conglomerate or breccia. In certain places, as on the river M'Poulou, north-east of N'Tima, the dolomitic limestone beds are upturned at a high angle beneath the subhorizontal conglomerate, while elsewhere ordinary erosion gaps are observable, but always with some angular discordance.

(e) The *série schisto-gréseuse*. The best recent descriptions are those of Nicolaï (1954), Cosson and Nicolini (1954, 1959) and Dévigne (1958).

The following are distinguished, from bottom to top:

The "Niari Breccia", well seen in the Niari Basin and on Mont Fouari (10 m.).

The "M'Pioka Series", beginning with beds of red argilites and fine-grained sandstones (100 m.), overlain by green or bluish sandstones (100 m.) and then further green or mauve sandstones.

In the Nyanga Syncline the succession *appears* to end here, but in the Niari Basin it continues with a second series. This is the Inkisi Series, which west of Brazzaville forms the Plateau des

Cataractes. The thickness ranges up to 600 to 700 m. It includes red or brown feldspathic sandstones of continental origin clearly later than and unconformable upon the M'Pioka. The rocks have been uplifted, folded and compressed towards the north-east with dips of the order of 20 to 25°. They are cut by a few veins.

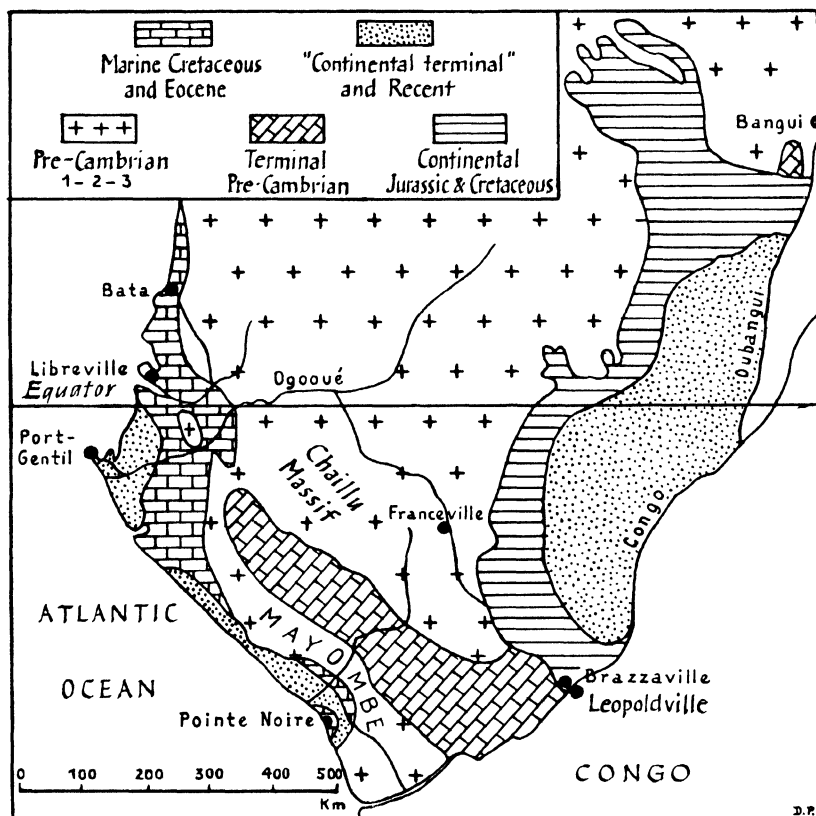


FIG. 23. Geological sketch-map of Gabon and the Congo Republic

The "West Congo System" has considerable economic interest, since it contains copper in the Niari Basin, together with lead and zinc.

Between Pointe-Noire and Brazzaville, along the Congo-Ocean railway, J. Cosson has established a section of the Mayombe which

is comparable to Dévigne's in Gabon, except at the base. More precisely, Cosson considers that his "Mayombe System" represents the extreme base of the Pre-Cambrian while Dévigne adds a "Pre-Mayombe System" at the expense of the lower half of the Mayombe System.

The mineralisation of the Niari Basin (copper, lead, zinc, mispickel, cobalt and uranium) has been studied in its more important aspects by G. Bigotte (1959) and P. Nicolini (1959). The mineralisation seems to be of epigenetic origin (Fe and Co at first, then Cu, Pb and Zn), due to a secondary renewal of hydrothermal activity. Several Niari galenas have been dated by the common lead method and L. Cahen gives them an age of 620 to 630 million years, like those of Katanga.

The experience acquired since 1945 seems to show that there is not one large copper deposit in the Niari but rather a number of small, isolated ones. G. Bigotte states, however, that this conclusion is only valid for the SC³ horizon, the only one that has been completely prospected.

(b) *Gabon north of the Ogooué*

All the northern zone of Gabon, north of the Ogooué, consists of Pre-Cambrian basement, which constitutes a vast peneplain. The western zone is known as the *Monts de Cristal* (Crystal Mountains); its mean altitude is from 400 to 600 m., with summits reaching 1,000 m. The *Monts de Cristal* are bounded in the west by a large fault. This forested region, which is drained by a large number of streams and rivers, is known to us through the works of B. Choubert (1937), V. Babet, R. van Aubel, Chochine, and J. J. Hausknecht and M. Aubague (1956).

The *Lower Pre-Cambrian* is represented by a granite-gneiss "Basal Complex".

The unconformable *Middle Pre-Cambrian* is known as the "Ogooué System". It comprises at the base the "N'Dole Series" (chlorite schists, slates (?) and quartzites) and at the top the "Okano Series" (mica-schists, slates (?) and quartzites).

The *Upper Pre-Cambrian* is represented by the "Intermediate System" of J. Cosson (1953), replaced eastwards by the Francevillian of L. Baud (1954).

The type succession of the Intermediate System is that of the Ouano, composed mainly of shales, argilites and feldspathic

sandstones. In the Ogooué Valley this last system is replaced by the Franceville System, 300 to 400 m. thick. Sandy at the base and shaly and siliceous in its middle part, it becomes sandy at the top. The important manganese deposit of the Moanda region, studied by Baud, occurs in the shaly Middle Francevillian.

The Terminal Pre-Cambrian has been given the name "Noya System" (Choubert 1937), which is the equivalent of the West Congo System of the more southerly regions. It begins with sandstones and a tillite resting with major unconformity on the older Pre-Cambrian, continues with a "série schisto-calcaire" and ends with a "série schisto-gréseuse".

(c) *The Batéké Plateaux*

The Batéké Plateaux extend to the north of the Congo and to the east of the Chaillu Massif. Their mean altitude is about 600 m. and decreases southwards. They are dissected by a well-developed river system and end in white cliffs on the northern bank of the River Congo.

J. Cosson (1955) has grouped all the geological formations of these plateaux into the "Stanley Pool Series" for those at the base and "Batéké Plateaux Series" for those at the top.

The poorly known Stanley Pool Series outcrops around Brazzaville and in the bottom of several valleys. One can distinguish, from bottom to top: sandstones and red argilites with *Estheria*, compact white sandstones and soft kaolinitic sandstones. The two upper horizons are compared with the Kwango Series of the Congo (Cretaceous) while the lower horizon with *Estheria* is still of undetermined age. It should be noted that certain authors formerly correlated this succession with the Karroo. It belongs in fact to the "Continental intercalaire".

The Batéké Plateaux Series is divided into two groups. At the base come the "Polymorphic Sandstones": very fine grained sandstones, often silicified, with lenses of chalcedony. V. Babet discovered freshwater molluscs in this group at Kounzoulou, 100 km. upstream from Brazzaville (Babet 1935). The Polymorphic Sandstones extend into the Congo. Their age falls within the Eocene and Oligocene ("Continental terminal").

At the top come 100 m. of unfossiliferous aeolian sands containing prehistoric implements, which, reworked or not, will one day allow them to be dated more precisely.

(d) *Cretaceous and Tertiary of the Atlantic Coast*1. *Gabon (or Ogooué) Basin*

References include Kossmat (1893), St. Meunier (1892), Lombard (1930), Furon (1932), Arambourg and Schneegans (1936) and Hourcq (1958).

The Gabon Basin (or Ogooué Gulf) extends from Rio Muni to the neighbourhood of Cape Matuti, near Mayoumba. It extends more than 150 km. into the interior, as far as the N'Djole district on the Ogooué, and surrounds the crystalline islet of Lambaréné-Chinchoua.

1. *Lower Cretaceous Sublittoral Sandstones.* The oldest beds rest directly on the Pre-Cambrian basement. They outcrop from the Rio Muni to the Ikoy in a belt 10 to 25 km. wide. The group begins with a basal conglomerate and continues with the following succession:

Agoula River Series: 400 m. of feldspathic sandstones and red shales, with a bed of silicified oolitic limestone.

M'Vone Marls: 40 m. of coarse sandstones overlain by 250 m. of red, purple or green marls, sometimes bituminous, with beds of marly limestone.

N'Dombo Sandstones: this is a continental succession, composed of 90 m. of compact sandstones, 250 m. of sands and purplish feldspathic sandstones, with intercalations of ferruginous duricrust, 80 m. of variegated shales, with a bed of green sandstone at the top.

2. *Cocobeach Fish Beds.* Above the N'Dombo green sandstone come grey-green bituminous marls full of fragments and scales of fish. At N'Kogho, south-west of N'Djole, these marls have yielded *Lepidotus* scales of the Lower Cretaceous.

The marls are overlain by the Cocobeach Series (*sensu stricto*): alternating marls and white sands, then silicified rocks, sandstones, clayey shales, bituminous shales with fish; dolomitic limestones and lignite beds at the top.

The total thickness is about 3,000 m. At Cocobeach itself, the bituminous shales have yielded a number of fish impressions belonging to two species: one of them large (23 cm.), *Parachanos aethiopicus* Weiler, previously recorded in Rio Muni; the other small (45 mm.), *Leptolepis congolensis* Arambourg and Schneegans. It is the same fauna as in the Bata Beds in Rio Muni and the

Bahia Beds in Brazil. They are here immediately older than the marine fossiliferous Upper Aptian and are therefore of Lower Aptian age. It is approximately at this horizon that one finds lenses of salt reaching 100 m. in thickness. These are Middle Aptian lagoonal deposits.

3. *Marine Upper Aptian*. In the Libreville region the Mendogh and Awaga Marls and Limestones (50 m.) contain *Deshayesites consobrinoides* Sinzow and *Cerithium binodosum* Roemer, of Upper Aptian age.

4. *Albian*. The N'Toum Marls and Limestones (200 m.) contain a Lower Albian fauna: *Trigonia* cf. *scabra* Lmk. and *Douvilleiceras mammillatum* Schloth. The Upper Albian with *Elobiceras schjasnochai* Spath is represented by 500 m. of sandstones, marls, dolomitic sandstones and grey and red dolomite rocks. These are the lagoonal beds with gypsum and lignite of Rembo-N'Komi.

5. *Cenomanian*. The Cenomanian is represented by poorly fossiliferous red beds: the Maringou Series (300 m. of sandstones and shales) and the Dibotinafala Series (800 m. of sands and gypsiferous marls).

6. *Turonian*. The Turonian is well represented in the Libreville region by the Sibang Limestones which are subdivided into four groups:

(a) River Abong Marls and Limestones (225 m.), containing *Pseudotissotia pavillieri* Perv., *P. gabonensis* Lombard, *Fagesia* sp., *Tylostoma aequatoriale* Kossm., *Arcophagia gabonensis* Kossm., *Lima grenieri* Coq., *Inoceramus baumanni* Kossm. and *Echinobrissus atlanticus* Kossm. (= Lower Turonian).

(b) Lowé Marls and Sandstones (150 m.).

(c) Libreville Limestones (80 m.) with *Pseudotissotia* sp., *Natica gabonensis* St. Meunier, *Lima grenieri* Coq. and *Inoceramus labiatus* Schl.

(d) Bolokoboué Limestones (125 m.) with *Actaeonella cylindracea* Stol., *A.* cf. *renauxi* d'Orb. and *Cytheria* aff. *plana* Sow. (= Upper Turonian).

7. *Senonian and Danian*. The Senonian and the Danian outcrop in the Setté-Cama, Iguéla and Fernan Vaz districts. They include sands, sandstones and olive green, bituminous marls with phosphatic nodules and strongly silicified horizons. The total thickness is about 1,500 m. The whole assemblage is gently folded and exhibits a series of domes.

Coniacian: (of Pointe Milango) with *Peroniceras dravidicum* Kossm., *Gauthiericeras margae* Schluth., *G. roquei* Person, *Barroisiceras habermanneri* v. Hauer and *Ostrea boucheroni* Coq. North of Libreville the siliceous facies disappears and the fauna includes *Texanites serrato-marginatum* Redt., *Trigonoarca gabonensis* Collignon, *Cyprimeria* cf. *oldhami* Sow. and *Gauldia trigonoides* Stol.

The Santonian and Campanian, at Pointe Komandji and the Assévé, contain *Mortoniceras texanum* Roemer, *Inoceramus* and phosphatic beds with *Gyroidina depressa* of Campanian-Maestrichtian age. The Campanian is, generally speaking, regressive.

The Maestrichtian-Danian of the Iguéla Lagoon consists of coarse limestone with quartz grains and pebbles. It contains fish teeth together with *Venericardia ameliae* Peron (Darteville and Freneix 1957).

8. *Tertiary*. The Port-Gentil borehole gave valuable information on the existence and importance of the Tertiary in this region (Hourcq and Reyre 1956). The total thickness is 2,000 m. The *Palaeocene* alone is some 1,000 m. in thickness (from -1,060 to -2,030 m.). It contains North American species of foraminifera: *Loxostomum applinae*, *Globorotalia crassata*, *G. wilcoxensis*, *G. pseudobulloides*, *Anomalina midwayensis*. It is overlain by 450 m. of shales and radiolarian cherts, with a foraminiferan at the top: *Hantkenia alabamensis*. This group seems to range from the *Ypresian* to the *Bartonian*.

The sea then retreated, before returning in the *Lower Miocene* (Aquitainian-Burdigalian). The Miocene, unconformable on the Eocene, measures 580 m. in thickness; it is composed of marly clays with calcareous or dolomitic nodules. The foraminiferal fauna includes *Globigerina venezuelana*, *Bulimina inflata*, *Sphaeroidina variabilis*, *Triloculina tricarinata*, etc.

500 m. of foraminifera-bearing *Upper Miocene* follow.

At the top come 200 m. of fluvial sands: the "série de cirques", of *Pliocene* age, which outcrops in various places in Gabon.

Tectonics. The basin is divided into two by the small crystalline horst of Lambaréné. The western basin contains over 4,000 m. of sedimentary deposits dipping to the west. Numerous faults of Middle and Upper Aptian age are related to fractures in the basement and have moved at several different times. The role played by salt serves to make detailed interpretation of the oil-bearing basin a difficult matter.

2. *Pointe-Noire Basin (Congo Republic)*

The sedimentary basin of Pointe-Noire begins south of Mayoumba and broadens to 50 km. in the Pointe-Noire region. It joins with the basin of the Lower Congo and Angola.

The sequence, from bottom to top, is as follows:

Lower Aptian? Conglomerates, arkoses and psammities (150 m.).

Upper Aptian-Lower Albian? 500 m. of oolitic limestones, cavity-ridden dolomites and coarse sandstones, without determinable fossils.

Lower Albian-Cenomanian? Blue shales and sandstones (250 m.).

Turonian: unfossiliferous red sandstones and marls of Pointe-Noire.

Coniacian. The fossiliferous sequence begins here, with recent determinations due to E. Dartevelle, S. Freneix and J. Sornay.

The Coniacian of Pointe-Noire and Loya contains *Peroniceras czornigi* Redt., *Trigonoarca camerunensis* Riedel, *Roudairea aurensensis* Coquand, *Plicatula hirsuta* Coq., *P. ferryi* Coq., *Pycnodonta vessiculari* Lamarck, etc.

Lower Santonian. Soft sandstones with *Roudairea drui* M-Ch., between Loya and M'Vassa.

Upper Santonian and Lower Campanian. At M'Vassa one finds *Mortoniceras soutoni* Bailly, *Hamites* sp. and *Trigonoarca curvatodonta* Riedel.

The higher beds are not seen on the coast but are visible in the centre of the basin, near Holle, 40 km. inland (Riedel 1959).

Maestrichtian. Phosphatic sands with *Plesiosaurus mauritanicus*, *Enchodus elegans*, *Lamna appendiculata*, etc.

Lower Eocene. Phosphatic sands with *Odontaspis*. The upper, lateritised, beds have yielded aluminium phosphates.

3. *Volcanism*

The only volcanic rock in the Cretaceous basins is the Pointe N'Gombe Basalt west of Libreville, described by B. Choubert. It is an olivine andesine basinitoid with a vitreous groundmass. The age of formation cannot be more precisely dated than post-Santonian.

2. THE UBANGI BASIN

The Ubangi Basin is separated from the Chad Basin by a line of hills whose uplift was perhaps quite recent. The upper Ubangi flows westwards from its source to Fort-Possel, where it makes a

sharp turn south-south-westwards towards the Congo. It is possible that it flowed formerly towards Chad and that the Fort-Possel bend was initiated by river capture. In support of this hypothesis, G. Borgniez (1935) recorded the presence of a large sheet of alluvium north-east of Fort-Possel. North-east of this locality a tributary of the Kouango, the Ouaka (an old tributary of the Chari) has been captured by the Ubangi. In many places the watershed is low.

Pre-Cambrian. The Pre-Cambrian covers most of Ubangi. Its detailed study is not yet completed, but useful information is available from the work of V. Babet (1939) in the west, G. Borgniez (1935) and L. Brustier (1923) in the centre, J. Lombard (1935) and E. Polinard (1935) in the east and other more recent work by G. Korableff (1940) and G. and J. Gérard (1952, 1958).

An *Old Pre-Cambrian* is distinguished. This complex includes monzonitic gneisses with microcline, oligoclase and andesine; biotite amphibole gneisses; two-mica gneisses; hypersthene gneisses; amphibolites and pyroxenites. The migmatites are of classical type.

The *Middle* and *Upper Pre-Cambrian* is represented by a less metamorphosed group comparable in all respects to the Birrimian of West Africa. It is composed mainly of schists and quartzites and has been studied particularly in the central region between Bangui and Bria. It is cut by granites: first grey granite and then a pink, pegmatitic variety. These granites form most of the uplands: the Yadé Massif in the west, on the Cameroun frontier, and the Bongo Massif north of Bambari. The latter ranges up to 1,400 m. in altitude.

The *Terminal Pre-Cambrian* is represented by the "Ubangi Group", defined by B. Aderca (1950) for the Congo. Aderca distinguished a lower pelitic and calcareous subdivision with stromatolites and an upper psammitic subdivision. This forms the equivalent of the West Congo System.

In Ubangi the group is succeeded north of the river by the "Lower Kotto System", defined by J.-L. Mestraud. This consists of a lower "Kassa Series" composed solely of cherts and an upper "Fouroumbala Series" composed of sandstones and conglomerates (Mestraud 1952). The Fouroumbala Series is subhorizontally disposed and much faulted. Traces of copper are known.

In the region south of Bangui we have the "Bobassa Series" (Wacrenier 1954).

Younger Rocks

The whole of the basin of the Lobaye and its left bank tributaries is covered by the *Carnot Sandstones*. This formation has been studied recently by J. Delorme and F. Delany. These authors distinguish a lower shaly and conglomeratic "fluvio-glacial?" horizon of unknown age (about 50 m.) and an upper horizon composed of 100 m. of sandstone, with an argillaceous cement, containing silicified wood, together with arkoses and conglomerates at the base. The sandstones are very reasonably considered as continental Cretaceous ("Continental intercalaire") (Babet and Furon 1935).

Much further to the east is the Ouadda Ndélé Plateau, dissected by the Kotto and its tributaries. This plateau is about 250 km. in mean diameter and 250 m. in height. The Ndélé cliffs show at the base some 50 m. of coarse sandstones and diamond-bearing conglomerates, overlain by 200 m. of sandstones, sometimes containing kaolin, with beds of argillite. The altitude of the base of the conglomerates varies from 570 m. at Ndélé to 1,000 m. at the source of the Kotto. Their thickness diminishes rapidly south-eastwards. The whole assemblage is faulted but not folded. These "Ndélé-Ouadda Sandstones", studied by H. Courtet, G. Borgniez, E. Polinard, F. Delhay, B. Bessoles and R. Delafosse, are of the same age as the Carnot Sandstones and the Kwango Series of the Congo, also diamantiferous at the base (Bessoles and Delafosse 1958).

The highest part seems to overlie a post-Kwango topographic surface. It has been compared to the Batéké Sandstones and assigned to the "Continental terminal" (Delorme and Delany 1956).

REFERENCES

- ADERCA, B., 1950. Étude pétrographique et carte géologique du district du Congo-Ubangi, Congo belge. *Mem. Inst. R. col. belge*, 18.
- ARAMBOURG, C. and D. SCHNEEGANS, 1936. Poissons fossiles du bassin sédimentaire du Gabon. *Ann. Paléontologie*, 24, 139-160.
- BABET, V., 1929. Étude géologique de la zone du chemin de fer, Congo-Océan et de la région minière du Niari et du Djoue. Paris (Larose).
- 1935. Les premiers Mollusques fossiles recueillis en A.O.F. dans les formations du bassin intérieur du Congo. *C.R. Ac. Sc.*, 200, 474.
- 1939. Sur les roches du soubassement de la région entre Bangui et le Cameroun. *Publ. Bureau Et. Mi. col.*, No. 10.

- and R. FURON, 1935. Sur les formations continentales post-hercyniennes de l'Ouest africain. *C.R. Ac. Sc.*, **201**, 86-88.
- BAUD, L., 1950. Étude descriptive des séries de la rivière Bouenza au Moyen Congo ou Étage Bouenzien. *Bull. Soc. Géol. Fr.* (5), **20**, 57-61.
- 1954. Notice explicative de la feuille Franceville-Est, avec carte géologique de reconnaissance au 1/500,000. 34 pp.
- BESSOLES, B. and R. DELAFOSSE, 1958. Les grès de Mouka-Ouadda, en Ubangi-Chari oriental. *Bull. Soc. Géol. Fr.* (6), **8**, 91-103.
- BIGOTTE, G., 1959. Contribution à la géologie du Bassin du Niari. Étude sédimentologique et métallogénique de la région minière. *Bull. Dir. Mi. Géol. A.E.F.*, No. 9, and thesis, Nancy, 1956.
- BORGNEZ, G., 1935. Esquisse géologique de l'Oubangi-Chari occidental et des régions voisines. *Chronique Mi. col.*, pp. 354-372.
- BRUSTIER, L., 1923. Sur la géologie du Kouango français. *Ann. Mi.*, pp. 137-161.
- CHUBERT, B., 1937. *Étude géologique des terrains anciens du Gabon*. 1 vol., 210 pp. (Thesis, Paris.)
- COSSON, J., 1953. Coupure géologique Port-Gentil-Est. *Rapp. ann. Serv. Géol. A.E.F.*, 103-117.
- 1955. Notice explicative sur les feuilles Pointe-Noire et Brazzaville. *Publ. D.M.G.A.E.F.*, 56 pp. 1 map.
- DARTEVELLE, E. and S. FRENEIX, 1957. Mollusques fossiles du Crétacé de la Côte occidentale d'Afrique, du Cameroun à l'Angola. 2 Lamellibranches. *Ann. Mus. R. Congo belge*, 20.
- DELHAYE, F. and M. SLUYS, 1921-2. La région métallifère du Niari et du Djué (Afrique équatoriale française); observations faites en 1914. *Ann. Soc. Géol. Belge, Publ. relat. Congo belge*, **45**, 54.
- DELORME, J. and F. DELANY, 1956. *XX Int. Geol. Congr.*, Mexico.
- DÉVIGNE, J.-P., 1958. Le Précambrien du Gabon occidental et des régions limitrophes en Afrique équatoriale française. (Doctorate thesis, Clermont).
- FURON, R., 1932. Observations géologiques sur la côte du Gabon. Les roches phosphatées. *Bull. Soc. Géol. Fr.* (5), **2**, 501-511.
- 1951. *Géologie de l'Afrique*. Paris (Payot). See p. 244.
- B. BRAJNIKOV and V. PÉRÉBASKINE, 1930. Contribution à l'étude géologique du Gabon et Carte géologique de reconnaissance au 2,000,000^e. *Rev. Géogr. phys. et Géol. dynam.*, 363-372.
- GÉRARD, G., 1958. Notice explicative de la Carte géologique de l'Afrique équatoriale française au 1/2,000,000. 198 pp.
- and J. GÉRARD, 1952. Stratigraphie du Précambrien de l'Oubangui-Chari occidental. *Bull. Soc. Géol. Fr.* (6), **2**, 467-483.
- HAUSKNECHT, J. J. and M. AUBAGUE, 1956. Nouvelle interprétation du socle sur la feuille Libreville. *Bull. Dir. Mi. Géol. A.E.F.*, No. 8, 53-60.
- HOURCQ, V., 1958. Le sédimentaire côtier. in Notice explicative de la Carte géologique de l'Afrique équatoriale française au 1/2,000,000, pp. 7-25.
- and D. REYRE, 1956. Les recherches pétrolières dans la zone côtière du Gabon. *XX Int. Geol. Congr.*, Mexico; *Sympos. Petrol. and Gas*, **1**, 113-141.
- KORABLEFF, G., 1940. *Contribution à l'étude de la géologie et de la géologie appliquée de l'Oubangui-Chari oriental et du Cameroun*. Paris.

- KOSSMAT, F., 1893. Ueber einige Kreideversteinerungen von Gabun. *Sitz. k.k. Ak. Wiss. Wien*, **102**, 575-589.
- LOMBARD, J., 1930. Céphalopodes et Lamellibranches crétacés du Congo français. *Bull. Soc. Géol. Fr.*, (5) **2**, 501-511.
- 1935. Structure géologique de l'Oubangui-Chari central. *C.R. Ac. Sc.*, **200**, 1953.
- MESTRAUD, J.-L., 1952. Formation du socle en Oubangui-Chari central. *Int. Geol. Congr., Algiers., Ass. Serv. Géol. Afr.*, 155-162.
- NICOLINI, P., 1959. Le Synclinal de la Nyanga (zone de la boucle du Niari). Contribution à l'étude des mineralisations stratiformes du Moyen Congo. *Bull. Dir. Mi. Géol. A.E.F.*, No. 10, and thesis, Paris 1959.
- POLINARD, E., 1935. Constitution géologique et pétrographique des bassins de la Kotto et du M'Bari, région de Bria-Yalinga. *Mem. Inst. R. Col. belge*, 4.
- RIEDEL, A., 1959. La série phosphatée de Holle region du Kouilou (Congo). *C.R. Soc. Géol. Fr.*, pp. 48-49.
- ST. MEUNIER, 1892. Contribution à la géologie du Congo. *Le Naturaliste* (2), No. 137, 266-269.
- WACRENIER, P., 1954. Coupures géologiques Bangui-Ouest et M'Baiki. *Rapp. ann. Serv. Géol. A.E.F.*, pp. 45-48.

CONGO AND CABINDA

Pioneers in the study of the geology of the Congo last century include E. Dupont and J. Cornet, whose work was followed up a little later by F. Delhaye, M. Robert and M. Sluys.

The geological formations are distributed in three zones; a littoral zone (marine Cretaceous and Tertiary); a central basin known from two boreholes and outcrops on the margins; a rim of Pre-Cambrian rocks (Katanga, Kasai, western Congo, northern Congo, Kivu and Ruanda-Urundi). There remain a number of difficulties in correlating the Pre-Cambrian from province to province. I shall give here the type successions of the western Congo and Katanga, following the classification of Cahen (1954) and Cahen and Lepersonne (1956) and the legend of the 4th and 5th editions of the Geological Map of the Belgian Congo and Ruanda-Urundi, undertaken by the *Commission de Géologie du Ministère du Congo Belge*.

1. PRE-CAMBRIAN OF THE WESTERN CONGO

The Pre-Cambrian of the western Congo outcrops over a wide area in the Mayombe and neighbouring regions. It is divided into two major groups: "Mayombe System" below and "Western Congo Group" above.

(a) *Mayombe System*

Without doubt the Mayombe System does not belong to the oldest Pre-Cambrian, which is represented by the Pre-Mayombe System of the Congo Republic and Gabon. The following are distinguished, from bottom to top:

Matadi and Palabala Series:

Sericite muscovite quartzites;
Mica-schists and gneisses.

Tshela Series:

Graphitic schists;
Feldspathic sandstones and quartzites, amphibolites.

Duinzi Series:

Schists with a satiny lustre and talc-schists;
Micaceous quartzites and lenses of limestone.

The Mayombe System is strongly folded and has been invaded by alkaline and calc-alkaline granites and migmatites. It is also cut by the hyperalkaline Noqui Granite, containing riebeckite and aegyrine. This belongs to the post "schisto-gréseux" orogeny and *could* be a "Younger Granite" (?).

(b) *Western Congo Group*

At present the Western Congo Group is considered to comprise from top to bottom: the *Système schisto-gréseux*, the *Système schisto-calcaire*, the Upper Tillite of the Lower Congo, the "Upper Shiloango System", the Lower Tillite of the Lower Congo and the "Sansikura System". The total thickness is about 4,000 to 5,000 m.

Beginning with the oldest group, we have:

Sansikura System:

Basal conglomerate, resting on older rocks with major unconformity (4 m.);
Phyllites and purple quartzitic phyllites (500 m.);
Schists, quartzites, phyllites, cherts (875 m.).

Lower Tillite of the Lower Congo:

Glacial and periglacial formation ranging up to 400 m. in thickness.

Upper Shiloango (Louila) System:

Mouyonzi Stage (5-700 m.) (or Little Bembezi):
Basal conglomerate;
Phyllites and feldspathic sandstones;
Grey-green phyllites and calcareous sandstones.
Sekelolo Stage (200 m.):
Dark-coloured shales with calcareous nodules;
Black argillaceous limestones;
Stromatolitic limestones;
Calcareous breccia.

Upper Tillite of the Lower Congo:

Glacial and periglacial formation ranging up to 150 m. in thickness.

Système schisto-calcaire (about 1,000 m.):

Kwilu (= Kouilou) Stage:

C¹—Pink and grey dolomite rocks (10 m.);

C²—Bulu horizon: shales and calcareous sandstones, varying in colour from green to dark red ("lie de vin") (350 m.);

C³—Luanza horizon: grey limestone, sometimes oolitic or stromatolitic (100 m.).

Lukunga Stage:

C⁴—Stromatolitic limestones with beds of chert (300 m.).

Bangu Stage:

C⁵—Dolomitic limestones, partly light-coloured and oolitic, partly black, bituminous and fetid (300 m.);

C⁶—Ngandu Shales and Limestones (90 m.) (only north of the river).

Système schisto-gréseux:

This is unconformable on the previous system.

Mfidi Series (100 m.), only in a local depression.

Mpioka Series (1,000 m.):

Bangu and Niari conglomerates (40 m.);

Vampa red slates (?) and quartzites (400 m.);

Kubuzi feldspathic quartzites (250 m.);

Liansama red and green slates (?) and quartzites (300 m.).

Inkisi Series (slightly unconformable) (1,000 m.):

Mont Bidi Conglomerate (15 m.);

Fulu Arkoses, of red and "lie de vin" colour (300 m.);

Morozi quartzites and slates (?) (20-30 m.);

Zongo Arkoses (300 m.);

Luvumvu slates (?) and quartzites (300 m.);

Red slates (?) and quartzites.

2. PRE-CAMBRIAN OF KATANGA

The Pre-Cambrian of the south-eastern Congo is subdivided at present into three major groups: "Basal Complex", "Kibara Group" and "Katanga Group".

(a) *Basal Complex*

This includes a very old granitised group with augen gneisses, grained gneisses, quartzites and amphibolites, situated between the granites of western Lubilash and Libishi. The "Ruzizi Group", included in this complex, appears to have a younger age limit of 2,275 million years, as determined from an alluvial monazite.

(b) *Kibara Group*

The term was proposed by M. Robert in 1931 for the rocks of a Pre-Cambrian range crossing Katanga diagonally in a SSW.-NNE. direction and broadening northwards. In the north-east the Kibara Group links up with the "Urundi Group".

The following succession is distinguished, from bottom to top:

Nzilo System:

- K1a. Phyllites and quartzitic phyllites (over 4,000 m.);
- K1b. Phyllites and quartzitic phyllites resting with slight unconformity on the above (1,800 m.),
- K2. Grey, white and reddish quartzites and phyllites (500 to 4,000 m.);
- KV. Volcanic group, predominantly diabase (0 to 2,000 m.).

Lubudi System:

- K3. Brightly coloured slates (?) and phyllites (1,400 m.);
- K4a. Black, carbonaceous slates (?) (600 m.);
- K4b. Quartzites (300 m.);
- Unconformity or non-sequence;
- K4c. Black, pyritic and purple slates (?) (400 m.);
- K5. Dolomitic limestones with stromatolites (1,300 m.).

The age of these formations is not known, but they are cut by pegmatites dated at 1,040 million years (Ledent *et al.* 1956).

(c) *Katanga Group*

This group comprises, from bottom to top: "Roan System", "Great Conglomerate and Mwashya System", "Kundelungu System".

Roan System (1 to 2,000 m.):

Conglomerate;

Arkosic complex, with conglomerates (2 to 600 m.);

Lower Dolomites (500 to 1,000 m.) (base of the Mines Series);

Siliceous and dolomitic rocks (22 m.);

Dolomitic shales with stromatolites (50 m.);

Limestone with black copper ore (over 350 m.) (top of Mines Series);

Dipeta shales and sandstones (300 m.);

Mofya magnesian limestones (450 m.);

Silicified oolites with *Girvanella roberti* and jaspers.

Great Conglomerate and Mwashya System (1,000 m.):

Mwashya Series (6 to 800 m.):

Tillite (Mwashya Conglomerate) and dolomitic shales;

Black shales;

Shales, sandstones and varves.

Great Conglomerate Series (up to 300 m.):

Tillite and periglacial rocks.

This conglomerate is often incorporated into the base of the Kundelungu System. It can readily be compared with the Upper Tillite of the Lower Congo.

Kundelungu System (1,500 to 3,000 m.):

Lower Series (0 to 1,500 m.):

Basal conglomerate (not to be confused with the Large Conglomerate);

Kakontwe calcareous shales and grey-blue stromatolitic limestones;

Shales;

Sandstones, quartzites and grey-brown limestones.

Small Conglomerate Series (glacial):

Middle Series—

Conglomerates (10 m.);

Pink, dolomitic limestone (20 to 45 m.);

Oolitic limestone of the Lubudi Cementworks (10 to 45 m.);

Shales and calcareous shales (100 m.).

Upper Series (1,500 m.)—

- Kyubo feldspathic sandstones (15 to 75 m.);
- Bed with micro-fossils (500 m.);
- Sandy shales (300 m.);
- Fine grained, thick-bedded sandstones (100 to 200 m.);
- Pink feldspathic sandstones of the plateaux (500 m.);
- Red shales (over 100 m.).

The Kundelungu System is strongly folded in Katanga and the upper, tabular part forms the Kundelungu plateaux. Its age remains a subject of dispute. L. Cahen has shown that in addition to uraniferous bodies dated at 620 million years there are some epigenetic plumbiferous bodies with an age of about 630 million years (as in the "schisto-gréseux" of the western Congo). This latter age suggests that the Kundelungu System should be put into the Pre-Cambrian (or Infra-Cambrian). Such a view is not accepted by everyone, in particular by M. Robert, who keeps all the Kundelungu System in the Palaeozoic. Robert naturally accepts the determined age of the uraniferous bodies of Shinkolobwe, which occur in the Roan System, but he considers that the emplacement of copper- and galena-bearing veins, at about the time of the Kundelungian movements, is associated with the reworking of older ores (Robert 1956).

H. and G. Termier (1957) show a good deal of hesitation in including the Kundelungu in the Pre-Cambrian and E. Krenkel (1957) includes the Inkisi and the Upper Kundelungu in the Palaeozoic.

Eastern and Northern Parts of the Congo

It is very difficult to correlate the Pre-Cambrian rocks of Katanga with those of the western Congo and to follow the described formations on the ground as one travels round the Congo Basin. However, after a study of rock specimens and the relevant literature, L. Cahen and J. Lepersonne have been able to establish satisfactory correlations.

1. The oldest rocks are known as the "Banzyville Group" in the north (Ubangi), the "Mont Stanley Group" and the "Western Nile Formation" in the north-east and the "Lukoshi Formation" in Kasai.

2. "Kibali Group" in the north-east, "Kalundwe Group" in Kasai and "Liki-Bembe Group" in the north.

3. Corresponding to the Katanga Group and the Western Congo Group we have the "Malagarasi Group" in Ruanda-Urundi (extending to Bukoban from Tanganyika); the "Lindi Group" (with stromatolites) in the north-east; the "Ubangi Group" (with stromatolites) in the north, and the "Bushimaie System" in Kasai and Lomami.

3. YOUNGER ROCKS

The Congo occupies an immense basin 750,000 sq. km. in area, surrounded by Pre-Cambrian uplands.

Throughout the whole of the central area the Pre-Cambrian is hidden by younger deposits which must be very thick since the basement has not yet been reached by boreholes, one of which, at Samba (on the equator and 22° W.), went down 2,040 m. (Evrard 1957). Seismic data offer support in suggesting that the basement is up to 3,500 m. below the surface.

This basin, however, is somewhat complex, consisting really of several smaller basins and grabens. The various deposits rise to the surface towards the borders and are visible as a discontinuous belt around the basin, between the Pre-Cambrian and the Quaternary.

The Samba Borehole went through the following rocks, from bottom to top:

1. Red sandstones: 1,167 to 2,040 m.
2. Clays and sandstones: 845 to 1,167 m.
3. Sandstones and argilites: 0 to 845 m.

Groups 2 and 3 represent the Jurassic and Cretaceous. No age has been assigned to group 1.

The Dekese Borehole (22° W. and 4° S.) went through:

1. Sandstones and shales: 860 to 1,680 m. (Karoo).
2. Argilites: 0 to 860 m. (Jur. and Cret.).

(a) *Marine Palaeozoic*

Cahen and Lepersonne having put all the Kundelungu and Western Congo Systems into the Pre-Cambrian, hardly any marine Palaeozoic is left in Central Africa. It is necessary to go to northern Kivu, in the Bilati Valley, to find a group of folded shales and sandstones which are doubtfully attributed to the Lower

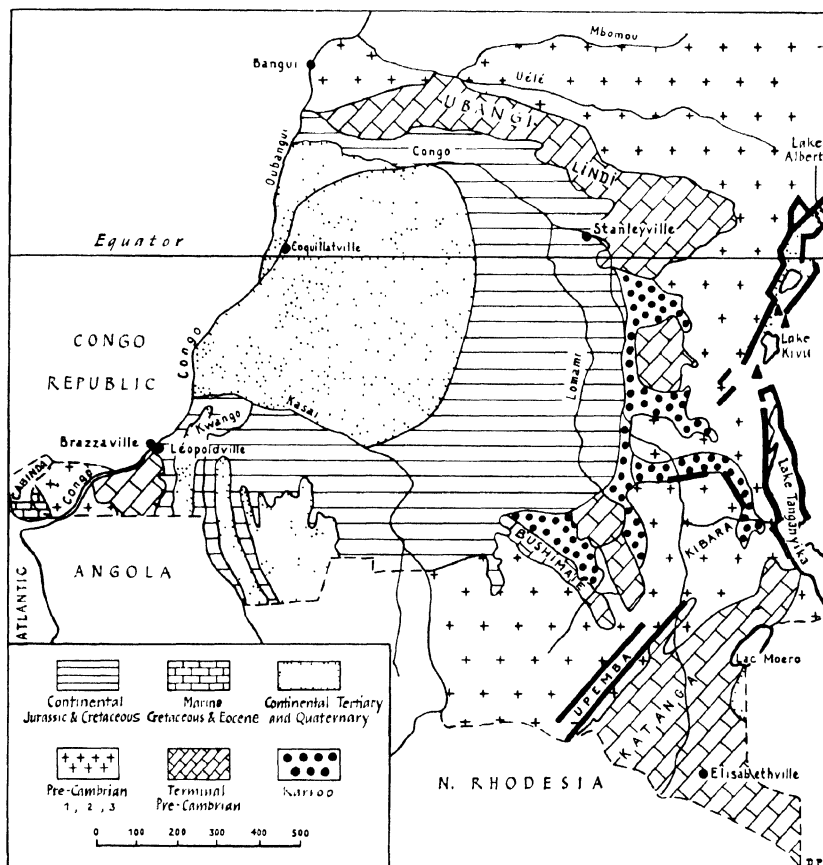


FIG. 24. Geological sketch-map of the Congo.

Palaeozoic because of the local discovery of two cephalopods not strictly *in situ* (Passau 1941; Miller 1951; Cahen and Lepersonne 1956; Cahen 1956).

(b) Karroo

The intense period of cold indicated in southern Africa by the Upper Carboniferous glaciation made itself felt also in Central Africa. Numerous glaciers have left traces in Katanga and neighbouring regions.

After the glaciation and during interglacial periods numerous enclosed basins with marshy bottoms supported a rich flora which gave rise to beds of coal. Deposits have been found both in pre-existing valleys and in grabens (though this does not necessarily imply they were formed in grabens) (Sluys 1950).

After long and valueless discussions as to their age, the "Lualaba Lubilash" and "Kwango" Series have yielded Jurassic and Cretaceous fossils and can no longer be correlated with the Karroo. I had to note them here because they encumber a great deal of geological literature and their names can provoke errors.

At present the Congolese Karroo is considered to consist only of the "Lukuga Series", sometimes called the "Walikale and Lukuga Series" (Boutakoff 1948; Pierart 1959; Renier 1951). The Trias, with phyllopoas, is not certainly dated.

It is subdivided into several horizons, from bottom to top as follows:

Lower beds of Walikale (Kivu) comprising locally 300 m. of tillites (of which there are five), conglomerates and varves. These are the equivalent of the Upper Carboniferous Dwyka Tillite in South Africa.

Lower Stage (Permo-Carboniferous):

Black shales (Permian) (120 m.) with *Gangamopteris cyclopteroides* Feistm., *Cyclodendron leslei* Seward, *C. mathiewi* Seward, *Noeggerathiopsis hislopi* Bunbury, *Phyllothea australis* Br. and an insect, *Boutakovia saleei* Pruvost.

Upper Stage (Permian):

Transitional group: arkoses, sandstones, shales, streaks of coal (50 m.);

Group with coal beds (125 m.) containing a Permian flora including *Glossopteris indica* Schimper, *Noeggerathiopsis hislopi*, *Phyllothea zeilleri* R. E., *Schizoneura* sp.

In the Luena (Katanga) these beds contain numerous spores (Pierart 1959).

The Walikale beds are more or less confined to a small part of Kivu and those of Lukuga have been named after the coal measures in the Lukuga Valley. This latter series is found in the south-east of the Congo, from Katanga to the Ituri and further west, in the south of Kasai.

(c) "*Continental Intercalaire*" (*Jurassic-Cretaceous*)

The Congo Basin contains Jurassic and Cretaceous deposits of the "*Continental intercalaire*". A three-fold division is made into the Stanleyville Stage (Upper Jurassic), the "*Loia Series*" and the "*Kwango*" Series (Cretaceous).

Stanleyville Stage (east of the Congo Basin)

The type locality is situated on the lower Lualaba between Ponthierville and Stanleyville. There are some 350 m. of fine-grained sandstones and multi-coloured argilites containing a fauna of fish and entomostracans (Sainte-Seine 1955). This is the lower unit of a "*Lualaba Series*", whose name can give rise to confusion.

The succession comprises fourteen horizons, from bottom to top as follows:

1. Argilites (over 50 m.).
2. "Lime fine" Songa marine complex: argilites with bed of marine limestone (0 m. 40).
3. Grey and green argilites with *Lepidotes congolensis* Huss and *Pleuropholis jamotti* (5 m. 60).
4. Bituminous shales with fish: *Lualabaea lerichei*, *Lombardina decorata*, *Parapleuropholis albrechtsi*, *Ligulella sluyisi*, *Pleuropholis lannoyi* etc. (2 m. 40).
5. Green argilites.
6. Loso Complex: argilites, sandstones and bituminous shales (7 m. 50).
7. Red argilites of the Mission Saint-Gabriel, with *Lepidotes congolensis* Hussakof (15 m.).
8. Argilites (1 m.).
9. Argilites (35 m.).
10. Usengwe Complex: argilites and bituminous shales with *Lepidotes congolensis* Hussakof.
11. Red and multi-coloured argilites (25 m.).
12. Bituminous shales, etc., with *Australopleuropholis lombardi* (70 m.). (At km. 108 of the railway.)
13. Red argilites (80 m.).
14. Red and "lie de vin" argilites and red sandstones (over 100 m.).

The fish fauna, collected and described by Sainte-Seine, is of Upper Jurassic (Kimmeridgian) age, at least as regards horizons 3 and 4; it is perhaps Wealdian at the top.

The thin bed of marine limestone at the base suggests the former existence of a small Kimmeridgian gulf connecting with the Indian Ocean.

The bituminous shales and argilites signify a lacustrine or lagoonal environment. They were deposited in lagoons or large shallow marshes where the water was stagnant, like that known at the present day in the Bahr-el Ghazal (in Chad and the Sudan) or in the Gran Chaco (in South America). The bottom is composed of a black mud 1 m. thick, resting on clays and sands. The ostracods have been described by N. Grekoff (1957): *Darwinula oblonga*, *Metacypris duboisi*, etc.

Loia Stage (terminal Jurassic-Wealdian)

The Loia Stage rests on the Stanleyville Stage and forms the top of the "Lualaba". It consists of green and brown sandstones and green and red clays and shales, sometimes bituminous. The type locality is on the lower Lomami. The stage has been found in the deep Samba Borehole, where the ostracods, identified by Grekoff, have indicated a terminal Jurassic and Wealdian age (*Iliocypris minor*, *I. lomamiensis*, *Metacypris polita*, etc.).

Kwango Series (Cretaceous)

The Kwango Series, put for a long time in the Karroo and the Trias, is actually Cretaceous in age. It is known in the Kwango and western Kasai regions and extends into the Middle Congo and Ubangi.

It is divided into two: Inzia Stage below, Nsélé Stage above.

Nsélé Stage, terminated by an end-Cretaceous erosion surface 100 to 200 m. of soft red and mauve arkosic sandstones, with lenses of red argilites. No fossils are known.

Inzia Stage (from bottom to top):

1. Lutshima Argilites (25 m.).
2. Varied sandstones (15 to 40 m.).
3. Kimko-Luzubi Complex: argilites and soft sandstones with fish scales (25 m.).
4. Compact sandstones (25 to 90 m.).
5. Kipala-Falaises Schwetz Complex: red and green argilites with fish (*Rhipis moorseli* Sainte-Seine) (25 to 40 m.).

The Kipala Complex has yielded fish which *could* be Cenomanian in age and of marine origin, which suggests there might have been a marine incursion from Gabon or the Benue. All the lower beds are of continental origin and contain diamonds.

Kimberlites

The diamonds have been freed during the erosion of kimberlite pipes. Such structures are known on the Kundelungu Plateau, in the Bushimaie region and in Kasai (Angola frontier).

The kimberlites of the Bushimaie are intrusive in beds regarded as "Lualaba" and are therefore younger than Upper Jurassic. In Kasai no diamonds are found in the Lualaba beds but do occur at the base of the Kwango Series. The kimberlite pipes are therefore probably basal Cretaceous in age.

(d) *Kalahari System (Tertiary)*

The Kalahari System, as defined in the Congo, is perfectly delimited: it rests on an end-Cretaceous peneplain and is older than the peneplains of Upper Pliocene age. Quaternary deposits are excluded from this system (Cahen and Lepersonne 1956), which is the equivalent of the "Continental terminal" of North Equatorial Africa.

Two series are distinguished: "Polymorphic Sandstones" below and "Ochre Sands" above.

Polymorphic Sandstone Series (Eocene-Oligocene)

The series is from 80 to 100 m. thick. It is known throughout the southern half of the Congo, from the Lower Congo to Katanga.

L. Cahen (1954) gives a type section, taken in the Kwango. It comprises, from bottom to top:

1. Basal conglomerate: silicified sandstone of "lie de vin" colour containing 1 to 5 cm. fragments of rounded or angular chalcedony (0.5 to 2 m.).
2. "Lie de vin" sandstone, more or less silicified (10 to 20 m.).
3. Grey sandstone with plant remains (1 m.).
4. Sandstone with chalcedony cement, chalcedony, quartzitic sandstones with fossiliferous lenticles.
5. Hard, silicified sandstones.
6. White and red soft sandstones, rarely silicified, or sands.

One of the most well-known localities is Mont Bunza, which is an outlier situated between the rivers Tchikapa and Longatchimo, left-bank tributaries of the Kasai close to the Angola frontier. Visible there are some 100 m. of "Polymorphic Sandstones" with 25 m. of fossiliferous deposits with ostracods (*Cypris farnharmi* Leriche), gastropods (*Physa parmentieri* Leriche, *Planorbis* sp.) and plants (*Chara rauwi* Leriche).

On the Kundelungu Plateau (Katanga) at altitudes between 1,600 and 1,750 m. one finds chalcedonic sandstones of this series containing *Planorbis*, *Limnea* and the oogonia of characeans. These faunules give no indication of the actual age of the Polymorphic Sandstones, which remains presumed from the penplanations which embrace them.

Ochre Sands Series (Neogene)

The Ochre Sands Series is older than the Quaternary and rests unconformably on the mid-Tertiary erosion surface which post-dates the Polymorphic Sandstones. The succession often begins with a limonitic duricrust and sands with limonitic gravel. Then come some 100 m. of ochre sands and soft sandstones, containing bones of mastodonts and rhinoceros of the Lower Miocene, in the tectonic trough of Lake Albert-Semliki-Lake Edward.

4. QUATERNARY

The Congolese Quaternary is all the more interesting because it is adjacent to the classic areas of East Africa and because it is found in great thickness in the tectonic troughs. Moreover, radiocarbon dating of charcoal from the last Great Pluvial of the Lunda (Angola, near the frontier) has revealed the exact synchronism of glacial periods in Europe and North America with pluvial periods in Africa. Finally, the Quaternary deposits contain abundant stone implements (Mortelmans 1957), vertebrates and molluscs (Adam and Lepersonne 1959).

First Pluvial: Kagerian (or Kaguerian) = Villafranchian

The Congolese Kaguerian is represented by the Kaiso Series of Uganda, found in the Congo in the Miocene trough of Lake Albert-Semliki-Lake Edward. It consists of an alternation of 300 m. of sands, gravels and clays containing a Villafranchian fauna

including *Stegodon*, *Mastodon*, numerous molluscs and a primitive industry (Pebble Culture = Kafuen).

Kaguerian-Kamasian Interpluvial

End of deposition of the Kaiso Series and formation of a lateritic cover on the gravels.

Second Pluvial: Kamasian

The Kamasian gravels contain the last traces of the Pebble Culture and the first two-faced implements.

Kamasian-Kanjerian Interpluvial

Second phase of lateritisation.

Third Pluvial: Kanjerian

Semliki Series. Sands and gravels with *Elephas recki* and an Acheulian industry. Mammal beds of the Songwe Pass (Upemba, Katanga) with *Hippopotamus* cf. *amphibius*, *H.* aff. *imaguncula*, *Elephas* (*Palaeoloxodon*) *recki*.

Kanjerian-Gamblian Interpluvial

This is the main dry phase of the Congo. It was subarid and even arid in the east but less so in the west. It was a period of tectonic activity, marked by faults, collapses, horsts and volcanic activity and marks the beginning of separation of Lakes Kivu and Edward and the formation of the Upemba Trough.

Fourth Pluvial: Gamblian (corresponding to the Würm-Wisconsin)

Definitive separation of Lakes Kivu and Edward, birth of the present Ruzizi linking Lake Kivu with Lake Tanganyika. Deposits of sands and gravels. Middle and Upper Palaeolithic industries.

Gamblian-Makalian Interpluvial Humid Phase: Makalian

Ashes of the Toro volcanoes north of Lake Edward and 12 m. terrace of Lake Edward. Mesolithic Ishango Man from the top of the Makalian, knowledge of which is due to a study in comparative anatomy by Fr. Twisselmann (1948), extending to a more general consideration of fossil man and apes, whose interest for human palaeontology cannot be stressed too strongly.

In addition, specimens of charcoal from the base of the Makalian terrace of the Lunda at Mufo (Angola), associated with the Lupembian industry, have been analysed by the C₁₄ method and

have given an age of 14,503 years. This age corresponds exactly with the Cary glacial advance in America (14,500 years), which corresponds with the Pomeranian in Europe.

Makalian-Nakurian Dry Phase

Dry episode, with Mesolithic (Tshitolian) industry. Deposit of sands on the gravels of the Makalian terrace. Other specimens of charcoal from the base of these post-Makalian sands have been dated at 11,189 (± 490) years by the radiocarbon method. This age corresponds to the dry episode of the Two Creeks Horizon of Wisconsin, U.S.A. (11,404 years).

Then comes a final humid phase in the Neolithic.

5. MARINE CRETACEOUS OF THE COAST

References include Darteville (1952-3), Darteville and Brebion (1956), Darteville and Freneix (1957), Darteville and Casier (1943-1956), Fortems (1958) and Freneix (1959).

The presence of marine Cretaceous in the Lower Congo and Cabinda was recorded in 1934 by E. Darteville. It is now known that there is a very complete fossiliferous succession from the Aptian to the Maestrichtian.

In the Boma region the Pre-Cambrian basement is covered by continental "Sublittoral Sandstones" of "Continental intercalaire" (Jur.-Cret.) age. They have yielded plants described under the name *Pagiophyllum* (Stockmans 1943), close to the genus *Sphenolepidium*, which originated in the Jurassic and reached its full development in the Lower Cretaceous.

The marine transgression began with the Aptian-Albian of the Mavuma containing *Nerita malheiroi*, *Cerithium silva-portoi* (?) and bituminous beds of Aptian age.

The Cenomanian-Turonian is represented by limestones with *Pteria* (*Avicula*) *zambiensis*, *Pinna decussata*, *Lopha* cf. *syphax*, *Grano-cardium productum*, *Tylostoma globosum* and fish, the most characteristic of which are *Anacorax falcatus* and *Onchosaurus pharao*.

Coniacian-Lower Santonian: 40 m. of calcareous sandstones and clays with *Lamna appendiculata*, *Enchodus crenulatus*, *Plicatula auresensis*, *P. ferryi* and *Venericardia nautiensis*.

Upper Santonian-Lower Campanian: 20 m. of yellow limestones with flints containing *Lamna appendiculata*, *Trigonoarca camerunensis*, *T. angolensis*, *T. curvaltodonta*, *Ostrea boucheroni*, *Veniella drui*, etc.

Upper Campanian: 20 to 30 m. of coarse-grained limestones with *Anacorax kaupi*, *Oxyrhina mantelli*, *Trigonoarca camerunensis*, *Macrocallista wohltmanni*.

Maestrichtian: basal conglomerate (2 to 5 m.), sandy clay with phosphatic beds and fish teeth (40 to 50 m.), fossiliferous yellow limestone (10 m.), with *Anacorax pristodontus*, *Ginglymostoma rugosum*, *Lamna appendiculata*, *Onchosaurus maroccanus*, *Pycnodus praecursor*, *Stephanodus libycus*, *Arca monodi*, *Trigonoarca manzadinensis*, *Venericardia ameliae* (non *beaumonti*) and *Lucina angoliensis*.

6. MARINE TERTIARY OF THE COAST

The presence of Palaeocene on the coast has been known since 1913, the date when E. Vincent, L. Dollo and M. Leriche published on the material collected by N. Diderrich (Vincent *et al.* 1913; see also Darteville and Casier 1943-1956). This comprises the well-known "Landana Beds" in Cabinda. Subsequently Yypresian and Lutetian strata have been found and the discoveries have been extended into the Lower Congo.

Palaeocene (or *Montian-Thanetian*).

These beds rest on the Maestrichtian. They include calcareous sandstones and sandy marls with *Ginglymostoma africanum*, *Myliobatis n'zadinensis*, *Pseudoeigertonia bebianoi*, *Turritella mayombica*, *Clinuropsis diderrichi*, *Venericardia mayombica*, *Hercoglossa diderrichi*, etc.

The *Yypresian* is known through a microfauna.

The *Lutetian* of Cabinda contains *Venericardia landanensis*, *Schizaster douvillei* and fish teeth.

The *Oligocene* is missing and the *Lutetian* is directly overlain by the Miocene. At Malembe (Cabinda) this is Lower Burdigalian with fish: *Odontaspis acutissima*, *Lamna cattica*, *Hemipristis serra*, *Gaelocerdo adunais*, *Carcharhinus egertoni*, *Rhinoptera cf. studeri* and *Aetobatis arcuatus*.

Pliocene? The cliffs of Moanda and Vista are composed of clayey gravels containing silicified wood and shells of forms living today. These are considered to belong to the Upper Pliocene.

7. VOLCANOES

In the eastern Congo is a graben at the bottom of which lie Lakes Kivu and Edward. This N.-S. graben is crossed from west to east

by a series of volcanoes forming what is known as the Virunga Range (*virunga* means volcano). This range is 80 km. long and the highest volcano, the Karisimbi, rises to 4,507 m.

The lavas erupted by these volcanoes, mainly basalts, have filled up the graben and isolated the two lakes. Only the two western volcanoes are still active. The Nyamlagira (3,058 m.), whose crater is 2 km. in diameter, had a long period of activity from January 1938 to 1942. The volume of lavas erupted has been estimated at 10 million cubic metres. The Niragongo (3,470 m.) began erupting in March 1948.

REFERENCES

- ADAM, W. and J. LEPERSONNE, 1959. Mollusques pléistocènes de la région du Lac Albert et de la Semliki. *Ann. Musée R. Congo belge*, **25**, 150 pp.
- BOUTAKOFF, N., 1948. Les formations glaciaires et post-glaciaires fossilifères, d'âge permo-carbonifère (Karoo inférieur) de la région de Walikale (Kivu, Congo belge). *Mem. Inst. Géol. Univ. Louvain*, **9**, 11.
- CAHEN, L., 1954. *Géologie du Congo Belge*. Liège.
- 1956. Le Cambrien existe-t-il au Congo belge? *XX Int. Geol. Congr., Mexico. Cambrian Symposium*, 265-279.
- and J. LEPERSONNE, 1956. *Lexique stratigraphique international. Vol. IV: Afrique, fasc. 7a: Congo belge*.
- DARTEVELLE, E., 1952-1953. Echinides fossiles du Congo et de l'Angola. *Ann. Musée R. Congo belge, Sc. Géol.*, **12**, 72 pp. and **13**, 240 pp.
- and P. BREBION, 1956. Gastéropodes fossiles du Crétacé de la côte occidentale d'Afrique, du Cameroun à l'Angola. *Ibid.*, **15**.
- and E. CASIER, 1943-1956. Les Poissons fossiles du Congo belge et des régions voisines. *Ibid.*
- and S. FRENEIX, 1957. Lamellibranches fossiles du Crétacé de la côte occidentale d'Afrique, du Cameroun à l'Angola. *Ibid.*, **20**, 270 pp.
- EVARD, P., 1957. Les recherches géophysiques et géologiques et les travaux de sondage dans la cuvette congolaise. *Mem. Ac. R. Sc. Coloniales (n.s.)*, **7**.
- FORTEMS, G., 1958. Étude des couches crétacées de l'entre-Lukula-Lubuzi et de Lundu 'Nsanzi (Congo belge). *Ann. Musée R. Congo belge*, **23**.
- FRENEIX, S., 1959. Mollusques fossiles du Crétacé de la côte occidentale d'Afrique. Conclusions. *Ibid.*, **24**.
- GREKOFF, N., 1957. Ostracodes du Bassin du Congo. I. Jurassique supérieur et Crétacé inférieur du Nord du bassin. *Ibid.*, **19**.
- KRENKEL, E., 1957. *Geologie und Bodenschätze Afrikas*. Berlin. 2nd edn. Sec p. 459.
- MILLER, A. K., 1951. Paleozoic Cephalopods from the Belgian Congo. *Bull. Soc. belge Géol.*, **60**, 70-77.
- MORTELMANS, G., 1957. La Préhistoire du Congo belge. *Rev. Univ. Bruxelles*, Jan.-April, pp. 1-53.

- PASSAU, G., 1941. Découverte d'un Céphalopode et d'autres traces fossiles dans les terrains anciens de la Province Orientale. *Mem. Inst. R. Col. Belgique*, 10.
- PIÉRART, P., 1959. Contribution à l'étude des spores et pollens contenus dans les charbons de la Luena (Katanga). *Mem. Ac. R. Sc. col.*, 8: 4.
- RENIER, A., 1951. Notes sur la flore des couches de la Lukuga de la région de Walikale (Kivu). *Mém. Inst. Géol. Univ. Louvain*, 12.
- ROBERT, M., 1956. *Géologie et Géographie du Katanga*. Brussels. pp. 80-100.
- SAINT-SEINE, P. DE., 1955. Poissons fossils de l'étage de Stanleyville (Congo belge). *Ann. Musée R. Congo belge, Sc. Géol.*, 14.
- SLUYS, M., 1950. Le système du Karroo dans le bassin du Congo. *Bull. Inst. R. Colonial Belge*, 21, 979-1019.
- TERMIER, H. and G., 1957. Quelques faits paléogéographiques et paléoécologiques relatifs à la limite de l'Antécambrien et du Cambrien. *Rev. gen. Sc.*, 64, 285-291.
- TWISSELMAN, FR., 1958. Les ossements humains du gîte mesolithique d'Ishango. *Publ. Inst. Parcs Nationaux du Congo belge*. Mission J. de Heinzclin de Braucourt (1950). Fasc. 5.
- VINCENT, E., L. DOLLO and M. LERICHE, 1913. La faune paléocène de Landana. *Ann. Musée R. Congo belge*, 3, 1.

ANGOLA

General references include Mouta (1954, 1956) and Montenegro de Andrade (1957).

1. THE PRE-CAMBRIAN BASEMENT

The Pre-Cambrian basement outcrops over a large area in Angola. Three major groups are distinguished at present: Lower Pre-Cambrian (Basal Complex), Middle and Upper Pre-Cambrian (Oendolongo System) and Terminal Pre-Cambrian (Bembe System).

(a) *The Basal Complex*

Authors have grouped in this all the strongly folded and metamorphosed gneissic and granito-gneissic rocks. They occupy the larger part of western Angola.

North of the Cuanza and extending into the Congo is a batholith composed of a light pink granite. South of the Cuanza is another batholith, elongated in a NNE.-SSW. direction over a distance of more than 700 km., composed of granito-diorites and quartziferous diorites. In the south, at the latitude of Mossamédès, is an anorthosite body occupying 6,000 sq. km. of ground.

Excluding the possibility of migmatisation, these are very old rocks comparable to those of the Pre-Mayombeian of the Middle Congo and Gabon.

(b) *The Oendolongo System*

The Oendolongo System is best developed south of the Cuanza. Generally aligned NW.-SE., it forms rugged upland country reaching 2,500 m. altitude (north of the Benguela Railway), in contrast to the monotonous terrain of the zone of granites and gneisses.

The system is divided into two groups: Lower, with a basal conglomerate, feldspathic sandstones and schists; Upper, with quartzites, ferruginous quartzites and sandstones. Further subdivisions cannot yet be recognised, but work begun near the frontier suggests that the Oendolongo System is equivalent to the

three systems of the Congo: Mayombe, Sansikura and Upper Shiloango. The latter is already well delimited.

(c) *The Bembe System*

The Bembe System corresponds to the Western Congo Group of the Lower Congo and to the "Katanga Group". Each province must be described separately.

Northern Angola or Western Congo

F. Mouta distinguishes from bottom to top:

1. "Série schisto-calcaire":

Tillite reaching 100 m. thickness in the west and thinning eastwards.

Lower Stage = C_1 , C_2 and C_3 of the Congo.

Middle Stage = C_4 : stromatolitic limestone.

Upper Stage = C_5 : oolitic dolomitic limestones.

2. "Série schisto-gréseux."

Mfidi Beds: conglomerates and feldspathic sandstones.

Mpioka Beds: grey and red fine-grained quartzites.

Inkisi Beds: shales, quartzites and conglomerates.

This succession passes directly into that of the western Congo and poses no problems of correlation.

Southern Angola

1. Tjamalindi Tillite.

2. Chella sandstones and shales.

3. Humpata dolomitic limestones with stromatolites, regarded as the equivalent of the "Otavi Dolomites" south of the frontier. Thickness: 200 m.

This succession is usually compared with the "série schisto-calcaire" of northern Angola. It ends with the Humpata Dolomites and is not overlain by an equivalent of the "série schisto-gréseux".

Upper Zambesi

The isolated formations of the Upper Zambesi are compared with the neighbouring formations of Katanga by P. Vasconcelos, who distinguishes, from bottom to top:

1. Roan Series: conglomerate (50 m.), red dolomite rocks (160 m.), sandstones and quartzites (400 m.), calcareous

shales (250 m.) and silicified dolomite rocks. This would seem to be the equivalent of the Mines Series of Katanga. Copper is found, as in the latter.

2. Kundelungu Series (?): fluvio-glacial conglomerate, calcareous shales (0 to 200 m.), massive limestones (200 m.) and shales (250 m.).

2. CONTINENTAL BEDS: KARROO, CALONDA, KALAHARI, QUATERNARY

The four systems have been recognised over a wide area in Angola and cover the period from the Carboniferous to the present day.

(a) *Karoo*

The Karroo of Angola is subdivided into three series definitively established by F. Mouta (1954, 1956): the Lutôe, Cassanje and Lunda Series.

1. *Lutôe Series*

This begins with a red *fluvio-glacial conglomerate* reaching 30 m. in thickness in the Lutôe Valley. It is regarded as contemporaneous with the Dwyka Tillite of South Africa (Upper Carboniferous).

This conglomerate is overlain by 10 to 12 m. of sandstones, then (NE. of the Lunda) by black shales with plant remains: *Neuropteridium* (*Gondwanidium*) *validum* Feist. and *Noeggerathiopsis* (?) (Freire de Andrade 1948; Teixeira 1948a), which are forms found in the Eccia in South Africa (Lower Permian).

2. *Cassanje Series*

The Cassanje Series, well seen in the Quella Cliff, comprises three groups, from bottom to top as follows:

1. Fish Beds (10 m.) with *Elonichthys moutai* Teixeira, *E. angolensis* Teix., *Ceratodus* (*Angolaichthys*) *lerichei* Teix., *Dimorpholepis lutoensis* Teix., *Microceratodus angolensis* Teix., *Hybodus pusillus* Teix. and *Estherias* (*Estheria anchietai* Teix.) (Teixeira 1947, 1948b, 1949).

According to Teixeira these faunas are late Permian or early Triassic.

2. Plant Beds (stems of equisetaceans) (50 m.).
3. Phyllopod Beds (400 m.), with *Estheria lerichei* Marl., *E. malanjensis* Marl., *Estheriella moutai* Leriche, etc. The age is considered to be Upper Triassic.

3. *Lunda Series*

This is an unfossiliferous series of sandstones and shales cut by dolerites.

(b) *Calonda Formation (Cretaceous)*

C. Freire de Andrade (1954) has given this name to a formation of diamantiferous gravels found in the north of the Lunda, north of the 11th parallel.

The diamonds serve here as good "fossils", since it is known that they have been derived from nearby kimberlites, which are younger than Kimmeridgian in the Congo. The Calonda Formation is therefore comparable with the Kwango Series of the Congo and is Cretaceous in age ("Continental intercalaire").

F. Real (1958) has given the following section, from bottom to top:

1. Conglomerate (1 to 5 m.) (diamantiferous horizon).
2. Coarse sandstones with beds of red argillite (10 m.).
3. Conglomeratic lenticles (5 to 10 m.).
4. Fine-grained, shaly, purple sandstones (5 to 10 m.).
5. Upper conglomerates (10 to 20 m.).

(c) *Kalahari System (Tertiary)*

Portuguese authors have adopted a "Kalahari System" composed of two units: "Polymorphic Sandstones" and "Ochre Sands".

1. "*Polymorphic Sandstones*" Stage

F. Mouta records large outcrops of Polymorphic Sandstones. The rocks first discovered in the Cassanje Plain were similar to those of Mont Bunza in the Congo. Nevertheless, F. Mouta and H. O'Donnell, in 1933, grouped this formation with the post-Tertiary superficial deposits. In 1935 C. Veatch correlated it with that of Mont Bunza and put it in the Oligocene. However, in 1954, F. Mouta and E. Darteville, having re-examined the

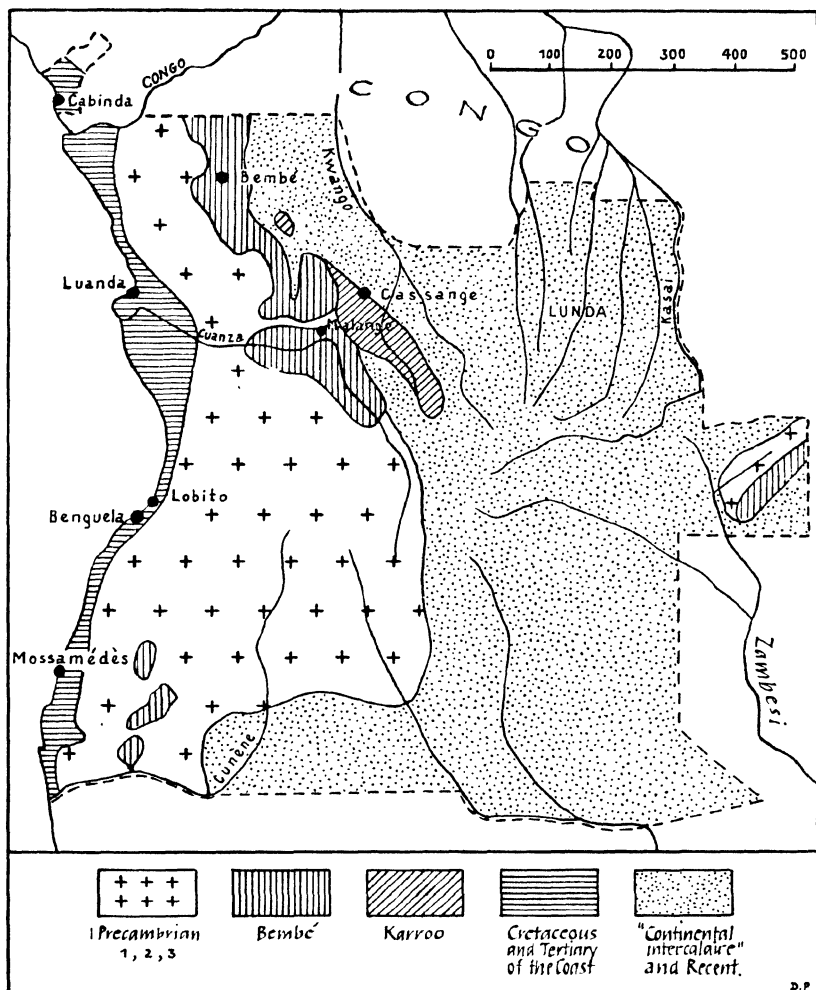


FIG. 25. Geological sketch-map of Angola.

ground and the faunas of the Cassanje Plain, judged that the molluscs are closely analogous to living forms and put the Polymorphic Sandstones of Cassanje into the Middle Pleistocene.

L. Cahen and J. Lepersonne (1952) believe nevertheless that there are some true Tertiary polymorphic sandstones apart from those of the Cassanje Plain.

2. Ochre Sands Stage

These comprise essentially Miocene sands of the high plateaux and certain unfossiliferous sands and gravels of Pliocene or Pleistocene age.

(d) Quaternary

The Quaternary of Angola is very similar to that of the Congo and the numerous stone industries have allowed the establishment of a very complete correlation. However, the Angola Quaternary is noteworthy for the fissure and grotto deposits of the Humpata Plateau (Mouta 1905, Arambourg and Mouta 1952). These have furnished a fauna of Lower Pleistocene (Villafranchian) age: *Taurotragus* cf. *oryx*, *Cricetomys* cf. *gambianus*, *Dinopithecus ingens* Broom. and *Papio* sp.

Next to be noted are the fossiliferous "Polymorphic Sandstones", to be distinguished from the "Polymorphic Sandstones" of the Kalahari System of Mont Bunza in the Congo, considered to be Tertiary. Cahen and Lepersonne (1952) and Mouta and Darteville (1954) agree entirely in putting into the Middle Pleistocene the Polymorphic Sandstones of the Cassanje Plain, seen near the catholic mission of the Bangalas. Darteville has recorded from these the oogonia of characeans, ostracods and molluscs (*Limnea* sp., *Biomphalaria* sp., *Bulinus* sp., etc.).

3. MARINE CRETACEOUS OF THE COAST

References include Spath (1922, 1951), Haas (1942), Douvillé (1932), Darteville (1952), Darteville and Brebion (1956), Darteville *et al.* (1957), Montenegro de Andrade (1957), Frencix *et al.* (1959) and Ferreira Soares (1959).

The Cretaceous seas developed two gulfs on the margins of the Angola coast: those of Loanda (with Lobito and Dombe Grande and Moçamedès (on the Nicolau and at Salinas).

The gneisses are directly overlain by continental and lagoonal Cretaceous beds (the "sublittoral sandstones"), comparable to those of the Congo and Gabon. These are the "Dondo" and "Cuanza Beds", with gypsiferous clays, conglomerates and sandstones with asphaltic coals containing rare plants such as *Pachypteris montenegroi* Teix., of Infra-Cretaceous age.

The marine Cretaceous, first recorded by P. Choffat and P. de

Loriol in 1888, is known through some fine fossiliferous strata, from which the following succession is reconstructed:

1. Aptian with *Pholadomya pleuromyaeformis* and *Puzosia matheroni* d'Orb.
2. Lower Albian with *Nerinaea capelloi*; Middle Albian with *Douvilleiceras mamillare*; Upper Albian with *Inflatoceras subrotunda* Spath, *I. aequatorialis* Kossm., *Elobiceras zsjajnochai* Spath, *E. lobitoense* Crick, *Protacanthoceras angolaense* Spath (found in Israel) and *Hamites attenuatus* d'Orb., reaching 800 m. thickness at Cabo Ledo.
The old record of *Knemiceras* from Salinas is to be disregarded (E. Basse de Menorval).
3. Cenomanian-Turonian with *Exogyra columba* Desh., *E. olisiponensis* Sharpe, *Pholadomya vignesi* Lartet (from 40 to 600 m.).
4. Coniacian-Santonian with *Texanites angolanus*, *Inoceramus langi*, *Hemitissotia* cf. *fritschi* (200 m.).
5. Campanian of Teba with *rosalinas*, *Ostrea vesicularis* and *Inoceramus niger* (500 m.).
6. Maestrichtian of Egito, Rio Dande and Benguella with *Pseudophyllites* sp., *Bostrychoceras polyplacum*, *Libycoceras angolense* Haughton, *Baculites subanceps* Haughton (100 m.).

4. TERTIARY OF THE COAST

The Tertiary seas covered approximately the same areas as those of the Cretaceous, on the edge of the Atlantic coast.

The Tertiary was first recorded in 1888 by P. Choffat and P. de Loriol, from the material of Capello and Ivens. Further study was undertaken by F. Mouta and H. O'Donnell in 1933 and by E. Dartevelle in 1952. Additional documents were produced in 1954 by the Société Purfina. Key references include Douvillé and Piveteau (1933), Caster (1938) and Miller and Carpenter (1956).

The following are now distinguished:

1. Palaeocene of Mossamédès and Cabinda.
2. Lower Eocene of Grati-dao: 150 to 300 m. of marls and limestones with a microfauna.

3. Middle Eocene: Cuanza Formation, with microfossils, fish and cephalopods (150 to 250 m.).
4. Upper Eocene-Oligocene (?): Quimbriz Horizon with *Raetomya schweinfurthi* Mayer-Eymar, *Venericardia angolae* Caster, *Leda africae* Caster, *Turricula angolensis* Caster and *Aturia luculoensis* Miller and Quifangondo Formation with *Raetomya schweinfurthi* M.-E. (500 m.).
5. Lower Miocene (Burdigalian) of Dombe Grande, with *Aturia aturi* Basterot, *Lepidocyclina canellei* Lemoine and miogypsines; of the Loanda region, with *Hemipristis serra* Ag., *Carcharodon megalodon*, *Fusus angolensis* Douv., *Cardium hians* Br., etc.; of Cuanza with *Ostrea crassissima*, belonging to a poorly defined upper horizon (200 m.).
6. The Pliocene might be represented by some layers of gravel and raised beaches, but proof is lacking.

5. MARINE QUATERNARY

At the mouth of the Congo the marine alluvium is over 100 m. in thickness. On the coastal plain extending from Benguela to Lobita, as well as in the Loanda region, there are a series of marine terraces ranging from 5 to 135 m. above sea-level.

The 5 and 20 m. beaches contain the same fauna as in Senegal: *Arca senilis* L., *A. diluvii* Desh., *Cardium ringens* Chemn., *Donax rugosus* L., *Tympanotonus fuscatus* L., *Nassa argentea* Marrat, *Purpura haemastoma* L., *Buccinum lyratum* L., etc.

REFERENCES

- ARAMBOURG, C. and F. MOUTA, 1952. Les grottes et fentes à ossements du Sud de l'Angola. 2^e Congr. Panafricain Préhist., Algiers.
- CASTER, K. E., 1938. Macroscopic Fauna of the Quimbriz (Eocene) Formation of the Luculo River (Angola). *Comm. Serv. Geol. Portugal*, 20.
- DARTEVELLE, E., 1952-1953. Echinides fossiles du Congo et de l'Angola. *Ann. Mus. R. Congo belge*, 12, 72 p.; 13, 240 pp.
- and P. BREBION, 1956. Gastéropodes fossiles de la côte d'Afrique, du Cameroun à l'Angola. *Ibid.*, 15.
- S. FRENEIX and J. SORNAY, 1957. Lamellibranches fossils de la côte d'Afrique, du Cameroun à l'Angola. *Ibid.*, 20.
- DOUVILLÉ, H., 1932. Les Ammonites de Salinas. *Bull. Mus. Miner. Geol. Fas. Sc. Lisboa*, No. 1.

- DOUVILLÉ, H. and J. PIVETEAU, 1933. Le Tertiaire de Luanda. *Bol. Mus. Lab. Min. Geol. Univ. Lisboa* (1), No. 2, 63-118.
- FERREIRA SOARES, A., 1959. Contribuição para o estudo da fauna fóssil entre Lobito e Catumbela (Angola). *Garcia de Orta*, **7**, 135-154.
- FREIRE DE ANDRADE, C., 1948. Breve notícia sobre um afloramento do Karroo inferior no Nordeste de Angola (Lunda). *Bol. Soc. Geol. Portugal*, **7**, 67-72.
- 1954. On the age of the so-called "Lunda stage" in the diamantiferous region of Northern Angola. *Ibid.*, **11**, 69-74.
- FRENEIX, S., V. HOURCQ and L. CAHEN, 1959. Mollusques fossiles du Crétacé de la côte occidentale d'Afrique. Conclusions stratigraphiques et paléontologiques. *Ann. Musée R. Congo belge*, **24**.
- HAAS, O., 1942. Some Upper Cretaceous Ammonites from Angola. *Amer. Mus. Novitates*, No. 1182, 1-24.
- MILLER, A. K. and L. B. CARPENTER, 1956. Cretaceous and Tertiary Nautiloids from Angola. *Est. Junta. Investig. Ultramar. Lisboa*, No. 21.
- MONTENEGRO DE ANDRADE, M. and J. B., 1957. Estado actual dos conhecimentos sobre a paleontologia de Angola. *Anais Junta Invest. Ultramar.*, **12**, 4.
- MOUTA, F., 1950. Sur la présence du Quaternaire ancien dans les hauts-plateaux du Sud de l'Angola (Humpata-Leba). *C.R. Soc. Géol. Fr.*, No. 14, 261-262.
- 1954. Notícia explicativa do Esboço geológico de Angola (1: 2,000,000). 1 map, 154 pp., 13 pl.
- 1956. Lexique Stratigraphique International. Vol. IV. Afrique: fasc. 7b: Angola.
- REAL, F., 1958. Sur les roches kimberlites de la Lunda (Angola). *Bol. Mus. Lab. Min. Geol. Fac. Ci, Lisboa*, No. 26, 1-33.
- SPATH, L. F., 1922. On Cretaceous Ammonoidea from Angola, collected by Professor J. W. Gregory. *Trans. R. Soc. Edinburgh*, **53**, 91-160.
- 1951. Preliminary notice on some Upper Cretaceous Ammonite faunas from Angola. *Comm. Serv. Geol. Portugal*, **32**, 123-130.
- TEIXEIRA, C., 1947. État actuel de nos connaissances sur la paléontologie du Karroo de l'Angola. *Broteria*, **16**, 53-60.
- 1948a. Fosséis vegetais do Karroo de Angola. *Bol. Soc. Geol. Portugal*, **7**, 73-76.
- 1948b. Os Peixes di género *Angolaichthys* (Holosteans di Karroo de Angola). *Ibid.*, **7**.
- 1949. La faune de Poissons du Karroo de l'Angola et du Congo belge. *Bol. Mus. Lab. Min. Geol. Univ. Lisboa* (5), No. 17, 27-31.

ETHIOPIA AND SOMALIA

References include Dainelli (1943), Stefanini (1933), Macfadyen (1933) and the *Lexique stratigraphique international*.

There are three major geological zones in this immense region: the Abyssinian Plateau in the north, the Somalian Plateau in the south and the tectonic trough of the Afar, which separates them.

The Abyssinian Plateau, which exceeds 4,000 m. in altitude, is bounded by a N.-S. cliff extending from the Massouah district in Eritrea to the east of Addis Ababa. The Somalian Plateau is bounded by an ENE.-WSW. fault and cliff along the prolongation of the southern coast of the Gulf of Aden, passing north of the Harrar and approaching the Abyssinian Plateau, from which it is separated only by the Aouache Trough and a series of lakes which continue into British East Africa.

Between these two plateaux is the Afar Trough, very narrow in the south-west (Aouache) but broadening considerably in the north-east, from the district south of Massaouah to Berbera in the former British Somaliland. French Somaliland is in the Afar.

Many French geologists have been engaged in the study of this region. We recall the names of Aubry, Faurot, Arsandaux, A. Lacroix, P. Teilhard de Chardin, P. Lamare, M. Dreyfuss, E. Aubert de la Rüe and H. Besairie, who have studied the French Coast of Somalia and Ethiopia.

1. THE PRE-CAMBRIAN BASEMENT

The Pre-Cambrian basement outcrops over a large area in Eritrea (Meder Series), Ethiopia proper (Boje Series) and Somalia (Basement Complex), but it is not yet subdivided.

As in all the African countries it consists of metamorphics: schists, quartzites, marbles, mica-schists, amphibolites, paragneisses and granitic bodies of different ages. These diverse elements are not yet grouped in such a fashion that one can recognise the three Pre-Cambrian groups revealed in better studied regions. The mineral riches include gold, platinum, iron and

manganese, which are usually found in the Middle Pre-Cambrian. The platinum of Birbir (Ouallaga) is associated with dunites (Duparc and Molly 1928). Tin and wolfram are recorded in the granites of the west.

2. THE JURASSIC AND CRETACEOUS SEDIMENTARY SUCCESSION

Long discussions have been published on the age and character of the older sedimentary successions and on the first certain marine transgression. It is now certain that the marine transgression came from the east and did not begin before the Rhaetic. It moved gradually westwards, reaching Eritrea in the Middle Jurassic. Very many fossils have been found in all areas, but many are new species and amongst those already known, authors have recorded associations indicating the presence of several stages at one horizon. The stratigraphy of the Jurassic thus lacks precision.

The Adigrat Sandstones

In the Tigrai, the Choa and the Dankali Alps, in Eritrea, the granito-gneissic basement is covered by 300 to 500 m. of continental sandstones known as the Adigrat Sandstones. Towards the south, in the Harrar, the formation is reduced to a few metres of arkoses or is lacking completely. No fossils whatsoever are known. The sandstones are overlain by the marine Antalo Limestones (Sequanian-Kimmeridgian) and appear analogous to the Kholan Series in the Yemen, which is Liassic (and perhaps Triassic at the base). The Adigrat Sandstones have been compared with the Upper Karroo of more southerly regions. At any rate they are continental (Trias-Lias).

The Lugh Series and the beginning of the Jurassic Transgression

Evidence of the beginning of the Jurassic transgression has been observed in the neighbourhood of Lugh, on the Juba in the former Italian Somaliland, a little south of the Ethiopian frontier.

The Lugh Series, transgressive on the Pre-Cambrian basement, is 130 m. thick. It begins with the Hele-Scid Group of gypsum and salt-bearing sandstones and shales (20 m.) containing fish: *Colobodus* cf. *maximus* Quenst. and *Hybodus* cf. *minor* Ag. This group is considered to be a lagoonal deposit of Triassic-Rhaetic

age. Above this come the Dolo-Godut gypsiferous sandstones (50 m.) containing *Mytilus psilonoti* Quent. and *Natica* sp., followed by the Mount Gurran sandy marls (35 m.). The first horizon is attributed to the Lower Lias and the second to the Upper Lias.

This is the only region where marine Lower Lias is recognised and it seems certain that the Rhaetic transgression could not have extended much further to the west. In contrast the post-Rhaetic Lias, represented by sandstones, conglomerates and shales, spread over a large area, embracing at least the former British Somali-land, the Harrar and the Choa. Only one fossil has been found,

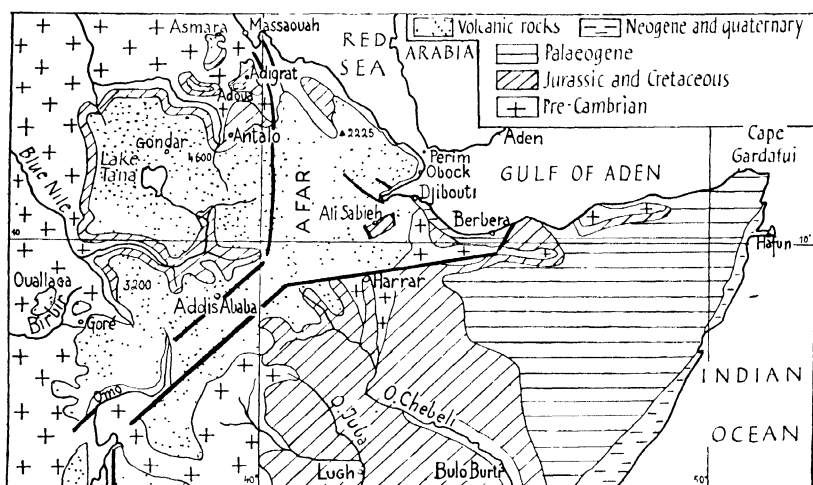


FIG. 26. Geological sketch-map of Ethiopia and Somalia.

in the Harrar. This is a fish (*Lepidotus* sp.), dated as uppermost Liassic.

The main marine transgression took place in the Middle Jurassic (Bajocian-Bathonian).

The Oolitic Series

The Oolitic Series is complete from the Bajocian-Bathonian to the Portlandian. It presents many palaeontological problems which, judging by the care taken in making the numerous collections and by the quality of the palaeontologists who have studied them, do not appear to be the result of mixing of specimens or errors of identification. It seems difficult at present to identify

individual stages because the faunas collected bed-by-bed indicated several of them together. It is therefore prudent in the present stage of knowledge to divide the succession into four groups: Bajocian-Bathonian, Callovian-Oxfordian, Lusitanian-Kimmeridgian and Kimmeridgian-Portlandian. The complete succession ranges up to several hundreds of metres in thickness.

Former Italian Somaliland. The Bajocian-Bathonian is represented by the Gondar sandy marls and limestones, which terminate the Lugh Series.

Above this come the Anole-Issa Beds, in the region of Bardera, south of Lugh. Five horizons are distinguished, from bottom to top as follows:

- (a) Horizon with *Rhynchonella gregoryi* Weir, *Plicatula cossmanni* Roll., *Astarte minima* Phill., *Pholadomya carinata* Goldf., *Lima strigillata* Laube and *Macrocephalites somaliensis* Stef.
This horizon is mainly Callovian, but certain species are found in the Bathonian and others in the Oxfordian.
- (b) Horizon of the same age with *Lima strigillata* Laube, *Pholadomya inornata* Sow., *Liostrea dubiensis* Contej., *Ctenostreon rugosum* Smith and *Mytilus jurensis* R.
- (c) Horizon with *Exogyra nana* Sow., *Pholadomya carinata* Goldf. and *Belemnites tanganensis* Futt. (Callovian-Oxfordian).
- (d) Unfossiliferous horizon.
- (e) Horizon with *Rhynchonella africana* Weir, *Pholadomya aequalis* Sow. and *Belemnites tanganensis* Futt. (Sequanian).

The Kimmeridgian with *Lima notata* Goldf., *L. elliptica* Whit. and *Stolmorhynchia azaisi* Cottr. has been observed further south, west of Muddo-Erri.

Former British Somaliland. In the Bihendula region British authors have measured a Jurassic section over 1,000 m. thick. It comprises, from bottom to top:

Lower Bathonian: limestone with *Pholadomya carinata* Goldf. and *Ceromya concentrica* Sow.

Upper Bathonian: limestone with echinoids (*Acrosalenia smelliei* Currie, *Hemicidaris bihinensis* Currie, *Clypeus rostellus* Currie, *Pygurus smelliei* Currie).

Callovian: coral limestone with *Astrocoenia newtoni* Greg., etc.

Callovian-Oxfordian: calcareous shales with *Parallelodon*

egertonianus Stol., *Nucula cuneiformis* Sow., *Trochus arabiensis* Newton and *Belemnites tanganensis* Futt.

Kimmeridgian: calcareous shales with *Belemnites tanganensis* Futt., *Idoceras farquarsoni* Spath, *Pseudovirgatites scruposus* Opp., *P. anavirgatoides* Spath, *Virgatospinctes* cf. *transitorius* Opp.

Portlandian: limestones and clays with *Lophrothyris subsella* Leym., *Alectryonia pulligera* Goldf., *Anavirgatites* cf. *ambiguus* Schneid., *Pseudovirgatites* cf. *silvescens* Schneid.

Harrar. The Jurassic succession of the Harrar has been studied in particular by French workers, J. Cottreau, P. Lamare, P. Teilhard de Chardin and E. Basse. It comprises from bottom to top:

Transgressive Bathonian: limestones with *Rhynchonella morieri* Davids., *R. concinna* Sow., *Exogyra imbricata* Krauss, *Mytilus sowerbyanus* d'Orb.

Callovian-Oxfordian: compact limestone with brachiopods, *Pholadomya lirata* Sow., *P. carinata* Goldf., *Gryphaea costellata* Douv.

Lusitanian-Kimmeridgian: (a) coral limestone with nerineas; *Helicocenia humberti* Et., *Cryptococenia subbrevis* d'Arch., *Nerinea desvoidyi* d'Orb.; (b) cephalopod limestone with *Belemnites tanganensis* Futt., *B. littlei* St., *Aspidoceras somalicum* Dacqué, *A. arglobbae* Dacqué, *A. irregulare* Dacqué, etc.

Kimmeridgian-Portlandian: beds with *Exogyra bruntrutana* Thurm., *Nucula cuneiformis* Newton, *Modiola subangustissima* Dacqué, *Astarte stefanini* Basse, *A. brumpti* Basse, *Hoplites* cf. *cerebrant* Uhlig, *Virgatites dorsoplanus* Burck., *V. dacquei* Basse, *Perisphinctes arussiorum* Dacqué, *P. gallarum* Dacqué, *P. breviceps* Quenst., *P. choffati* Dacqué, *Aspidoceras somalicum* Dacqué.

Spath has determined a group of *Virgatospinctes* from Tug Terfa which defines the Upper Portlandian.

Choa. The Choa succession is very similar. It begins with a bed of Bathonian crystalline limestone containing *Trigonia pullus* Sow.

Tigrai. In the Tigrai the marine Lias is absent and the higher Jurassics are directly transgressive on the Adigrat Sandstones. The marine oolitic series is known as the "Antalo Limestone". Some 300 m. thick, it begins with gypsiferous beds containing *Cyrena*. Further north, south of Makallé, there are some Bathonian limestones with *Trigonia pullus* Sow.

The Lusitanian-Kimmeridgian is indicated by *Hemicidaris*

abyssinica Blanf., *Trigonia costata* Sow., *Ceromya concentrica* Sow., *C. similis* Sow. and *Exogyra bruntrutana* Thurm.

The Portlandian is not represented by marine beds in the Antalo Limestone. It is perhaps included in the overlying Nubian Sandstone.

The same succession is present still further north in the Dankali Alps, Eritrea.

Cretaceous

The passage from the Jurassic to the Cretaceous is generally marked by a period of regression and deposits of continental sandstones. These are the equivalent of the "Continental intercalaire".

The sea returned in the Barremian. This stage, indicated by *Pholadomya alternans* Roem., *P. picteti* M.-E., *Hoplites champlioni* M.-E., *H. ruspolii* M.-E. and *H. somalicus* M.-E. is found throughout the southern zone, in the Ouebbi Chebeli (former Italian Somaliland) and in the former British Somaliland.

The Aptian with orbitolines and *Chelonicerias* is known at the same localities and much further west, where limestones with *Exogyra couloni* Defr. cover the Aroussis and Harrar country.

In the same regions the Cretaceous succession continues with Albian, containing *Douvillerias mamillare* Schloth., Cenomanian with *Exogyra flabellata* Goldf. and *E. africana* Lmk., Turonian with *Terebratulina gracilis* d'Orb. and rudists and Senonian in Somalia with *Venericardia beaumonti* d'Arch. and H., *Exogyra overwegi* v. Buch, *Salenia somaliensis* Hawkins and rudists.

The Cretaceous is at present much less well known than the Jurassic, with the number of species identified only 73 as opposed to 552 for the latter.

3. EOCENE

The Eocene rests conformably on the Upper Cretaceous of Sokotora Island.

The Lower Eocene covered Somalia as far as a little beyond Berbera. The type succession is at Auradu, a short distance south-east of Bihendula. It begins with limestones containing nautiloids and corals, described by J. W. Gregory in 1900: *Calamophyllia aylmeri* Greg., *Columnastreae phillipsiae* Greg., *Favia somaliensis* Greg., *Cyclolites phillipsiae* Greg.

Above comes a group of limestones with foraminifera whose

stratigraphical position has already been fixed in the north-west of the Indian sub-continent. From bottom to top come:

- (a) Beds with *Siderolites miscella* and *Lockhartia neuboldi* d'Arch. and H. (of the Lower Ranikot).
- (b) Beds with *Alveolina subpyrenaica* Leym. and *Flosculina globosa*.
- (c) Beds with *Lockhartia tipperi* Davies and *Linthia somaliensis* Currie.

At Daban, south of Berbera, and in the Carcar, in the former Italian Somaliland, the Middle Eocene is represented by shales with gypsum and anhydrite, together with limestones with a Lutetian fauna: *Dictyoconoides kohaticus* Davies, *Dictyotyconus aegyptiensis* Chapm., *Nummulites discorbinus* var. *major* Rozl., *N. somaliensis* Nutt. and Bright, *Orbitolites complanatus* Lmk., *Lucina metableta* Cossm., *Spondylus radula* Lmk., *Campanile giganteum*, *Euspatangus formosus* de Lor., with *Nummulites perforatus* Montf. and *N. gizehensis* Forsk. coming in towards the top.

No Upper Eocene has been recognised anywhere and seems to be genuinely absent.

4. OLIGOCENE

The Oligocene is clearly transgressive. It exhibits a generally marly facies, forming a discontinuous strip along the coast of the Gulf of Aden from the south of Berbera to Cape Gardafui and along the coast of the Indian Ocean to Illig.

The two type localities are Daban, south of Berbera, studied by Gregory and Newton, and Hafun on the coast of the Indian Ocean, studied by Stefanini, Silvestri and other Italian geologists.

The fauna includes *Echinolampas jacquemonti* d'Arch., *E. discoideus* d'Arch., *Parasalenia fontannesii* Cott., *Orbicella reussiana* M.-E. and H., *Prionastraea crassisepta* Phill. and numerous other corals; *Alectryonia rectangularis* Roem. and *Nummulites intermedius-fichteli*.

Near the top Stefanini has discovered an indisputable association of *Nummulites intermedius-fichteli* and large lepidocyclines: *Lepidocyclus marginata* Mich., *L. dilatata* Mich., *L. elephantina* M. Ch. and *L. formosa* Schlumb.

5. MIOCENE

The Miocene occurs in the same localities as the Oligocene. According to Stefanini, the Miocene is unconformable and transgressive upon the Oligocene at Hafun.

The Miocene begins with calcareous Aquitanian, characterised by the absence of nummulites and by the presence of the lepidocyclines, which had appeared in the Oligocene, together with *Lepidocyclina sumatrensis* Brady, *L. verbeeki* N. and H., *L. morgani* Lem. and Douv., *Miogypsina irregularis* Mich., *Heterostegina margaritata* Schlum., *Lithothamnium ramosissimum* Reuss., *Archaeolithothamnium batuense* Airoidi, *Lithophyllum praelichenoides* Lem., *Melobesia melobesioides* Foslíe, *Corallina somaliae* Airoidi, and echinoids.

Following the sandy limestones of the Aquitanian comes a bed of much less fossiliferous compact limestone attributed to the Burdigalian.

G. Dainelli emphasises that the coral limestones of the Eritrean coast and the Dahlak Islands, sometimes regarded as Miocene, must be put in the Plio-Pleistocene. The question of whether or not Miocene is present in Eritrea is not, however, resolved (Montanaro Galitelli 1947).

6. THE VOLCANICS OF THE PLATEAU

The major part of the surface of the high Abyssinian Plateau is covered by a great thickness of lavas. Isolated patches are found also in the north, in the Tigrá and as far as Asmara in Eritrea. Other outcrops occur in the south, near Lake Rudolph.

Blanford, who described these lavas for the first time, in the Tigrá, has distinguished two successive series: a lower series of basalts (Achanguí Series) and a higher one of rhyolites and basalts (Magdala Series). Several French geologists have confirmed the existence of this succession, as for example in the Aouache Canyon (Arsandaux 1906; Teilhard de Chardin *et al.* 1930; Molly 1934; Lamare 1935).

However, G. Dainelli (1943) contested the validity of the subdivision into two series, citing a number of regions where the succession is different. Thus in the western Amhára, west of Lake Tana, Graham and Black (1925) indeed revealed a lower basaltic series, but the upper series is composed of an alternation of basalts, trachytes and rhyolites. From place to place an upper basaltic series is present.

The age of these volcanics has been the subject of much dispute: end-Cretaceous or Lower Eocene like the Deccan Traps, or younger. Throughout almost the whole of the Ethiopian plateaux

there is no fossiliferous intercalation which allows a dating to be made. G. Dainelli, after a reconsideration of all the arguments, dates the whole assemblage by comparison with the Lake Rudolph succession, where C. Arambourg has discovered a mammalian fauna of Burdigalian age in the Losodok basaltic tuffs.

The large volcanic masses would appear to be younger than the first big fractures, of Oligocene age. It was not until the Upper Pliocene that the second group of big fractures was produced, allowing the uplift of the plateaux and the relative sinking of the Afar. The youngest, Quaternary, volcanoes are associated with these new fractures. Some are still active. It was in the Upper Pliocene that a series of structural collapses gave rise to the formation of the Red Sea, which was immediately invaded by the faunas of the Indian Ocean. The geological map of East Africa published in 1943 by G. Dainelli shows a belt of Oligocene and Miocene sediments on the Eritrean coast north of Massaoua. In the text (vol. 3, pp. 63 *et seq.*) the author stresses the uncertainty of this attribution based as it is on determinations of doubtful faunas. The doubt is conceded, but there exists nevertheless the possibility of marine Miocene sediments being present on the coast of the Red Sea.

7. THE AFAR

Is the Afar a graben of classic type or indeed a continental dislocation fissure as envisaged by Wegener and Argand? If the Afar is a fissure filled by Sima, the bulk of the lavas found there should be basic. This is not the case. The lavas of the Afar lack magnesium. Many of the younger lavas, later than the fractures, are hyperalkaline and reveal the existence at depth of silico-aluminous, not basic, magmas. Moreover, the Jurassic and Cretaceous sedimentary terrains found below the volcanics of the plateaux are present also beneath the volcanic succession of the Afar, in the Ali Sabieh and Garbes domes. The problem therefore appears resolved. The Afar is not a continental dislocation fissure but a normal graben.

Jurassic and Cretaceous of the Afar

The sedimentary succession of the Afar has been studied in the mountainous region of Ali Sabieh by M. Dreyfuss (1931), between the railway and the former British Somaliland. The total thick-

ness is about 600 m.: 300 m. of limestones below and 300 m. of sandstones above.

Dreyfuss gives the following section, from bottom to top:

Lusitanian: 15 m. of grey or bluish limestones with *Anavirgatites* cf. *subambiguus* Spath, *Perisphinctes* cf. *abadiensis* Choffat, *P.* cf. *pottingeri* Sow., *P. beyrichi* Futt. and *Subplanites* cf. *simoceroideus* Pavlow.

Kimmeridgian (200 m.):

- (a) Light grey unfossiliferous limestones.
- (b) Sublithographic limestones with *Pterocera* cf. *ponti* Br.
- (c) Platy limestones with *Lima subdensepunctata* Futt., *Thracia incerta* Desh., *Pholadomya protei* Br.

Kimmeridgian and Portlandian:

- (a) Compact limestone overlain by unfossiliferous marls.
- (b) Sandy limestone with *Corbis subclathrata* Thurm., *Lucina substriata* Roem., *Nucula* cf. *spitiensis* Holdh.
- (c) Sandy, thin-bedded marls with *Terebratula subsella* Leym., *Mytilus jurensis* Mer., *Nucula menkei* Roem., *Pholadomya protei* Br., *Thracia somalica* Drefy.
- (d) Purplish sandstone, sandy limestone.
- (e) Limestone with *Exogyra bruntrutana* Thurm.
- (f) Limestone with nerineas.
- (g) Limestone with *Exogyra bruntrutana*.
- (h) Sandy limestone.

The succession continues with 300 m. of sandstones with conglomeratic beds, correlated with the Nubian Sandstone. This marks a continental episode beginning in the Portlandian and continuing into the Cretaceous ("Continental intercalaire"). The beds dip at about 30° NNE.

Between Dikkil and the Hanleh Plain, near the Garbes Post, E. Aubert de la Rüe discovered an outcrop of sandstones and conglomerates underneath the basalts (Aubert de la Rüe 1939; Besairie 1946). These sandstones, of uncertain age, contain small pebbles of rhyolites.

Volcanics

The lower basalts, several hundreds of metres thick, are seen in the Ali Sabieh region, at the base of the Mabla, in the Dakka,

the Aeale Mountains, the Gouda, etc. They are olivine basalts, sometimes porphyritic, with zeolites.

In many places the lower basalts are overlain by rhyolites of different colours. They include true rhyolites together with hyperalkaline types, pantellerites and comendites. The abundant obsidians have sometimes been described as coals. The eruptions lasted a long time, for one sees alteration products between successive flows.

After a certain time large fissures were produced through which poured some 1,000 m. of new basaltic lavas, which may or may not rest unconformably on the rhyolites. No tuffs or volcanic centres are known in this assemblage.

The major fractures were formed, permitting the subsidence of the Afar and the uplift of the plateaux which overlook it. The Dankali Horst, parallel to the Red Sea, is still preserved in relief. Numerous lakes were produced, in which were laid down over 50 m. of argillaceous, saliferous and calcareous sediments. The finest example is the old Lake Gagadeh. There are other old lakes: Lake Gobad, now reduced to the existing Lake Abbé, in which were deposited calcareous and salty muds containing *Melania tuberculata* Müller; Lake Hanleh; Lake Assal, separated from the Ghoubbet-Karab Gulf by lavas. The present Lake Assal is 156 m. below sea-level; it is surrounded by older sediments: gypsum, sands with *Melania* diatomites and limestones with *Cerithium* and oysters, up to the height - 20 m. These are overlain by lacustrine sediments with *Melania* up to + 200 m. The highly saline water of the lake (31 per cent NaCl) comes from the sea through a series of fissures.

A final, Quaternary, phase of volcanic activity is marked by a fresh group of basalts emitted through craters which are still well preserved. Between Lake Assal and the Ghoubbet-Karab is a recent basaltic flow with several craters, resting on lacustrine deposits. Other craters occur further west and north in Eritrea: the Jalau, Alid, Maraho, Erta-Alé and the Assab volcanoes. Many of the volcanic islands in the Red Sea are of the same age.

Marine Quaternary

A coastal plain 10 to 20 km. wide stretches from the Obock district to Ras Doumeira in French Somaliland and continues further north into Eritrea. This coastal plain is covered by marine deposits resting on basalts. The Quaternary deposits, 10

to 15 m. thick, consist of madreporic beds at the base and a bed of soft fossiliferous limestone and coral reefs at the top (Abrard and Aubert de la Rüe 1939, Abrard 1942).

The richest fossiliferous horizon occurs 2 km. west of the Obock Post and 1,200 m. from the shore. The fauna is very abundant: *Clypeaster scutiformis* Gmel., *Ostrea hyotis* L., *Ostrea crista-galli* L., *Pecten sanguinolentus* Born., *Venus lacerata* L., *Lucina tigerina* L., *Turbo petholatus* L., *Cerithium madreporium* Jouss., *Cypraea arabica* L., *Strombus gibberulus* L., *Rostellaria curvirostris* Lmk., *Conus maria* Hw., etc.

Present-day volcanism

The data of the *Institut International de Volcanologie* indicate the existence of five active volcanoes in the north of the Afar Trough, the largest of which, the Afdera, rises to 2,225 m. above sea-level.

REFERENCES

- ABRARD, R., 1942. Mollusques pléistocènes de la Côte fr. des Somalis. *Arch. Mus. Nat. Hist. Nat.* (6), **18**, 1-105.
- and E. AUBERT DE LA RÜE, 1939. Les dépôts marins quaternaires du Nord-Est de la Côte française des Somalis. *C.R. Ac. Sc.*, **208**, 820.
- ARSANDAUX, 1906. Contribution à l'étude des roches alcalines de l'Est africain. (Thesis.)
- AUBERT DE LA RÜE, E., 1939. Itinéraires géologiques en Somalie française. *Rev. Géog. Phys. et Géol. dynam.*, **12**, 3
- BESAIRIE, H., 1946. Carte géologique de la Côte française des Somalis. Notice explicative.
- DAINELLI, G., 1943. Geologia dell'Africa orientale. Publ. *Reale Acc. Italia*, 3 vols., 1 geol. map (1: 2,000,000).
- DREYFUSS, M., 1931. Études de géologie et de géographie physique sur la Côte française des Somalis. *Rev. Géog. Phys. et Géol. dynam.*, **4**, 4.
- DUPARC, L. and E. MOLLY, 1928. Les gisements platinifères du Birbir (Abyssinie). *Bull. suisse Miner. Petr.*, **8**, No. 1.
- LAMARE, P., 1935. Sur l'âge des coulées du fosse de l'Aouache. *C.R. Soc. Géol. Fr.*, 217.
- LEXIQUE STRATIGRAPHIQUE INTERNATIONAL, 1956, vol. 4: Afrique. Fasc. 5a: British Somaliland, by J. A. Hunt; 5b: Somalie française, by M. Dreyfuss; Somalia italiana, by G. Dainelli and G. Tavani; Ethiopia-Eritrea, by G. Dainelli.
- MACFADYEN, W. A., 1933. *Geology of British Somaliland*.
- MOLLY, E., 1934. Études pétrographiques en Ethiopie. *C.R. Soc. Phys. H. Nat. Geneve*.
- MONTANARO GALITTELLI, E., 1947. Nuovo reperto a conferma della miocenicità di un deposito eritreo costiero al Nord di Massaua. *Atti. R. Acc. Ital.*, **3**, 387-391.

STEFANINI, G., 1933. Staggio di una carta geologica dell'Eritrea, della Somalia et dell'Ethiopia. 1 vol., 1 map (1:2,000,000).

TEILHARD DE CHARDIN, P., P. LAMARE, E. BASSE, A. LACROIX and M. DREYFUSS, 1930. Études géologiques en Ethiopie, Somalie et Arabie meridionale. *Mem. Soc. Géol. Fr.* n.s., No. 14.

EAST AFRICA: KENYA, UGANDA, TANGANYIKA

References include Dixey (1948), Pulfrey (1947), Stockley (1947), Davies and Bissett (1947), MacConnell (1956, 1959), King (1959) and the *Lexique stratigraphique international*.

1. PRE-CAMBRIAN

Lower Pre-Cambrian. The Basement System (Archaean) of central and western Kenya is composed of gneisses, mica-schists, schists, quartzites and marbles. The same system is found in Uganda.

In Tanganyika W. G. Aitken, A. C. M. McKinlay and A. M. Quennell have analysed the basal complex and ascertained that it really is very old. This "Dodoma System", defined in the centre of Tanganyika, includes granito-gneissic rocks, schists and quartzites, some of them ferruginous. An age determination gave 3,250 million years. There is a constant WNW.-ESE. fold direction.

Lower Middle Pre-Cambrian. The "Nyanzian" of Kenya (older than 2,800 million years) is well represented near Lake Victoria Nyanza, both in Kenya and Tanganyika. The succession includes basic volcanics, followed by acid volcanics and magnetitic quartzites. The rocks are folded and intruded by granitic bodies associated with gold mineralisation. In Uganda the "Toro System" is perceptibly of the same age, as are the lower part of the "Buganda Group" and the "Ruwenzori".

Upper Middle Pre-Cambrian. The typical "Kavirondian" has been studied in the Kavirondo Gulf off Lake Victoria, in Kenya. It is composed predominantly of conglomerates, slates and feldspathic sandstones, intruded by a third granitic group.

Treating the Middle Pre-Cambrian as a whole, a Kibali-Toro-Kavirondian-Nyanza-Muva correlation is accepted. The age range is from 2,650 to 2,900 million years.

Upper Pre-Cambrian. This is a group, well developed in Uganda and Tanganyika, composed predominantly of slates and quartzites. It has been termed the Karagwe-Ankole Series; correlation with

other successions is uncertain. It is intruded by a stanniferous granite.

Terminal Pre-Cambrian. Included in this are the "Bukoba System", the "Malagarasi System", the "Kisii Series" and the "Uha Series", formed of sandstones and dolomitic limestones with stromatolites. In Uganda it would include the Bunyoro stromatolitic limestones and the Singo Sandstones.

2. THE KARROO

The Karroo sediments are only found preserved in the tectonic troughs.

Tanganyika. The fullest succession appears to occur in Tanganyika, in the Ruhuhu Basin north-east of Lake Nyasa (Stockley 1931; Nowack 1937). It ranges up to 1,860 m. in thickness.

The succession is, from bottom to top, as follows:

- K-1. Sandstones and conglomerates resting unconformably on the Pre-Cambrian basement. The conglomerate, 30 m. thick, may be the equivalent of the Dwyka Tillite. The yellowish sandstones reach 500 m. thickness.
- K-2. Lower Coal Measures: 150 m. of sandstones and shales with seams of coal and iron ore.
- K-3. Intermediate group of sandstones and clays (110 m.), with a calcareous bed.
- K-4. Upper Coal Measures: 110 m. of sandstones and shales with coal seams.
- K-5. Ruhuhu Beds: 300 m. of sandstones, shales and calcareous beds, with *Gangamopteris*, *Glossopteris*, *Dadoxylon* and five species of *Palaeomutela*. K-2 to K-5 correlate with the Ecca of South Africa (Permian).

Unconformity, perhaps corresponding to the time of the Upper Permian marine transgression of the eastern region.

- K-6. Lower Bone-bed: 100 m. of sandstones containing wood (*Dadoxylon*), amphibians and reptiles (labyrinthodonts, cotylosaurs, therocephalians, cynodonts, etc.) with *Cisticephalus* sp. and *Dicynodon hueni* Haughton. This horizon represents the upper *Endothiodon* Zone and the *Cisticephalus* Zone of the Beaufort Beds in South Africa (= Upper Permian).

- K-7. Kingori Sandstone: 400 m. of unfossiliferous pink sandstone (Lower Trias?).
- K-8. Upper Bone-bed or Manda Beds: 150 m. of feldspathic sandstones with silicified wood (*Rhexoxylon tetrapteroides* Walton), *Unio karrooensis* Cox and reptiles. This correlates with the Stormberg red beds in South Africa (Upper Trias).

In the Ruhuhu Basin the Karroo is found at a mean altitude of 800 m. Its outcrops are bounded by SW.-NE. faults connecting with the Rift Valley System and overlooked by 1,000 m. cliffs of Pre-Cambrian gneisses.

In the east the Karroo sediments outcrop in a SW.-NE. belt extending from the Ruhuhu Basin to the Indian Ocean at Tanga and continue into Kenya.

The reconstructed succession comprises, from bottom to top:

K-1. Ndeke sandstones and conglomerates (1,000 m.), correlated both with the Dwyka and the Lower Eccca.

K-2 to K-5. Sandstones and shales with coal of the Ulugura Mountains, Kidogi and Tanga, with *Glossopteris browniana*, *Schizoneura gondwanensis*, *Noeggerathiopsis* sp., *Dadoxylon* sp. and a fresh-water fauna: *Palaeonodonta okensis*, *Palaeomutela semilunulata*, *P. keyserlingi*, *P. obliqua*, *P. oblonga* (= most of the Eccca = Lower Permian).

Marine bed of Upper Permian age with *Liebea squamosa* Sow., *Modiolopsis* sp. and a few other molluscs known in the Sakamena Beds of Madagascar: *Modiolopsis stockleyi* Cox and *Gervillia elianae* Cox.

K-6. Upper Tanga Sandstones with *Glossopteris*, *Ulmannia*, *Voltzia* and a classic reptile: *Tangasaurus mennelli* (= Beaufort) (Janensch 1927).

Kenya-Uganda. In Uganda the Karroo has been recorded in the Entebbe district, on the shores of Lake Victoria, and much further to the east, at Bugiri (Davies 1952).

Near Entebbe there are over 300 m. of shales and sandstones with *Glossopteris indica*, *Gangamopteris cyclopteroides*, *Bothrodendron*, *Psygmodphyllum*, etc. (= Middle Eccca).

In Kenya the Karroo outcrops parallel to the coast in a belt 80 km. wide, crossed by the Mombasa-Nairobi railway.

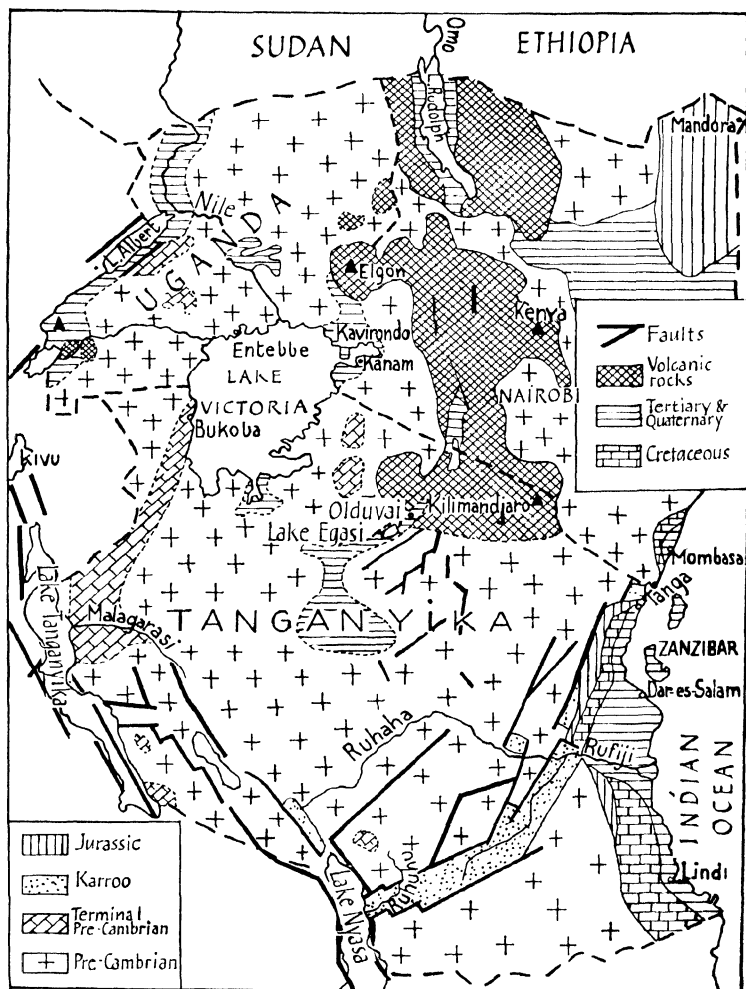


FIG. 27. Geological sketch-map of East Africa.

The complete succession is from bottom to top as follows:

1. Taru Sandstones and Sabaki Shales: coarse, current-bedded, feldspathic sandstones with beds of conglomerate. Gregory recorded the presence in the shales of fish scales and *Palaeoanodonta fischeri* Amal., a species of the Russian Permian. This would be the equivalent of the Ecca.

2. Majiya-Choumvi Beds: red calcareous or shaly sandstones containing *Estheria greyi* J., known from the Permian, and a few plants: *Thuyites*, *Carpolites* (= Lower Beaufort = Upper Permian).
3. Mariakani Sandstones.
4. Mazeras and Shimba Sandstones (with *Dadoxylon sclerosum*). These two groups (3 and 4) probably represent the Trias.

3. FROM THE JURASSIC TRANSGRESSION TO THE DINOSAUR-BEARING WEALDIAN

The Jurassic transgression affected the coasts of Kenya and Tanganyika and penetrated in places as much as 150 km. into the interior. Fossiliferous beds are known in Kenya and all along the Tanganyika coast from Tanga to Lindi.

The stratigraphy of the Jurassic has been confused for a long time, but the studies of L. F. Spath on the Jurassic of Cutch have enabled him to revise the East African faunas and fix the position of the beds (Spath 1927-1933, pp. 819-821 in particular; Dixey 1948). I note for the record the doubtful Lias of Ngerengere (Tanganyika) which was claimed by Hennig on the basis of very poor fossils.

The Jurassic succession begins with the Bajocian transgression and connects with that of Somalia.

The section at Mombasa (Kenya) shows, from bottom to top: Bajocian with *Posidonomya alpina*.

Bathonian with *Phylloceras* (*Sowerbyceras*) aff. *tortisulcatus*.

Callovian with *Perisphinctes* (*Kinkelinceras*) *kinkelini*, *P. (Choffatia) recuperoi* and *Oppelia* (*Sindeites*) *sindensis* Spath, a species known from Cutch and Madagascar.

Oxfordian with *Peltoceras arduennense* and *Macrocephalites rabai*.

Argovian with *Perisphinctes* (*Pachyplanulites*) *subevolatus*, *P. (P.) subcolubrinus*, *Oppelia* (*Taramelliceras*) *kobyi* and *O. (T.) costata* (Lower Changamwe Shales).

Lower Kimmeridgian with *Aspidoceras wyneei*, *A. richthofeni* and *Perisphinctes* (*Pachysphinctes*) *major* of the *tenuilobatus* Zone (Upper Changamwe Shales).

Another much more complete succession is found further south, in Tanganyika, in the Tendaguru region between Lindi and Kilwa. First comes the "Mandawa-Mahokondo Series", a marine series 500 m. thick ranging from the Bajocian to the

Lower Kimmeridgian (Quennell, McKinlay and Aitken 1956). Then come the famous Tendaguru reptile beds (Upper Kimmeridgian-Portlandian-Wealdian). These beds are partly regressive, with intercalations of marine and estuarine deposits. We have the following succession resting on gneisses:

1. Lower Reptile Horizon.
2. *Nerinea* Beds: 25 m. of calcareous sandstones with plants and *Harpoceras priscum*, *Perisphinctes staffi*, *Nerinea credneri*.
3. Middle Reptile Horizon: 15 m. of marls with *Brachiosaurus brancai*, *B. fraasi*, *Kentrurosaurus aethiopicus*, *Nanosaurus*.
4. *Trigonia smeei* Beds: 20 m. of calcareous sandstone with *T. smeei*, *T. ventricosa*, *Nerinea credneri*; *Perisphinctes* (*Subdichotomoceras*) *gajinsarensis* and *Oppelia* (*Hildoglyoceras*) *kobeli*, a form found in the Portlandian of Cutch and Madagascar.
5. Upper Reptile Horizon: 40 m. of sandstones and marls with *Gigantosaurus africanus*, *Brachiosaurus brancai*, *B. fraasi* and a Wealdian fish: *Lepidotus minor*.
6. Marine transgressive beds with *Trigonia schwarzi* and *Hoplites neocomiensis* (Barremian-Aptian).

The reptile beds, well dated by the cephalopods found in the marine intercalations, belong to the Portlandian and Lower Cretaceous. Among the reptiles, the brachiosaurs reach a size greater than that of *Diplodocus*. From the size of their femurs and other parts which have been found, they are attributed a length of from 25 to 45 m. (Hennig 1914; Fraas 1908). According to J. Parkinson (1930), who re-examined the strata, the upper dinosaur horizons contain silicified wood and a certain quantity of aeolian grains.

I can note in passing the identity in facies of these Wealdian dinosaur beds with the "Continental intercalaire" of North-West Africa. The Makonde Beds contain, moreover, silicified wood, among which *Dadoxylon dantzii* Potonie is close to Saharan species. *Weichselia reticulata* is known also in the Danissa Beds in north-eastern Kenya (Saggerson and Miller 1955).

4. CRETACEOUS AND TERTIARY OF THE COAST

Cretaceous beds occur in the neighbourhood of Mombasa.

In Tanganyika, in the Tendaguru district, the marine Creta-

ceous begins with the Makonde Beds (Urgonian) with *Trigonia schwarzi*, *Ostrea bulgarica* var. *janenschi*, rudists and orbitolines. A Cenomanian horizon with *Exogyra columba* has been recognised. The Upper Cretaceous is recorded, without precision.

The Tertiary of Lindi (Tanganyika) is important. Oppenheim (1916) records:

Lower Eocene with *Rhynchonella polymorpha* and *Conoclypeus delanovei*.

Middle Eocene with *Nummulites perforatus*.

Upper Eocene with *Nummulites pengaroensis*, *N. fabianii* and *Orthophragmina pratti*.

Oligocene (Hatu Limestone) with *Nummulites intermedius* and *Lepidocyclus dilatata*.

Aquitania with lepidocyclines (*L. formosa*) and clypeasters.

5. NEOGENE OF ZANZIBAR AND PEMBA

References include Davies *et al.* (1927) and Stockley (1942).

The oldest beds discovered on the two islands are the "Pemba Series", of Lower Miocene age, with *Lepidocyclus gallienii* Lem. and Douv., *L. martini* (?) Schlumb., *Miogyris thecidaeformis* Rütten, *Temnopleurus rousseaui* d'Arch. and H., *Aturia narica* Vred., *Telescopium charpentieri* Bast., *Ostrea gryphoides* Schloth., *Amussiopecten africanus* Cox, *A. gregoryi* Cox and *Teredo* (*Kuphus*) cf. *polythalamia* L.

In Zanzibar there is some Pliocene (Zanzibar Series) with *Operculina complanata* DeFr., *Temnopleurus hardwickii* Gray, *T. toreumaticus* Leske, *Laganum depressum* Ag., *Pecten vasseli* Fuschs, *Ostrea virleti* Desh., *O. hyotiformis* Philippi. The Pliocene is known on the coast of Tanganyika (Tanga-Sadani) and in a borehole at Dar-es-Salam.

The heavy minerals in these various sediments come from the Pre-Cambrian of the continent, as do the pebbles in the post-Pliocene beds of Mazingini (Zanzibar).

Zanzibar is linked with the coast by a sill less than 100 m. below sea-level, which is marked by a number of shallows and little islands. The isolation of Zanzibar is therefore very recent (Quaternary). The Quaternary of Zanzibar contains, in addition, copal trees (*Trachylobium verrucosum* Oliv.). In contrast, Pemba, separated from the African coast by a trough 800 m. deep, has been an island since the Pliocene and lacks copal trees.

6. CONTINENTAL POST-CRETACEOUS

Between the end of the Cretaceous and the Middle Pleistocene important tectonic movements provoked uplift and warping of the African basement, large fractures and the development of large grabens. Faulting and trough formation led to the development of a system of volcanoes and large lakes. Two parallel troughs are distinguished in East Africa: in the east, the Great Rift Valley (Gregory 1921; Dixey 1956), with Lakes Nyasa, Natron, Magadi, Naiviasha, Nakuru and Rudolph; in the west Lakes Tanganyika, Kivu, Edward and Albert. The two troughs joined in the south, at Lake Nyasa. The troughs are bordered by high cliffs always higher on the western side: 800 m. more next to Lake Tanganyika and 2,000 m. more next to Lake Albert. These movements have very great importance but they are only the continuation of a long sequence of events which began in the Pre-Cambrian.

Ring Dykes and Carbonatites

Between the time of deposition of the Karroo sediments and the alkaline eruptions of Mount Elgon in the Miocene, igneous structures of a very special type (ring dykes) were intruded. These are alkaline complexes with or without carbonatites at the centre. There are five in Uganda: Tororo, Sukulu, Butusu, Sekululu and Budeda, of which the first three have a core of carbonatites surrounded by ijolites, nepheline syenites, syenites and fenitised granites on the periphery. These structures have an average diameter of about 5 km.: they are bounded by arcuate faults and are more or less aligned on faults. Their age is unknown precisely but is presumed to be Cretaceous or Eocene. Similar structures have been described in Kenya and Tanganyika.

References include Davies (1956), Campbell Smith (1956) and Pecora (1956).

The Miocene Eruptions

New fractures provoked new volcanic eruptions and a large part of East Africa is covered by more than 1,000 m. of stratified lavas whose composition varied with time.

Three successive groups are distinguished, from bottom to top:

1. Basalts, with basanites and tephrites.

2. Phonolites.

3. Trachytes and rhyolites.

On the edge of Lake Rudolph, on the slopes of Mount Losodok, C. Arambourg (1943) dated the first basaltic eruptions by a mammal fauna discovered in the interstratified tuffs: *Mastodon* cf. *angustidens* Cuv., *Aceratherium* sp., *Pliohyrax championi* Aramb., *Listriodon jeanneli* Aramb., *Docatherium chappuisi* Aramb. This is a fauna of Lower Miocene age.

The same fauna has been found in the lacustrine formations of the Kavirondo Gulf, off Lake Victoria. These beds, 800 m. thick, contain tuffs which came from a large volcano to the east. P. E. Kent and G. MacInnes record an important fauna: *Limnopithecus legetet* Hopwood, *Xenopithecus koruensis* Hopwood, *Proconsul africanus* Hopwood, *Dinotherium hobleyi* Andrews, *Aceratherium* sp., *Pliohyrax championi* Aramb., *Brachyodus africanus* Andrews, *Listriodon jeanneli* Aramb., *Docatherium chappuisi* Aramb., crocodiles, turtles and fish (Kent 1944).

At the top of the succession come the trachytes and nephelinites of Mount Elgon, attributed to the Pliocene (Searle 1952).

Large Fractures of Upper Pliocene Age

The whole of the Mio-Pliocene volcanic group was fractured at some time during the Upper Pliocene, and this phase is considered to be one of the most important.

Pleistocene

After the formation of the large fractures came a group of deposits which are difficult to date. The oldest are those of Serengeti (Tanganyika), Kaiso and Kanam (Lakes Victoria and Albert), Gaza (south of Lake Rudolph) and the Omo Valley (Arambourg 1943-1947). The fauna includes an elephant close to *Elephas planifrons*, *Mastodon* and a few molluscs: *Cleopatra ferruginea* Lea and *Unio abruptus* Fuchs. These deposits are probably Villafranchian (*Kaguerian*).

The so-called Omo fauna includes: *Dinotherium bozasi* Aramb., *Elephas recki* Dietrich (which is related neither to *E. antiquus* nor *E. namadicus* but to a variety of *E. planifrons*), *Stylohipparion albertense* Hopwood, *Menelikia lyropera* and other antelopes, *Equus zebra* L., *Sivatherium olduvaiense* Hopwood, *Hippopotamus*, crocodiles (*Euthecodon*) *brumpti* Joleaud (peculiar to the Nile Basin) and molluscs.

It was in horizon 1 of Olduvai (Upper Villafranchian) that Dr. and Mrs. Leakey discovered in July 1959 an australopithecine (*Zinjanthropus boisei*) accompanied by stone implements. This is the oldest known fossil man (Leakey 1959).

The succeeding beds are grouped together under the name Kamasian. They correspond with the second Pluvial and are well seen at Olduvai (Tanganyika) as well as in Kenya and Uganda. They contain Chellian-Acheulian stone implements and a fauna entirely of vertebrates: *Simopithecus*, *Ceratotherium simum germano-africanum*, *Potamochoerus majus*, *Hippopotamus gorgops*, *H. imaguncula*, *Giraffa capensis*, etc.

The third Pluvial or Kanjerian contains an Acheulian industry and a fauna little different from that of the Kamasian, but with molluscs in addition: *Corbicula radiata* Phil., *Parreysia rothschildi* Neuv. and Anth., *Isidora tchadiensis* Germain, *Melania tuberculata* Ol., *Cleopatra arambourgi* Roger, etc.

After the Kanjerian came a dry interstadial and some important epeirogenic movements. It was during this phase of large-scale fracturing that the rift valleys assumed their present appearance.

In the Upper Pleistocene followed a fourth Pluvial: the Gamblian. L. S. B. Leakey has distinguished within it three humid phases separated by three dry ones, with Mousterian-Levalloisian industries first, then Upper Palaeolithic and finally Capsian (Leakey 1931; Van Riet Löwe 1952; Cole 1954). The Lower Capsian is dated at about 11,000 years B.P. The Gamblian fauna includes *Bos bubalus antiquus*, *Equus hollisi*, *Hippopotamus amphibius*, *Rhinoceros bicornis*, *Orycteropus aethiopicus*, etc.

In the Pleistocene East Africa was subjected to the climatic cooling which affected the whole world. The high mountains were covered by glaciers which descended to 3,000 m. above sea-level, whereas today they are only found on Mounts Kenya and Kilimanjaro above about 4,500 m.

REFERENCES

- ARAMBOURG, C., 1943-1947. Mission scientifique de l'Omo. *Publ. Mus. Nat. Hist. Nat.*, vol. 1, fasc. 2 (1943); fasc. 3 (1947).
 CAMPBELL SMITH, W., 1956. A review of some problems of African carbonates. *Q.J. Geol. Soc. London*, **112**, 189-219.
 COLE, S., 1954. *Prehistory of East Africa*.

- DAVIES, A., L. R. COX, C. J. STUBBLEFIELD and E. I. WHITE, 1927. Report on the palaeontology of the Zanzibar Protectorate, based mainly on the collection made by G. M. Stockley, 1925-1926. *Zanzibar Gov. Report*.
- DAVIES, K. A., 1952. Karroo System in Uganda. Symposium on the Gondwana System. *XIX Int. Geol. Congr.*, Algiers, 191-194.
- 1956. The geology of part of South-East Uganda, with special reference to the alkaline complexes. *Mem. Geol. Surv. Uganda*, No. 8.
- and C. B. BISSET, 1947. Geology and mineral deposits of Uganda. *Bull. Imp. Inst.*, **45**, 161-180.
- DIXEY, F., 1948. Geology of Northern Kenya. *Rep. Geol. Surv. Kenya*, No. 15.
- 1956. The East African Rift System. *Bull. Col. Geol. Miner. Res.*, suppl. No. 1.
- FRAAS, E., 1908. Ostafrikanische Dinosaurier. *Palaeontographica*, **55**, 10-144.
- GREGORY, J. W., 1921. *The Rift Valley and Geology of East Africa*.
- HENNIG, E., 1914. Beitrag zur Geologie und Stratigraphie Deutsch-Ostafrika. *Arch. für Biont.*, **3**, 3.
- JANENSCH, W., 1927. Beitrag zur Kenntnis der Karroo Schichten in ostlichen Deutsch-Ostafrika. *Palaeontographica*, suppl. 7.
- KENT, P. E., 1944. The Miocene beds of Kavirondo, Kenya. *Q.J. Geol. Soc. London*, **100**, 85-118.
- KING, B. C., 1959. Problems of the Pre-Cambrian of central and western Uganda. *Science Progress*, **47**, 528-542.
- LEAKEY, L. S. B., 1931. *The Stone Age Cultures of Kenya Colony*. Cambridge.
- 1959. A new fossil skull from Olduvai. *Nature*, **184**, 491-493.
- LEXIQUE STRATIGRAPHIQUE INTERNATIONAL, 1956. Vol. IV; Afrique. Fasc. 8a: Kenya, by W. Pulfrey; 8b: Uganda, by J. W. Pallister; 8c: Tanganyika, by W. G. Aitken, A. C. M. McKinlay and A. M. Quennell.
- MCCONNELL, R. B., 1956. The Buganda Group, Uganda, East Africa. *Int. Geol. Congr.*, Mexico.
- 1959. Outline of the geology of the Ruwenzori Mountains. *Overseas Geol. Miner. Res.*, **7**, 245-268.
- NOWACK, E., 1937. Zur Kenntnis der Karroo-Formation im Ruhuhu-Graben. *N.Jb. Miner. Geol. Pal.*, **78**, 380-412.
- OPPENHEIM, P., 1916. Die Tertiärbildungen von Deutsch-Ostafrika. *Z.D. Geol. Ges.*, **68**, 103-113.
- PARKINSON, J., 1930. Notes on the geology of the country around Tendaguru, Lindi District. *Short Paper Geol. Division Tanganyika*, No. 6.
- PECORA, W. T., 1956. Carbonatites, a review. *Bull. Geol. Soc. Amer.*, **67**, 1537-1556.
- PULFREY, W., 1947. Geology and mineral resources of Kenya. *Bull. Imp. Inst.*, **45**, 277-299.
- QUENNEL, A. M., A. C. M. MCKINLAY and W. G. AITKEN, 1956. Summary of the geology of Tanganyika. Part I. Introduction and Stratigraphy. *Mem. Geol. Surv. Tanganyika*, **1**, 1.
- SAGGERSON, E. P. and J. M. MILLER, 1955. *Rep. Geol. Surv. Kenya*, No. 40.
- SEARLE, D. L., 1952. *Ibid.*, No. 19, p. 56.
- SPATH, L. F., 1927-1933. Revision of the Jurassic Cephalopod Fauna of Katch (Cutch). *Palaeont. indica*, **9**, 945 pp.

- STOCKLEY, G. M., 1931. Report on the geology of the Ruhuhu Coalfields. *Bull. Geol. Surv. Tanganyika Terr.*, No. 2.
- 1942. The geology of Zanzibar Protectorate and its relation to the East African mainland. *Geol. Mag.*, **79**, 233-240.
- 1947. Geology and mineral resources of Tanganyika. *Bull. Imp. Inst.*, **45**, 375-406.
- VAN RIET LÖWE, C., 1952. The Pleistocene Geology and Pre-history of Uganda. *Mem. Geol. Surv. Uganda*.

THE RHODESIAS AND NYASALAND

General references include the *Lexique stratigraphique international*, Cooper (1957), Guernsey and Bancroft (1950) and Macgregor (1947).

1. PRE-CAMBRIAN

The Pre-Cambrian basement outcrops over a large area in the Federation of the Rhodesias and Nyasaland.

Lower Pre-Cambrian

This includes the very poorly known "Basement Complex" of Northern Rhodesia and the "Sebakwian" of Southern Rhodesia. The Sebakwian is almost completely granitised and contains chromiferous serpentines (at Selukwe in particular).

Middle Pre-Cambrian

The Middle Pre-Cambrian has for a long time been called the "Upper Basement" in Northern Rhodesia, and doubtfully dated at about 2,650 million years. In Southern Rhodesia two gold-bearing systems have been distinguished, a lower "Bulawayan" (2,850 million years) and an upper "Shamvaian" (2,650 million years). Granitic intrusions were associated with and followed upon the tectonic movements that affected these systems.

Upper Pre-Cambrian

Nothing is known which can be attributed to the Upper Pre-Cambrian (between one and two thousand million years ago) except, perhaps, the *Great Dyke*.

The Great Dyke is the most extraordinary geological phenomenon in Southern Rhodesia. It extends some 500 km. in a SSW.-NNE. direction and is 5 to 6 km. wide. It is composed of igneous rocks, of which the deepest accessible to observation are serpentines with bands of chromite, visible for a thickness of 300 m. At the top the serpentine passes up into a pyroxenite with nickel and platinum and then sharply into a norite, visible for 300 m.

The Great Dyke occupies a fissure in the midst of granites and forms a series of hills. The top of the pyroxenite rises to an altitude of 1,250 m. in the south, 1,650 m. at Lalapanzi, descends to 1,400 m. on the Umfuli and rises again to 1,900 m. at Umvukwe. In the extreme north it is broken up and twisted.

The exact age of the Great Dyke is not known, but some of its minerals have been dated at 1,250 million years.

Terminal Pre-Cambrian

In Northern Rhodesia one finds the Katanga Group as defined in the Congo, with its three subdivisions: Roan System, Mwashya and Great Conglomerate System and Kundelungu System, in upward succession.

In Southern Rhodesia we have the "Lomagundi System", which is subdivided into three as follows, from bottom to top:

Deweras Series	{ Basaltic lavas and basal conglomerate (0 to 1,000 m.). { Arkose and conglomerates (1,300 m.). { Quartzites and sandstones (400 m.). { Sinoia Dolomites (250 m.).
Piriwiri	{ Lower Slates (1,000 m.). { Sandstones (500 m.). { Upper Slates (varved?) (700 m.). { Graphitic Slates (700 m.). { Childomo Sandstones (350 m.). { Kanyaga Slates (c. 3,000 m.).

The cupriferous zone of Katanga continues into Northern Rhodesia.

2. THE PRE-KARROO PALAEOZOIC

The question of the possible existence of pre-Karoo marine Palaeozoic has frequently been discussed. W. G. Cooper (1957) considers the Mafingi System in Nyasaland, composed of feldspathic sandstones and shales, to be Cambrian. In the absence of fossils, this is based upon the presence of an unconformity.

Also in Nyasaland, the "Nachipere Series" (feldspathic and calcareous sandstones) is attributed doubtfully to the Cambrian (Cooper and Dixey 1956 in *Lexique stratigraphique international*).

There are no sediments in the territory of the Rhodesias that are attributed for certain to the Palaeozoic.

3. THE KARROO

The glacial deposits corresponding to the Dwyka Tillite in South Africa are not known at the base of the Karroo formations in Southern Rhodesia. There are only isolated patches of tillites whose age is still undetermined.

The Wankie coal basin reveals a good section of continental Permian, from bottom to top as follows:

Lower Wankie Sandstones (50 m.).

Black shales and coal seams (12 to 40 m.).

Clay (0 to 30 m.).

Upper Wankie Sandstones (25 to 40 m.).

Madumabisa Shales (250 m.).

The Lower Wankie Sandstones are fine- or coarse-grained, with thin beds of black shale. At the top, some grey, micaceous sandy shales form a constant marker horizon.

The coal measures begin with a seam of coal that thickens south-westwards from 2 to 13 m. and rests directly on the grey micaceous shales. A second coal seam, 1 m. 80 thick, occurs 8 m. above the first.

The Upper Wankie Sandstones contain a fossil flora including *Glossopteris browniana* Brongn. and its variety *indica* Schimper, *Cordaite hislopi* Bunb., *Sphenopteris* sp., *Sphenophyllum thonii* Mahr., *Asterotheca* sp., *Pecopteris unita* Brongn., *Cyclodendron leslii* Sew. and *Cardiocarpus* sp. This is a mixed European and Gondwana flora (Walton 1929). A. L. Du Toit compares it with that of the Middle Ecca of South Africa (Lower Permian *sensu lato*).

In the Busi Valley a sandstone of the same horizon contains the fish *Acrolepis molyneuxi* Woodward in abundance.

The Madumabisa Shales contain a freshwater fauna: pelecypods (*Palaeomutela neglecta* Jones, *P. wadei* Cox, *P. parallela* Amal., *P. castor* Eichw., *P. subcastor* Amal.), ostracods (*Darwinula globosa* Duff. var. *stricta* Jones) and fish (*Palaeoniscus sculptus* Egerton) together with a coelacanth (Cox 1953).

In addition, the discovery has been made of herbivorous reptiles comparable with those which occur in the *Tapinocephalus* Zone of South Africa. This is the equivalent of the lower part of the Beaufort, at the Middle-Upper Permian boundary.

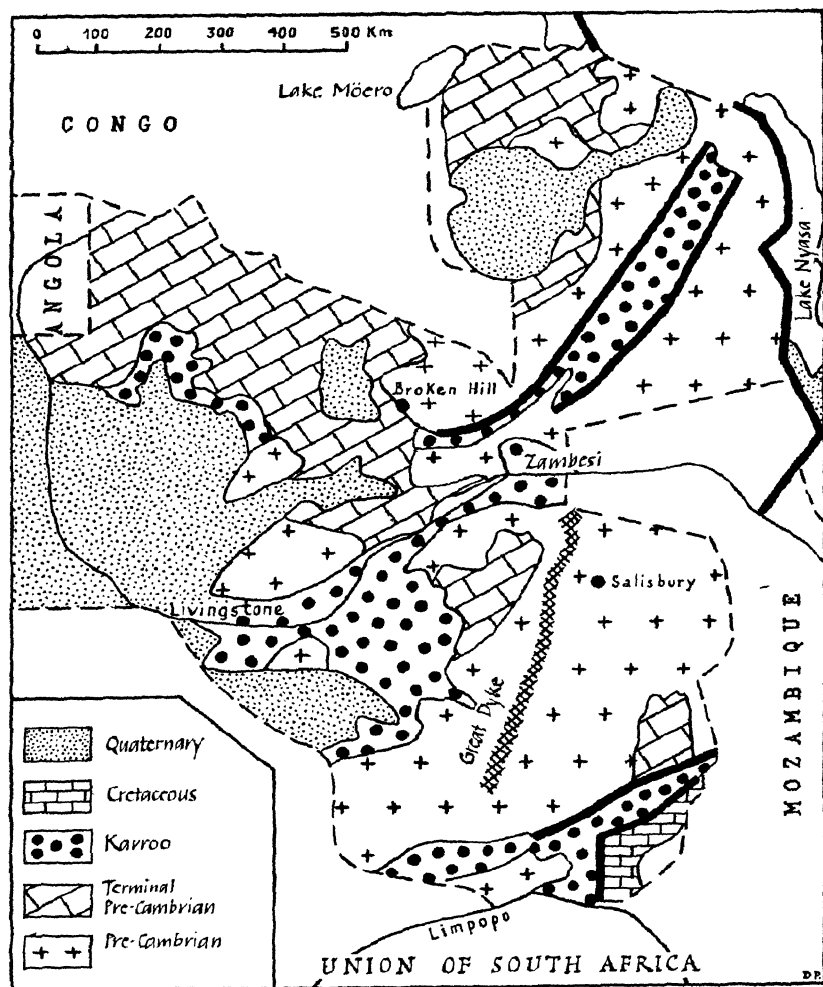


FIG. 28. Geological sketch-map of the Rhodesias and Nyasaland.

The Madumabisa Shales also contain poor-quality coal seams some 50 cm. thick.

Three coal basins are known at present: those of Wankie, which is exploited, Shangani and Sengwe.

Trias. The Upper Permian appears to be absent. Sandstones attributed to the Trias rest unconformably on the Madumabisa Shales and overlap them south-westwards, coming to lie on the Pre-Cambrian basement.

The best section is that of the Mafungabusi Cliff, north of Gokwe; from bottom to top as follows:

Conglomerate	20 m.
Red, fine-grained shaly sandstones	80 m.
Arkoses and conglomerates	90 m.
Minor unconformity	
Forest Sandstone	70 m.
Nyamandhlovu Sandstones (aeolian)	20 m.
	280 m.

The top of the arkoses and the Forest Sandstone contain trunks of petrified trees: *Dadoxylon* sp. and *Rhexoxylon africanum* Bancr. and impressions of *Thinnfeldia lancifolia* Morr., *T. feistmanteli* John., *Taeniopteris maclellandi* Old. and Morr. and *Schizoneura gondwanensis* Feist.

North and west of Bulawayo, the Forest Sandstone has yielded reptile bones: *Massospondylus carinatus* Owen, *Thecodontosaurus skirtopodus* (?) and *Gyposaurus africanus* (?). The flora and fauna correspond to the Stormberg of South Africa (= Upper Trias).

Volcanic Beds. In many places the Forest Sandstone is overlain by basaltic lavas. Their finest development is seen at the Victoria Falls, where the gorge of the Zambesi cuts through four flows of basalt interstratified with red aeolian sandstones. The total thickness of these volcanics is about 700 m.

These basalts spread out over a wide area in the west, where they disappear under the Kalahari formations, and in the south-east where they continue into Portuguese territory.

Between the Sabi and the Limpopo, and further south in the Lebombo Mountains, the basalts are overlain by rhyolites. The whole assemblage is cut by a granitic intrusion extending 150 km. in an ENE.-WSW. direction and passing into the Transvaal. The contact of the granites and basalts is mineralised, with chalco-

pyrite and scheelite. The age of these granites is unknown, but the basalts are contemporaneous with those of the Drakensberg in South Africa (end-Trias or Lias).

Northern Rhodesia and Nyasaland. The same formations are known in a number of places in Northern Rhodesia and Nyasaland, where they are likewise capped by the Forest Sandstone. They begin with a tillite (Upper Carboniferous) in the Luano Basin, in Northern Rhodesia (Gair 1955).

4. TECTONIC MOVEMENTS, KIMBERLITES AND CONTINENTAL CRETACEOUS

First must be mentioned the granitic intrusion cutting the end-Karoo basalts. Next, a number of large fractures developed, giving rise to grabens containing Karroo sediments, which have been eroded away everywhere else. These grabens also contain sediments of the "Continental intercalaire" (continental Lower Cretaceous). A number of diamantiferous kimberlite pipes must also be dated as Lower Cretaceous.

North of Darwin, in the Zambesi Trough, P.-A. Wagner has described conglomerates and arkoses overlying Triassic basalts. Such sediments have been found in a number of places at variable altitudes up to 1,100 m. On Mount Chirambakadoma the arkoses and conglomerates are 800 m. thick. No fossils have been found yet, but F. Dixey regards them as similar to the dinosaur-bearing beds of Wealdian age that he has studied in Northern Rhodesia and Nyasaland. In southern Nyasaland these are termed the Lupata Sandstones; in the north, the "Dinosaur Beds", which contain large dinosaurs such as *Gigantosaurus*, tortoises (*Platycheloides*) and silicified wood (Haughton 1926, 1928; Dixey 1928; Walton 1956).

5. THE KALAHARI SYSTEM

The Kalahari System is understood in the Rhodesias as in the Congo, being the beds between two peneplains of end-Cretaceous and Upper Pliocene age.

Some 100 m. thick and almost barren (apart from a few freshwater molluscs), it is split up into a lower ("Botletle Beds") and an upper division ("Kalahari Sands"). The Kalahari formations cover the plateaux from the Congo to the southern part of the Rhodesias.

REFERENCES

- COOPER, W. G. C., 1957. The geology and mineral resources of Nyasaland. *Bull. Geol. Surv. Nyasaland*, No. 6.
- COX, L. R., 1953. Gastropoda from the Karroo Beds of Southern Rhodesia. *Geol. Mag.*, **90**, 201-207.
- DIXEY, F., 1928. The Dinosaur Beds of Lake Nyasa. *Trans. R. Soc. South Africa*, **16**, 55-56.
- GAIR, H. S., 1955. *Bull. Geol. Surv. N. Rhodesia*, No. 1.
- GUERNSEY, T. D. and J. A. BANCROFT, 1950. A summary of the provisional geological features of Northern Rhodesia. *Col. Geol. Miner. Res.*, **1**, 121-151; 1 map.
- HAUGHTON, S. H., 1926. On Karroo vertebrates from Nyasaland. *Trans. Geol. Soc. South Africa*, **29**, 69-83.
- 1928. Some reptilian remains from Lake Nyasa. *Trans. R. Soc. South Africa*, **16**, 67-75.
- LEXIQUE STRATIGRAPHIQUE INTERNATIONAL, vol. 4: Afrique, fasc. 9: Federation Rhodesies et Nyasaland (Nyasaland by W. G. C. Cooper and F. Dixey; Northern Rhodesia by R. T. Brandt, H. B. Maufe, K. A. Phillips, W. H. Reeve; Southern Rhodesia by G. Bond, H. B. Maufe and R. Tyndale-Biscoe).
- MACGREGOR, A. M., 1947. An outline of the geological history of Southern Rhodesia. *Bull. Geol. Surv. S. Rhodesia*, No. 38; 1 map.
- WALTON, J., 1929. The fossil flora of the Karroo System in the Wankie district. *Ibid.*, No. 15, 62-75.
- 1956. *Rhexoxylon* and *Dadoxylon* from the lower Shire region of Nyasaland and Portuguese Africa. *Col. Geol. Miner. Res.*, **6**, 159-168.

PORTUGUESE EAST AFRICA: MOZAMBIQUE

General references include de Freitas (1957) and Bettencourt Dias (1956).

1. THE PRE-CAMBRIAN BASEMENT

The Pre-Cambrian basement covers some 500,000 km. of ground, over two-thirds of the territory.

Lower Pre-Cambrian. A highly metamorphosed granito-gneissic "Basal Complex" occurs in the Manica, Sofala, Tete and Cabo Delgado e Zambezia districts.

Middle Pre-Cambrian. This is the most important system (Mozambiquian), comprising gneisses, schists, and quartzites. At the base are some large bodies of basic rocks, and granites cut the whole assemblage. The general fold trend is N.-S. The Mozambiquian is the equivalent of the "Graphite System" in Madagascar.

Upper Pre-Cambrian. This cycle, still very badly defined, consists of little but granitic intrusions younger than the Mozambiquian.

Terminal Pre-Cambrian. This is represented by the Umkondo Series, composed of sandstones and quartzites but lacking limestones, unlike in the Rhodesias. It is possible, however, that these beds are older. Pegmatites containing samarskite have been dated at 630 million years (Holmes and Cahen 1957).

2. PRE-KARROO PALAEOZOIC

There are no pre-Karroo Palaeozoic sediments, but there are some pegmatite veins containing uraniferous minerals which have been dated at 350 million years, which puts them in the Silurian or Lower Devonian (Cahen 1957). There is likewise evidence of an older Cambrian mineralisation, detected by the analysis of minerals from certain pegmatites in the Alto Ligonha region. The datings are (1) between 408 and 428, (2) between 425 and 465 and (3) between 435 and 540 million years (Mouta

and Bettencourt Dias 1957). This corresponds very well with what is known in Madagascar, where the same phase of mineralisation is recognised.

3. KARROO

Karoo sediments are recorded in a number of places in Mozambique. The most complete successions are found in the Tete and Nyasa districts.

The Tete district has a coal basin, with 5 to 7 m. of exploitable coal. The succession begins with a fluvio-glacial conglomerate and passes up into sandstones and shales with coal seams, which have yielded a flora including *Glossopteris browniana* Br., *G. indica* Schimper, *Sphenophyllum thorii* Amhr., *Pecopteris* sp., *Sphenopteris lobifolia*, *Schizoneura africana*, *S. gondwanensis* Feist., *Noeggerathiopsis* sp. and *Asterotheca*.

The mixture of European and Gondwana species, noted by Zeiller in 1883, has been confirmed by the recent studies of C. Teixeira (1947, 1948, 1950). The same mixture is known in Rhodesia. The Tete coal horizon belongs to the Ecca. The succession ends with red sandstones and basalts.

At Lunho, in the Nyasa district, the same succession is found, but the middle sandstones have yielded remains of reptiles (endotheriodonts and anomodonts) of Beaufort age (Permo-Trias).

4. CRETACEOUS

The Cretaceous outcrops in the coastal region for a distance of up to 100 km. into the interior, but it has been little studied. The succession, 100 m. thick, appears to be complete from the Lower Cretaceous to the Danian. References include Besairie (1930), Teale (1924), Spath (1925) and Houghton and Boshoff (1956).

Neocomian. The Valanginian is represented by the fauna of the Camadas de Fernao Veloso, including *Rogersites schenki* Oppel, *Neocomites neocomiensis* d'Orb. and *Bochianites africanus* Spath. Spath considered that this fauna is the same age as that of the Uitenhage Beds in South Africa.

Many years ago Neumayr figured a Mozambique ammonite under the name *Phylloceras semistriatum* d'Orb., of the Neocomian, but discussion on this subject has not ended. J. Swietzycki

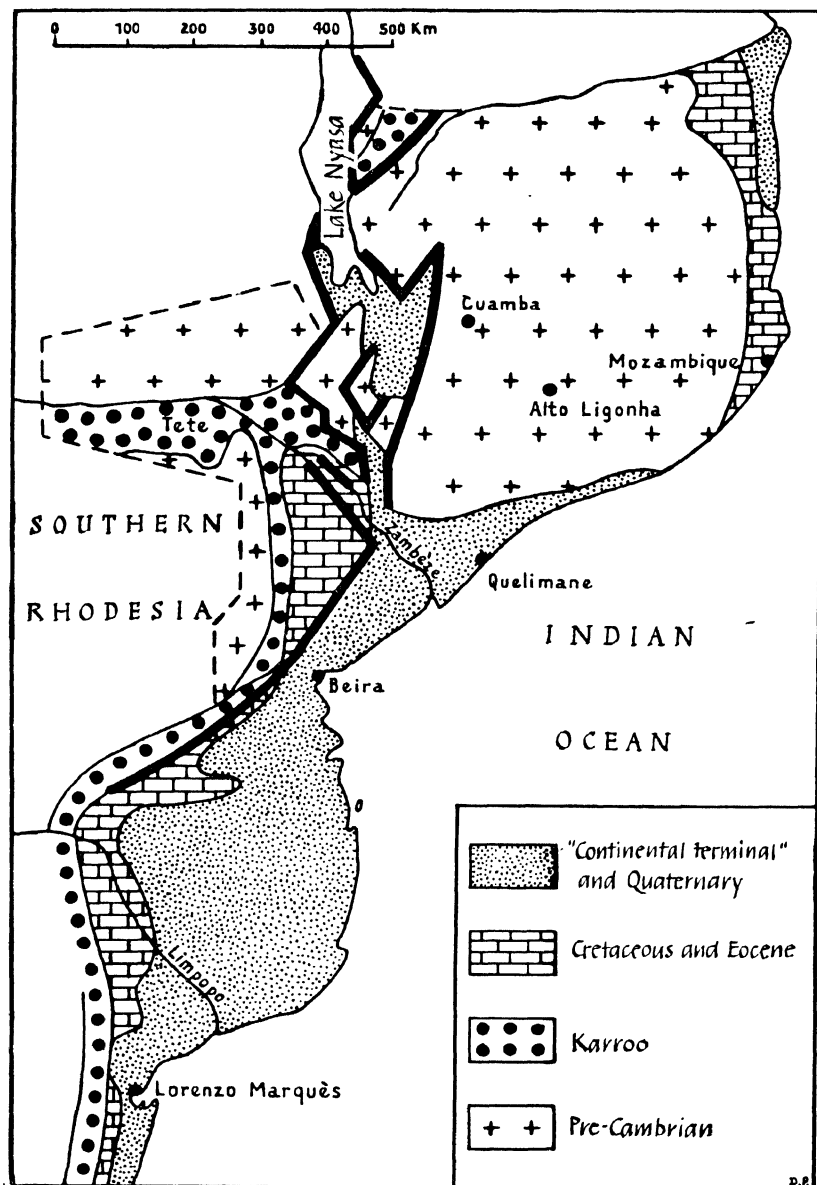


FIG. 29. Geological sketch-map of Mozambique.

accepts Neumayr's identification, Choffat calls it *Phylloceras velledae*, of Vraconnian-Cenomanian age and M. Sayn regards it as a *Phylloceras* close to *P. serum* Oppel.

A little further north, near Changa (or Port-Amelia), there are beds with *Lytoceras* and *Duvalia*.

Aptian. The region of the Libombo Mountains, west-north-west of Lorenzo Marques, has yielded: *Chelonicerias gottschei* Kilian, *C. delagoense* Krenkel, *C. royerianum* d'Orb., *Ancyloceras fallauxi* Uhlig, etc.

Albian. The Catuane Beds, south of Lorenzo Marques, contain: *Phylloceras velledae* Mich., *Desmoceras latidorsatum* Mich., *Inflatoceras africanum* Spath, *Elobiceras newtoni* Spath and crioceratids with Australian affinities. This fauna may be dated as the middle part of the Upper Albian.

Cenomanian. This stage is known by the Conducia fauna, immediately north of Mozambique, with *Lytoceras sacya* Forbes, *Desmoceras beudanti* Brongn., *Acanthoceras marques-costai* Choffat, etc.

The *Turonian* and Lower *Senonian* have not been defined.

Upper Senonian. The whole of the Upper Senonian (Campanian-Maestrichtian) is known in two regions: the Cheringoma Plateau (between Beira and the mouth of the Zambesi) and the Buzi Valley (west of Sofala).

The Upper Senonian is characterised by *Alectryonia unguolata* Schloth., *Exogyra decussata* Goldf., *Pycnodonta vesicularis* Lmk. and *Baculites* cf. *vagina* Forbes. This is the same fauna as in the Ariyalur Beds of India.

5. TERTIARY

Eocene. The Eocene overlies the Upper Cretaceous between the Zambesi and the Sabi Rivers (Teale 1924, Abrard 1928). Two horizons are recognised: Lutetian with *Nummulites atacicus* Leym. and orthophragmines (*O.* cf. *pratti* Mich.) and Bartonian, represented by pink limestones with *Numm. variolarius* Lmk. and orthophragmines.

Neogene. The Lower Miocene and the Pliocene with *Pecten vasseli* are present in the coastal region (Cox 1939).

The Termination of the Rift Valleys

The Rift Valleys terminate in Mozambique in the Urema Trough, bordered on the west by gneisses, granites and Karroo

beds and on the east by the cliff which bounds the Cheringoma Plateau (Cretaceous-Tertiary) (Mouta 1957).

REFERENCES

- ABRARD, R., 1928. L'Eocène de Cheringoma (Mozambique). *C.R. Soc. Géol. Fr.*, pp. 91-92.
- BESAIRE, H., 1930. Les rapports du Crétacé malgache avec le Crétacé de l'Afrique australe. *Bull. Soc. Géol. Fr.* (4), **30**, 621-622.
- BETTENCOURT DIAS, M., 1956. Esboço tectónico de Moçambique. *Bol. Serv. Indust. Geol. Moçambique*, No. 18; 34 pp., 1 map (1:3,000,000).
- CAHEN, L., 1957. L'âge de la "Davidite" de Mavuzi (Tete). *Ibid.*, No. 24, 35-38.
- COX, L. R., 1939. *Ibid.*, No. 3.
- FREITAS, A. J. DE, 1957. Notícia explicativa do Esboço geológico de Moçambique. *Ibid.*, No. 23; 82 pp., 1 map (1:2,000,000).
- HAUGHTON, S. H. and J. H. BOSHOFF, 1956. Algumas Ammonites aptianas de Chalala. *Ibid.*, No. 17.
- HOLMES, A. and L. CAHEN, 1957. Géochronologie africaine 1956. Résultats acquis au 1^{er} juillet 1956. *Mém. Ac. R. Sc. Col.*, Brussels 1957 (n.s.), **5**, 1; 169 pp.
- MOUTA, F., 1957. L'effondrement de l'Urêma, extrême Sud des "Rift Valleys" au Moçambique. *Ibid.*, No. 24, 31-32.
- and M. BETTENCOURT DIAS, 1957. Quelques éléments nouveaux sur les formations anciennes du Moçambique. *Ibid.*, No. 24, 44.
- SPATH, L. F., 1925. Upper Albian Ammonoidea from Portuguese East Africa. *Ann. Transvaal Museum*, vol. II.
- TEALE, E. O., 1924. The geology of Portuguese East Africa between the Zambesi and Sabi Rivers. *Trans. Geol. Soc. South Africa*, **26**, 103-156.
- TEIXERA, C., 1947. Contribuição para o conhecimento geológico do Karroo da Africa Portuguesa. *Junta Invest. Col., Anais*, 2.
- 1948. Present state of our knowledge concerning the palaeontology of the Karroo of Portuguese Africa. *Int. Geol. Congr. London*, p. 214.
- 1950. La flore fossile du Karroo de la Zambézie et la notion de continent de Gondwana. *Estudios coloniais*, **2**, 1-15.

SOUTH AFRICA

1. PRE-CAMBRIAN

Despite the large amount of published work on the Pre-Cambrian of South Africa there still remains a great deal of uncertainty about the actual position of the older formations. This uncertainty has been aggravated by the variation in dates proposed by workers on geochronology. Analysis of the basement is therefore especially difficult and only very provisional successions can be proposed, from study of publications which do not agree with one another (Rogers *et al.* 1929; Du Toit 1954; Holmes 1951; Macgregor 1952; H. and G. Termier 1956).

The *Lower Pre-Cambrian* appears to be represented by all or part of the Swaziland System of the eastern zone, which is attributed an age of about 3,350 million years. It consists of granitogneissic rocks and the schists and quartzites of the Moodies and Fig Trees Series (containing itabirites), perhaps also by the Jamestown and Havelock Series (the latter with greenstones which cut the Jamestown). All the rocks are highly metamorphosed and intruded by an older granite (G I), with gold, tin and columbite mineralisation. It is quite possible that a part of this group belongs to the Middle Pre-Cambrian.

The *Middle Pre-Cambrian* seems to be represented by the Limpopo-Messina (2,060 to 2,080 million years) and Pongola orogenic cycles (lavas, schists and quartzites), which have been intruded by a younger granite (G II).

The *Upper Pre-Cambrian* is represented by the Witwatersrand and Ventersdorp Systems, the latter, however, being only the youngest part of the former.

The Witwatersrand Systems, known in the southern Transvaal and the northern Orange Free State, consists of some 7,000 m. of sediments; slates, ferruginous and non-ferruginous sandstones and gold-bearing conglomerates. The gold is derived from the Swaziland System. The Witwatersrand auriferous conglomerates represent fossil placer deposits. There are many such beds, with a total thickness of about 600 m.; the most important ones have a thickness of 20 m. The richest occur in the Main Reef succession,

with average contents of from 10 to 40 gm. per ton. The gold occurs associated with pyrite in small particles usually invisible to the naked eye. Detrital uraninite also occurs.

The Witwatersrand Basin forms a large syncline 180 km. long from east to west and 70 km. wide. There are some 300 working mines, the deepest of which reached 2,600 m.

South of Johannesburg the Witwatersrand beds are overlain by 4,000 m. of andesitic lavas. These link up with the Koras rhyolites in the Orange Valley.

The Upper Pre-Cambrian has also been folded, but less strongly so than the Middle Pre-Cambrian.

The *Terminal Pre-Cambrian* is very important in the northern province. It connects up with that in Rhodesia and is embraced by the Transvaal and Waterberg Systems.

The Transvaal System in the Transvaal reaches a thickness of 6,000 m. Three series are distinguished, from bottom to top as follows:

Black Reef Series.

Dolomite Series.

Pretoria Series.

1. *The Black Reef.* The Black Reef Series, composed of conglomerates, sandstones, quartzites and a few shales, rests unconformably on the Pre-Cambrian basement. It is 800 m. thick on Mount Marieps. The thickness diminishes southwards and south-westwards to only 7 m. near Carolina.

2. *The Dolomite Series.* In the Transvaal this series is formed of cherty dolomite rocks with a few beds of shales and quartzites. It follows conformably upon the Black Reef and reaches up to 2,500 m. in thickness. This thickness decreases southward to 40 m. east of Carolina. The Dolomite Series passes into Rhodesia, Bechuanaland, South-West Africa and Cape Province.

The dolomitic limestones contain stromatolites which were first discovered in 1932 in the Hol Valley in Griqualand West (Young 1932, 1934).

3. *The Pretoria Series.* The Pretoria Series succeeds conformably on the Dolomite Series. It marks a sharp change of facies, being composed of over 3,000 m. of shales and quartzites with in addition some 1,000 m. of basic lavas in the Lydenburg district. In the south-west it is known as the Griquatown Series. This comprises a few calcareous beds.

In the lower third of the Pretoria and Griquatown Series there is a tillite 20 m. in average thickness, which extends over an area of 8,000 sq. km. in Griqualand West.

The Bushveld Complex of the Transvaal was emplaced at the end of this period, before the deposition of the sediments of the Waterberg System. A basin 450 km. long and 240 km. wide was filled up with 3,000 m. of dolerites and norites. The last phase of intrusion involved more acid material, the Red Granite, which is locally stanniferous.

The Waterberg System. The Waterberg System rests unconformably on the Pretoria Series in the Transvaal. It begins with a basal conglomerate and is composed of 2,000 m. of coarse sandstones showing ripple marks and cross bedding. The system extends into Griqualand West and Bechuanaland.

The stratigraphical position of the Waterberg System is not absolutely certain and it is quite possible that it belongs to the Palaeozoic, being the continental equivalent of the Nama System (Haughton 1950, 1956b).

2. PRE-KARROO PALAEOZOIC (CAMBRIAN—LOWER CARBONIFEROUS)

In the south, in Cape Province, the pre-Karoo Palaeozoic reaches about 6,000 m. in thickness. It is subdivided as follows:

I. Nama System.

II. Cape System:

1. Table Mountain Series;
2. Bokkeveld Series;
3. Witteberg Series.

1. *Nama System*

The Nama System, first described in 1885 by A. Schenk, was recognised in South-West Africa by P. Range in 1912. The following series are distinguished, from bottom to top (Haughton and Martin 1956):

- (a) *Kuibis Series* (200 m.); tillite, followed by cross-bedded quartzitic sandstones with rare coelenterate fossils (Richter 1955).
- (b) *Schwarzalk Series* (300 m.); black dolomitic limestones from which doubtful archaeocyathids have been recorded.

(c) *Schwartzrand Series* (350 m.); with black limestones.

(d) *Fish River Series* (800 m.); sandstones and quartzites.

2. Cape System

(a) *Table Mountain Series*. This series is named after the mountain which overlooks Capetown. It is 1,700 m. in thickness and

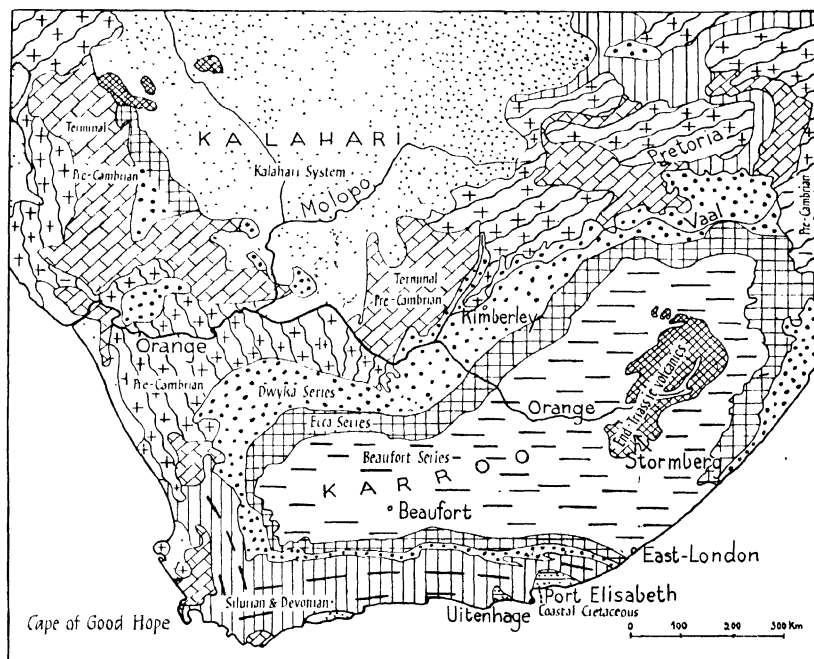


FIG. 30. Geological sketch-map of South Africa.

includes a tillite, seen in the Cedarbergen, 300 m. from the top. The bulk of the series is composed of sandstones and quartzites which have yielded only rare, indeterminate lamellibranchs. The beds are horizontally disposed.

The Table Mountain Series is known in Pondoland, Natal and Zululand, where the thickness is much less.

The sandstones of the series seem to be comparable with those in the Pretoria and Griquatown Series. They are probably

Silurian in age, since they are overlain by a dateable Devonian succession.

(b) *Bokkeveld Series*. The Bokkeveld Series rests concordantly on the Table Mountain sandstones. It is about 800 m. thick and is known only in Cape Province, south and west of the Karroo. It is composed of shales and sandstones which have yielded a fine Lower Devonian fauna including *Homalonotus herscheli* Murch., *Phacops africanus* Salt., *Leptocoelia flabellites* Conr., *Spirifer orbignyi* Morr. and Sharpe, *Chonetes falklandicus* M. and Sh., *Ambocoelia umbonata* Conr., *Palaeoneilo antiqua* Sh., *Bellerophon quadrilobatus* Salt., *Tentaculites crotalinus* Sh., *Conularia africana* Sh., etc.

This fauna, characterised by the abundance of *Leptocoelia flabellites*, includes a number of species known in the Falkland Islands, Brazil, Bolivia and Oriskany (United States), as well as in north-west Africa.

(c) *Witteberg Series*. This last series measures about 800 m. in thickness. Composed of shales and sandstones, it contains "problematica" such as *Spirophyton* and a few traces of plants belonging to the genera *Lepidodendron*, *Sigillaria*, *Cyclostigma*, *Knorria*, etc. There occurs in addition a psilophyte: *Dutoitia pulchra* Hoeg (Hoeg 1930).

The Witteberg Series represents the transition from the Upper Devonian to the Lower Carboniferous.

3. THE KARROO

The Karroo formations extend over some 600,000 sq. km., half the area of the Union of South Africa. They are very important economically, since they contain exploitable coal seams; they are no less important scientifically because of their special flora and their fine series of fossil reptiles. The mean thickness is 7,000 m.

The Karroo Basin extends some 1,300 km. from the south-west to the north-east, with a maximum width of 600 km. between Kimberley and East London. From Karroo Poort in the west to the coast of the Indian Ocean, a distance of 700 km., the Karroo appears to rest conformably on the Witteberg Series. This concordance has been observed in eight different places over a distance of 32 km., in the Willowmore district. There is visible unconformity where the Karroo rests on beds older than the Witteberg.

The Karroo formations are subdivided into four series, from bottom to top as follows:

1. Dwyka Series (Upper Carboniferous).
2. Eccas Series (Lower Permian).
3. Beaufort Series (Upper Permian-Lower Trias).
4. Stormberg Series (Upper Trias).

1. *The Dwyka formations (Upper Carboniferous)*

The Dwyka formations, when complete, comprise the Lower Shales, Tillite and Upper Shales.

The Lower Shales, 150 to 400 m. thick, comprise black carbonaceous shales with beds of sandstone. Numerous plant impressions occur, unfortunately not identifiable.

The Dwyka Tillite, blue in colour, contains numerous striated pebbles and more important boulders. Lenticles of quartzite represent consolidated sands. The tillite outcrops over a distance of 2,250 km., all around the Karroo Basin. Its thickness varies. It reaches a maximum of 427 m. in the south, where it seems to have been deposited in the sea. In the north, observation of striations on the glaciated pavement has enabled Du Toit to suggest the existence of four glacial centres, in Namaqualand, Griqualand West, the central Transvaal and a submerged region east of Natal. The general direction of glacier flow would appear to have been from north to south.

On the Atlantic coast a minor marine transgression led to the deposition of beds containing conularias and *Eurydesma* (Lower Uralian?), mixed up with the youngest glacial conglomerates.

The Upper Shales mark a very sharp change of sedimentation in the west and south of the Karroo. In contrast, in the north of Cape Province intercalations of glacial conglomerates occur, indicating glacial and interglacial episodes. In the north (Orange Free State, Transvaal and Natal) the Upper Shales are absent, suggesting that the glaciation had perhaps not ended.

In several places plants have been found which belong to the genera *Lepidodendron*, *Gangamopteris* and *Phyllothea*.

Towards the top of the Upper Shales is the "White Band", which contains a small marine reptile: *Mesosaurus*. The White Band can be regarded as marking the transition from the Upper Carboniferous to the Lower Permian.

2. *Ecce formations* (*Lower Permian*, sensu lato)

The Ecce formations are represented in all four provinces of the Union, outcropping along all the periphery of the Karroo Basin. Their thickness reaches a maximum of 1,800 m. in the south, near Aberdeen. This is apparently related to the presence of upland in the south and south-east of the continent.

In Pondoland, Natal and the south-eastern Transvaal Du Toit has been able to subdivide the Ecce into three groups.

The Lower Ecce, formed of an average of 300 m. of bluish shales, wedges out northwards, so that the Middle Ecce comes into contact with the Dwyka Tillite or even older rocks.

The Middle Ecce (500 m. maximum thickness) begins with feldspathic sandstones and continues with an alternation of sandstones and shales. It contains coal seams, mined over a wide area, containing a fine flora including *Glossopteris browniana* Brongn., *Gangamopteris cyclopteroides* Feist., *Noeggerathiopsis hislopi*, *Schizoneura* sp. and *Phyllothea* sp., representing the typical Gondwana flora, together with elements with European affinities: *Ptygmophyllum kidstoni*, *Sigillaria brardi* and *Bothrodendron leslii*. At Vereeniging one finds in addition complete tree trunks recalling *Cordaites* in Europe. The Middle Ecce also contains petroleum (Rilett 1956).

The Upper Ecce (200 m. in Natal) consists of bluish shales.

All the Ecce formations belong to the Lower Permian (*sensu lato*), that is, to certain Lower Permian plus a part of the Middle Permian.

3. *The Beaufort formations* (*Permo-Trias*)

The Beaufort formations are composed essentially of sandstones with a few beds of shales. They contain a few lenticles of coal in their lower part. The maximum thickness of 3,000 m. is in the south.

The Beaufort Series is well known because of its reptile fauna (Von Huene 1940; Watson 1942, 1956; Haughton 1956). Its flora in contrast is reduced to a few impressions of *Glossopteris* and *Phyllothea*, with *Thinnfeldia* and *Taeniopteris* at the top.

The abundance of reptiles has enabled the succession to be subdivided into six zones, from bottom to top as follows:

Tapinocephalus Zone (I) (= Zone III with pelycosaurs in Russia). This marks the top of the Middle Permian and is the zone con-

taining the large pareiasaurs, which are known only in South Africa.

Endothiodon Zone (II), not known outside the Karroo. It must represent the base of the Upper Permian. *Pareiasaurus* has completely disappeared.

Cisticephalus Zone (III) (= Zone IV in Russia), attributed to the Upper Permian. This contains dicynodonts, among which the herbivorous *Dicynodon* is very common. *Pareiasaurus* reappeared at the end of this period.

Lystrosaurus Zone (IV) (= Zone V in Russia), attributed to the basal Trias. It marks a considerable event, with all the fauna of herbivorous reptiles disappearing. *Dicynodon* is replaced by another dicynodont, *Lystrosaurus*, which was aquatic and carnivorous like its contemporary, *Chasmatosaurus*.

This zone is known also in Sinkiang.

Procolophon Zone (V). *Procolophon* has the appearance of a small lizard and lived in company with a small amphibian, *Micropholis*.

Cynognathus Zone (VI), contains a single large herbivore, *Kannemeyeria*, known also in South America and Shansi. There is also a cosmopolitan amphibian, *Capitosaurus*, known from South Africa to Spitzbergen. Fish also occur: *Ceratodus capensis*, *C. ornatus* and ganoids. The flora contains a mixture of *Glossopteris*, *Thinnfeldia* and *Taeniopteris*. This is Lower Trias, *sensu lato*, but the exact boundary is still much disputed.

For many authors, Zone IV marks the dawn of the Trias, but others, like D. M. S. Watson, only accept Zone VI in the Trias.

Taken together, the Beaufort formations belong to the Upper Permian (*sensu lato*) and Lower Trias (*s.l.*).

4. Stormberg formations (Upper Trias)

The Stormberg formations, much less widespread than the older ones, cover the whole of Basutoland and extend as far as the Rhodesian frontier.

The following four groups are recognised:

1. Molteno Beds.
2. Red Beds.
3. Cave Sandstone.
4. Drakensberg Volcanics.

1. *The Molteno Beds.* These range up to 600 m. in the south and thin northwards. They rest conformably on the upper

formations of the Beaufort and consist of sandstones and shales with a few coal seams and a flora with *Glossopteris*, *Thinnfeldia odontopteroides* Morr., *Taeniopteris carruthersi* T. Woods, *Cladophlebis roesserti* Presl., *Sphenopteris elongata* Carr., *Baiera*, *Zamites*, *Neocalamites*, etc.

2. *The Red Beds*. These sandstones and shales are red in colour and have a variable thickness, from 50 to 500 m. They rest conformably on the Molteno. The flora is unknown, being represented only by silicified trunks (*Rhexoxylon*). There is a fauna of crocodiles and dinosaurs.

This is the place to mention the studies of F. and P. Ellenberger in Basutoland, where the base of the Red Beds of Maphutseng contains bones including those of a saurischian quadruped. Both the Molteno and Red Beds contain a number of trails, indicating a biological environment of great variety (F. and P. Ellenberger 1956, 1958; Crompton and Ellenberger 1957).

3. *The Cave Sandstone*. This group consists of massive white sandstones, often feldspathic, containing numerous caves at their base. As in the Red Beds one finds only silicified tree trunks, indicating a very dry climate. The fauna is reduced to a few dinosaurs and crocodiles.

Northwards the group passes into the Triassic sandstones of Rhodesia. Near the top the Cave Sandstone contains a few intercalations of volcanic rocks.

4. *The Drakensberg Volcanics*. The end of the Trias was marked by large-scale faulting and considerable volcanic activity. Basaltic lavas escaped from fissures and covered half of South Africa. Their thickness is extraordinary, reaching 1,000 m. in Cape Province and over 2,000 m. in Basutoland. The exact age of these lavas is not known. It is presumed to be end-Trias or Rhaetic.

The basalts are cut by doleritic sills and dykes which invaded the whole of the Karroo System. Local differentiation of magma has given rise to the formation of more acidic rocks: quartziferous gabbros, quartziferous diorites and even microgranites and rhyolites (Du Toit 1920; Gevers 1928).

4. "CONTINENTAL INTERCALAIRE"

This series is confined to the coastal zone of Cape Province. Outcrops occur in the Uitenhage region, north of Algoa Bay.

The succession begins with the Enon Beds: conglomerates with quartz pebbles, sandstones and shales, in which fragments of wood and moulds of *Estheria* have been found. Above these come the Wood Beds, similar lithologically, ranging up to 300 m. in thickness and containing tree trunks and plant impressions (Seward 1903, 1907). Seward has identified cycads (*Zamites recta*, *Cycadolepis jenkinsiana*), conifers (*Araucarites rogersi*) and ferns (*Cladophlebis browniana* and *Onychiopsis mantelli*), known from the Wealdian of Sussex. The plants show resemblances both to those of Western Europe and the Upper Gondwana System of India.

Calcareous lenticles have yielded small pelecypods: *Psammobia atherstonei*. Finally in the Bushman Valley, in particular, dinosaur remains have been found comparable to those in the upper part of the Tendaguru in Tanganyika (Upper Jurassic-Lower Cretaceous) (Schwarz 1913; Rogers 1917; Haughton 1917).

The continental Uitenhage succession, 500 m. thick, represents the passage from the Upper Jurassic to the Lower Cretaceous. Authors consider it as Wealdian.

The Kimberlite Pipes. It is presumed that a very unusual sort of volcanic activity in the Cretaceous gave rise to pipes of kimberlite (Wagner 1929). These pipes, being diamond-bearing, have been mined to a depth of 1,000 m. They are of variable diameter at outcrop, from 25 m. for the smallest to 762 m. for the largest (First, near Pretoria). The diameter diminishes at depth, where the pipes usually pass into dykes.

The pipes are filled with a serpentinous breccia which is soapy to the touch, grey-blue in its fresh state (*blue ground* of the miners) and yellow in the zone of weathering (*yellow ground*). The rock is ultrabasic. It must have been intruded violently, since one finds many foreign elements torn from their surroundings at depth and the rocks enveloping the pipes are frequently upturned. This special rock, kimberlite, contains diamonds which vary in character with the different pipes. The diamonds are usually microscopic but some weigh a few carats and are used in jewellery. The largest diamond is the "Cullinan", from the First Mine, which weighed uncut 621 gm.

These diamantiferous pipes are known at Kimberley and other localities in Cape Province, Griqualand, the Orange Free State and the Transvaal.

The diamonds are presumed to have come from a deep-seated peridotitic magma.

5. MARINE CRETACEOUS

The coast of South Africa was invaded by the Cretaceous seas in certain places.

Neocomian. The oldest beds are those in the Uitenhage region, near Port Elisabeth (Cape Province). Above beds with plants and dinosaurs come the "Sunday River Beds" with *Rogersites* and trigonias (*Trig. herzogi* Gold., *T. rogersi* Kitch.). L. F. Spath dated these beds as Upper Valanginian.

Aptian. The Aptian outcrops in Zululand, at Ndabana (north of Durban). It consists of conglomerates and sandstones with *Trigonia obesa* v. Hoep. and *T. crassitesta* v. Hoep. The Aptian age of these beds with large trigonias was established from their position at the base of barren sandstones overlain by fossiliferous Upper Albian.

Albian. The Upper Albian (Umsimene Beds) occur above the barren sandstones which cover the Aptian of Ndabana. It contains further species of trigonias and cephalopods: *Inflatoceras aequitorialis* Kossm., *I. bispinosa* Spath, *Phylloceras velledae* Mich., *Puzosia stoliczkaia* Kossm. and crioceratids of Australian affinities.

Cenomanian. The Cenomanian is represented in the same region by the Skoenberg Beds with *Acanthoceras rothomagensense* Deufr., *A. newboldi* Kossm. and *Turritiles costatus* Lmk.

Turonian. At the confluence of the rivers Mkuzi and Umsindusi the Turonian must be represented by beds with large oysters, occurring below a fossiliferous Coniacian horizon.

Coniacian. Still at Skoenberg, the Coniacian is developed as limestones with *Peroniceras subtricarinatum* d'Orb., *Placentoceras kaffrarium* Eth. and *Rondaireia forbesiana* Stol.

Santonian. Van Hoepen attributes to the Upper Santonian the Pondoland fauna with *Phylloceras woodsi*, *Gaudryceras varicostatum*, *G. rouvillei*, etc., but L. F. Spath puts it in the Campanian-Maestrichtian.

The horizon with *Baculites capensis* Woods and *B. baileyi* Woods of Umkwelane Hill is put in the Santonian by H. Besairie, on the basis of the well-dated horizon he has recognised in Madagascar.

Campanian. The cliffs of False Bay contain a Campanian horizon with *Mortoniceras woodsi* Spath and *Pachydiscus newberryanus* Meek.

Not far from this locality, the fauna of Manuan Creek contains *Kossmaticeras bhavani* Stol., *Gaudryceras pulchrum* Crick and *G. cf. kayei*.

Lower Maestrichtian. To this stage is attributed the horizon in Zululand with *Parapachydiscus colligatus* Bink and *P. cf. wittekindi* Sch.

The Upper Maestrichtian has not yet been defined by fossils.

6. TERTIARY

Eocene of Lüderitz Bay (South West Africa). South of Lüderitz Bay, in the Pomona region, marine diamantiferous conglomerates are known, younger than the lower horizons of the Kalahari System. They are overlain by fossiliferous clays with *Ostrea subradiosa*, *Tellina oppenheimi*, *Macra tumida*, *Turritella kaiseri*, *Heligmotoma claviforme* and *Aturia lotzi*, local and new species. There is also a fish fauna: *Notidamus serratissimus*, *Cestracion vincenti*, *Odontaspis macrota*, *O. winkleri*, *Oxyrhina desori* var. *praecursor*, *Lamna vincenti*, *Galeocerdo blanckenhorni*, *Squatina prima*, *Cylindracanthus cf. rectus*, *Myliobatis cf. dixonii*. Many of these species are known in the Lower and Middle Eocene of the west coast of Africa.

REFERENCES

- CROMPTON, A. W. and F. ELLENBERGER, 1957. On a new cynodont from the Molteno Beds and the origin of the tritylodontids. *Ann. South Afr. Mus.*, **44**, 1-14.
- DU TOIT, A. L., 1920. The Karroo Dolerites of South Africa. *Trans. Geol. Soc. S. Africa*, **23**, 1-42.
- 1954. *Geology of South Africa*. 3rd edn., London.
- ELLENBERGER, F. and P., 1956. Le gisement de Dinosauriens de Maphutseng (Basutoland, Afrique du Sud). *C.R. Soc. Géol. Fr.*, 99-101.
- 1958. Principaux types de pistes de Vertébrés dans les couches du Stormberg au Basutoland (Afrique du Sud). *Ibid.*, 65-67.
- GEVERS, T. W., 1928. The volcanic vents of the western Stormberg. *Trans. Geol. Soc. S. Africa*, **31**, 43-62.
- HAUGHTON, S. H., 1917. On some dinosaur remains from Bushmanland. *Trans. R. Soc. S. Afr.*, **5**, 259-264.
- 1950. The age relationships of the Matsap, Boskop, Waterberg and Nama Systems. *Trans. Geol. Soc. S. Africa*, **35**, 205-208.
- 1956a. Gondwanaland and the distribution of early reptiles. *Geol. Surv. S. Africa, Annex.* vol. 56 (A. L. du Toit Mem. Lectures, No. 3).
- 1956b. Notes on the Waterberg System. *XX Int. Geol. Congr.*, Mexico, Cambrian Sympos., 335-336.
- and H. MARTIN, 1956. The Nama System in South and South-West Africa. *Ibid.*, Cambrian Sympos., 323-335.
- HOEG, O. A., 1930. A psilophyte in South Africa. *Forh. k. Norske Vidensk. Selskab.*, 3, No. 24, 92-94.

- HOLMES, A., 1948 (1951). The sequence of Pre-Cambrian orogenic belts in South and Central Africa. *Rep. XVIII Int. Geol. Congr.*, London, part 14, 254-269.
- MAGGREGOR, A. M., 1952 (1953). Pre-Cambrian formations of tropical South Africa. *C.R. XIX Int. Geol. Congr.*, Algiers, f. 1, 39-50.
- RICHTER, R., 1955. *Senckenbergiana Lethaea*, **26**, 243.
- RILETT, M. H. P., 1956. An occurrence of oil in the Middle Ecca beds near Dannhauser, Natal. *XX Int. Geol. Congr.*, Mexico., Petrol. Gas Sympos., **1**, 13-21.
- ROGERS, A. W., 1917. On the occurrence of dinosaurs in Bushmanland. *Trans. R. Soc. South Africa*, **5**, 265-272.
- A. L. HALL, P. A. WAGNER and S. H. HAUGHTON, 1929. *Geology of the Union of South Africa*.
- SCHWARZ, E. H. L., 1913. South African Cretaceous dinosaurs. *Geol. Mag.*, **10**, 263.
- SEWARD, A. C., 1903. Flora of the Uitenhage Series. *Ann. South Africa Mus.*, **4**, 1-46.
- 1907. Notes on fossil plants from South Africa. *Geol. Mag.*, **4**, 481-487.
- TERMIER, H. and G., 1956. L'Évolution de la Lithosphere. T. 2. Orogénèse, pp. 371 *et seq.*
- VON HUENE, F., 1940. Die Saurier der Karroo, Gondwana—und verwandten Ablagerungen in faunistischer, biologischer und phylogenetischer Hinsicht. *N. Jb. Miner. Geol. Pal.*, 83-B, 246-347.
- WAGNER, P. A., 1929. Volcanic pipes younger than the Drakensberg Lavas and Karroo Dolerites. In *Geology of the Union of South Africa*, pp. 148-154.
- WATSON, D. M. S., 1942. On Permian and Triassic Tetrapods. *Geol. Mag.*, **79**, 81-116.
- 1956. The two great breaks in the history of Life. *Quart. Journ. Geol. Soc.*, **112**, 393-412.
- YOUNG, R. B., 1932. The occurrence of stromatolitic or algal limestones in the Campbell Rand Series, Griqualand West. *Trans. Geol. Soc. South Africa*, **35**, 29-36.
- 1934. A comparison of certain stromatolitic rocks in the Dolomit. Series of South Africa with modern algal sediments in the Bahamase *Ibid.*, **37**, 153-162.

MADAGASCAR

The island of Madagascar forms a large plateau inclined westwards towards the Mozambique Strait. It is terminated abruptly on its eastern side by a large fault.

The geological structure may be described in its major features thus: the whole of the eastern part (some three-quarters of the total area) is composed of crystalline and metamorphic Pre-Cambrian rocks; the western coastal region is covered by a belt of sedimentary rocks, on average 150 km. wide, which young progressively towards the coast.

Scientific study of Madagascar began after its annexation by France in 1896. On the occasion of the International Geological Congress of 1900 Marcellin Boule presented the first geological map of the whole island, summarising the knowledge acquired up to this time.

The minerals and rocks of the crystalline massif are dealt with by A. Lacroix in the three volumes of his *Minéralogie de Madagascar*.

Among the most important regional studies one must cite those of P. Lemoine (1906) in the northern part of the island, H. Besairie (1930, 1936, 1946, 1959) in the south-west and north-west, L. Barrabé (1929) in the Sakalave country, E. Basse de Ménorval (1934) in the south-west, together with the work of E.-F. Gautier, R. Decary, A. and G. Grandidier, H. Perrier de la Bâthie, V. Hourcq, Mme. Brière and A. Lenoble. Palaeontological memoirs have been written by M. Boule, J. Cottreau, J. Lambert, P. Lemoine, A. Thévenin, E. Basse de Ménorval, H. Besairie, M. Collignon (1959) and J. Piveteau. This work is published in the *Annales de Paléontologie*, the *Mémoires de l'Académie malgache* and the *Annales du Service géologique de Madagascar*. The complete bibliography now comprises over 2,000 works.

H. Besairie got published in 1951 a 1 : 1,000,000 geological map and in 1956 numerous 1 : 500,000 regional sheets.

1. PRE-CAMBRIAN

The crystalline massif which occupies three-quarters of the island was first studied by A. Lacroix, from the mineralogical and petro-

graphic point of view, and subsequently by H. Besairie and his collaborators.

The Pre-Cambrian comprises several groups which have been dated utilising galena, monazite, uraninite, thorianite and zircons (Besairie 1957, 1958).

After the charnockitic complex of Ranomena, the oldest system is the *Androyan*, found in the south of the island, which is composed of gneisses, leptynites and pyroxenites. This belongs to the ancient Pre-Cambrian, over 3,000 million years old (Pr. 1).

Next comes the *Graphite System*, composed of migmatites, gneisses mica-schists and a considerable quantity of graphite. It has been dated using monazite and galena, giving ages of 2,420 and 2,140 m.y., which enabled Holmes and Cahen (1957) to include it in a known cycle of 2,650 m.y. (Pr. 2).

Following the Graphite System come:

The Vohibory System, migmatised in layers, and comprising quartzites and marbles. Three galena measurements have given a corrected date of 1,890 m.y.

The Marbles System, unconformable on the Vohibory, folded and granitised and cut by veins of galena dated at 1,170 m.y.

The Schists and Quartzites Series, also unconformable and cut by granites and pegmatites containing beryl and columbo-tantalite, which have been dated as Cambrian (485 m.y.), belonging to a cycle of mineralisation known in Mozambique, South Africa, India and South America.

It is perhaps in this group that we must place the stratified granites so common throughout the island. They occur as sheets of variable thickness interstratified in Pre-Cambrian schists or more usually, gneisses, and have a granoblastic texture. Authors consider that they result from the metasomatic transformation of sills or the enveloping gneisses.

Measurements of absolute age of rocks from different parts of the island always range between 485 and 550 m.y., which correspond to the age of the thorianite mineralisation (485 m.y.) (Emberger 1958; Roch 1958).

2. PRE-KARROO PALAEOZOIC

No Cambrian sediments are known, but the 485 m.y. mineralisation is of this period.

No Silurian is known either, and the Devonian is only suspected, from a small fragment of fusain-bearing shale, collected in 1936 by A. Lenoble. This contained what P. Bertrand called a *Lepidodendron* scale and what, more recently, P. Pruvost regarded as the fragment of the woody axis of a vascular cryptogam with a foliate scar. This could not be older than Devonian but it could be Lower Carboniferous.

3. THE MADAGASCAN KARROO (SAKOA, SAKAMENA, ISALO)

By analogy with the sedimentary formations of South Africa H. Besairie has given the name "Madagascan Karroo" to the deposits of Carboniferous to Jurassic age. This assemblage is subdivided into three groups separated by unconformities and well dated by marine intercalations. The Madagascan Karroo outcrops extensively in the western part of the island.

Sakoa Group (Upper Carboniferous-Lower Permian)

The Sakoa Group outcrops in the south-west in the Onilahy region, over a distance of about 100 km. The following horizons are distinguished, from bottom to top:

1. *Tillites*. The base of the group is represented by 150 m. of black shales and conglomerates. The latter are similar to the Dwyka tillites in South Africa. The black shales, sometimes intercalated between the tillites, contain plants, *Schizoneura* impressions in particular.
2. *Coal Beds*. The coal beds, about 100 m. thick, consist of sandstones, shales and seams of exploitable coal. The flora includes *Gangamopteris cyclopteroides* Feist. at the base and *Glossopteris indica* and *Schizoneura gondwanensis* Sch. near the top. It is a flora characteristic of the South African Ecca (Carpentier 1935, 1936).
3. *Lower Red Series*. The coal beds are overlain by a group of feldspathic sandstones and red clays with silicified wood, with conglomerates at the top. The whole series reaches 5 to 600 m. in thickness.
4. *Vohitolia Marine Beds*. Along the road from Betioky to the Sakoa, at Vohitolia, the red sandstones are overlain by

marine limestones containing *Productus* cf. *curvirostris* Schellw. and *Spirifer* cf. *rectangulus* Kut. This horizon extends all along the western coast as far as the Ankitokazo district in the north. It belongs to the Lower Permian *sensu lato* and provides the first evidence of the Mozambique Strait.

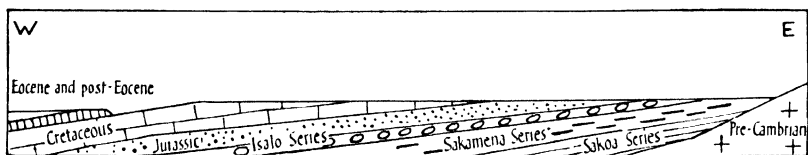


FIG. 31. Diagrammatic section of the sedimentary formations in western Madagascar.

Sakamena Group (Upper Permian-Lower Trias)

(a) *Marine Facies*. This outcrops in the north of Madagascar in the Barabanja and Ankitokazo Basins. The following are distinguished from bottom to top:

1. *Xenaspis and Cyclolobus Beds*. The *Productus* limestones of Ankitokazo are overlain by shaly sandstones containing *Productus abichi* W. var. *ankitokaso* Astre, *Spiriferina roissyi* Leveille, *Xenaspis carbonarius* Waagen and *Cyclolobus walkeri* Diener at the top. This is a fauna of the lower half of the Upper Permian.
2. *Claraia Beds*. Shales with *Claraia* but without ammonites, representing the upper half of the Upper Permian.
3. *Fish and Ammonite Beds*. Yellow and red shales with numerous lenticular nodules containing fine impressions of fish belonging to the genera *Australosomus*, *Perleidus*, *Bobasatrania*, *Parasemionotus*, etc. and ammonites (*Glyptophyceras*, *Clypeoceras*, *Aspidites*) of Lower Eotriassic age.
4. *Barabanja Beds*. Sandstones, shales and limestones containing a fine fauna of Upper Eotriassic ammonites: *Vishnuites fournieri* Collignon, *Flemingites compressus* Waagen, *F. pulcher* W., *Meekoceras khoorensis* W., *Clypeoceras spitiensis* v. Krafft, *Proptychites cottreaui* Collignon, etc.

(b) *Continental Facies*. The continental facies occurs in the south-west as far as Cape Saint-Andre. It rests unconformably

on the Sakoa Group and is dated by marine intercalations. Northwards it passes into an entirely marine facies.

Three horizons are distinguished, from bottom to top as follows:

1. *Glossopteris Shales*. These begin with a conglomerate resting variously on Permian limestones, the top of the Sakoa and the crystalline basement. Above this come shales with plant remains, no longer including *Gangamopteris* but still with *Glossopteris indica* Sch. together with *Thinnfeldia callipteroides* Carpentier, *Pecopteris* sp. and *Voltzia* cf. *heterophylla* Br. There are thin marine intercalations with *Modiolopsis stockleyi* Cox and *Gervillia elianae* Cox (of the topmost Permian of Tanganyika) (Cox 1936). The flora is like that of the Beaufort Series in South Africa, an interpretation confirmed by a study of the overlying reptile beds.
2. *Reptile Beds*. These have yielded a very fine fauna, studied by J. Piveteau (1926, 1928, 1937). Among the reptiles can be cited *Tangasaurus menelli* Haughton, *Hovasaurus boulei* Piveteau and *Coelurosauravus elivensis* Piveteau. Swamps were still widespread, judging from the presence of amphibians such as *Rhinesuchus senekalensis* v. Hoepen. The beds mark the end of the Permian and beginning of the Trias.
3. The Lower Trias (Middle Sakamena) comprises argilites and marlstones with fish: *Parasemionotus labordei* Priem. and *Ecrinosomus dixonii* Priem., abundant in the north and associated with ammonites. There are also an archaic batracian, *Protobatrachus massinoti* Piveteau and amphibians known from Russia and Greenland. The succession terminates with shales and sandstones (Upper Sakamena).

Isalo Group (Upper Trias-Bajocian)

Unconformable on the underlying beds, the Isalo Group begins with a basal conglomerate and extends uninterruptedly from the north to the south-west of the island. It is subdivided into three units:

Isalo I (Upper Trias). This lower division, locally reaching 500 m. thickness, is composed of soft unfossiliferous sandstones. The top of this formation is bituminous in the Morafenobe region,

south of Majunga. Isalo I is overlain by a marine horizon of the Lower Lias.

Isalo II (Lias). In the northern half of the island, Isalo II exhibits a marine and lagoonal facies. In the Kandrehu region one finds at the base a horizon with *Spiriferina rostrata* Schloth. var. *madagascariensis* Thevenin, *Protocardia striatula* and *Bouleicerias nitescens*, while at the top is a horizon of lignites and bituminous shales.

In the Ampasindava Peninsula the Jangoa Limestones with *Spiriferina* are overlain by a plant horizon with *Equisetum jolyi*, *Pecopteris cyatoides*, *Sphenolepidum*, *Yuccites*, etc. The upper marine horizon contains *Dumortieria* cf. *dumortieri* and *Harpoceras*, of the Toarcian and Aalenian.

In the south-west of Madagascar Isalo II is, in contrast, represented by a continental facies, with some 1,000 m. of red sandstones and shales containing silicified wood fragments of large size (*Dadoxylon*, *Cedroxylon*), fish (*Ceratodus*) and reptiles (phytosaurids) (Besairie 1948).

Isalo III (Bajocian-Bathonian). The lower boundary of Isalo III corresponds with the beginning of the great basal Bajocian transgression (with *Witchellia* beds). In certain regions, in the south-west for example, no continental Isalo III is present; it is replaced entirely by a marine facies.

The continental facies can be observed between Betsiboka and the Ampasindava Peninsula. Two horizons are distinguished: a lower one of sandstones with silicified wood (quite rare and small in size) and an upper one of sandstones and clays containing large dinosaurs (*Bothriospondylus madagascariensis* Lyd.).

4. BAJOCIAN-BATHONIAN

In the north-west of the island, at Ambilobe, the Lias with *Spiriferina rostrata* is overlain by fossiliferous marls and limestones containing a Bajocian fauna: *Witchellia* sp., *Diplocidaris besairiei* Lambert, *Stomechinus bigranularis* Lmk., *Rhynchonella fageae* Bes.

The Lower and Middle Bathonian is represented by reef limestones with *Girvanella* (in the south-west) and by beds with corbulars in the north and south-west, with *Corbula pectinata* Sow., *Astarte baroni* Newton, *Pseudotrapezium ventricosum* Newton, *Perna latoconvexa* Newton and *Mytilus madagascariensis* Newton. Crocodile remains are also present: *Steneosaurus baroni* Newton.

Following on these brackish water *Corbula* beds come clearly marine beds of the Upper Bathonian.

It was in Upper Bathonian times that the marine transgression completely covered the north and west of Madagascar. The Upper Bathonian is characterised by a fine fauna including abundant *Macrocephalites* (*M. madagascariensis* Lemoine, *M. formosus* Sow., *M. habyensis* Spath, *M. colcanapi* Lemoine), *Phylloceras mediterraneum* Neumayr, *P. jaraense* W., *Lytoceras adeloides* Kud., *Pygurus depressus* Ag. and *Rhynchonella paolii* Stef.

This correlates with the Upper Bathonian of Cutch (Lower *macrocephalus* Beds); generally marly or calcareous, with an oolitic facies, it is known all along the west coast and also on the north coast.

5. UPPER JURASSIC

Callovian. The thin Lower Callovian has the same geographical distribution as the Upper Bathonian. It corresponds with the "Upper *macrocephalus* Beds" of Cutch. The type locality in Madagascar is at Antsiareza (Maintirano) with a marl-limestone facies with *Macrocephalites charriensis* W., *Belemnopsis calloviensis* Oppel.

The Upper Callovian, with *Reineckia anceps* Rein., *Kinkelinceras kinkelini* Dacque, *Hecticoceras* spp. and *Belemnopsis calloviensis* Oppel, is not known south of the Onilahy.

Oxfordian. The marly Oxfordian has a distribution similar to that of the Upper Callovian. Two horizons are distinguished: a lower one with *Peltoceras athleta* Phill. and *Sindeites sindensis* Spath. and an upper one with *Metapeltoceras*.

Argovian. The Argovian, mainly calcareous, contains *Epimayaites transiens* W. and *Belemnopsis gerardi* Oppel.

Kimmeridgian. Like the preceding stages the Kimmeridgian is missing south of the Onilahy. The lower horizon, which is composed of marls and limestones, contains *Aspidoceras* of the *acanthicum* group, *Torquatisphinctes madagascariensis* Besairie and *Belemnopsis casterasi* Bes. The middle horizon, sandy and calcareous, contains *Waagenia hildebrandti* Beyr. and *Physodoceras avellanoides* Uhlig. The stratigraphy of the Upper Kimmeridgian has not yet been worked out in detail; it is characterised in the Maintirano Province by *Streblites* beds.

Portlandian. The Lower Portlandian (= Lower Volgian) con-

tains *Virgatosphinctes colcanapi* Lemoine, *V. haughtoni* Spath, *V. denseplicatus* W., *Aulacosphinctes parvulus* Uhlig, *Hildoglycoceras kobelli* Oppel, *Hibolites claviger* W. and *H. flemingi* Spath.

The Upper Portlandian (=Tithonian=Upper Volgian), locally oolitic and glauconitic, contains *Aulacosphinctes hollandi* Uhlig, *Blanfordiceras hourcq* Bes. and *Himalayites* sp. This correlates with the Umia Group of Cutch.

Except south of the Onilahy and in Maintirano Province the Madagascan Upper Jurassic forms a continuous and very fossiliferous succession in which all the classic zones are recognised, particularly those of Cutch (Besairie and Hourcq 1935; Besairie 1936).

From Bajocian-Bathonian times the relations between Madagascar and Africa are very uncertain. There can have been some connection only during brief periods of regression or in the south, where, however, the absence of marine sediments does not constitute a proof. Land connection with Australia is excluded by the presence of marine sediments on the western coast of that continent. Only India can have been in connection with Madagascar.

6. CRETACEOUS

The most up-to-date reference is Besairie and Collignon (1956).

Infra-Valanginian. The Cretaceous succession begins with calcareous Infra-Valanginian with *Kilianella pexiptycha* Uhlig and *Spiticeras* sp., identified by H. Besairie in the provinces of Maintirano and Analalava.

Valanginian. The Lower Valanginian consists of marls with *Duvalia dilatata* Blainv. The Upper Valanginian, known on both coasts of the Mozambique Strait, contains a Mediterranean fauna including *Neocomites* of the *neocomensis* group, *Hoplitoides provincialis* Sayn and *Duvalia dilatata* Blainv., accompanied by South African forms such as *Rogersites* and *Belemnopsis africanus* Tate.

Hauterivian. This stage, still poorly known, is represented by unfossiliferous beds and beds with *Belemnites pistilliformis*. The Hauterivian marks the termination of the great stratigraphical break in south-western Madagascar.

Barremian. The Barremian is also little known, but it has furnished a *Paracrioceras* and *Saynella* fauna south of Onilahy and a crioceratid fauna in the Sitampiky district.

Aptian. The sandy Lower Aptian is unfossiliferous. In contrast the Upper Aptian, which is transgressive on both sides of the Mozambique Strait, it is very rich in fossils, in particular *Acanthoplites* (provinces of Tulear, Maintirano and Analalava).

Albian. The base of the Albian contains a classic fauna with *Acanthoplites nolani* Seunes. The Middle Albian contains *Douvillerias mammillare* Schloth., *Phylloceras velledae* Mich. and *Oxytropidoceras*. The Upper Albian is marked by beds with *Pervinquieria inflata* Sow., etc.

Cenomanian. The Madagascar Cenomanian is very complete and its faunas described by M. Collignon have permitted the distinction of four classic horizons.

Turonian. The sandy Lower Turonian contains a fine fauna including *Vascoceras*, *Fagesia* and *Mammites*. It is overlain by the Upper Turonian. The first large basalt flows date from this time, viz. the lower flows in the south-west and the extensive sheets in the north-west.

Coniacian. Beds with *Barroisiceras* and *Gauthiericeras* and three *Inoceramus* zones.

Santonian. This stage is generally regressive. In Majunga Province it is represented by cross-bedded sandstones and clays containing large dinosaurs (*Titanosaurus madagascariensis* Deperet, *Megalosaurus crenatissimus* Deperet, *Stegosaurus madagascariensis* Piveteau).

Campanian-Maestrichtian-Danian. The Lower Campanian is regressive like the Santonian. A large sheet of basalt is attributed to this epoch.

There are several flows and Mme. Basse de Ménorval has recorded five between the Onilahy and the Manambolo. The black, compact basalts, which fall within the *sakalavite* group, contain augite visible to the naked eye, rare olivine and free silica.

Above the basalts is a group of limestones, ranging in age from the Upper Campanian to the Maestrichtian inclusive.

The Upper Campanian is of particular interest because it is transgressive on the eastern coast. The fauna described by Boule and Thevenin includes: *Pseudophyllites indra* Forbes, *Alectryonia unguolata* Sch., *Gryphaea vesicularis* Lmk. and *Noetlingia boulei* Lb., discovered at Fanivelona (Boule *et al.* 1905). *Lepidorbitoides socialis* Leymerie is recorded from beds further north (Vatomandry) and south (Mananjary) (Cottreau 1922).

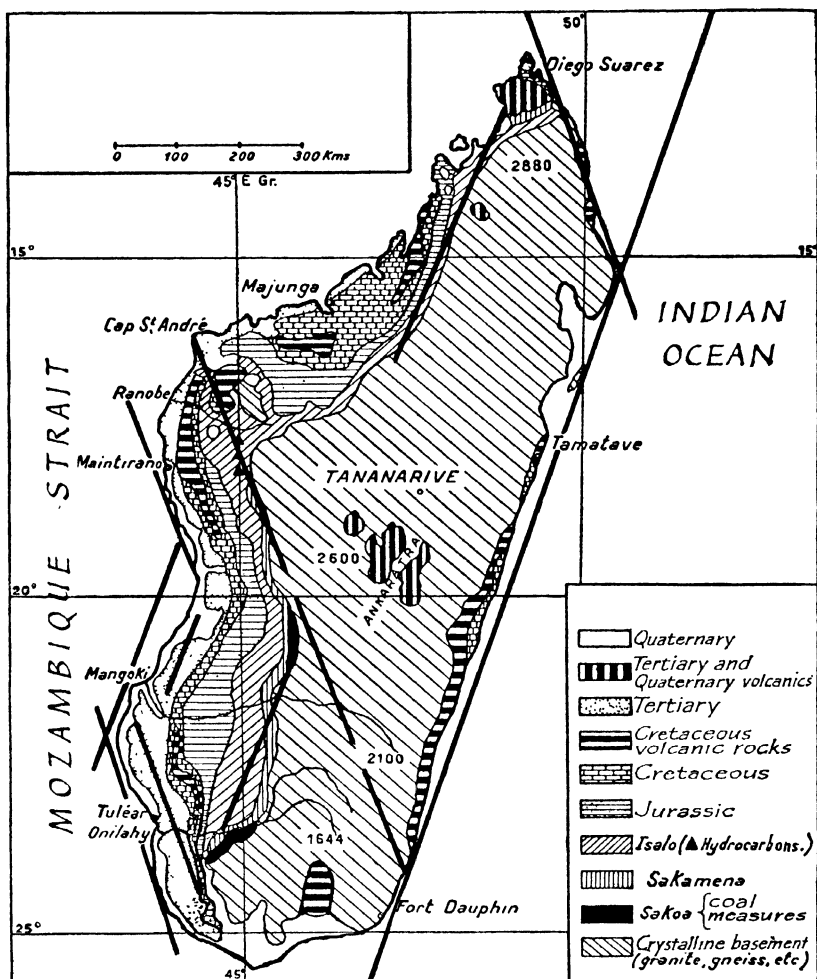


FIG. 32. Geological sketch-map of Madagascar (after Besairie and Lenoble. Faults after Cliquet 1957).

This transgressive Campanian is faulted. Its presence indicates that at this time Madagascar was already an island. The Cretaceous forms of eastern India could now enter the Mozambique Strait.

On the western coast of Madagascar the Upper Campanian is represented by beds with *Hoplitoplacenticas vari* Schluter, *Lepidorbitoides socialis* Leym. and distinctive echinoids: *Lampadaster gauthieri* Lambert, *L. grandidieri* Lambert, *Menuthiaster cottreaui* Lambert and *Micraster meunieri* Lambert.

The chalky Maestrichtian-Danian is very rich in echinoids, enabling three zones to be distinguished, from bottom to top those of *Micraster trangahiensis* Lb., *Hemiaster madagascariensis* Cottreau and *Hemiaster hawkinsi* Lambert.

Hercoglossa danica Schloth. is known in Madagascar from the Maestrichtian onwards. H. Besairie and M. Collignon cite it in the top part of the *Hemiaster hawkinsi* chalk at Antonibe and Ampasindava (in the north-west) but a specimen has also been found in Maintirano Province, in the *Pachydiscus gollevillensis* beds. Mme Basse de Ménorval also records *H. danica* in the south-west, near Mitsinjo, in beds which are "almost certainly above" the *Pachydiscus* beds, and which correlate with the Ninnyoor Beds of the Trichinopoly district of eastern India. These may therefore be accepted as Danian.

Apart from this, H. Besairie, studying the terminal Cretaceous of Betioky Province (west of Edjeda) records several species from the *Venericardia beaumonti* Beds of Baluchistan: *Mesalia fasciata* Lmk., *Bellardia vicina* Douv., *Haustator* cf. *congregatus* Douv. and *Volutocorbis indica* Douv. These species belong in part to the *Venericardia vredenburgi* Beds of Sind and were considered by Douvillé to be Montian.

Therefore there appears to be a *Hercoglossa danica* horizon, at the end of the Cretaceous, which passes insensibly without a break into the Eocene, along the whole of the middle part of the west Madagascan coast.

7. PALAEOGENE

The Lower Eocene is characterised by the echinoid fauna of Katsepe and Majunga (*Schizaster eopneustes* Lambert and *Linthia gibba*) and by the *Lithothamnium* limestones of the south-west.

The Middle Eocene, reaching 50 m. in thickness, is complete, and very fossiliferous at Diego, in the Radama Islands and Betsi-

boka Bay. H. Besairie distinguishes Lower and Middle Lutetian with *Nummulites atacicus* Leym., *N. guettardi* d'Arch., *N. globulus* Leym., *N. uroniensis* Heim, *N. gallensis* Heim, *Assilina exponens* Sow., *A. mamillata* d'Arch. and *Orthophragmina colcanapi* Douv., and Upper Lutetian with *Nummulites acutus* Vred.

The Upper Eocene (Bartonian) is represented by limestones with *Porocidaris schmideli* Desor and *Cidaris daguini* Castex and Lambert.

The Oligocene is known in the north-west on Nosy Kalakajoro Island, where P. Lemoine records *Nummulites intermedius* d'Arch. and *N. fichteli* Mich. and *Lepidocyclina dilatata* Mich.; and in the south-west, where it reaches 400 m. in thickness (Cliquet 1957).

8. MARINE NEOGENE

The marine Miocene is known all along the western coast, exhibiting different facies.

The Aquitanian of the Diego-Suarez region, discovered by P. Lemoine, comprises transgressive Lower Aquitanian with *Lepidocyclina formosa* Schlumb. and *L. raulini* Morton, and Upper Aquitanian with *Lepidocyclina mariae* Douv. (Douville 1909).

The Burdigalian of the Betioky and Maintirano is characterised by an abundance of *Kuphus arenarius* L. and *Ostrea pelecypdion* Fischer and an echinoid fauna (Collignon and Cottreau 1927).

The Vindobonian, with *Miogypsina irregularis* Mich. and *Operculina complanata*, has been described from Mahakendy Island (Majunga) (Bertrand and Joleaud 1924; Lenoble 1939).

There were volcanic eruptions in the Miocene, beginning in the Aquitanian and continuing into the Burdigalian. They seem to have been confined to the northern extremity of the island.

9. PLIO-PLEISTOCENE

A certain number of continental deposits are attributed to the Pliocene. The most interesting are lacustrine clays containing bituminous shales and lignites, in particular in the Antsirabe region.

The Pliocene was also a period of major volcanic eruptions, in particular the first flows of the Ankaratra Massif (ankaratrites), which have favoured the development of lakes.

The volcanoes of the Montagne d'Ambre, Nosy-Be, the Ankaisina, the Itasy and Antsirabe date from the Quaternary; basalts and phonolites are the dominant rocks. Craters are

locally very well preserved. In the neighbourhood of the Ankara-tra, near Lake Itasy, one can observe volcanic plugs, from which have flowed well-preserved lavas.

All these volcanoes, even the most recent, are extinct. The only active volcano is the Karthala on the Grande Comore, between Madagascar and the African coast (De Saint-Ours 1956).

The Quaternary is still little studied. Authors have recorded, however, the presence of river terraces up to an altitude of 80 m. The raised beaches are at about the same height and the presence of oysters shows that the sea extended some 70 km. into the interior in the provinces of Majunga and Analalava. In addition one can trace several submerged valleys over a wide area, indicating a retreat of the sea.

To the recent Pleistocene belong the lacustrine sediments in which have been found subfossil faunas of the greatest interest, studied in detail by A. Milne-Edwards, A. Grandidier and C. Lamberton (1934). The fauna includes lemurs, whose Tertiary ancestors we should like to know. L. Jolcaud records a small felid (*Aerulictis minor madagascariensis*), closely resembling *A. minor* from the Oligocene phosphorites of Quercy. A very abundant small hippopotamus with archaic features (*H. lemertei* = *H. madagascariensis*) recalls *H. imaguncula* of the Lower Pleistocene of East Africa. It might have migrated to Madagascar via a chain of islands.

Finally there existed until the very recent past a giant bird, *Aepyornis maximum*. This was a ratite 2m. 50 to 3 m. in height, whose eggs reach 32 cm. in length and 7 litres mean volume. Skeletons and eggs have been found associated with bones of *Hippopotamus lemerlei* both in dune sands and peat bogs; they are accompanied by traces of a human industry, sometimes very recent, which suggests that these birds must have disappeared due to the hunting activities of Man. *Aepyornis* could only have become extinct within the last thousand years.

10. MASCARENE ISLANDS, REUNION, MAURITIUS, RODRIGUEZ

1. Reunion

The island of Reunion (formerly île Bourbon) has been studied by C. Velain (1878), A. Lacroix (1912, 1923), E. Aubert de la Rüe (1931) and P. Bussière (1958).

It consists of two volcanic massifs: the Piton de la Fournaise (2,650 m.) and the Piton des Neiges (3,069 m.).

The Piton des Neiges, completely extinct, is covered by very basic lavas. The principle crater has been removed by erosion but the slopes of the volcano are covered by little adventitious cones. Basalts and basaltic scoriae are the dominant rocks, but phonolitic trachytes and andesites occur in addition. Furthermore A. Lacroix has described coarser-grained rocks, notably alkaline syenites, forming dykes and sills, which may thus have crystallised under a thin cover.

The Piton de la Fournaise, south of the first volcano, exhibits in contrast constant activity. Two huge semicircular cliffs delimit former calderas. The present volcano is known as the "Cratère brulant". The lavas of the Piton de la Fournaise are mainly labradorite basalts very poor in olivine. Basalts rich in chrysolite (oceanites) occur rarely.

The eruptions are of a mixed Hawaio-Strombolian type, involving very fluid lavas which frequently have aropy structure.

No *in situ* sedimentary rock is known in Reunion. E. Aubert de la Rüe collected from a ravine at the foot of the Piton des Neiges a fragment of limestone which must have been carried up from the basement during the ascent of basaltic magma.

2. *Mauritius*

The island of Mauritius (formerly île de France), 185 km. north-east of Reunion, is also volcanic, but there is no sign of present activity (Nicolaysen and Walker 1954; Simpson 1950). The old volcanoes, completely exposed by erosion, emitted highly fluid basaltic lavas in a succession of flows (the oldest of which are Cretaceous) separated by tuffs and breccias. The highest point, on the Piton de la Rivière Noire, is at 825 m. Several conserved craters are occupied by lakes: the Trou aux Cerfs and the Grand and Petit Bassin.

A. Lacroix distinguished doleritic and other basalts marking a transition from ankaramites to oceanites. He established that there is no trace of a basement.

Coral reefs in the north of the island have been raised 15 m. above sea-level. As they are only 4 m. above sea-level in the south uplift must have been irregular. They must be comparatively old, for some reef material occurs between successive basaltic flows.

The coast, more sharply delineated than that of Reunion, is fringed by an almost uninterrupted belt of reefs.

R. Hoffstetter has described from Mauritius a large subfossil lizard, *Didosaurus mauritianus*, which disappeared from Rodriguez in historical times (Hoffstetter 1949).

3. Rodriguez

Rodriguez, 600 km. from Mauritius, is yet another volcanic island (Reed 1949). An E.-W. ridge reaches 450 m. in altitude. The lavas are basaltic and occur as flows with reddened tops.

The plain in the south-west of the island is formed of coralline limestones locally elevated to 150 m. and containing caves from which have been collected skeletons of an extinct bird, the "Solitaire" (*Pezophaps solitaria*).

REFERENCES

- AUBERT DE LA RÜE, E., 1931. Une excursion géologique à la Reunion et à l'île Maurice. *Revue Géogr. Phys. et Géol. dynam.*, **4**, 201-221.
- BARRABÉ, L., 1929. Contribution à l'étude stratigraphique et pétrographique de la partie médiane du pays sakalave. *Mém. Soc. Géol. Fr.*, No. 12.
- BASSE DE MÉNORVAL, E., 1934. Étude géologique du Sud-Ouest de Madagascar. *Ibid.*, No. 24.
- BERTRAND, L. and L. JOLEAUD, 1924. Sur quelques faits relatifs aux formations néogènes et quaternaires des environs d'Antsirabe (Madagascar). *C.R. Ac. Sc.*, **178**, 1293-1295.
- BESAIRIE, H., 1930. Recherches géologiques à Madagascar. (Thesis.) *Bull. Soc. Hist. Nat. Toulouse*, **60**.
- 1936. Recherches géologiques à Madagascar (1^{re} suite). La Géologie du Nord-Ouest. *Mem. Ac. Malgache*, **21**.
- 1946. La Géologie de Madagascar en 1946. *Ann. Geol. Serv. Mines Mad.*, **12**.
- 1948. *Mém. Ac. Malgache*, pp. 137-141.
- 1957. La carte tectonique de Madagascar 1957 et la géochronologie. *C.R. Congrès de la PIOSA (Tananarive 1957)*. *Publ. Serv. Géol. Madagascar*, pp. 1-17.
- 1958. Note pour servir aux correlations du vieux socle. *C.R. CCTA (Tananarive 1957)*. *Ibid.*
- 1959. La recherche géologique à Madagascar de 1948 à 1958. *Ibid.*, 59 pp.
- and M. COLLIGNON, 1956. Le système crétacé à Madagascar. *Comm. XX Int. Geol. Congr.*, Mexico.

- BESAIRIE, H., and V. HOURCQ, 1935. Sur la stratigraphie du Jurassique supérieur de Madagascar. *C.R. Ac. Sc.*, **201**, 228.
- BOULE, M., A. THEVENIN and J. LAMBERT, 1905. Paléontologie de Madagascar. Fossiles de la côte orientale. *Ann. Paléont.*, **1**, 43-59.
- BUSSIÈRE, P., 1958. Étude géologique de l'île de la Reunion. *Trav. Bureau Géol. Madagascar*, No. 84, 64 pp. 1 map.
- CARPENTIER, A., 1935. Études paléobotaniques sur le groupe de la Sakoa et le groupe de la Sakamena. *Ann. Géol. Serv. Mi. Madag.*, **5**, 7-32.
- 1936. Additions à l'étude de la flore du groupe de la Sakamena. *Ibid.*, **6**, 35-40.
- CLIQUET, P. L., 1957. La tectonique profonde du Sud du bassin de Morondava. C.R. CCTA (1957). *Publ. Serv. Géol. Madagascar*, 375-396.
- COLLIGNON, M., 1959. Nombreux Mémoires et Atlas des fossiles caractéristiques de Madagascar. *Ibid.*
- and J. COTTREAU, 1927. Paléontologie de Madagascar. Fossiles du Miocene marin. *Ann. Paléont.*, **6**, fasc. 4.
- COTTREAU, J., 1922. Paléontologie de Madagascar. Fossiles de la côte orientale. *Ibid.*, **21**, pp. 115.
- COX, L. R., 1936. Karroo Lamellibranchia from Tanganyika Terr. and Madagascar. *Quart. J. Geol. Soc. London*, **92**, 32-57.
- DE SAINT-OURS, J., 1956. Étude géologique et morphologique de l'Archipel des Comores. *Bull. Ac. Malgache*, **34**, 7-39.
- DOUVILLE, R., 1909. Lepidocyclines et *Cycloclypeus* malgaches. *Ann. Soc. R. Zool. Malac. Belgique*, **44**, 125-139.
- EMBERGER, A., 1958. Les granites stratoïdes du Pays Betsilco (Madagascar). *Bull. Soc. Géol. Fr.* (6), **8**, 537-554.
- HOLMES, A. and L. CAHEN, 1957. Géochronologie africaine 1956. Resultats acquis au 1^{er} juillet 1956. *Mem. Ac. R. Sc. Col.*, Brussels, **5**, fasc. 1, 169 pp.
- HOFFSTETTER, R., 1949. Les Reptiles subfossiles de l'île Maurice. *Ann. Paleont.*, **35**, 45-72.
- LACROIX, A., 1912. Le volcan de la Réunion. *C.R. Ac. Sc.*, **154**, 538.
- 1923. La Réunion (étude lithologique), in *Mineralogie de Madagascar*, **3**, 227-237.
- LAMBERTON, C., 1934. Contribution à la connaissance de la faune subfossile de Madagascar. Lemuriens et Ratites. *Mem. Ac. Malgache*, fasc. 17, 168 pp.
- LEMOINE, P., 1906. Études géologiques dans le Nord de Madagascar. Contributions à l'histoire géologique de l'océan Indien. (Thesis, Paris.)
- LENOBLE, A., 1939. Le bassin lacustre d'Antanifotsy-Iano-borona. *Bull. Ac. Malgache*, **22**.
- NICOLAYSEN, L. O. and F. WALKER, 1954. The Petrology of Mauritius. *Q. Bull. Col. Geol. Surveys*, **4**, 3-43.
- PIVETEAU, J., 1926. Amphibiens et Reptiles permien. *Ann. Paleont.*, **15**, 55-179.
- 1928. *Ibid.*, **17**, 23-47.
- 1937. Un Amphibien du Trias inférieur. Essai sur l'origine et l'évolution des Amphibiens anoures. *Ibid.*, **26**, 135-177.
- REED, F. R. C., 1949. *The Geology of the British Empire*. London (Arnold).

- ROCH, E., 1958. Granites laccolithiques et granites stratoïdes de Madagascar.
C.R. Soc. Géol. Fr., 130-132.
- SIMPSON, E. S. W., 1950. The Geology and mineral resources of Mauritius.
Q. Bull. Col. Geol. Surveys, 1, 217-238.
- VELAIN, C., 1878. Description géologique de la presqu'île d'Aden, de l'île de la Réunion, des îles Saint-Paul et Amsterdam. Paris.

INDEX

- Abadie, J., 211
 Abrard, R., 61, 177, 225, 315, 339
 Accra, 231
 Adar Douthi, 203
 Aderca, B., 273
 Adigrat, 305
 Adoudounian, 9
 Adrar des Iforas, 197
 Adrar Tiguirirt, 200
 Afar, 313
 Agadem, 210
 Ahnet, 21, 90
 Aicard, P., 200, 235
 Aïr, 207
 Aitken, W. G., 317
 Akjoujt, 121
 Alimen, H., 115
 Alto Ligonha, 336
 Amsaga, 120
 Amstutz, A., 262
 Andrew, G., 165
 Andrews, C. W., 162
 Androyan, 355
 Angola, 295
 Annobon, 259
 Aouker, 185
 Apollonian, 232
 Arabia, 170
 Arambourg, C., 54, 65, 70, 72, 164, 202,
 204, 269, 300, 325
 Arnould, M., 62, 214
 Arsandaux, H., 237, 312
 Assaba, 187
 Asselar, 200
 Atacora, 235
 Atacorian, 236
Atlantropus, 72
 Aubert de la Rüe, E., 304, 314, 315, 366
Australopithecus, 71
 Awad, G. H., 155
 Awat Series, 165
 Aymé, J. M., 214
 Azaouak, 206

 Babet, B., 261, 268
 Bakel, 174
 Bamako, 189
 Bandiagara, 200
 Barbeau, J., 209, 211
 Barber, W., 244
 Barbier, A., 12, 19, 22
 Bardet, G., 78
 Barrabé, L., 354
 Barthoux, J. C., 43, 152
 Basse, E., 311, 354, 362
 Basins, 77
 Bata, 255
 Batékés Plateau, 268
 Bates, D. A., 226
 Bather, F. A., 246
 Bauchi, 243
 Baud, L., 189, 267
 Beaufort, 31
 Bebiano, 181
 Bellair, P., 149
 Bembe, 296
 Bende-Ameki, 246
 Bense, C., 122, 126, 128, 185, 187
 Benue, 244
 Berkaloff, E., 25
 Bernard, E. A., 70
 Berthois L., 181
 Bertrand, P., 356
 Besairie, H., 313, 314
 Bessoles, B., 274
 Bettencourt Dias, M., 336
 Bigotte, G., 265
 Bilati, 283
 Bilma, 210
 Birrimian, 226
 Bizard, C., 132
 Blanchot, A., 120, 130, 200
 Bobo-Dioulasso, 224
 Bodin, L., 222
 Bokkeveld, 343
 Bolgarski, M., 221
 Bonnet, A., 139
 Bordet, P., 90, 101
 Borngniez, G., 272, 274
 Borkou, 209
 Boshoff, J. H., 338
 Bouenzian, 264
 Boule, M., 362
 Bourcart, J., 7, 21, 38, 63, 90, 101, 180
 Bourreau, E., 40, 41, 68, 98, 100, 103, 136,
 147, 202, 208, 251
 Boutakoff, N., 283
 Brajnikov, B., 262

- Brichant, L., 28, 142
 Brock, B. B., 77
 Buem, 228
 Bukoba, 318
 Bulawayan, 328
 Bunyoro, 318
 Bussière, P., 366

 Cabinda, 275
 Cahen, L., 3, 23, 76, 266, 275, 337
 Caire, A., 62
 Calonda, 298
 Cambrian, generalities, 11
 Cameroun, 249
 Campbell Smith (W.), 324
 Canary Islands, 181
 Cape Verde, 178
 Cape Verde Islands, 182
 Carbonatites, 324
 Carboniferous, generalities, 18, 22
 Carnot Sandstones, 274
 Carpenter, L. B., 301
 Carpentier, A., 153, 357
 Cassange, 297
 Castany, G., 37, 73
 Caster, K. E., 301
 Chanut, C., 96
 Chavaillon, J., 115
 Chélat, E. de, 217
 Choffat, P., 303
 Choubert, B., 267, 269
 Choubert, G., 8, 10, 107
 Chudeau, R., 78, 87, 129, 192, 204, 206
 Cizancourt, M. de, 177
 Claracq, P., 41, 98
 Cliquet, P. L., 364
 Cocobeach, 269
 Cole, S., 326
 Collignon, M., 100, 355, 362, 365
 Colomb Béchar, 116
 Congo, 261, 275, 277
 Conrad, G., 115
 Continental hamadien, 47
 "Continental intercalaire", 40, 47, 99,
 125, 142, 147, 154, 166, 172, 204,
 210, 250, 284
 Continental post-tassilien, 98, 136
 Continental terminal, 66, 119, 126, 149,
 162, 166, 202, 210, 225, 254, 268
 Cooper, W. G., 328
 Coppens, Y., 211
 Cornet, A., 275
 Corsin, P., 138
 Cosson, J., 264, 266, 268

 Cotonou, 238
 Cottreau, J., 363
 Courtet, H., 274
 Cox, L. R., 166, 173, 232, 323, 339,
 358
 Craters of Mauritania, 130
 Cretaceous, generalities, 47
 Crick, G. C., 338
 Cross River, 252
 Cuvillier, J., 20, 155, 158, 177
 Cyrenaica, 142

 Daguin, F., 39, 116
 Dahomey, 235
 Dahomeyan, 235
 Dainelli, D., 173, 205
 Dakar, 118
 Dalloni, M., 39, 135, 137
 Daly, R. A., 260
 Damergou, 204
 Dars, R., 110, 126, 127, 128, 185, 189,
 219, 220
 Darteville, E., 271, 292, 300
 Davies, K. A., 231, 320, 323, 324
 Dechaseaux, C., 34
 Defossez, M., 199
 Defretin, S., 251
 Delafosse, R., 274
 Delany, F., 165, 274
 Deleau, P., 18, 116, 118
 Delhay, F., 265, 275
 Delpy, J., 122, 127, 186, 187
 Denaeyer, M. E., 126, 255
 Desio, A., 96, 142
 Dévigne, J.-P., 262, 265
 Devonian, generalities, 16
 Dibella, 210
 Dixey, F., 76, 317, 321, 328, 335
 Djado, 135
 Djebel Ouenat, 150
 Djebel Tebaga, 25
 Djeddah, 173
 Djoua, 98
 Djouf, 126
 Dohone, 139
 Dokhan, 153
 Dollo, L., 293
 Domes, 76
 Douvillé, H., 26, 155, 300
 Douvillé, R., 364
 Dreyfuss, M., 304, 312
 Dschang, 253
 Duparc, L., 305
 Durnand Delga, M., 14, 38, 62

- Du Toit, A. L., 29, 331, 349
 Dwyka, 29, 346

 Eccä, 30, 346
 Edwards, W. N., 166
 Egypt, 152
 Ehrmann, F., 12
 Ellenberger, F. and P., 348
 Elobi, 255
 Élouard, P., 134
 Emmidir, 93
 Empty Quarter of the Sahara, 126
 Ennedi, 136
 Eocene, generalities, 53
 Erdi ma, 139
 Erhart, H., 74
 Ethiopia, 304
 Evrard, P., 281

 Fabre, J., 81
 Falconer, J. D., 247
 Falemian, 122, 175
 Fallot, P., 38, 63
 Farag, I., 155
 Farsan Islands, 173
 Faure, H., 79, 210, 211
 Fernando Po, 258
 Fezzan, 145
 Flamand, G. B. M., 64, 90, 96, 116
 Flandrin, J., 40, 55
 Flora :
 Carboniferous, 19, 30, 117, 125, 139, 285
 "Continental intercalaire": see above
 terminal: see above
 Permian, 30, 285, 297, 319, 331, 237, 345
 Triassic, 32, 333
 Quaternary, 102
 Follot, J., 93
 Fort Polignac, 41, 95, 98
 Fourtau, R., 157
 Francevillian, 267
 Freire de Andrade, C., 297
 Freitas, A. de, 336
 Freneix, S., 252, 271, 292, 300
 Freulon, J. M., 96, 135, 149
 Freydenberg, H., 205, 209
 Fritel, P. H., 139, 156
 Furon, R., 71, 76, 78, 122, 136, 184, 196, 193, 202, 211, 216, 225, 238, 261

 Gabon, 261
 Gamblian, 72, 290, 326

 Gao, 78, 202
 Garde, G., 205, 211
 Gazel, J., 248
 Gentil, L., 14, 27, 53
 Geochronology, 3
 Gérard, G., 261, 272
 Germain, L., 186, 211
 Gevers, T. W., 349
 Gevin, P., 107, 111, 122
 Gèze, B., 136, 139, 210, 248, 256
 Ghallaman, 121
 Ghana, 227
 Gigout, M., 69
 Glangeaud, L., 38, 57, 58, 62
 Goloubinow, A., 212
 Gorodiski, A., 176, 179
 Gourma, 199
 Graindor, M. J., 9
 Graphite System, 355
 Gravelle, M., 88
 Great Dyke of Rhodesia, 329
 Gregory, J. W., 323
 Greigert, J., 204
 Grekoff, N., 285
 Guelb el Hadid, 122
 Guillaume, R., 216
 Guillemain, C., 248
 Guinea, 215, 249
 Guir, 117
 Guirian, 116

 Haas, O., 300
 Hammamat, 152
 Haroudj el Assoued, 149
 Hassi Messaoud, 81
 Haug, E., 98
 Haughton, S. H., 335, 338, 341, 347
 Hennig, E., 251, 322
 Hirst, T., 228, 229
 Hoffstetter, R., 72, 368
 Hoggar, 87
 Holmes, A., 3, 340
 Homodji, 211
 Hourcq, V., 248, 253, 269, 271, 361
 Hubert, H., 178, 212, 235
 Hudeley, H., 139
 Huene, H. von, 346
 Hume, W. F., 152
 Humpata, 296
 Hupé, P., 23, 77
 Huzayyin, S. A. S., 164

 Immadouézène Series, 90
 Infra-Cambrian, generalities, 8

- Isalo, 359
 Ivory Coast, 222
 Jacquet, F., 109, 127, 175
 Jérémme, E., 219, 258
 Jodot, P., 64, 102, 118, 126, 189, 191
 Joleaud, L., 141, 204, 364
 Jongmans, W. J., 117, 154
 Joulia, F., 97, 204, 208
 Junner, N. R., 226, 228, 235
 Jurassic, generalities, 40
 Kagerian, 69
 Kalahari, 81, 288, 298, 333
 Kamasian, 70
 Kanjerian, 70
 Kaouar, 211
 Karpoff, R., 89, 97, 103, 170, 197, 198, 205, 213
 Karroo, 29, 284, 297, 318, 331, 337, 345
 Katanga, 4, 6, 279, 280
 Kavirondian, 317
 Kavironde, 317
 Kenadza, 116
 Kenadzian, 116
 Kent, P. E., 325, 327
 Kenya, 317
 Kibara, 280
 Kikoine, J., 202
 Kilian, C., 16, 23, 45, 67, 87, 88, 94, 97, 104, 136, 141, 198
 Kimberlites, 288, 334, 350
 King, B. C., 76, 327
 King, L. C., 76, 83
 Kitson, A. E., 231, 234
 Koch, P., 249, 250, 260
 Koert, W., 237, 238
 Korableff, G., 273, 275
 Kouriatchy, N., 238
 Koutous, 205
 Krenkel, E., 77, 83, 282, 293
 Kuhne, W. G., 32, 34
 Kundelungu, 6, 281
 Kwango, 287
 Labbezenga, 200
 Lacoste, J., 53, 60, 61, 67
 Lacroix, A., 73, 75, 145, 151, 179, 219, 221, 223, 226, 354, 366, 367, 369
 Laffitte, R., 37, 39, 57, 60, 61, 62, 67
 Lama, 238
 Lamare, P., 170, 173, 174, 311, 315
 Lambert, A., 12, 24
 Lambert, R., 204, 209, 213
 Lamberton, C., 366, 369
 Lamotte, M., 216, 221
 Landana, 292
 Langlois, X., 141
 Lapparent, A. de, 211, 213
 Lapparent, A. F. de, 28, 41, 46, 47, 52, 96, 97, 98, 99, 104, 142, 151, 205, 206, 208, 213
 Lasserre, M., 249
 Laterites, 73, 191
 Latrilhe, E., 179
 Lavocat, R., 119, 133, 202
 Leakey, L. S. B., 69, 326, 327
 Lecointre, G., 14, 24, 61, 67, 68, 75
 Lefranc, J. P., 100, 104, 145, 147, 150, 151
 Legoux, P., 216, 223, 226
 Lehman, J. P., 28, 34, 35, 99, 104
 Lelubre, M., 15, 20, 24, 88, 89, 90, 96, 99, 104, 136, 139, 141, 145, 147, 151, 197, 198, 213
 Le Maitre, D., 129, 133
 Lemoine, P., 354, 369
 Lenoble, A., 178, 365, 369
 Lepersonne, J., 76, 83, 277, 289, 299
 Leriche, M., 292, 294
 Lessard, L., 97, 104
 Libya, 142
 Limpopo, 4, 341
 Lindi, 323
 Loia, 287
 Lomagundi, 330
 Lombard, J., 141, 269, 273, 276
 Los Islands, 220
 Lucas, G., 14, 24, 41, 43, 46
 Lüderitz, 352
 Lugh, 305
 Lukuga, 285
 Lutôc, 197
 McConnell, R. B., 327
 MacFadyen, W. A., 164, 169, 173, 174, 315
 MacGregor, A. M., 335, 341, 353
 MacGregor, D. P., 233
 McKinley, A. C. M., 322, 327
 Macina, 191, 194
 Madagascar, 354
 Maignien, R., 74, 75
 Malagasari, 318
 Malagasy: see Madagascar
 Malavoy, J., 225
 Mali, 185, 197
 Man, Massif de, 223
 Mann, O., 250, 260

- Marampa, 215
 Marçais, J., 27, 28, 68
 Martin, H., 352
 Mascarene Islands, 366
 Mathieu, G., 26, 28
 Mattauer, M., 67
 Maufe, H. B., 30
 Maugis, P., 176, 179, 225, 226
 Mauritania, 106, 185
 Mauritanian Adrar, 126
 Mauritius, 367
 Maync, M. W., 183, 184
 Mayombe, 261, 262, 277
 Mazzerian, 115
 Medina, 170
 Menchikoff, N., 10, 18, 20, 39, 42, 46, 94,
 96, 105, 106, 107, 108, 110, 112, 119,
 121, 123, 133, 146, 150, 151
 Menzel, P., 260
 Messak, 147
 Mestraud, J. L., 273, 276
 Meyendorff, A., 97, 105, 112, 133
 Mézarif, 117
 Michel, P., 131, 132
 Miller, A. K., 293, 303
 Millot, G., 219, 221
 Mitiq, 152
 Monod, Th., 16, 103, 121, 123, 125, 126,
 129, 130, 133, 193, 196
 Montenegro de Andrade, M. and J., 295,
 300, 303
 Moret, L., 36, 39, 54, 60
 Mortelmans, G., 289, 293
 Mounio, 205
 Mourdi, 139, 141
 Mourzouk, 81
 Mouta, F., 295, 297, 300, 303, 340
 Mouydir, 93
 Mozambique, 336
 Mozambiquian, 336
 Mungo, 252
 Mutvei, H., 112, 133

 Nachipere, 330
 Nafirdeih, 165
 Nama, 343
 N'délé, 274
 Neltner, L., 8
 Neogene, generalities, 61
 Nesteroff, W. D., 75, 80, 174
 Newton, R. B., 246, 248
 Niari, 264
 Nicklès, M., 15, 24, 110, 133, 175, 179,
 249
 Nicolaysen, L. O., 367, 369
 Nicolini, P., 264, 265, 267, 276
 Niger, 197
 Niger, bend of, 199
 Niger, fossil delta, 192
 Nigeria, 242
 Nigerian, 199
 Nigritian, 6, 89, 198
 Nikolaysen, L. O., 367, 369
 Nougarede, F., 28, 99, 103
 Nowack, E., 318, 327
 Nubian Sandstone, 153
 Nyanza, 317
 Nyanzian, 317
 Nyasa, 329
 Nyasaland, 329

 Obermuller, A., 215, 221
 Obock, 314
 O'Donnell, H., 220, 221
 Oendolongo, 295
 Ogooué, 267, 269
 Olduvai, 326
 Omo, 325
 Oppenheim, P., 238, 241, 327
 Ordovician, generalities, 12
 Oti, 229
 Ougarta, 112
 Ougartian, 116
 Ouljian, 68
 Ounianga el Kebir, 140

 Palaeogene, generalities, 53
 Palausi, G., 195, 196, 199, 200
 Pallister, J. W., 327
 Parkinson, J., 322, 327
 Passau, G., 294
 Pccora, W. T., 324, 327
 Pemba, 323
 Pérebaskine, V., 200, 201, 213, 275
 Permo-Trias, generalities, 25
 Pervinière, L., 27
 Petter, G., 114, 133
 Pfender, J., 125, 134
 Pharusian, 5, 89, 197
 Pires Soares, J. M., 182, 184, 220, 221
 Piveteau, J., 33, 34, 35, 75, 303, 358, 369
 Plateau, H., 46
 Pobeguinn, Th., 24, 217, 221
 Pointe-Noire, 272
 Pollett, J. D., 215, 221
 Polymorphic Sandstones, 288, 298
 Pondoland, 344
 Pons, A., 105

- Port-Etienne, 131
 Poueyto, A., 105, 112, 134
 Pougnet, 236, 237, 241
 Pre-Cambrian, generalities, 3
 Pre-Mayombe, 261
 Principe, 258
 Prunet, J., 226
 Pruvost, P., 10, 356
 Pulfrey, W., 327

 Quaternary, generalities, 68
 Quennell, A. M., 322, 327
 Quezel, P., 105
 Quimbriz, 302

 Radier, H., 78, 200, 203, 213
 Raulais, M., 207, 208, 213
 Real, F., 298, 303
 Reed, F. R. C., 368, 369
 Reguibat Swell, 120
 Relaidinian, 89
 Renaud, L., 122, 134, 175, 187
 Renault, Ph., 97, 105, 214
 Réunion, 366
 Reymont, R. A., 244, 248, 251, 260
 Reyre, D., 275
 Rhodesias, 329
 Riedel, L., 251, 260, 272
 Rift Valleys, 80, 324
 Ring complexes, 220, 243, 324
 Rio Muni, 249
 Riyadh, 172
 Robert, M., 282, 294
 Rocci, G., 121, 122, 134
 Roch, E., 36, 39, 42, 46, 74, 75, 112, 134, 250, 251, 260, 355, 370
 Rodriguez, 368
 Roger, J., 61, 67
 Rogers, A. W., 341, 350, 353
 Rokell Series, 6
 Roques, M., 175, 179, 180, 199, 214, 215, 221, 235, 237, 241
 Rouaix, S., 126
 Routhier, P., 216, 221
 Ruhuhu, 318
 Russo, L. and P., 36, 39
 Ruxton, B. P., 165, 169

 Sadek, H., 169
 Sagatsky, J., 222, 224, 226
 Sahara, central, 87
 — eastern, 135
 — western, 106
 Saint Helena, 259
 Saint-Ours, P. de, 365, 369
 Sakamena, 357
 Sakoa, 356
 Sander, R., 172, 174
 Sandford, K. S., 169
 São Thomé, 258
 Saoura, 112
 Saourian, 116
 Savornin, J., 36, 39, 103
 Schisto-calcaire, 264, 279
 Schisto-gréseux, 265, 279
 Schneegans, D., 204, 214, 269, 274
 Schoeller, H., 120, 134
 Schürmann, H. M. E., 152, 169
 Schwarz, E. H. L., 350, 353
 Sebakwian, 4, 329
 Senegal, 175
 Serdélès, 96
 Sérouénout Series, 90
 Seward, A. C., 350, 353
 Shadli Series, 152
 Shamwaian, 4, 329
 Sierra Leone, 215
 Silurian, generalities, 14
 Silva, G. H. da, 260
 Simandoux, G., 96, 103
 Simpson, A., 245, 248
 Simpson, E. S. W., 367, 370
 Sinai, 155
 Sinclair, H., 217
 Slansky, M., 238, 241
 Sluys, M., 30, 35, 285, 294
 Sokoto, 244
 Solignac, M., 43, 46, 60, 67
 Somalia, 304
 Sonder, R. A., 78
 Sornay, J., 176, 180, 302
 Soudan: see Mali
 Sougy, J., 121, 128, 132, 134, 189, 190, 200
 Soule de Lafont, D., 222, 224, 226
 Sousa Torres, A., 182, 184, 220, 221
 Spath, L. F., 244, 248, 300, 303, 321, 327, 337, 340, 351
 Stahlecker, R., 182, 184
 Stanleyville, 286
 Stchepinsky, V., 67
 Stefanini, G., 316
 Stockley, G. M., 318, 323, 327
 Stormberg, 348
 Stromatolites, 7
 Stromer, E., 154, 169, 238, 241, 249
 Sudan, 165
 Suggarian, 5, 88, 197

- Swaziland, 4, 34¹
 Swinton, W. E., 246, 248
- Table Mountain, 344
 Tademaït, 100
 Tagant, 186
 Takoradi, 232
 Tamesna, 206
 Tanganyika, 317
 Taoudéni, 81, 122, 124
 Tarkwaian, 6, 224, 228
 Tassilis, 13, 87, 90, 92
 Tattam, C. M., 248
 Tavani, G., 315
 Teale, E. O., 337, 339, 340
 Tectonic deformations, 76
 Tectonic troughs, 76
 Tegama, 204
 Teixeira C., 258, 260, 297, 303, 337, 340
 Tempère, C., 13, 24, 93, 105
 Tendaguru, 322
 Termier, H. and G., 12, 18, 21, 24, 26,
 27, 28, 40, 42, 46, 134, 282, 294,
 341, 353
 Tessier, F., 176, 179, 180, 189
 Thevenin, A., 369
 Thiès, 177
 Tibesti, 81, 136, 137
 Tidikelt, 94
 Tiguentourine 99
 Tilemsi, 200
 Tilho, J., 141, 209, 210, 214
 Timétrine, 89, 198
 Tindouf, 106, 109
 Tingher, 100
 Togblékové, 238
 Togo, 235
 Toummo, 136
 Transvaal, 6, 342
 Tripolitania, 142
 Tunisia, 25
 Twisselmann, Fr., 290, 294
 Tyrrell, G. W., 258, 260
- Ubangi, 272
 Uganda, 317
- Uitenhage, 351
 Umkondo, 336
 Upper Volta, 222
 Urvoy, Y., 193, 195, 196
- Valette, Dom. A., 28
 Van der Heide, S., 169
 Van Riet Löwe, C., 326, 327
 Vasconcelos, P., 296
 Vaufrey, R., 75
 Velain, C., 366, 370
 Villemur, J. R., 125, 132
 Vincent, E., 292, 294
 Vincent, P., 140, 141
 Vohibory, 355
 Voltaian, 229
- Wacrenier, P., 273, 276
 Wadi Azaouak, 206
 Wadi Fatima, 170
 Wagner, P. A., 334, 350, 353
 Walidiala, 217
 Walikale, 285
 Walker, F., 367, 369
 Walton, J., 331, 334, 335
 Wankie, 331
 Waterberg, 6, 343
 Waterlot, G., 24
 Watson, D. M. S., 32, 35, 347, 353
 Wayland, E., 69, 75
 Weiller, 255, 260
 White, E. I., 246, 248, 327
 Witteberg, 345
 Witwatersrand, 6, 341
- Yetti, 121
 Young, R. B., 342
- Zanzibar, 323
 Zarzaitine, 99
 Zemmour, 110
 Ziguinchor, 178
 Zimmermann, M., 190
 Zinder, 205
Zinjanthropus, 326

