Photo by] [*Dr. J. W. Arthur*

KENYA.

View from the Lewis Glacier showing the rounded glaciated contours beyond the lakes on Two Tarn Col in contrast to the rugged arete which stood above the ice.

THE RIFT VALLEYS AND GEOLOGY OF EAST AFRICA

AN ACCOUNT OF THE ORIGIN & HISTORY OF THE RIFT VALLEYS OF EAST AFRICA & THEIR RELATION TO THE CONTEMPORARY EARTH-MOVEMENTS WHICH TRANSFORMED THE GEOGRAPHY OF THE WORLD. WITH SOME ACCOUNT OF THE PREHISTORIC STONE IMPLEMENTS, SOILS, WATER SUPPLY, & MINERAL RESOURCES OF THE KENYA COLONY

BY

J. W. GREGORY, D.Sc., F.R.S.

PROFESSOR OF GEOLOGY IN THE UNIVERSITY OF GLASGOW

Author of "The Great Rift Valley," "Dead Heart of Australia," &c. &c. &c.

WITH APPENDICES ON THE EDIBLE EARTHS, SOILS, FOSSILS, ROCKS, & MASAI PLACE-NAMES BY PROF. E. P. CATHCART, F.R.S., PROF. R. A. BERRY, R. B. NEWTON, ESQ., MISS AGNES NEILSON, & A. C. HOLLES, ESQ., C.M.G.

WITH MANY MAPS & ILLUSTRATIONS

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Preface

THE contributions to the geography and geology of British East Africa in this volume were collected in 1892–3 and 1919. The conclusions based on the results of the expedition of 1892–3, were summarized in *The Great Rift Valley* (1896), but the series of papers intended to give the full evidence was not completed owing to pressure of other work. In 1919, on the invitation of H.E. General Sir E. Northey, I had the pleasure of a second visit to British East Africa, and then had the privilege of several journeys in company with Mr. Hobley, Mr. W. McGregor Ross, and Captain H. L. Sikes. The country, now Kenya Colony, has reached a stage in which geology can be very useful in the development of its water supply, soils, and mineral resources. I have therefore in this book given an account of the geological structure and history of the Colony, and in the hope of encouraging further research and study have shown the relation of its problems to those of the rest of East Africa.

Progress in East African geology requires a scheme by which new facts may be classified. The classification adopted is tentative and must be amended as well as amplified. Pioneer geology has to choose between the rashness of using imperfect evidence or the sterility of uncorrelated, unexplained facts.

A geological description of a new country is necessarily technical, but I have endeavoured by the addition of a glossary (pp. 412–17) and a table of geological horizons (p. 411) to render the main story intelligible to those interested in African geography and to those who, as residents and travellers in East Africa, can supply the needed further information. The descriptive chapters usually begin with reference to their special problem and end with a tabular summary of the correlation of the rocks considered.

One special interest in the geography of East Africa is the Great Rift Valley. A general statement of its problems is given in Chapter I. Chapters XXIII–XXXI describe its variations and course from Palestine to south of the Zambezi and show its continuity except for a possible gap in southern German East Africa. The last chapter summarizes the conclusions as to its origin and history, and considers its relation to the earth-movements that during the period of its formation were transforming the geography of the whole world.

The pleasure of a preface is in the memories it recalls. Amongst those to whom I owe hospitality and help are H.E. the Governor and Lady Northey at Nairobi, Captain Caldwell, Mr. and Mrs. Hobley at Mombasa, Mr. and Mrs. J. W. T. McClellan of Naivasha, Mr. and Mrs. Tyler Smith at Kisumu, Mr. and Mrs. McGregor Ross, Mr. A. L. Lawley, Captain F. O. B. Wilson, Mr. H. Stedman, and Mr. A. G. Bush.

For the photographs I am indebted to Mr. McGregor Ross, Dr. J. W. Arthur, Mr. J. D. Melhuish, and Mr. H. L. Sikes, who have generously given me leave to select from their valuable collections of East African photographs. I wish I could have used their kindness more freely. Mr. Blackburne-Maze has lent me the two illustrations of Kenya and of the trees of its alpine zone on Plate XI. The cost of the illustrations has been largely met by a generous grant from the Trustees of the Carnegie Trust. I am indebted to the Council of the Royal Geographical Society for loan of four illustrations (p. 16 and Plates II, XVI, and XVII) prepared for my paper in *The Geographical Journal*, January, 1920.

For scientific help I am indebted to Mr. C. W. Hobley, whose intimate knowledge of British East Africa has been most generously at my disposal; to Professor A. C. Seward for the examination of fossil plants ; to Mr. R. B. Newton for the great care he has devoted to the fossil mollusca ; to Mr. L. F. Spath whose description of the Cephalopods collected has settled the correlation of the limestones and shales of the coastal region ; to Professor R. A. Berry and Mr. D. N. McArthur for two analyses of the soils ; to Professor Cathcart for a report on the Cave Earth ; to Dr. G. T. Prior and Dr. F. Oswald for the loan of rock specimens from Kavirondo ; to Miss Neilson I am especially indebted for the appendix on the igneous rocks, the results of a laborious investigation in which Mr. G. W. Tyrrell, after his return to this country, helped with his great experience of the alkalic rocks.

Mr. A. C. Holles has kindly contributed a list (Appendix IX) of the correct spelling of the Masai place-names.

Geographical nomenclature in East Africa is unusually difficult; I decided at first to adopt the names and spellings used on the latest Government maps; but complete adherence to that policy would have continued obvious errors and misprints. Whenever a name has been fixed, however misspelt, by use for a railway station or a town, it seems advisable to accept it; but the simple plan of accepting priority on maps would perpetuate such accidents as calling Jombeni the John Bayne Mountains.

The names Kenya Colony for British East Africa and of Tanganyika Territory for the former German East Africa were not sufficiently well known when the work was prepared for use in the text (*cf.* p. 272).

In reference to the literature, special difficulty has been experienced with the German contributions during the war, and some important papers were only available just before the completion of the MS. (August, 1920).

This book will have failed in one chief purpose if it does not lead to the collection of further evidence as to the physical geography and geology of East Africa by those whose lot is cast in those most promising and pleasant of tropic lands.

J. W. GREGORY.

UNIVERSITY, GLASGOW.
January, 1921.

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List of Abbreviations

B.E.A. British East Africa.

G.E.A. German East Africa.

G.R.V. "The Great Rift Valley," by the author. Pub., J. Murray, 1896.

G.S., G.S. Geographical Section, General Staff. Used in reference to its maps.

Nos. in ( ) without initial are those of the collection of 1919 in the University Museum, Glasgow. Those after the letter G refer to the author's 1893 collection in the British Museum (Nat. Hist.).

U.R. Uganda Railway.

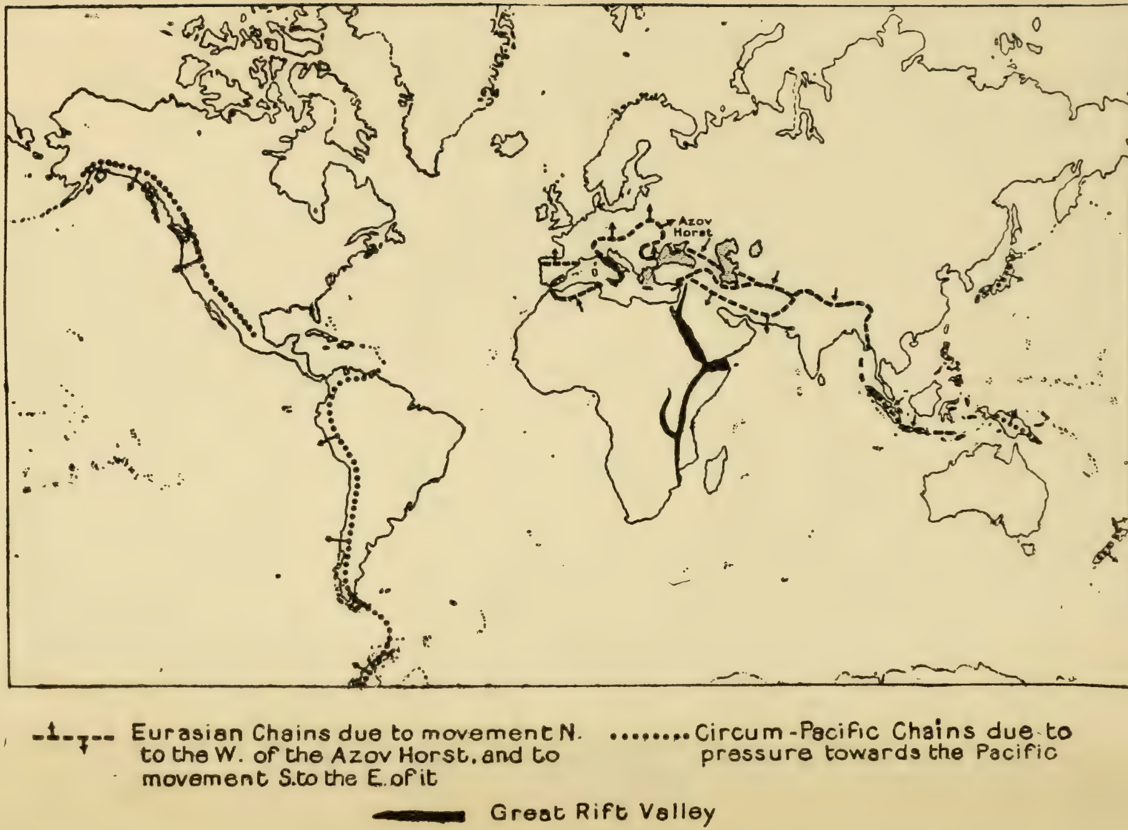
1 : 1m., etc.—1 to a million, etc.

$\frac{15}{6}$ used for distances along the U.R., etc.; the lower figure is distance in miles; the upper figure the number of telegraph poles (18 to the mile) from the last mile post.

References to authorities are given by the Author's name and date in the Bibliography, pp. 423–453.

As the text necessarily refers frequently to Geological dates the following table of the names most used is given for convenience of reference :—

Era.	*Period.*	*Representatives in B.E.A. include—*
Kainozoic	Pleistocene.	Raised coral reefs; alluvial flats glacial beds, etc.
	Pliocene	Naivashan
	Miocene	Laikipian
	Oligocene	Nyasan
	Eocene	Doinyan
Mesozoic	Cretaceous	Kapitian
	Jurassic	Shales, limestones and sandstones of coastlands
	Trias	Duruma sandstones (Trias and Permian)
Paleozoic	Permian	
	Carboniferous to Cambrian	No known representatives
Archeozoic	—	Karagwe Series
Eozoic	—	Gneisses, schists, etc.


Azov Horst
Eurasian Chains due to movement N. to the W. of the Azov Horst, and to movement S. to the E. of it
Circum-Pacific Chains due to pressure towards the Pacific
Great Rift Valley

The Rift Valleys & Geology of East Africa

PART I

CHAPTER I

The Discovery & Range of the Great Rift Valley

"THE natural boundaries of the geographer," said Hugh Miller,[1] "are rarely described by right lines; wherever these occur the geologist may look for something remarkable." Among the most conspicuous of such geographical boundaries are the parallel shores of the Red Sea, whose features early suggested their origin by fracturing of the earth's crust. The northern continuation of the Red Sea trough lies along the Dead Sea and the Jordan; and the exceptional nature of this valley was realized when the Dead Sea was found to be 1293 ft. below sea-level—the lowest land surface[2] on the earth—while its floor is another 1300 ft. deeper still. The Dead Sea and Jordan lie in a valley, so narrow, straight, and steep-sided that Leopold von Buch (in Robinson, 1841, II, p. 673) described it as a crevasse in the earth's crust. The Very Reverend Principal Sir George Adam Smith (1897, p. 468) exclaims of this formation: "There may be something on the surface of another planet to match the Jordan Valley; there is nothing on this."

The trough-shaped basin of the Red Sea is also continued southward through Eastern Africa in long fiord-like lakes, lying in steep, parallel-walled valleys, which in form resemble fiord valleys. That these fiord-like lakes and valleys were made by earth movements, and were not worn out by rivers, was recognized by some of the great African pioneers, including Burton and Stanley. Thus Burton, the first geographer to see one of the African fiord-like lakes, aptly expresses the difference between them and the Victoria Nyanza by remarking of Tanganyika (Burton, 1860, II, p. 137) : " The general formation suggests, as in the case of the Dead Sea, the idea of a volcano of depression—not like the Nyanza or Ukerewe [i.e. the Victoria Nyanza] a vast reservoir formed by the drainage of the mountains."

The extension of the Red Sea fractures into Africa was recognized by the French geologist, H. Douvillé (1886, p. 240). He attributed the abruptness of the eastern front of Abyssinia to the same fractures as those that had made the Red Sea and Jordan Valley ; and he suggested that this fracture-line is continued southward across " the Eastern Horn of Africa," and along the coast from Mombasa to Mozambique. He claimed it, therefore, as " one of the most important ' accidents ' on the surface of the earth." Douvillé, however, was not quite on the right track ; for Teleki's discovery of Lake Rudolf linked the Red Sea fractures not with the coast, but with the lake chain in the interior.

In 1891, after the discovery of Lake Rudolf, Suess made this fact clear. He showed that the extension of the Jordan–Red Sea fracture skirts the eastern face of Abyssinia, follows the Hawash Valley between the plateaus of Abyssinia and of Somaliland, continues S.E. enclosing the lake chain of S.E. Abyssinia, crosses B.E.A. to Lake Manyara, and then, after a gap, is resumed by the trough-shaped basin of Lake Nyasa and extends through the Shire Valley as far S. as the Zambezi. The basins of Lakes Tanganyika, Kivu, and the Albert Nyanza Suess regarded as occurring along a similar fracture to the W.

That these valleys were made by the sinking of the material that once filled them, between parallel fractures of the kind known as faults, is now generally accepted. They were not formed by the removal grain by grain, by rivers or wind, of the rocks which originally occupied them, but by the rock sinking in mass, while the adjacent land remained stationary ; what is now the floor of the valley formerly stood level with the highlands on each side. For this type of valley I suggested the name of Rift Valley, using the term " rift " in the sense of a relatively narrow space due to subsidence between parallel fractures. Such valleys are known in many parts of the world, but that of East Africa may justly be called the Great Rift Valley, as it extends from Northern Palestine to Southern Africa.

The Great Rift Valley begins to the N. in Palestine, where its formation by faults has been clearly shown. A section by Prof. Hull (1886, p. 106) represents Mount Hor as a mass of granite, capped by limestones which also lie at its foot, where they have been dropped by a fault with a downthrow of at least 5000 ft. According to sections by Blanckenhorn (1914, pp. 88, 97) the Jordan Valley and Dead Sea lie in a trench left by a strip of the limestones having sunk between faults with a drop of 4500 ft. into the older rocks, which are exposed in places on the walls.

From the Dead Sea the Rift Valley continues southward, over a divide at the height of 660 ft., into the Arabah Valley and the Gulf of Akabah, between the plateaus of Sinai and Edom. The fiord-like character of the Gulf of Akabah was remarked by Prof. Bonney (1873, p. 395). This cleft is described as a rift valley by Dr. Hume (1901, pp. 198–199), Director of the Geological Survey of Egypt, who has shown, moreover, that parallel to it in Sinai are five other rift valleys. In Sinai the N.–S. movements along the Rift Valley have been crossed by E.–W. movements, which have had a conspicuous influence in Egypt. The intersection of these different movements has produced the rectangular branching which gives the valley system of Eastern Sinai its fiord-like plan (Gregory, 1913, p. 227).

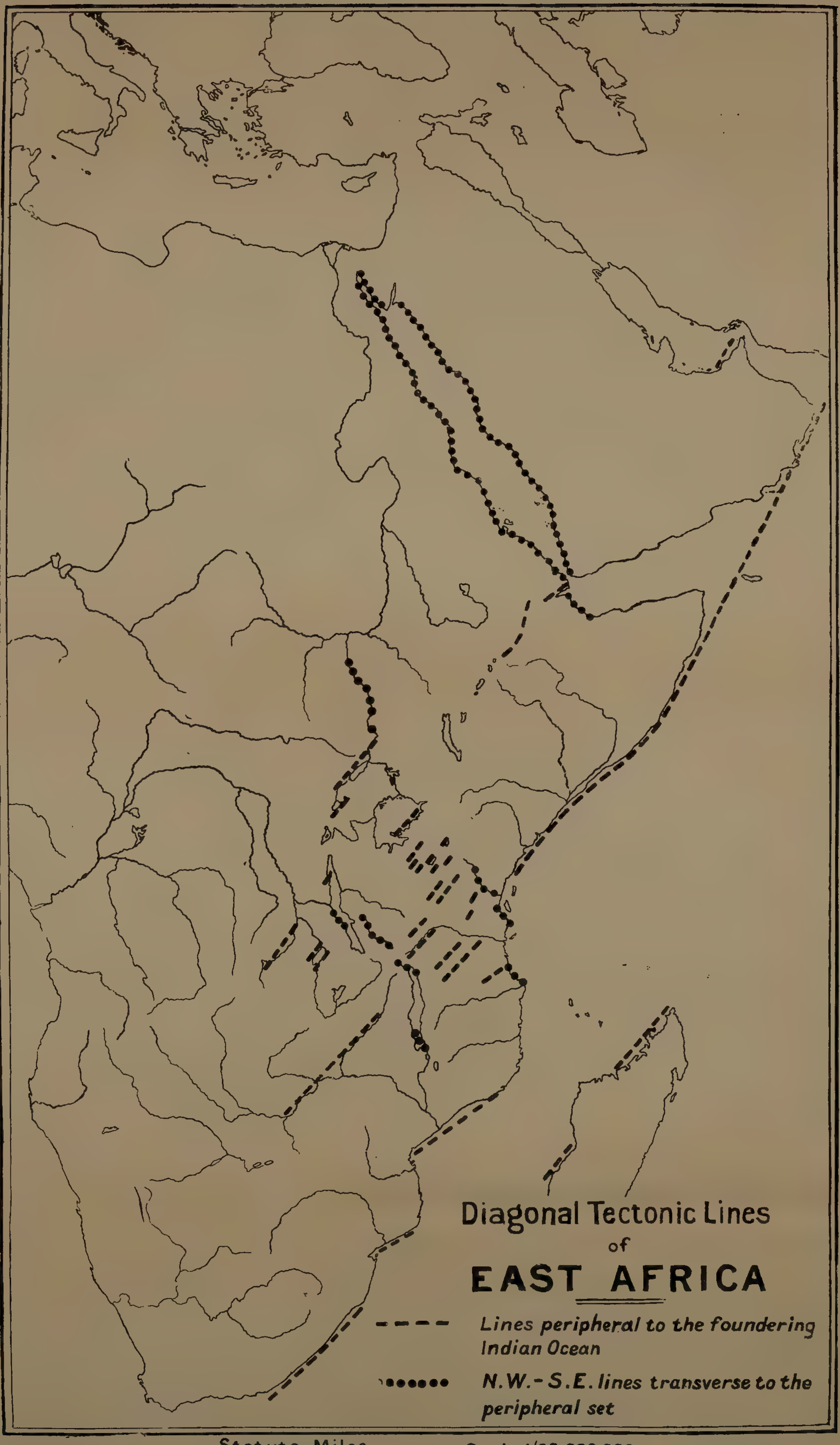
The Gulf of Suez is probably of the same origin, but the evidence is less clear, for the Gulf of Suez is older than the Gulf of Akabah and is the direct continuation of the trough of the Red Sea; it disappears beneath the alluvium of Northern Egypt, and the farther prolongation of its faults have sunk beneath the Levant. The main trough of the Red Sea is much older than the basin of the Dead Sea, and was clearly formed by the subsidence of its floor at different dates. Thus, according to Mr. Cyril Crossland (1913, pp. 122, 155), the Red Sea lies in a rift valley of most pronounced character, and was formed by repeated faults with a total downthrow of 11,000 ft.; while the narrow harbours or "Khors" at the southern end are secondary side cracks. The Red Sea narrows to its outlet through the Straits of Bab-el-Mandeb, but the Red Sea trough maintains its full width, as its western wall, the face of the Abyssinia Plateau, continues parallel to the Arabian and not to the African shore. Between Abyssinia and the sea lie the desert plains of Afar, which enclose lakes lying deep below sea-level. These plains are the northern entrance to the African portion of the Great Rift Valley. South of Afar, the valley of the Hawash runs southward through an area of former vigorous volcanic activity.

The walls of this part of the Rift Valley are irregular ; but these irregularities occur where the lines that bound the sunkland of the Gulf of Aden intersect the Rift Valley. Except at these positions the walls are scarp-like ; their continuity and the trench-like form of the valley—in spite of two breaks at cross-fractures—is clearly shown on Bottego's early map and, amongst later authorities, on the War Office Map of Abyssinia (1 to 3 m., 1908) ; the abrupt edges of the plateaus on each side and the precipitous nature of the walls are described by many travellers.

Across B.E.A. the Rift Valley continues as a vast trench. The abruptness of its walls may be realized by its impression on travellers such as Sir Frederick Treves (1910, pp. 113, 116), who describes it as " a gigantic moat," than which " no scene in the world is so novel and unexpected," and as Sir John Bland-Sutton, who describes its sides " as steep and abrupt as those of a grave " (1911, p. 227).

The walls naturally vary in accordance with the structure of the adjacent plateaus. They are sometimes so abrupt that where the Uganda Railway reaches the eastern wall the trains were formerly run up and down an incline by a cable and fixed engine. There was in 1919 still no road for wheeled traffic between Nairobi and the floor of the Rift Valley ! The plateaus in places project as great bastions, and elsewhere the valley invades them in wide bays. On the bastions the rocks have been broken into tilted blocks by successive faults, as shown by Captain Sikes' photograph of the northern face of the Cathedral Bastion, where the plateau descends to the valley in six steps, each of which is tilted between its bounding faults (in Gregory, 1919, Fig. 1).

The floor of the valley often consists of porous volcanic rocks, and permanent water is scarce ; but the drainage from the cliffs feeds occasional water-holes. Numerous faults have broken the floor into secondary rift valleys, which are especially well developed S.W. of the extinct volcano of Suswa. The scarps of these secondary valleys consist of bedded lavas and volcanic ashes. Some of the volcanos from which these rocks were discharged are old and very denuded, but some of the eruptions must have been recent ; the magnificent volcanic caldron of Menengai is obviously modern, and Mount Longonot has a steam vent still discharging in its well-preserved crater. Behind the dam formed by its lava lies Lake Naivasha, the highest in the Rift Valley. That lake has no visible outlet, and, as its waters are fresh, it probably has a subterranean outlet southward



By Permission of The Royal Geographical Society

Statute Miles 0 500 1000 Scale 1/60.000.000

where the valley descends till it is 5000 ft. lower at Lake Magadi. There the evaporation of alkaline water has accumulated great deposits of soda, which are worked by the Lake Magadi Soda Company. The lake itself lies in a down-faulted trough; above its floor rise island-like block-mountains which have been left upstanding.

At Lake Magadi the Rift Valley is unsymmetrical; the western wall is the lofty Nguruman Scarp, while the eastern side rises by a series of wide platforms, separated by low steps, up which the Magadi railway climbs on to the Kapiti Plains. South of the British frontier this asymmetry is still more developed; the eastern wall beside Lake Manyara is a gentle slope, and Uhlig (1908, p. 91) claims that the Rift Valley has disappeared and been replaced by a single fault-step, which separates the plains of Masailand from the highlands of the Giant Caldron Mountains. This condition, however, represents only a further development of the Lake Magadi structure, in which the eastern scarps have been dressed down to an even slope; for, though faults occur there, they have been worn down so that they have no direct effect upon the surface features.

This scarpless eastern slope does not extend far. South of Lake Manyara the eastern wall reappears, and a well-defined rift valley continues southward to Kilimatinde on the railway from Dar-es-Salaam to Lake Tanganyika.

The characteristic feature of the Rift Valley in German East Africa is its repeated deflection to the S.W. Two important branches break off in that direction, forming the Lake Eyasi and Hohenlohe rift valleys, both of which end in the granite uplands south of the Victoria Nyanza. The southward course of the main valley is zig-zag, owing to the apparent conflict between its own tendency to continue due southward and some influence periodically jerking it to the S.W. (Pl. II). This south-westward deflection is doubtless due to the valley crossing the belt of Africa where the dominant geographical lines are diagonal. The major set of diagonal lines runs from N.E. to S.W.; they are dominant in the band bounded to the N.W. by the line along the southern coast of Arabia, the Albert Nyanza, and the rift valleys of the Eastern Congo, and to the S.E. by the tectonic lines in Madagascar and South Africa, where a comparatively young fault has cut off the south-eastern corner of the continent. The Rift Valley in Central G.E.A. traverses the middle of this band and shows its influence in the repeated deflection south-westward.

Suess accepted a break in the Rift Valley in this area of 350 miles between Lakes Manyara and Nyasa, and according to some authorities the Nyasa Basin has no connection with the Great Rift Valley. The gap left by Suess has been greatly reduced at both ends, and now only a short break of about 60 miles, between Kilimatinde and the Ruaha Valley, separates the well-defined parts of the Rift Valley. The Rift Valley movements may have been continued across this gap, as held by Krenkel (1910, p. 224), by simple faults, and not as trough faults; but some tectonic continuation across it is highly probable.

Further S. the Rift Valley is again unmistakable; for Lake Nyasa has been shown to be due to the subsidence of its floor between faults by Andrews and Bailey (1910). At its northern end the Nyasa Valley is joined by a branch from the N.W., which encloses Lake Rukwa and connects, through a breach in the eastern rim of Tanganyika, with the Western or Central African branch of the Rift Valley. In this branch lies Lake Tanganyika, the largest of the Rift Valley lakes and the second deepest lake in the world, it being 4190 ft. deep, and its floor lying 1664 ft. below sea-level. From Tanganyika this western branch of the Rift Valley continues northward through one of the most striking sections of the Rift Valley System. It leads past Lake Kivu, the Edward Nyanza, and the Albert Nyanza to the Nile. The north-western wall is so abrupt that Colonel Jack (1914, pp. 85, 134), who describes the valley as "a big rift," points out that the watershed between the Nile and the Congo is so close to the Albert Nyanza that its adoption as the frontier between the British and Belgian territories, instead of giving us, as was expected, a valuable strip of territory, gave us "a strip not a mile wide of rough, rocky ground falling sheer into the lake."

That the western branch of the Rift Valley cuts like a trench through the highlands is shown, for example, in the map by Wichmann (1911, Pl. 46). The structure, however, is rendered locally irregular by two causes. The floor and the walls have been buried by the eruptions that built up the chain of still vigorous volcanos, which Speke described as "sky-scraping cones," and which agree in important respects with Ptolemy's "Mountains of the Moon." The chief irregularity in this part of the Rift Valley is due to projecting spurs and to branches which overlap with the main valley. The Rukwa Rift Valley overlaps Southern Tanganyika; the two breaches in the western rim of Tanganyika occur in line with the two rift valleys of the Eastern Congo; the Ubwari Peninsula breaks the even shore of the lake, similar to the projecting spur at Lake Kivu and to that south of the Edward Nyanza which forms the western boundary of Sir Alfred Sharpe's Pass.

It is also significant that the valley which encloses Lake George continues the line of the main valley, but as a short blind branch. These irregularities are the result of the valley breaking across the grain of the country ; and as in a fractured plank of grained wood the cracks follow the grain or send off side cracks along it, so the Western Rift Valley gives off branches which follow the grain till they die out in the mountains.

A similar deflection from the north-eastern end of the Albert Nyanza forms the valley of the White Nile, which Dr. Holmes and the late Captain Stigand have shown to be a well-marked rift valley ; but whether the western branch has any continuation north-eastward to Lake Rudolf is doubtful.

Returning now to Lake Nyasa, the Rift Valley continues thence southward along the Shire Valley, and the recent work by Teale and Wilson has shown that between the Sheringoma Plateau and the eastern front of Rhodesia is a rift valley of the same age as that of the Red Sea. This valley, at its southern end, passes south-westward across the Sabi River, and the long, straight coast from Sofala to Cape Corrientes may have been determined by the southernmost movements of the Rift Valley series.

The Great Rift Valley, therefore, extends from Lebanon to the Sabi River, and its branches reach eastward to the mouth of the Gulf of Aden, and westward beyond Tanganyika to the rift valleys of the Central Congo. It is no local fracture, as its length is more than one-sixth of the circumference of the earth. It must have had a deep-seated, world-wide cause, the first promising clue to which is its date of formation.

There are alternative views as to the age of the Rift Valley According to the first, adopted by Suess, its history is geologically short, and this view commends itself on first inspection of the valley, as its walls are often as fresh as comparatively recent sea cliffs. Local legends from many parts of it support this supposition by reporting catastrophic movements within the time of man, such as the destruction of Sodom and Gomorrah, or the drowning of many villages at the formation of Lake Tanganyika.

Geological evidence is conclusive that some of the Rift Valley faults are, geologically speaking, quite modern. Such evidence was clear in 1893; but still stronger evidence forced me to the view that the Rift Valley has had a long and complex history. I accordingly suggested a classification (G.R.V., p. 235) which represented some of its lavas as discharged during the time of the Chalk, and some of its faults as older than the elevation of the Alps. The fuller evidence now available seems fully to confirm the classification then adopted. For example, it was concluded from physiographic evidence that some of the lake deposits in B.E.A. were of Miocene age. There was no fossil evidence; but specimens obtained by Mr. Hobley and Dr. Oswald have since proved the extension of these lake beds in Kavirondo to be Miocene. There is clear evidence at many parts of the Rift Valley—as in Palestine, Egypt, Somaliland, and south of the Zambezi—that its formation began later than the Upper Eocene; and that it started very shortly after that date is indicated by a fossil sea-urchin from Lake Nyasa. The southern end of the Rift Valley is doubtless, like the Red Sea, of Oligocene age.

The first stage in the development of the Rift Valley was the formation of a low, broad arch trending north and south. Then the weakening of the supports led to the collapse of the keystones along the top of this arch by the first series of Rift Valley faults. That the Rift Valley cuts across the highest ground along its course is shown on the map illustrating the paper by General Smuts (1918, opp. p. 192) and by the orographic map of B.E.A. prepared at the Public Works Department by Mr. McGregor Ross. The sinking of the keystone of the East African arch forced the plastic rock material below up the adjacent cracks, and it was discharged in volcanic eruptions. Each series of subsidences was followed by further eruptions.

The dates of these events may be inferred from the relations of East Africa to the Arabian Sea, for which it is necessary to go back to the time when East Africa and India were included in a continent which extended from Brazil to Australia. When this continent, Gondwanaland, began to break up, the sea invaded the coastlands of India and of East Africa. The movements were at first gentle and undisturbed by volcanic eruptions, but later on the foundering of the floor of the Indian Ocean between East Africa and India led to volcanic outbreaks on a colossal scale. The lavas discharged by these eruptions, known as the "Deccan Traps," cover about a quarter of a million square miles in India, and perhaps an equal area is buried under the Indian Ocean. As the formation of the Arabian Sea led to such violent volcanic activity in India, eruptions might naturally be expected on the other sides of the foundered land ; and the widespread lavas beside the Persian Gulf, in Southern Arabia, and in Abyssinia are generally regarded as belonging to the same epoch as the Deccan Traps.

The volcanic history of B.E.A. probably began at about the same date with the discharge of the soda-rich lavas of the Kapiti Plains.

The determination of geological dates in East Africa is attended by the difficulty that there are no marine rocks in the interior ; and though fossils may be expected in the beds associated with the volcanic rocks, very few have yet been discovered. Hence the geological history of B.E.A. is dependent upon the character of the rocks and the succession of volcanic eruptions and earth movements. The following chapters on the geology of B.E.A. will, it is hoped, show that from these materials may be learnt the general geological history of the country and of its most remarkable feature, the Great Rift Valley.

[1] Miller, *Old Red Sandstone*, 1847 edit., p. 137 ; first edit., 1841.

[2] The discovery was made by Moore and Beek in March, 1837, who announced that the Dead Sea " appears to be considerably lower than the ocean " (*Journ. R. Geog. Soc.*, 1837, p. 456). Various early measurements have been recorded by E. Robinson (1848, pp. 77–79).

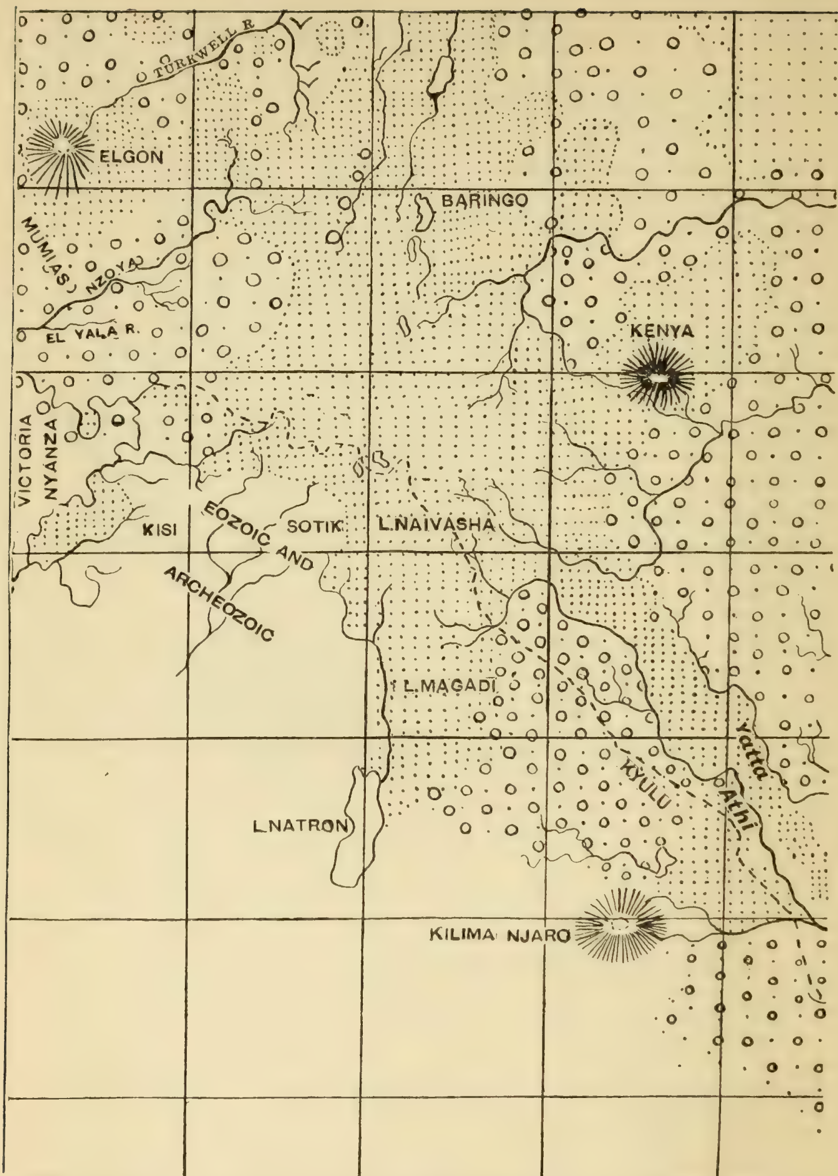
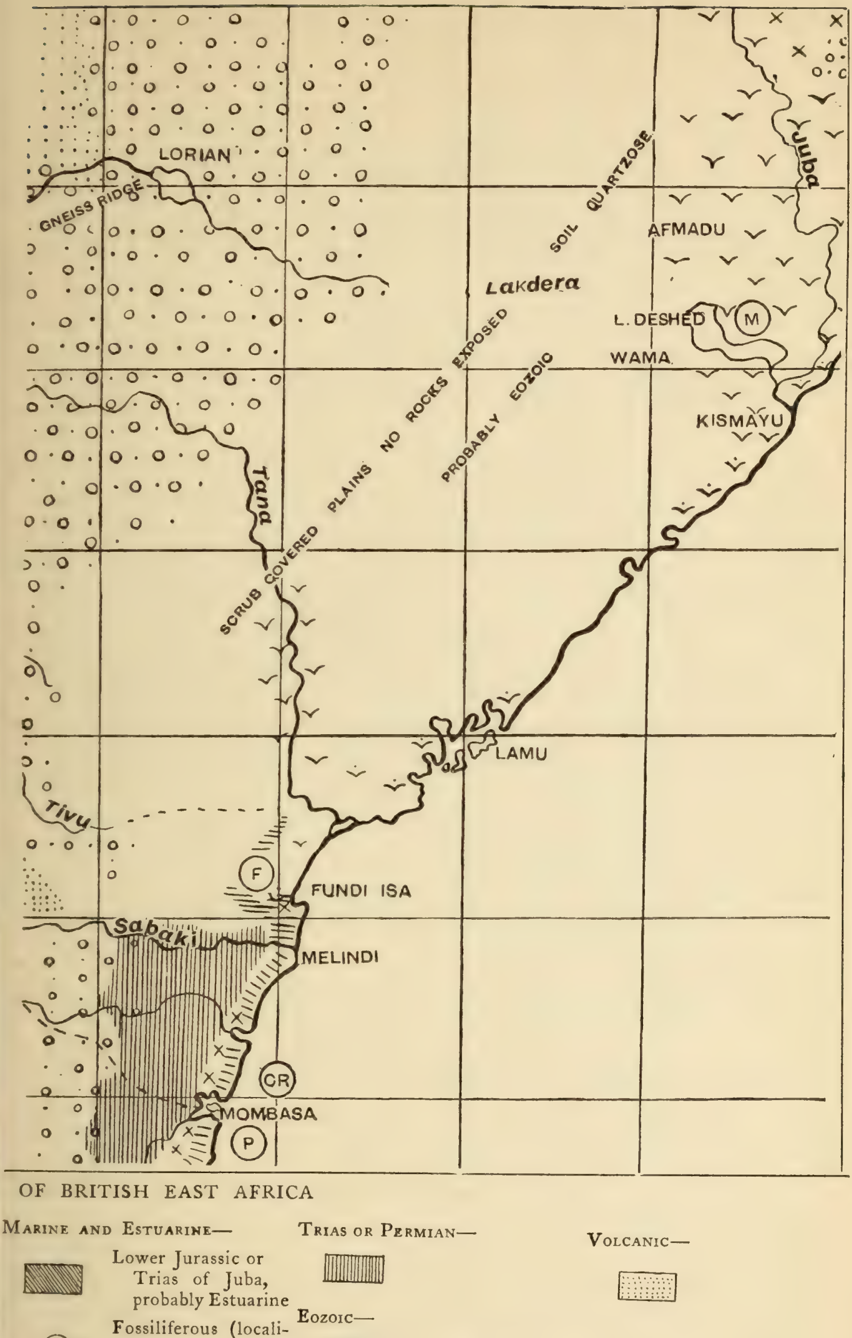


FIG. 1.—GEOLOGICAL SKETCH MAP

PLEISTOCENE—
Alluvium
Dunes and Raised Reefs

PLIOCENE—
(P) Mombasa Crags
Magarini Sand

MARINE AND ESTUARINE—
(M) Miocene
(CR) Cretaceous
Jurassic



OF BRITISH EAST AFRICA

MARINE AND ESTUARINE—

Lower Jurassic or Trias of Juba, probably Estuarine

(F) Fossiliferous (localities west of Fundi Isa)

TRIAS OR PERMIAN—

EOZOIC—

Gneiss, Schist, etc.

VOLCANIC—

PART II

The Geology of British East Africa

CHAPTER II

The Eozoic Geology of British East Africa

THE earth's crust—the lithosphere—consists of three layers or shells composed respectively of sedimentary, metamorphic, and deep-seated igneous rocks. The outermost shell is incomplete ; it consists of sedimentary rocks, such as sandstones, clays, and limestones, and of volcanic rocks. The middle shell consists of rocks which were probably mainly sedimentary in origin, but have been completely altered by heat and pressure ; they are therefore known as metamorphic rocks, of which the chief kinds are schist, gneiss, quartzite, and crystalline limestone. This shell is almost continuous around the world. The only gaps are where invasions of molten rock have forced their way through it from below. The third shell consists of deep-seated (" plutonic ") igneous rocks, such as granite and diorite ; they are not arranged in layers, and were clearly once molten. This shell is, no doubt, complete around the earth. It forms the main thickness of the lithosphere, and everywhere rests upon the metallic sphere, or " barysphere," which forms the bulk of the earth.

The rocks of the middle shell are the oldest known to Geology, as most, if not all, of those below it have been molten in times later than the formation of this shell of gneiss and schist.

I. The Nomenclature of the Oldest Rocks

The names for the pre-Paleozoic systems are confused and there is no general agreement regarding them. The upper part contains obscure relics of the life of the time as well as abundant indirect evidence of it. The organisms then living were all of very primitive archaic types. Therefore, in analogy with the names Paleozoic, Mesozoic, and Kainozoic for the groups characterized respectively by ancient, middle, and recent life, Archeozoic is appropriate for the group deposited while the earth was inhabited only by archaic life. The term was proposed in 1872 by Dana for those pre-Paleozoic rocks in which he expected fossils to be ultimately found.[1]

These Archeozoic sediments are limited below by one of the greatest breaks in the geological record. Below that break (the Eparchean interval) all the rocks are crystalline and there is no direct evidence of life. Seams of graphite and bands of limestone occur, and they may have been due to living agents, but they may have been formed by chemical processes. The rocks of this group were laid down as stratified deposits, either before the appearance of life on the earth, or at its very dawn. This group is therefore known either as the Azoic or Eozoic, i.e. either without life or belonging to the time of the dawn of life. The indirect evidence that life probably existed then renders the name Eozoic the most suitable for this earliest of geological divisions.

It is convenient to adopt distinctive names in different parts of the world for the local representatives of both the Eozoic and Archeozoic groups, since their correlation is uncertain. The Archeozoic group includes the Torridonian in the British Isles, the Keweenawan in North America, the Purana in India, the Karagwe series in B.E.A., etc. The Eozoic group includes the Swazi System in South Africa, the Kewatin in North America, the Dalradian and Lewisian in Scotland, and the Dharwar System in India. A typical series of Eozoic rocks in B.E.A. has been called by Mr. J. Parkinson (1914, p. 534) the Turoka Series, and this term may be conveniently used for the altered sedimentary rocks in B.E.A. which belong to the Eozoic Group.

The crystalline Eozoic rocks are not always sharply marked off either from the sedimentary rocks above or from the igneous plutonic rocks below. They were, therefore, called the "transition series." Their typical rocks are schists and gneiss, in which the crystalline constituents are arranged in thin layers or folia. They are therefore described as "foliated." The rocks as a whole are stratified; sheets of schistose quartzites representing altered sandstones are interbedded with schists formed from altered clay, and with bands of marble which are altered limestone. The metamorphic rocks have been the subject of one of the most famous of geological controversies. According to one school, these rocks had all been altered into their present foliated condition before the beginning of Paleozoic time;

according to another school, the zone of schists includes rocks of Archeozoic, Paleozoic, and even later ages, which have been so altered and mixed that their original date cannot be determined. There is no doubt that schist may be formed at any part of geological time ; but the bulk of the evidence supports the view that the great Eozoic zone of gneiss and schist had been formed before the beginning of the Archeozoic Era ; for in many parts of the world the oldest members of the Archeozoic and Paleozoic Groups were deposited upon worn surfaces of Eozoic rocks, whose metamorphism was already complete.

B.E.A. yields no important evidence upon this controversy, since its oldest known fossiliferous rocks belong to the Carboniferous Period ; it affords no direct evidence that the crystalline rocks may not belong to the Lower Paleozoic. But by analogy with parts of the world where the metamorphic rocks are pre-Paleozoic it is probable that the crystalline schists and gneiss of East Africa had been altered into their crystalline condition in pre-Archeozoic times.

The study of these rocks is of interest, as they form the foundation of almost the whole of Africa and are exposed on the surface over a large portion of the continent. They, moreover, are often rich in valuable mineral deposits, and the main mineral wealth of Africa, except its coal and phosphate, comes from the Eozoic and Archeozoic rocks.

II. The Eozoic Rocks of British East Africa

Gneiss and schist constitute the foundation of all B.E.A. and occupy the largest part of the surface. They once extended beyond their present eastern limits, as the coastal sandstones are largely made up of grains derived from the Eozoic rocks ; and a remarkable limestone, beside the landing stage at Kilindini on Mombasa Island (Gregory, 1900, p. 227), is full of fragments of garnet, microcline and other felspars, tourmaline, quartz, epidote, etc., obtained from the same source.

The Character of the Eozoic Rocks.—The Eozoic rocks of Equatorial Africa have in recent years been studied in detail, as by Grosse for Eastern Katanga (1918, pp. 280–300) and by Dr. A. Holmes for Mozambique (1919). Those of B.E.A. are normal members of the Eozoic Group. The characteristic rock is a gneiss composed mainly of microcline and quartz ; it is associated with a gneiss containing the dark mica, biotite, and sometimes the white mica, muscovite.

Sometimes hornblende is abundant, and when it is the predominant constituent the rock is a schistose amphibolite. The gneiss is often cut through by veins of pegmatite, with which occurs the mica of the Ulu Mountains. Tourmaline is often present near pegmatite veins. The gneisses rich in mica and amphibolites are probably altered igneous rocks. The banded amphibolites are altered basic dykes. The gneiss is also traversed by granitic veins. The presence of rocks of the Charnockite Series is shown by the description of G. Rose (1863) of a hypersthene-labradorite rock collected at Taveta by Baron von der Decken. Some of the Eozoic rocks, such as the Turoka Series of Mr. Parkinson (1913, p. 534), are altered sediments. They include beds of granulitic quartzite, which is a metamorphic sandstone, as in the upper Nguruman Scarp, W. of Lake Magadi, crystalline limestones, like the dolomites near Machakos, the limestone flags of Kilima Kiu, and the graphitic schists of the Taita Mountains. Among the altered sediments is kyanite-schist, found in the Ulu Mountains, and recorded from Kajiado by Parkinson (1914, p. 537). One of the most beautiful of the Eozoic rocks is a garnet-granulite, found on the Sabaki, and by Mr. Hobley on the Tana, W. of Hameye. A garnet schist allied to kinzigite—an altered sedimentary rock in the Black Forest—has been described by Parkinson (1914, p. 538).

The Sabaki Section.—The variations of the gneiss are well shown along the Sabaki E. of Tsavo. Most of the gneiss along the Sabaki is the typical quartz-microcline gneiss. The strike varies within a few degrees of N. and S. It is due N. a little E. of Tsavo ; N. ½ W. just W. of the sharp bend of the Sabaki at 38° 46′ E. ; it is N.N.E. at 39° 18′ E., that is, S.E. by S. from Loga Hill. The foliation is often regular ; but the gneiss is very contorted in places, as near Tsavo. Some bands are so rich in granular quartz as to suggest that some of the rock is a foliated quartzite. Igneous intrusions in the gneiss are numerous. These include veins of granite and of pegmatite, the latter of which are especially frequent at the western end of the section at Tsavo and near the easternmost outcrop of the gneiss.

An especially instructive exposure of the gneiss is at Lugard's Falls, where several acres of bare rock, composed of successive bands of hornblendic-gneiss, basic granulite, and amphibolite, are traversed by veins of granite and banded quartz. The gneiss is composed of three constituents. The oldest is a hornblendic-granulite, containing biotite and sahlite ; amphibole is sometimes the chief constituent, and the rock is then an amphibolite and often contains garnet.

The amphibolite occurs in lines of rounded blocks, of which the arrangement suggests that they were formed by the breaking up and alteration of basic dykes. After the intrusion of such dykes the rock must have been subjected to intense pressure from E. or W. ; the dykes were altered into granulite and broken into blocks, around which the gneiss was forced to flow and acquired a foliation along the lines of flow. Subsequently a series of granite veins from 3 in. to 2 ft. in width was injected into the gneiss ; these veins usually run along the foliation, but they often cut across it and send off small branches along it. Finally, a series of banded quartz-veins were deposited along fractures through the rock.

A garnet-granulite occurs at intervals along the Sabaki from Tsavo to about 6 miles W. of the Second Stockade. Dr. Prior (1903, p. 230) has described the microscopic character of this rock from Lugard's Falls and of a specimen collected by Mr. Hobley from W. of Hameye on the Tana. Prior regards the garnets as secondary and formed from hornblende, in agreement with the view of Sir Thomas Holland,[2] as to the origin of the garnets in the granulites of Southern India.

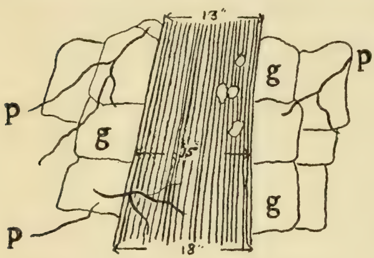


Fig. 2.—Foliated amphibolite dyke in gneiss, both penetrated by later pegmatite veins. Thika Valley. (Widths in inches). g = gneiss, p = pegmatite.

The Gneiss of the Thika-thika.—The Eozoic rocks of the upper Tana are well displayed along its southern tributary, the Thika-thika. The gneiss there is often hornblendic and contains bands of amphibolite which resemble dykes as they cut across the structural lines in the gneiss, and have a banding, probably due to original differences in structure during consolidation. Their intrusive origin is certain in one case, where an amphibolite dyke, 13 inches wide, includes fragments of the adjacent gneiss ; both the gneiss and the amphibolite are cut through by veins of pegmatite. This section (Fig. 2) shows that the intrusion of the amphibolite was followed by that of pegmatite. S. of this exposure the trend of the foliation suddenly alters to W.N.W.–E.S.E., and the gneiss forms Voroni—the northernmost of the transverse ridges of the Ulu Mountains. This Voroni gneiss is of igneous origin, as its structure is often granitic and it includes large porphyritic felspars, around which the lines of mica or hornblende pass in curving stream-lines. The gneiss also includes many lenticular masses and pebbles of hornblende-schist.

Voroni rises into a series of peaks, each capped by tors, which looked like remnants of a layer of hard stratified rock resting on rounded bosses of gneiss. This appearance is due to weathering, and the ridge is gradually worn lower by the gneiss breaking up into loose blocks. The eastern face of these tors is often deeply pitted by wind erosion. Voroni is an intrusion of granitic gneiss into an older finer-grained gneiss, probably along one of the cross-fractures which determined the geographical lines of the Ulu Mountains. S. of Voroni, beyond a band of spheroidally weathering gneiss, the rock is finer-grained and more regularly foliated, and the strike is N.N.W. This gneiss is well shown at the lower falls of the Thika-thika, the picturesque effect of which is due to the breaking of the water in its rush down steeply tilted slabs of gneiss.

The Eozoic rocks form a continuous belt of country behind the East African coast. On the Abyssinian frontier the gneiss is about 80 miles wide (exclusive of outcrops further W.), from the Buri escarpment, near Moyale, to the E. of the hills of Kurdisha, W. of the Juba. The eastern margin goes southward past Mandera, near the meridian of 40°. According to Mr. Deck, gneiss forms the high ground on the northern side of the Lorian swamp and a long ridge to the S.W. of it, ending at about 39½° E. Thence it continues southward to the Tana River, near Hameye. S. of that river the gneiss disappears to the E., about the meridian of 39°, beneath the plains of the Tana alluvium, which, judging from their soils, are underlain either by gneiss or the Duruma Sandstone. Peters marked on his map (1891), E. of the Tana bend, ranges which he called the Galla and Friedrich Franz Mountains. Doubt has been thrown on their existence, so they are probably unimportant. Hills in this neighbourhood were crossed by C.W. Haywood (1913, p. 465), but he gives no information as to their structure.

Southward on the Sabaki the gneiss disappears under Permian Sandstone, 2 miles W. of the "Second Stockade." Thence, the boundary between the gneiss and the Duruma Sandstone crosses the plains beside the Voi River to the Uganda Railway, just W. of Mackinnon Road Station; it continues, E. of Kilibasi, to the southern frontier.

The western boundary of the Eozoic belt is formed by the volcanic rocks beside the Rift Valley. In the remote N. the boundary has been approximately determined by various travellers, and notably by Mr. J. Parkinson; most of the country E. of the southern part of Lake Rudolf is volcanic, including the extinct volcano of Marsabit, and extending to the meridian of 39°. Further S. the volcanic belt suddenly narrows as the gneiss extends westward to the meridian of 37° in the Sugota Valley and the hill known to the Masai as Ol Barta—the horse. This gneiss outcrop is again restricted by the extension of the volcanic rocks south-eastward till they end at or beside the plateau of Siria, or Marti, on the northern bank of the Guaso Nyiro. The gneiss boundary is deflected eastward by the volcanic plateaus of Loroki and Laikipia; but the gneiss was found by von Höhnel along the upper Guaso Nyiro, and it forms the Lol Daika Hills, which are reported to contain graphite, mica, pyrites, and gold. The gneiss zone is again narrowed by the eastern projection of the volcanic area of Kenya and the Jombeni Range.

The gneiss is seen below basalt at the Tana Bridge; it occupies the lower valley of the Thika-thika, and forms the Ulu Mountains, which overlook the Kapiti Plains. Further S. the gneiss area widens, S. of the Magadi railway line, to about 60–70 miles along the southern frontier W. of Lake Amboseli.

Occasional inliers of the Eozoic rocks occur in the volcanic area, and show that they directly underlie the lavas. Amongst these inliers are Turbi, Kulal, and Lol Marak; while in the lava plains at the western foot of Kenya the occurrence of a block of gneiss in the agglomerates on the Meru Road, N. of the Amboni River, shows that the gneiss is there not far below the surface. W. of the volcanic zone the gneisses form the arid area W. of Lake Rudolf, including the Suk country; and between the volcanic plateau of Nandi and Elgon they are exposed in the valley of the Nzoya River; thence they extend southward, outcropping from below the volcanic rocks and crossing the Uganda Railway near Koru Station (542 miles). They form most of the country to the E. of the Victoria Nyanza, both N. and S. of Kavirondo Gulf; while in Sotik they extend eastward from the lake to the Loita Plains and the plateau of Subugo Loita Endasegera, and reach the Rift Valley on the Nguruman Scarp near Lake Magadi.

The characteristic features of areas formed of gneiss and schist are widespread plains with a sandy soil, which so soon loses its water during the dry season that the country is parched and supports only scattered tufts of dry herbage and such drought-resisting trees as the candelabra-euphorbia and spiny acacias, and, at moderate elevations, the Baobab.

Tors.—The Eozoic rocks, therefore, form the desert plains known as the Nyika, between the turf-clad volcanic highlands and the coastal district (or " temborari ") which is kept fertile during the dry season by dew. Upon the Nyika are numerous isolated, steep-sided mountains which rise as abruptly from the plains as rocky islands from a sheet of water. Baumann (1890, p. 149, *cf.* pp. 85, 107) described these mountains as rising from the plains of Usambara in " inselartig " independence ; and the German term, " Inselberge," has often been adopted for such mountains by British authors. A foreign word seems unnecessary in this case, especially as the analogy it suggests is not exact. The expression " island-mountain " seems more appropriate for peaks that have been isolated by submergence of their lower slopes beneath a sheet of alluvium, such as, to quote an English example, the Isle of Ely in the Fens. For peaks formed by the removal of the surrounding rock the German term " Rumpfberg " (i.e. hump-mountain) would seem more appropriate ; in old-established British nomenclature they were called " mountains of circumdenudation," and American physiographers classify them as monadnocks. A convenient and self-explanatory name for their class is that of residual mountains. The best English term for peaks of this class is probably that of Tor, which is used not only for crags and pinnacles as on the granite of Dartmoor and sandstone near Harrogate, but also for isolated hills such as Mam Tor, near Castleton in Derbyshire, and for some of the higher hills in Devonshire and Cornwall, such as Kilmarth Tor. British tors have been made by slow removal of the rocks around them ; and the isolated gneiss and granite mountains of tropical Africa have had the same origin.

The formation of these hills has been much discussed, for their forms are very impressive. Some of them are tent-shaped or table-topped ; the sides are often precipitous, and they may consist of unscaleable towers or lofty pinnacles. One in Angola, during an expedition with Dr. C. J. Martin, we referred to as Chichester Cathedral, as we were reminded of its detached belfry by a natural granite obelisk beside the hill. Their surprising shapes early attracted attention. Thomson (1882, p. 72) described the Rovuma Valley as " dotted with the most fantastic hills," which he said were " composed of compact granite without a flaw"; he called them "strange isolated mountains," and one "a broken column." He explained them as intrusive bosses of granite which have been stripped by the weathering and removal of the overlying softer rocks.

In many cases the tors are, however, parts of a wider sheet of uniform rock, and that explanation is inapplicable. The formation of the tors no doubt varied in detail, but they are in general a special form of hill left by denudation in a sub-arid tropical climate. When greatly denuded they are conical, with concave slopes, as in Melilli, Pl. III; and such tors look at first sight like volcanic cones.

Denudation without reference to the nature of the country upon which the denuding forces acted is not a full explanation. The tors are often remarkably regular in arrangement, and they indicate the earlier geographical plan of the country. Thus in B.E.A. the chief tors are in two series, one beside the Uganda Railway from the Taro Plains to the Ulu Mountains, and the other on the eastern side of the Athi. These two series of tors are the remnants of ancient mountain ranges trending from about N.N.W. to S.S.E. These ranges were broken up into two lines of isolated hills by rivers flowing from W. to E. (see pp. 188–189); and these hills have been gradually reduced in size, first by continued stream action, and later, as the climate became drier, by the splitting off of thin slabs (exfoliation) by sudden heating and cooling at sunrise and sunset—aided, to some extent, by bush fires. This process of exfoliation has produced the cliffs which bound the tors. The height of the tors diminishes toward the Sabaki, as the mountain ranges near that valley were lower and more deeply worn by river action. S. of the Sabaki another series of tors is connected with the mountain lines of Usambara.

The tors are, therefore, residual hills, left by the denudation of mountain ranges, which have been reduced first by water when the rainfall was heavier, and then shaped into tors by exposure to sun, wind, and storms in an arid tropical climate.

The position of the cliffs on the tors is due in part to the slope of their constituent rocks, and sometimes to faults, to which Mr. Hobley attributes the bluffs on the southern sides of the tors west of Sultan Hamud Station.

The Primitive Mountain Axis of East Africa.—The tors represent fragments of old mountains destroyed by denudation; and the distribution of the ancient mountains may be inferred from some features of the Eozoic band which constituted the foundation of the

(*a*) Melilli,

One of the Ulu Mountains, a conical hill of gneiss. In the distance are the Kapiti lava plains.

Photo by] *W. McGregor Ross, E*

(*b*) Granite Tors

on the shore of the Victoria Nyanza, at Mwanza.

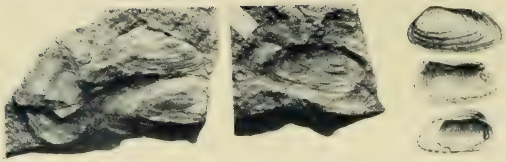
East African highlands from Egypt to Natal. It forms the mountains along the Red Sea, which were once continuous with those of Arabia, and the foundation of Abyssinia ; it underlies the Buri Peninsula and the Italian colony of Eritrea ; it projects eastward as the "Eastern Horn of Africa" in Somaliland. Further S. it is often separated from the coast by a zone of sedimentary rocks, but it forms the highland belt between the coastal rocks and the Rift Valley, while further W. its rocks reappear from beneath the volcanic belt near the Victoria Nyanza. It continues behind the coast all across Eastern Equatorial Africa ; in parts of Mozambique it occupies the whole country from Lake Nyasa to the sea. Its range is then interrupted by the Zambezi Valley, but it reappears in South Africa in the eastern face of Rhodesia and the Eastern Transvaal ; and isolated outcrops of it appear from under the younger rocks in Natal. The Eozoic rocks also occur in western South Africa and extend northward through Damaraland, the plateau of Southern Benguella, and the West African highlands, into Nigeria (e.g. Falconer, 1911, pp. 108–123) and the Gold Coast (e.g. Kitson, 1916, p. 376). Between these two Eozoic rims lies the basin in which were deposited the Archeozoic sedimentary rocks of Central Africa. Throughout East Africa the rocks of the gneiss belt are remarkably uniform in composition, variation, and structure. The prevalent strike is from N. to S. It deviates for considerable distances, as in the plateau E. of Tanganyika, to from N.E. to S.W., or from N.W. to S.E. The prevalent meridional strike rules from Egypt to Natal, and it was probably due to pressure from E. and W. by the earth movements which raised along East Africa its primeval mountain chain. Some features of this old mountain chain are revealed by the variations in the strike and dip of the Eozoic rocks. The record of their strike is therefore important. The following list shows some of the variations, mostly noted during the march in 1893, between the Upper Tana and the southern end of the Taita Hills :—

	STRIKE.	DIP.
N. of the Tana ford[3] (above the junction of the Thika-thika) ; gneiss with much pegmatite	N.W. by W.	60°. N.E. by E.
S. of the Tana ford ; gneiss with amphibolite and pegmatite veins	N.W. by N.	—
S. of Camp 94 : Thika-thika R. .	N. by W.	—
2 miles N. of Voroni . . .	E.N.E.	—
Lower Falls of Thika-thika . .	N.N.W.	—

	STRIKE.	DIP.
Augen-gneiss, near the same . .	N. by E.	80°. W. by N.
W. of Machakos, near Lanjoro; quartzose gneiss and pegmatite	N.E., ½ N.	5°. E.
Lokenya	N.	40°. W.
Kilima Kiu and Tiziome . .	N. by W., ½ W.	—
Kilima Kiu and Tiziome; fine biotite gneiss	W.N.W.	—
Pass	N. by W.	45°. W.
Kwazome Peak	—	70°. W.
Tututha; hornblende gneiss . .	N. by W.	70°. W.
Camp at Zuni	N. by W., ¼ W.	nearly vertical
S. of Zuni; coarse gneiss . .	W. by N.	—
,, ,, kyanite-gneiss . .	N.N.E.	—
,, ,, ...	N. by E. to N. ½ W.	45°–80°. W.
Near Kilungu	N.E. ½ E.	W.
,, ,, ...	N.E. by N.	W.
,, ,, ...	N.	70°. E.
Malmani; sinuous pegmatite vein .	N.E., ½ N.	W.
N. of Nzoi	N.N.W., ½ W.	N.E. by E., ½ E.
Nzoi	W.N.W.	N.N.E.
,, ...	N.E. by E.	N. by E.
Dangi R. ford; contorted gneiss, with pegmatite veins in all directions	N. by E.	E.
Gurungani; gneiss seamed with schist	N.E. by N.	20°. S.W. by W.
Masongaleni; 5 miles N. of . .	N.N.E.	W.S.W.
,, Camp	N. by W.	W. by N.
Kambu R.	N.	20°–25°. W.
N. of Mtoto wa Andei; gneiss with pegmatite . .	N. by W.	slight W. by S.
Kinani	N. by W.	—
Ngomeni	N. by W.	—
S. of Tsavo; quartzitic gneiss .	N.N.W.	—
Ngurunga Nyoka; long gneiss hummock . . .	N.N.W.	15°. W.S.W.
Mtu Itala	N., ½ E.	—
Mhololo, S. of Ndi . . .	N.	—
N. by W. of the N.W. spur of Ndara	N.E.	—
Ditto; hornblendic knots . .	N., ½ E.	steep E., ½ S.
Near Maungu	N. by E.	50°. E. by S.

The Ulu Mountains represent a break in the ancient mountain system, by which the foliation, and consequently the existing hills, were given a cross trend, as the rocks, instead of yielding to the pressure in a system of small folds, snapped under it along cross-

A 1



2 3

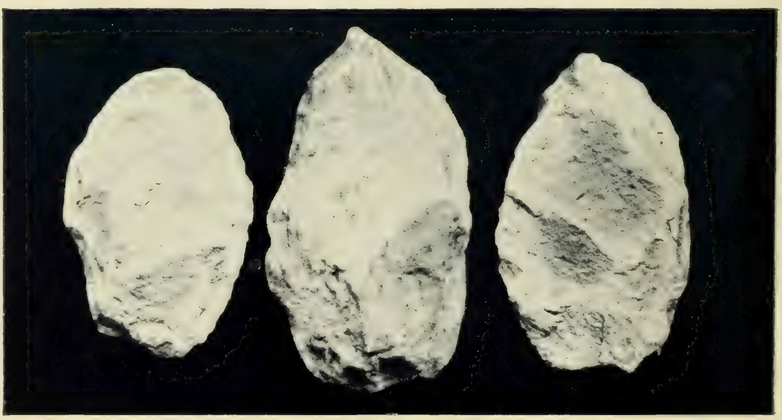
(*a*) Palaeanodonta Fischeri (Amal.)

Figs. 2 and 3 from the Second Stockade, Sabaki R., E.A. Figs. to the right, reproduced from original illustrations of the species by Amalitzky, reduced one-third natural size.

Fig. 2.

(*b*) Echinolampas Discoideus (Arch. & H.)

An Oligocene Sea Urchin from the Lake Nyasa district British Natural History Museum (E2419).



(*c*) Paleolithic Stone Implements

from Ol Keju Nero, North of Mount Ol Gasalik ; reduced to one quarter natural size.

slips and cross-faults.[4] The strike of the rocks being thus thrown E. and W., some of the Ulu ranges trend in the same direction (*v.* inset map, Gregory, 1894, opp. p. 384). With such exceptions the foliation of these rocks throughout Eastern Africa is so regular that it was probably the result of the pressure that formed the ancient mountain system trending N. and S. from the Mediterranean to Natal. The East African highland belt of gneiss and schist is probably the worn-down axis of this mountain system.

The Northern End of the Primeval Mountain System.—The Eozoic belt of East Africa now ends in Northern Egypt, but its probable former continuation northward across the Levant is suggested by the structure of the areas of schists and gneiss in southern and south-western Asia Minor and the ancient rocks of Cyprus. A belt of schist enters Asia Minor at Cape Anamur (Fig. 3) and trends N.N.W. to Lake Beishehr, beyond which, and slightly eastward, the Sultan Dagh and the Emir Dagh are parallel ranges of schist. The predominant grain of Asia Minor is W. and E.; but the strike of these ancient rocks is from between about N.W. and N. by W.[5] This belt of crystalline schists lies across the grain due to the later movements of Asia Minor. This fact led to the suggestion (G.R.V., p. 223) that the pre-Cambrian mountain chain of East Africa formerly extended northward across the Levant, and fragments still exist, though broken and buried by the later

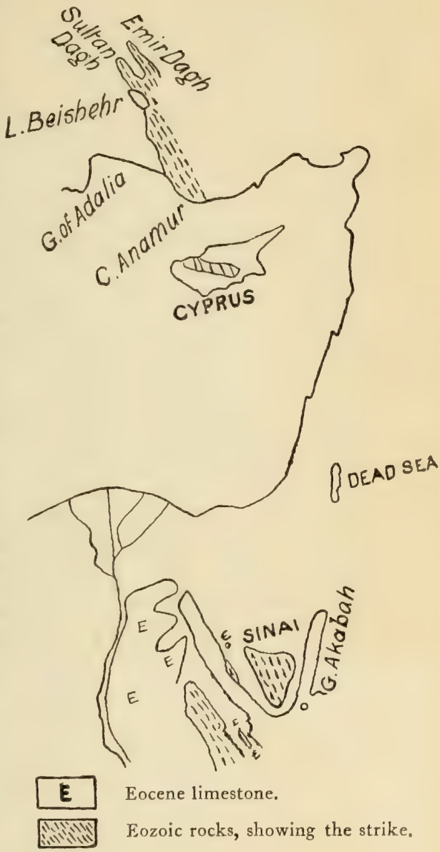


FIG. 3.—The northern end of the Eozoic belt of East Africa. Scale, 1″ = about 210 miles.

earth movements, which impressed on Asia Minor its modern grain running E. and W.

[1] Dana defined the term Archean (" Green Mountain Geology. On the Quartzite," *Amer. Journ. Sci.* (3), III, p. 253) as including all the pre-Paleozoic rocks, including both the metamorphic and those which are comparatively unaltered. He remarked : " Whatever part of the Archean beds are proved to belong to an era in which there was life will be appropriately styled the Archeozoic." Unfortunately, the term Archeozoic has been restricted by some authors to the metamorphic pre-Cambrian rocks, which was obviously the opposite to Dana's intention. If the pre-Paleozoic be subdivided into two, according to Dana's view Archeozoic should be adopted for the upper division.

[2] Holland, *Rec. Geol. Surv. India*, 1896, XXIX, p. 20.

[3] The strike higher up the Tana at the Suspension Bridge is N.W. by N. ; dip 60° to N.E. by E.

[4] A parallel instance from the Alps is the well-known Judicarien line, which runs N.N.E. from W. of Lake Garda to Meran across the normal E. to W. strike from Villach and from Trient to Belluno and the Isonzo Mountain (*cf.*, e.g., Frech, 1893, in *Richthofen Festschrift*, Pl. opp. p. 28).

[5] See, e.g., de Tchihatcheff, *Asie Mineure*, Part IV, Géologie, I, 1867 ; the strike of the mica schists at Cape Anamur, N.W. or N.W. by W., p. 659 ; that of the vertical or highly inclined mica schists near Tchork, which is a little E. of Cape Anamur, is N. by W., *ibid.*, p. 661 ; the mica schists in the Sultan Dagh, strike N. 30° W., *ibid.*, p. 607. The old rocks in Cyprus, generally grouped as igneous, include jaspers, " wacke," and other ancient sedimentary rocks. Gaudry (1862, p. 181) gives a list of dips at eleven localities ; at six of these his table shows that the strike is to N.N.W. ; at another to N.N.E. According to this list, the predominant strike in the oldest rocks of Cyprus is also to N.N.W. and almost at right angles to the later grain of the island.

CHAPTER III

The Archeozoic Group—The Karagwe Series

ONE of the major unsolved problems of African geology is the age of a series of unfossiliferous sedimentary rocks, mainly sandstones, which occupy vast areas of Central and South Central Africa. These rocks are as little altered as many of the older fossiliferous rocks of Europe, and if fossils had been deposited in them there seems no reason why they should not have been preserved. The sandstones are often reddish, and strikingly resemble some of the British Old Red Sandstone (a member of the Devonian System), which is often unfossiliferous as it was laid down on land or on shallow river beds. The Central African sandstones have often been correlated with the Old Red Sandstone, as an inland extension of the Table Mountain Sandstone of Cape Town, which is proved by its fossils to be of Devonian age. These Central African sandstones are clearly older than the fossiliferous rocks in the same regions, but this limit in B.E.A. only proves that they are pre-Carboniferous. In the Transvaal the unfossiliferous sandstones are associated with slates and dolomites, which are also unfossiliferous; the discovery has been claimed (Hermann, 1908, pp. 265–266) in the Otavi dolomite (about 270 miles inland in Damaraland, 19⅔° S., 17½° E., in South-West Africa) of an *Orthoceras*, which, if correctly identified, would define the age of that dolomite as Paleozoic; according to Hermann, it is probably Ordovician.[1] The occurrence of dolomite, claimed as Ordovician on the western part of the South African plateau and of Devonian sandstones at its southern foot, has been regarded as evidence that the sandstones and dolomites of the Transvaal are also Paleozoic. This conclusion seems to me, however, extremely doubtful. The Transvaal rocks have been most diligently studied; and thirty years' search has failed to discover in them a single fossil. The absence of fossils from the dolomites and red sandstones of the Transvaal is the essential difference between them and the rocks which have been compared with them in the marginal zone of South Africa; and the absence of fossils from these rocks in the Transvaal cannot be dismissed as due to inadequate search.

These unfossiliferous sedimentary rocks, moreover, strikingly resemble those of a pre-Paleozoic unfossiliferous system, representatives of which are widely distributed in Europe, Asia, and America. This system includes the Torridon Sandstone of the north-west of Scotland, the corresponding "sparagmite" of Scandinavia, the Longmynd rocks of Shropshire, the Keweenawan Sandstone of North America, and the Vindhyan Sandstone of India. The African rocks in question correspond in stratigraphical position, general character, and the absence of fossils with these pre-Paleozoic sandstones; and, until the conclusion is disproved by the discovery of fossils, it seems most convenient to regard these Central African sandstones as pre-Paleozoic and as the African equivalent of the Torridon Sandstone of the British Isles.

This conclusion, it must be admitted, is rejected by many African geologists. Thus, F. E. Studt (1914, pp. 90, 91) considers that the sandstones in question are Devonian; and Bornhardt (1900, pp. 73, 160, 460) correlates those of G.E.A., though doubtfully, with the Cape Series, which is also Devonian; and Grosse (1918), in an important memoir on the geology of Eastern Katanga, has recently advocated the view that the sedimentary rocks of Equatorial Africa include representatives of all the Paleozoic Systems. According to him, the Kundelungu, Katete, and Moachi beds, including the Tanganyika Sandstone, are all Permo-Carboniferous;[2] the Kabele beds are Devonian; and the Nzilo beds, and therefore the Karagwe Series, are doubtfully referred to the Silurian and Cambrian. This correlation is largely dependent on the identification of a glacial conglomerate at the base of the Katete beds N. of Lake Moeru, with the Dwyka Conglomerate of South Africa. The bed was undoubtedly deposited by ice; but there is no convincing evidence that it is of the same age as the Dwyka Conglomerate. If that conglomerate were the only ancient glacial deposit in S. Africa, the probabilities would be greater of the Katanga glacial bed being on the same horizon; but in Northern Cape Colony a glacial conglomerate occurs in the Black Reef Series, a division of the Transvaal System, and, so far as can be judged from the descriptions (see, for example, Rogers and Du Toit, *Geology of Cape Colony*, 2nd edition, 1919, pp. 96–97), the Katanga glacial bed is at least as similar to this Transvaal glacial conglomerate as it is to the much younger Dwyka Conglomerate.

Behrend (1918, p. 75) has called attention to the complete absence of glacial traces from the Karroo beds of Central Africa ; and both he and Tornau (1913, p. 34) have remarked that the unfossiliferous sandstones of Central Africa are strikingly similar to the Transvaal (or, to quote the term they use, the Potchefstroom) System of South Africa. Hennig (1915, p. 163) also considers the Katanga glacial beds described by Stutzer as much earlier than the Dwyka.

In many parts of Equatorial Africa beds containing fossils of the Karroo formation have been found, and I am reluctant to accept the Katanga sedimentary beds as including representatives of all the Paleozoic systems until fossils are found in them. I have previously referred (1916, pp. 525–526, 528) to the resemblances of the unfossiliferous sandstones of Benguella to the pre-Cambrian sandstones ; and from those resemblances, combined with the significant absence of fossils from the beds below the admitted representatives of the Karroo Formation, it is probable that the pre-Karroo Central African sandstones are pre-Paleozoic. That opinion seems to be steadily growing, as it is held by, e.g., Schwarz (*South African Geology*, 1912, table opp. p. 124, pp. 187–188), Tornau (1913, p. 34), and Behrend (1918, p. 75).

Archeozoic rocks are less extensively developed in B.E.A. than in Uganda, where their representatives were named the Karagwe Series in a joint paper by Mr. Scott Elliot and myself (1895, p. 678). They are also well developed in G.E.A., where they include the Tanganyika Sandstone, which forms part of the eastern wall of the Tanganyika trough. They are very widespread in the Belgian Congo (see especially Studt, 1914, pp. 49, 55, etc.), and they extend westward into southern Portuguese West Africa (Gregory, 1916, pp. 525–526, 528).

This series of rocks, like the Torridonian rocks of North-western Europe, were laid down as continental deposits, and appear to have been formed in a great depression which extended from the Transvaal and the Orange Free State northward through Central Africa. B.E.A. either formed part of the rim of this basin or these rocks have been swept from most of it by denudation. They occur only in Western B.E.A. as an eastern extension of the Karagwe Series of Uganda. There is no evidence of their deposition over the high country between the Rift Valley and the coast. They occur in the Karagwe district to the W. of the Victoria Nyanza, where they are chiefly reddish brown sandstones, with beds of hæmatite, schistose and granular quartzites, and argillaceous beds, ranging from shales to slates. The rocks have a high dip and are sometimes contorted. As they occupy almost the whole of the districts of Karagwe, Ankole, and Koki, they are obviously of great thickness. They are shown on an early map (Scott Elliot and Gregory, 1895, p. 671) as ranging from the Uganda gneisses southward between the Victoria Nyanza and the Edward Nyanza to Lake Tanganyika; and we then suggested that the Tanganyika Sandstone belongs to the same series. To the E. of the Victoria Nyanza the Karagwe beds occur between Nandi and the lake; they include cherty and pinkish quartzites, and are sometimes micaceous. In the Samia Hills they are folded into a syncline, at the base of which occur the ironstones around Berkeley Bay. These ironstones, according to analyses of specimens collected by Mr. Scott Elliot, yielded respectively 41, 43, and 62 per cent of iron. They are siliceous phosphatic ores, and occur as pockets, 40 yards in diameter, in a bed 200 ft. thick, which strikes from N.N.E. to S.S.W. and dips 80° E.S.E.

Dr. Prior (1903, pp. 231–233) has shown that the Karagwe beds are widely distributed in Uganda, where they occur in Unyoro, Busoga, the Buvuma and Bugaya Islands, at Bukonge on the northern shore of the lake, and in Kisubi and Tagana on its north-western shores. Dr. Prior (1903, p. 232) has called attention to the close resemblance of the ferruginous shales and phyllites which, according to the original account of the series, form the basal division, to the Hospital Hill slates of Johannesburg, that underlie the gold-bearing conglomerates and associated quartzites of the Witwatersrand, and also with similar rocks in the foundation of the Abyssinian Plateau, near Adowa and Axum.

The sandstones and quartzites which form the two upper divisions of the Karagwe Series have been recorded by Dr. Prior from the northern and north-western shores of the Victoria Nyanza.[3]

One of the most impressive features of these Central African Archeozoic rocks is that over wide areas the beds are often still horizontal. They frequently lie upon steeply inclined older formations which had been tilted and worn down before their deposition.

[1] The evidence for this fossil is not conclusive. Prof. Schwarz informs me that other reported fossils from this dolomite have been found to be inorganic structures.

[2] Mathieu (1911) has identified plants from the Lualaba beds as belonging to the Glossopteris flora, in which case they would be decidedly lower than Upper Trias; and the Katanga glacial bed, being so much lower, could hardly be included in the Karroo formation. Cornet, however, regards these

plants as too badly preserved for reliable identification. The Katete beds, with the basal glacial deposit, appear to be markedly unconformable upon the underlying Moachi Series ; so that, even if the Katanga glacial beds represent the Dwyka, the underlying unfossiliferous series may be much older than Middle Paleozoic.

[3] Dr. Prior (1903, p. 233) refers to a white fine-grained sandstone on the eastern coast of Lake Naivasha ; but this rock may be an outcrop of Nyasan Sandstone interbedded with the volcanic series, and therefore of much later date.

CHAPTER IV

The Duruma Sandstone

THROUGHOUT Southern B.E.A. (Fig. 4) the Eozoic rocks are separated from the sea by a broad belt of sandstones which overlie gneiss to the W. and underlie Jurassic beds to the E. These sandstones were united by Stromer von Reichenbach (1896, p. 22) as the Duruma Sandstone. This formation was divided by Maufe (1908, pp. 4, 8–13) into four divisions, from which, however, the limestone should be excluded and to which another division added for the Shimba Grit. The five divisions in descending order, and their positions in regard to the Uganda Railway (Fig. 5 B), are as follows: The Shimba Grit, not exposed on the railway; the Mazeras Sandstone, crossed by the railway from $\frac{11}{10}$ to $\frac{13}{1}$ miles;[1] the Mariakani Sandstone, from $\frac{13}{1}$ to $\frac{31}{9}$ miles; the Maji ya Chumvi Beds, from $\frac{31}{9}$ to $\frac{41}{10}$ miles; and the Taru Grits from $\frac{41}{10}$ to the first outcrop of gneiss at $\frac{57}{16}$ miles.

The Shimba Grit (see Fig. 5 A and Fig. 6, p. 51) forms the high range which rises behind the coast plain from the Shimba Hills and Mombasa Gap, through the Rabai, Ribe, Kambe, and Jibana Hills, to Mangea Hill, which is S. of the Sabaki River. It is not exposed along the railway, which passes at once from the Kambe Limestone to the Mazeras Sandstone. The typical Shimba Grit is a coarse quartzo-felspathic grit, with micaceous bands, layers of quartz-conglomerate, and beds of ferruginous sandstone from which is no doubt derived some local veins of ironstone. The rocks are traversed by joints which store water and feed many springs along the western face of the hills. The beds which cap the Shimba Hills dip about 5° to the S.E.

The rock shows by its wind-polished, faceted pebbles, rounded sand grains, and the nature of numerous nests or nodules of coarse quartzite that it was deposited on land in a desert climate. Though some layers are carbonaceous, it apparently does not contain fossil trees, as during a visit to the Shimba Hills with Mr. McGregor Ross and Mr. Stedman we only found them at a lower horizon. N. of the railway the Shimba Grit forms the range from Rabai to Jibana. The

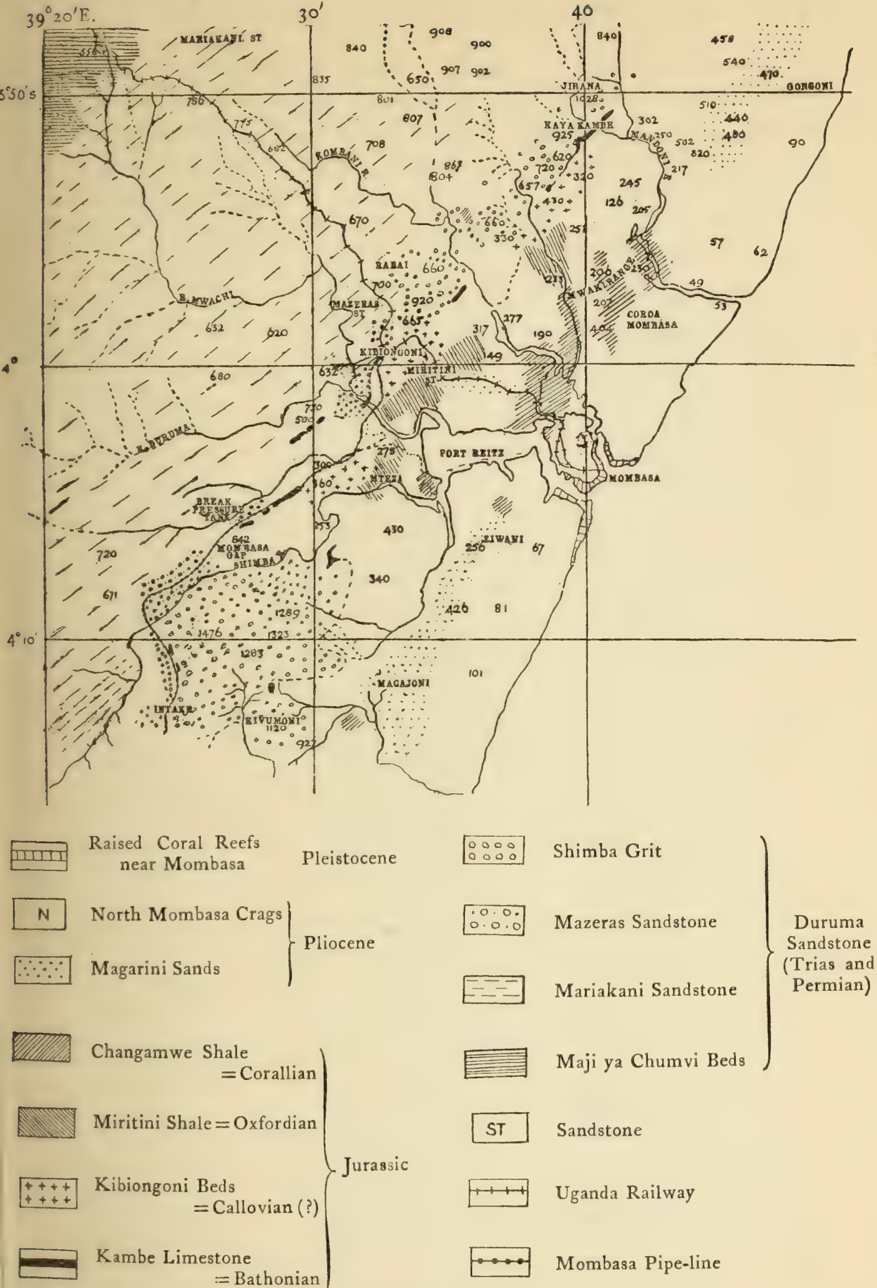


FIG. 4.—Map of the Duruma Sandstones and Jurassic Beds in the S.E. districts.
Scale, 1 inch = about 8 miles.

rocks are well exposed at the ford across the Kombeni River, near Rabai; but the Mazeras Sandstone may outcrop on the hill-top at Rabai, as in the Commissioner's garden Mr. Hobley found a small fragment of fossil wood. It is possible, however, that this may have been carried there. Further N.E., between Ribe and Kambe, the Shimba Grit contains carbonaceous streaks, but the search for silicified wood was unsuccessful.

Kinangoni Hill, the north-eastern summit of the Kambe Hills, is capped by coarse breccia, which was probably formed by a layer of sandstone fragments having been cemented by ironstone and calcite.

Jibana Hill (Fig. 5 C), further to the N., includes quartz pebbles half an inch in diameter, which have been polished and faceted by wind action during the deposition of the grits. The sandstone at Kaye Jibana includes many small nests or nodules of coarse white quartzite, such as are often found in desert sandstones. They are well exposed in England in the New Red Sandstones of Grimshill, N. of Shrewsbury. Their origin is obscure, but I have seen hollows of about the same size made by the circular movement of grass stems under the influence of the wind. Such depressions become filled with a coarse sand which, when cemented, gives rise to the quartzite nodules. These structures are also seen in the Shimba Grit beside the Mombasa pipe-line (Fig. 6 A) at the northern foot of the Shimba Hills, near the Manolo River, about 7 miles from the intake.

The dip of the Shimba Grit in the southern and northern parts of its range is gently south-eastward. Thus to the S., in the Shimba Hills, the dip is 5° S.E.; and to the N., a plateau of Shimba Grit, with a gentle dip slope to the E. and a steep escarpment to the W., is seen from the summit of Kinangoni Hill, about 8 to 10 miles further N. In intermediate places the dip is steeper; it is 22° N.E. in the S.E. cliff of Kaye Jibana, and steep dips also occur W. of the break-pressure tank of the Mombasa pipe-line; these steep dips are probably near faults, as they are local. In the districts between Ribe and the Uganda Railway the dip is reversed. Thus the first river crossed by the track from Ribe to Rabai exposes large surfaces of Shimba Grit, which dips 6° N.W.; and at the ford of the Kombeni River the dip is 4° N.W. Along the Uganda Railway the Mariakani Sandstone also dips inland. In fact, in the Rabai Hills the dip slope is to the interior, and the seaward front is an escarpment. Further W., however, the dip resumes the prevalent south-easterly direction.

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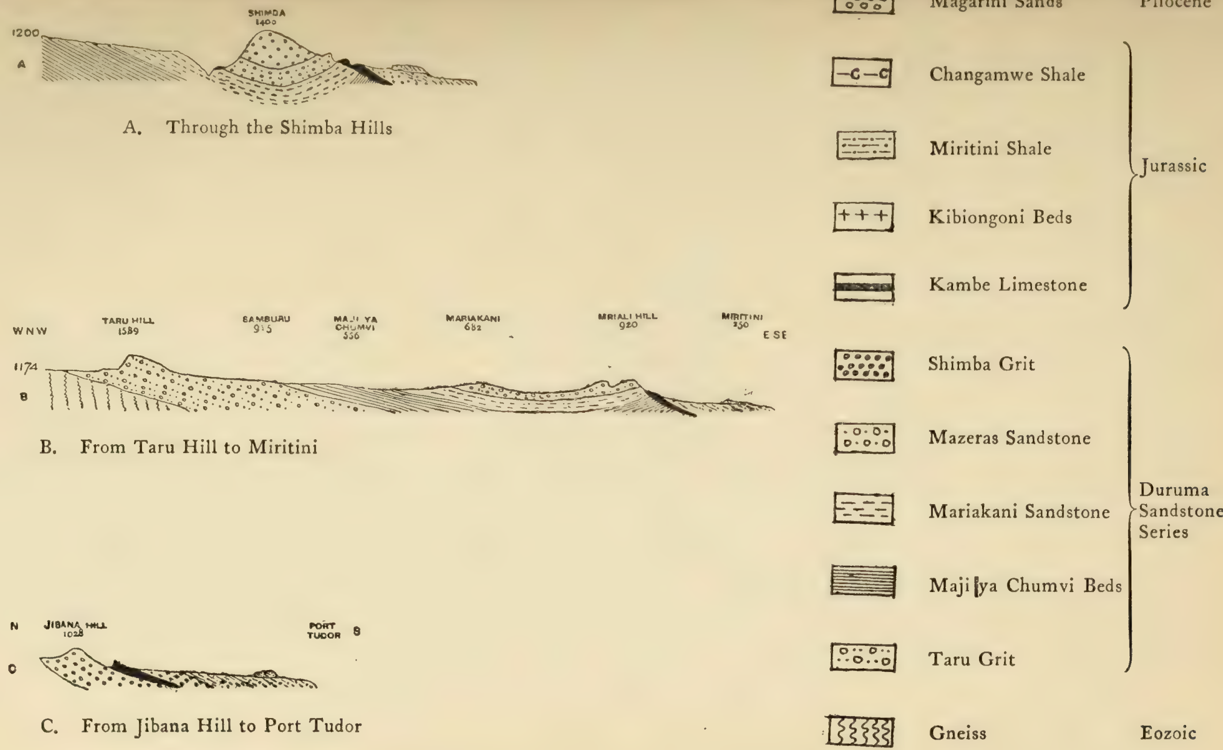


FIG. 5.—Sections across the Duruma Sandstones, showing the unconformity between them and the Jurassic beds.
Scale of length :—A 1 inch = about 12 miles; B, C, 1 inch = about 10 miles.

The Mazeras Sandstone.—The Duruma Sandstone from Rabai southward to the Shimba Hills has long been known to contain silicified tree trunks, which led Thornton (1862, p. 449) to refer the beds to the Carboniferous. These trees occur on a well-marked horizon, which is below the Shimba Grit and may be conveniently called the Mazeras Sandstone. The railway passes abruptly on to this bed at its sharp bend, just W. of the Kibiongoni pumping station; thence the railway runs N.N.E. and crosses these beds for $2\frac{1}{2}$ miles to Mazeras Station.

The railway, unfortunately, does not show the relation of these sandstones to the Kambe Limestone that succeeds them to the E.; the abruptness of change suggests a faulted junction, but I saw no clear evidence of a fault at that position, and the deposition of the limestones on a worn surface of the sandstones would better explain the facts observed.

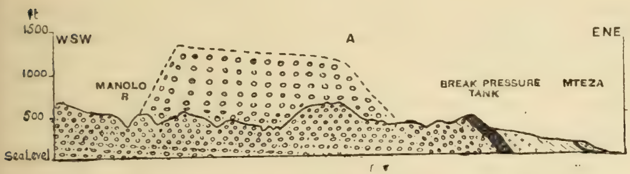
The first exposure of Mazeras Sandstone on the railway cuttings is 400 yards above the pumping station, by telegraph post $\frac{11}{10}$. Hence it extends for some distance up the line, and is disturbed by several faults; at $\frac{11}{14}$, a fault trending N.E.–S.W. separates a false bedded sandstone to the N. from downthrown shale, the lower part of which is interbedded with hard calcareous bands; the shale is separated by an eroded surface from an overlying pale bluish grey sandstone; this rock occupies a shallow synclinal to the S. of which is banded shale dipping W.N.W.

At $\frac{11}{18}$ the railway cutting is in ripple-marked white sandstone interbedded with thick shales. A fault at $\frac{12}{4}$ has the downthrow to the N.E., and has brought the shales against the overlying sandstone. At $\frac{12}{8}$ another fault, trending to 60°, has thrown white sandstone, dipping 8° N.E., against yellow, grey, and brown shales.

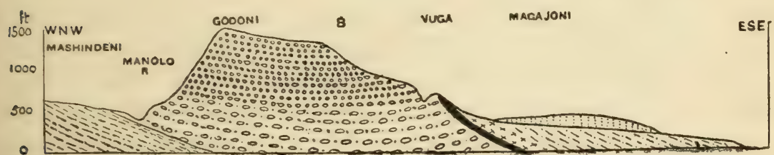
Near Mazeras Station cuttings at $\frac{12}{11}$ and $\frac{13}{1}$ expose coarse felspathic grits, some of which is cemented to quartzite, interbedded with red, buff, and white sandy shales.

Mariakani Sandstone.—Nearly a mile S. of Mazeras Station the railway passes on to fine-grained, compact sandstones, which underlie the Mazeras Sandstone; they are often flaggy and, owing to the abundant minute scales of white mica, readily disintegrate to white sand. These sandstones extend along the railway for $18\frac{1}{2}$ miles. Maufe (1908, p. 11) has called them the Mariakani Sandstone. At first the beds dip to the N.W., sharing the inland dip slope near Rabai; but beyond the 23rd mile-post the beds acquire a gentle easterly to south-easterly dip, which is maintained by the remaining members of the Duruma Sandstone.

The predominant colour is grey, but in places, as at Mariakani Station, $\frac{23}{1}$, it is yellowish. A compact, durable variety is worked for road metal in a series of quarries along the railway line from



A. Section along the Mombasa pipe-line : 1 inch = about 18 miles



B. Section across the Shimba Hills : 1 inch = about $4\frac{1}{2}$ miles.

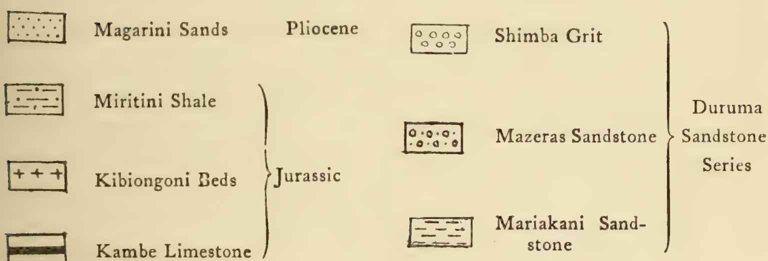


Fig. 6.—The Shimba Grits and relations of the Upper Duruma Beds to the Jurassic Beds

$\frac{17}{5}$ to $\frac{17}{9}$. One interesting variety of the sandstone is crowded with small white spherules, which are sometimes so regular and crowded that they give the rock the aspect of a spherulitic trachyte. Microscopic sections show that the rock consists of quartz, felspar, and epidote, and that the spherules are composed of finer particles of these three minerals.

The flaggy Mariakani Sandstone is seen at the southern foot of the Rabai Hill above the bridge over the Msapuni River, and they outcrop at the north-western foot of the Shimba Hills near the Manolo River. In none of these localities, however, do they appear to contain any fossil wood ; but in railway ballast, S. of Mazeras Station, most of which was Mariakani Sandstone, Mr. Hobley and I found two plant stems which probably came from the Mariakani beds. Prof. Seward says they are indeterminable ; they resemble the stems described as "Calamitoid" by Potonié (1900, p. 503), from sandstones on the Rufiji River, which contained leaves of *Glossopteris* and are therefore Permo-Carboniferous.

Maji ya Chumvi Beds.—The flaggy sandstones are succeeded after about $\frac{31}{9}$ by a lower series of beds consisting mainly of hard shales, olive-green mudstones, and jointed bands of sandstone up to about 5 ft. in thickness. As this sandstone is resistant, it litters the surface with rectangular blocks. The prevalent dip is a few degrees from between N.E. to E.N.E. The sandstones are grey or blue when fresh, but weather brown or red. Fraas (1908, p. 648), from the resemblance of these shales to those near Changamwe, identified them as Kimmeridgian and Oxfordian. Maufe (1908, p. 12) records *Estheria* from one of the shale bands and some plant remains from $\frac{38}{\bar{1}0\text{-}\bar{1}1}$, which were identified by Newall Arber as *Thuyites* and *Carpolites ;* hence these beds, as suggested in 1906 (G.R.V., p. 216), may be provisionally regarded as Triassic ; but if so, the "Calamitoid" stems either did not come from the Mariakani Sandstone or were not the same as those from the *Glossopteris* beds of the Rufiji. The palæontological evidence is inconclusive, for the fossils collected by Maufe have not been determined specifically, and each of the three genera has a wide range. *Carpolites*, according to Seward (*Fossil Botany*, 1919, IV, p. 34), occurs in the Trias and the Jurassic. *Thuyites* was formerly thought to include fossils from the Jurassic and Cretaceous, but Seward (*ibid.*, IV, p. 305) now limits it to the Oligocene. According to Newton (*Geol. Mag.*, 1915, p. 276), the *Estheria* is allied to *E. grayi* Jones of the Karroo, which is a Permian species. The evidence of the fossils as to the age of the Maji ya Chumvi shales is indefinite. Their stratigraphical position indicates that they are either Permian or Trias.

Taru Grit.—Near Samburu Station, $\frac{41}{10}$, the Maji ya Chumvi beds are succeeded by the Taru Grit, which outcrops in the station ground and extends along the railway till the gneiss rises from beneath it at $\frac{57}{16}$. The typical rock is a coarse quartzo-felspathic grit, which is often blue in unweathered specimens and has often been cemented into quartzite. The grits are interbedded with hard black shales. The constituents, both grains and pebbles, of the Taru Grit have been derived from the gneisses that form the mountains to the W. The Taru Grit is well exposed, as it gives rise to bare downs and domes, the surfaces of which break into thin slabs by exfoliation, due to sudden cooling after sunset. The dip, as may be judged from the slope of the Taru Hills, which are seen from the railway at about mile 53, is to E. or S.E.

The black shale is similar to that which in the Sabaki Valley contains the fossil *Palæanodonta fischeri* (Amal.) (*v.* p. 57), of Permian age.

A bore, 450 ft. deep, was put down through these grits at Samburu[2] (mile $\frac{41}{10}$); another bore, at Mackinnon Road, was wholly in the gneiss. By the kindness of Mr. A. Church I was allowed to inspect the cores on the chance of finding an impression of *Palæanodonta*, but without success. The Sabaki fossils remain the only direct evidence as to the age of the Taru Grit. Its Permian age is, however, supported by the discovery of a block of coal in black carbonaceous shale in the railway cutting at $\frac{53}{14}$. Most of this coal was removed and used for fuel, but fortunately Mr. Hobley arrived while some of it was still *in situ*. It was only a boulder, but it indicates the original existence of coal seams in this district. Some of them may yet be found along the outcrop between the railway and the Sabaki, or by boring near where the coal was found.

Fraas (1908, p. 648) found in the grit quarried at Samburu some plant remains, a cross-section of a Belemnite, and an indistinct impression of an Ammonite; he therefore assigned the beds to the Lower Jurassic. This record has been emphatically rejected by Maufe (1915, pp. 275–277). The unconformity at the top of the Duruma Sandstone (*v.* pp. 69–70) renders the occurrence of Jurassic beds on the Taru Grit not impossible, although in this district they might not be expected so high above sea-level. As Fraas's specimens are admittedly obscure, they may be regarded as inconclusive until confirmed by further material.

Though coal specks are found in the Taru Grit, I am not aware of any fossil tree stems having been discovered in it. Baron von der Decken (1869, *Reisen in Ostafrika*, I, p. 238), impressed by the cylindrical pipe-like character of some of the "Ngurungas" or water-holes, suggests that they were due to the weathering out of fossil tree stems. This view has been rejected by Kersten (*ibid.*, II, p. 16), who regarded them as pot-holes, and by Meyer (1890, pp. 62–63, Pl. V), who regarded them as due to weathering. Stromer von Reichenbach (1896, p. 23) has, however, adopted von der Decken's view. None of the Ngurungas which I have seen appear due to tree trunks. They were probably formed by the decomposition and weathering of rock at weak points along joints. Kersten's view may be true in part, as some of them may have been deepened by pot-hole action by surface floods after rain.

At $\frac{57}{16}$ occur the first exposures of gneiss, which mark the western margin on the railway of the Duruma Sandstone.

The Sabaki Section.—The Duruma Sandstone occurs also along the Sabaki Valley, where, at the " Second Stockade," it has yielded the fossils upon which the determination of the age mainly depends. Descending the Sabaki Valley from Tsavo, the sandstones are first met with 2 miles W. of the Second Stockade, which was, judging from the course of the river, as shown on the G.S. map (Mackinnon Road to Malindi, 1914), at 39° 9′ E., 3° 2′ S. The sandstones rest upon the gneiss, and the basal bed is a coarse conglomerate containing large pebbles of gneiss and granite up to 9 in. in diameter, and layers of coarse quartzite. Having at that time no evidence as to the age of these sandstones, I searched the conglomerates for fragments of the phonolite which is exposed N. of the river ; I, however, found none. Between the layers of conglomerate are beds of red flaggy sandstone and coarse grit which, like the matrix of the conglomerate, are formed from the waste of the gneiss. At the Second Stockade the grits are interstratified with black shales containing some fish scales and a fresh-water bivalve shell (G.R.V., 1896, p. 229). I submitted specimens to the late Prof. Amalitzky, who was then the chief authority upon their group. He identified them as *Palæanodonta fischeri* (Amal.) (Pl. IV, Fig. 1). The age of these beds is therefore Permian.

The sandstones on the western side of this outcrop dip 25° N.W. ; further E. the dip declines to 15° W. by S. The sandstone exposed is weathered ; but it agrees essentially with the Taru Grit, with which similar black shales are interbedded. Further E. the gneiss reappears from beneath the sandstone, and, judging from their form, the Loga Hills, 1410 ft., N. of the Sabaki, and Yatta, a conical hill to the S., are both formed of gneiss. This belt of gneiss is about

8 miles wide ; it is succeeded eastward by coarsely jointed, flaggy buff sandstone, of which the strike, at one clear exposure, is to N.N.W., with a steep dip to W.S.W. Further E. the dip becomes very slight to the S.W., and still more to the E. the beds are horizontal. The rocks are a grey weathering sandstone occurring in flat rectangular slabs, which give a terraced aspect to the hill-sides. These beds resemble the Maji ya Chumvi beds. The gneiss once again outcrops from about 39° 25′ to 39° 30′ E. just W. of Janjani, where a sandstone bluff rises above the gneiss on the northern bank, and a little further E. the gneiss finally disappears beneath a sheet of false-bedded sandstone which has a slight dip to the E. This sandstone extends eastward to the old boma at Makongeni, which was built on a sandstone hill at 39° 37′ E., in a great bend of the Sabaki. The sandstones here are grey, well-bedded, and flaggy, and resemble the Mariakani Sandstone of the section along the railway. This sandstone disappears at Lango Baya beneath red sandy soils formed from the Magarini Sand which, with sheets of alluvium, cover the country from Lake Jilori to Malindi.

After reaching the eastern end of the Duruma Sandstone at Lango Baya I turned S.S.W. to examine the structure of the Coast Range between Mangea, a little S. of the Sabaki, and the hills W. of Mombasa. The summit of the Coast Range consists mainly of Shimba Grit, which forms the upper part of Mangea ; but the lower beds in an 80-ft. well, about 1¼ miles S.E. by E. from the summit (1702 ft.) of Mangea, according to specimens collected by Mr. Lamb and sent to me by Mr. Hobley, contain *Dadoxylon*, so that the well reaches the Mazeras Sandstone. The eastern face of Mangea resembles an escarpment, so that the beds appear there to dip westward. On the western side of the range near the pass at Sinikumbi is an ironstone breccia, similar to that in the Shimba Grit, near Kambe. The normal Shimba Grit is exposed around Fuladoyo (520 ft.) and also on the Mwangudo Hill (765 ft.), which was reached by a retraverse through the range along the valley of the Vitengeni. Further S., between that river, which is the upper part of the Rare River, and the Koyeni, near the hill of Mwa Eba (614 ft.), are numerous exposures of white, soft, clayey sandstone with a slight dip to the N.E. These beds agree in general character with the Mazeras Sandstone, which is again exposed further S., W. of Cha Shimba (1154 ft.), Kizingo (1010 ft.), and Kaya Jibana (1028 ft.), three hills in the Coast Range, which is formed of the Shimba Grit. At Ribe silicious tree stems mark an outcrop of the Mazeras Sandstone.[3] From the foot of the Ribe Hills an undulating tract of Jurassic sandstones intervenes between the Duruma Sandstone and the Changamwe Shale of Coroa Mombasa and Mwakirunge.

The Age of the Duruma Sandstone.—Thornton—Livingstone's colleague in the Zambezi expedition—who crossed from Mombasa to Kilima Njaro with von der Decken, described the flags and sandstones of the Coast Range as probably Carboniferous owing to the presence of silicified wood in the Shimba Hills, and of plant stems which he recorded as like the Calamites of the Zambezi Coal Measures. Joseph Thomson (1879, p. 558) extended this conclusion from the plant-bearing sandstones to the coastal limestones, as he regarded their corals and marine shells as Carboniferous. He described the sandstones of Usambara as similar to those W. of Mombasa, and concluded : " We have apparently, then, a band of so-called Carboniferous strata, extending from Mombas or further, along the whole east coast to the Zambezi, and probably on to the Cape."

Dacqué (in Dacqué and Krenkel, 1909, pp. 155–158) classified the Duruma Sandstone as the British East African representative of a formation which he called the African Sandstone and traced from Egypt to South Africa. It would include the Usaramo Sandstone of G.E.A. ; the Adigrat Sandstone of Abyssinia ; the pre-Cretaceous part of the beds once included in the Nubian Sandstone (that term now being restricted to Cretaceous beds) and the Karroo Sandstones of South Africa. The African Sandstone would include beds of somewhat different age ; but they are all pre-Jurassic (or at least pre-Bathonian) ; they are non-marine in origin and contain fossil trees and plant remains, which indicate an age ranging from Carboniferous or Permian to Trias or even, in Madagascar, to the Lias. The Duruma Sandstone is clearly part of this widespread East African series of sandstones. The Lower Duruma Sandstone is probably of the same age as the coal measures of G.E.A. and represents the Karroo System of Southern Africa. The exact correlation must remain uncertain until further fossils are discovered ; but the lower members of the series may be provisionally accepted as Permian, and the upper members as probably Triassic.

The fossil wood in the Upper Duruma Sandstone has failed to give definite evidence as to its age. The specimens have been kindly examined by Prof. Seward, who has identified a specimen from mile 9 on the Mombasa pipe-line as a *Dadoxylon*—a tree of the Araucaria type, familiar in England as the "monkey-puzzle." *Dadoxylon*, remarks Prof. Seward, "is widely distributed and tells me nothing of the age. It may be Rhaetic, Jurassic, Cretaceous or Tertiary, or even Trias." The specimen, however, throws some light on the climate under which it grew, since, adds Prof. Seward, "it is interesting to find the annual rings very ill defined, indeed barely visible, and, where they are recognizable, extremely narrow."

Some other specimens from closely adjacent exposures Prof. Seward regards as probably belonging to the same genus; but he remarks that as the pits in the tracheids are very rarely preserved he cannot be sure of the genus. The most westerly specimens of fossil wood collected by Mr. McGregor Ross, Mr. Stedman, and myself during our visit to Shimba were found E. of the Manolo Bridge. Prof. Seward regards them as probably also of the *Dadoxylon* type, but the preservation is too poor for certain identification; and so also is a probable *Dadoxylon* from the sandstone in the well at Mangea collected by Mr. Lamb. A stem 16 in. long and 9 in. in diameter from the cutting on the Uganda Railway, a little W. of the pumping station at Kibiongoni (at mile $\frac{1}{10}$), was determined by Newell Arber as *Cedroxylon* (Maufe, 1908, p. 9). This genus occurs in the Upper Lias of Madagascar (H. Douvillé, 1904, p. 211). I was able to extract another piece of the same trunk and obtain other specimens from the same railway cutting; but Prof. Seward regards the wood as too poorly preserved for generic identification.

The fossil woods examined by Prof. Seward, however, show that *Dadoxylon*[4] ranges through B.E.A. from Mangea, S. of the Sabaki, southward to the Shimba Hills. This old *Dadoxylon* forest is a useful datum line, though the determination of its age is dependent upon its stratigraphical position. It is certainly pre-Bathonian, and is the uppermost member of the Duruma Sandstone. In 1896 I referred the upper part of these sandstones to the Trias, and, in view of the marked unconformity between them and the Bathonian limestones, their uppermost member is not likely to be later than Rhaetic. In consideration of the absence of any recognized break between them and the Permian Taru Grit, it seems advisable to leave this *Dadoxylon* horizon provisionally in the Trias.

The Taru Grit is shown to be Permian by the *Palæanodonta fischeri* from the Sabaki. This species (Pl. IV, Fig. 1) was founded (*Palæontographica*, XXXIX, 1892, p. 191) on specimens from the Upper Permian beds (Zechstein) around Nijni Novgorod in

Central Russia. The genus, according to Amalitzky (1895, p. 347), ranges from the Devonian to the Permian.

[1] In the distances along the Uganda Railway the upper figure is the distance from Mombasa in miles ; the lower, the number of the telegraph pole from the last mile. There are eighteen to the mile.

[2] The journal of the bore has been recorded by Maufe (1908, p. 14).

[3] Fossil wood near Ribe was collected by Hildebrandt and recorded by Beyrich (1878, p. 774).

[4] A species of this genus, *D. dantzi*, was founded by Potonié (1902) from the Makonde beds of the lower Mbaragandu River in G.E.A. ; this species, according to recent evidence, is Lower Cretaceous.

CHAPTER V

The Coastal Jurassic & Cretaceous Series

THE first landmark seen when approaching Mombasa from the sea is a break through the sandstone hills which is known as the Mombasa Gap. Nearer the land three hills, the Coroa Mombasa—the Crown of Mombasa—serve as a guide to the harbour, and nearer still the long white line of surf marks the front of raised coral reefs and sand dunes. The country between the sandstone hills of the Mombasa Gap and the relatively recent rocks of Mombasa Island consists of a belt of shales, sandstones, and limestones, as to the age of which the first evidence was an Ammonite, collected by Krapf in 1857 at Kisulutini—his mission station at Rabai. This fossil was identified by Fraas (1859, p. 356) as *Peltoceras athleta*, and as Callovian in age. The specimen was redetermined by Beyrich (1877, p. 97) as the Callovian *Ammonites annularis*, and later by Dacqué (1909, p. 166), who described it as a new species of *Perisphinctes*, *P. krapfi*, and as Oxfordian.

A much fuller series of fossils was collected by Hildebrandt in 1877 and described by Beyrich (1877 and 1878), who assigned them to two distinct ages: Lower Cretaceous–Neocomian, based on *Exogyra aquila* Br. and *Ostrea macroptera* Sow., found on the way from Kisauni (Freretown) to Takaungu (Beyrich, 1878, p. 773); and Upper Jurassic–Kimmeridgian, based on Ammonites including *Aspidoceras iphiceroides* Waag., *Asp. acanthicus* (Oppel), *Phylloceras* cf. *silesiacum* (Oppel), *Perisphinctes pottingeri* (Sow.) (Beyrich, 1878, p. 769). Dacqué (1909, p. 172) has remarked that some of these species, such as *P. pottingeri*, are Oxfordian and not Kimmeridgian; and some of Beyrich's specific determinations have been revised. Crick, however, identified some specimens which I collected in 1893 as belonging to the *Aspidoceras acanthicus* group, and I accordingly accepted the beds as including a Kimmeridgian horizon.

Futterer, in 1894 and 1897, described a further series of fossils collected between the " Nash " and " Barretté " Rivers, i.e. between the Mwachi and the Kombeni. He referred the British East African horizons to six successive series, ranging from Middle Jurassic to Lower Cretaceous :—

Cretaceous—

Aptian : based on *Exogyra* cf. *aquila* Brongn.
Neocomian : based on *Ostrea macroptera* Sow.

Jurassic—

Tithonian : based on *Lytoceras* cf. *montanum* (Oppel).
Kimmeridgian : based on *Aspidoceras longispinum* (Sow.).
" " " *Perisphinctes pottingeri* (Sow.).
Sequanian (Corallian) : based on *Perisphinctes* cf. *pralairei* Favre.
Oxfordian : based on *Aspidoceras iphiceroides* Waag.

From Futterer's conclusion that a long series of Lower Cretaceous and Jurassic horizons are known in B.E.A. there has been a reaction to the view that the only Jurassic beds are Oxfordian and Corallian, i.e. Sequanian. Dacqué, in Fraas (1908, p. 647, and 1909, p. 173), and Krenkel (1909, p. 198), in the same memoir, admits the Cretaceous in B.E.A. on the evidence of *Ostrea macroptera* Sow. and on E. Fraas's identification as Cretaceous of some unfossiliferous sands which appear to be decidedly later. However, in addition to these two Jurassic series occur also the Bathonian and Callovian and probably the Kimmeridgian, for fossils have been thus identified by Beyrich, Futterer, and Crick. That the Changamwe Belemnite (*B. tanganensis* Futt.) is Kimmeridgian is apparently the view of Tipper (*Rec. Geol. Surv. Ind.*, XXXVIII, pp. 336–341). The presence of the Kimmeridgian has been accepted by E. Fraas, who doubtfully marks the Changamwe Shale at its typical locality as Kimmeridgian in his joint paper with Dacqué (1908, p. 650) ; and he assigned part of the brown Maji ya Chumvi marls to the Oxfordian and Kimmeridgian, though this view has not been accepted (*v.* p. 53). Dacqué (in Fraas, 1908, No. 2, p. 647) and Krenkel (1909, p. 161 ; 1910, No. 1, p. 216, etc.), however, doubts the existence of the Kimmeridgian in B.E.A. Dacqué says that he cannot believe Crick's identification (in Gregory, 1900, No. 4, p. 226) of Kimmeridgian Ammonites from the Mombasa beds, as he considers that though the sea remained in Northern East Africa until the Upper Kimmeridgian it had receded from Mombasa and G.E.A. by the Lower Kimmeridgian.

The general sequence of the coastal beds and Duruma sandstones is best known along the Uganda Railway. The railway sections were described by Maufe and Fraas. According to Maufe (1908, p. 6), the Changamwe Shale forms a belt 7 miles wide and overlies the Mazeras Sandstone conformably. According to E. Fraas (1908, pp. 646–647, 650–651), a large part of this belt is Cretaceous. There is no convincing evidence for either view (*cf.* Hennig, 1914, pp. 110–111); for the characteristic Changamwe fossils have been found only along the western edge of the belt; while the reported Cretaceous fossil (*Ostrea minos* Coq.), to which Fraas refers (1908, pp. 650–651), was found N.E. of Mombasa.[1] The belt between the coast and the Duruma Sandstone includes four distinct series.

1. *Changamwe Shale.*—The uppermost of the four Jurassic divisions is the Changamwe Shale, which takes its name from the Changamwe Peninsula, N.W. of Mombasa Island. It is typically an olive-green and yellow shale with calcareous and ironstone nodules, septaria, and many Ammonites and Belemnites. The Changamwe Shale also forms the hills of Coroa Mombasa on the mainland, to the N.E. of Mombasa Island; it occurs on the northern side of Port Reitz, and Mr. Hobley tells me that it may also be seen further S., just N. of Ziwani; it probably forms the north-western corner of Mombasa Island, as similar shales are exposed in the cliffs there S.W. of the Makupa Bridge. The Changamwe Shale is well exposed along the branches of Port Tudor, including the Mleje River, the creek leading to Mwakirunge, and at the head of the creek which receives the Kombeni River. An outcrop very similar to the Changamwe Shale occurs above the ford over the Kombeni River, on the track from Rabai to Ribe. Mr. Hobley has also seen the shales along the River Rare, which goes northward from the head of Kilifi creek past Konjora (3° 34′ S.), and he tells me that the northernmost observed occurrence is at Lake Chem-chem, near Melindi.

The confusion as to the correlation of the Mombasa Jurassic beds has been largely due to the mixture of fossils from different horizons. Most of the earlier fossils, including Hildebrandt's and those which I collected in 1893, came from the shales between the railway bridge and Changamwe Station; they include *Oppelia trachynota* (Opp.), *Perisphinctes pottingeri* Waag., *Phylloceras malayanum* Bohm, *Belemnites tanganensis* Futt. (for fuller lists, see Dacqué, 1909, pp. 172, 180, 181). This horizon is Corallian, though it has affinities with the Kimmeridgian.

A lower fossiliferous horizon—probably the source of Krapf's ammonite—was discovered on the shore of Rabai creek by Fraas (1908, pp. 646, 649), who collected there *Peltoceras aff. arduennense* (Orb.), *Macrocephalites rabai* Dacqué, and *Belemnites tanganensis* Futt. Dacqué (1910, pp. 3–4 and Table p. 54) has pointed out that these Ammonites belong to a lower horizon than that at Changamwe, are Oxfordian, and correspond to those of the well-known Ammonite Bed of G.E.A. at Mtaru (*v.* p. 281).

The Changamwe and Rabai shales must be ultimately separated ; but the position of the Rabai Oxfordian Shale in the succession along the Uganda Railway is unknown ; it may be represented by the upper part of the Miritini Shale, which is apparently below the level of the shales containing the Ammonites and Belemnites. Fraas records fossil wood from the Rabai Shale ; but it was probably derived from the Mazeras Sandstone.

The Changamwe Shale weathers into hard, brown, barren, and often soil-less slopes. As the grade becomes gentler along the spur leading to Miritini a bed of red and yellow sands rests on the shale, which keeps them moist so they support the Miriti trees that give the place its name, large groves of coconuts, and fertile " shambas " (gardens). These sands Fraas interpreted as due to the decomposition of a Cretaceous Sandstone. They appear, however, to belong to the much younger Magarini Sand, which are not earlier than Pliocene (*v.* p. 77).

Some shales further inland have been identified as Changamwe Shale on lithological evidence only, as the characteristic fossils have not been found in them. It is advisable to limit the Changamwe Shale to the upper horizon, in which fossils are usually abundant.

2. *The Miritini Shale.*—The sands along the Miritini Ridge rest upon dark grey to black shale, which is exposed in deep gullies S. of the railway. This shale contains calcareous nodules ; but though I broke up dozens of them they yielded no definite fossils. The shale is interbedded with layers, about half an inch thick, of fibrous aragonite. Thin sections show it to be inorganic.

I did not see any section showing the relation of these grey unfossiliferous shales to the Ammonite-bearing Changamwe shales. Similar black shales occur one mile or more W. of Mteza Jetty, at the head of navigation on the Shimba River, and also near the Mwachi River, where it is crossed by the Mombasa pipe-line.

According to Fraas's sketch map, the Miritini Shale is Cretaceous ;

but this age is only possible if the bed has been lowered by folding or by faulting, as in the diagram by Fraas (1908, p. 650). It is more probable that the Miritini Shale underlies the Changamwe Shale, and is either Lower Oxfordian or Callovian in age. It may correspond to the nodular marls and sandstones, with few badly preserved fossils, which occur in G.E.A. for 14 km. along the railway W. of Pendambili, 127 km. from Dar-es-Salaam (Fraas, 1908, p. 644).

The dark Miritini Shale appears from beneath the Magarini Sand further inland along the railway, and at $\frac{10}{6}$ they include a crag of shelly, sandy limestone about 15 ft. wide and about the same height. The shales on the eastern side dip W. and project into the undercut base of the crag. On the western side the shale is tilted up and crushed, suggestive of a fault; but there is no conclusive evidence of faulting. The boss is probably a fragment of a reef of sandy limestone left as a pinnacle and buried by the shales, which were crushed against it as they shrank on drying. The shell fragments in the rock are indeterminable; it may belong to the horizon of the Kambe Limestone, or more probably to some limestone band in the Callovian.

3. *The Kibiongoni Beds.*—Inland of the Miritini Shale is a belt of shales, yellow micaceous sandstones, cherty mudstones, and shelly sandstones. Some of the sandstones are strongly false-bedded; some of the beds are traversed by shrinkage cracks and pitted by rain marks, so they include terrestrial or shore deposits. These beds are seen E. of the Mteza Jetty, near the pipe-line, and are crossed by the track to Kambe, about 4 miles N. of Mwakirunge. As they are well developed in the hills around Kibiongoni, along the Uganda Railway, this division may be conveniently called the Kibiongoni beds.

In a railway cutting at $\frac{11}{2}$ I found a lamellibranch in dark shales. Apparently no Changamwe ammonites have been found so far inland. These beds are probably the yellow sandy marls with obscure cephalopods and plant remains that have been recorded by Dacqué (1910, p. 159) and identified by him as Bathonian.

Mr. Newton has kindly examined a specimen containing shell casts, collected beside the pipe-line E. of the break-pressure tank, but they are indeterminable.

4. *The Kambe Limestone.*—The oldest marine Jurassic rocks in B.E.A. are limestones which, as they are strikingly developed at Kambe, may be called the Kambe Limestone. Its distribution in B.E.A. is best known by the careful observations of Mr. Hobley. It has been worked in small quarries and outcrops near the railway at the Kibion-

goni pumping station, which is at the end of the railway branch of the Mombasa pipe-line, 2½ miles S.S.W. of Mazeras Station.

Mr. Hobley has found the limestones at intervals along a line extending northward from Kivumoni Hill, 18 miles S.W. of Mombasa, across the Mwachi River, thence north-eastward, E. of Ribe, through Kambe and Jibana, and finally on the eastern flank of Mangudo Hill.[2] Mr. Hobley has practically proved its occurrence as a well-marked horizon across the southern coastlands of B.E.A. A considerable development of the same limestone to the N. of the lower Shimba River was proved during the construction of the Mombasa pipe-line.

The limestone occurs in three main varieties. The most abundant variety is dark grey, compact, and unfossiliferous ; it is often sandy and contains pyritic nodules, among which are casts of Ammonites—*Phylloceras kudernatschi* (Hauer) and *Sowerbyceras aff. tortisulcatus* (Orb.)—of which I obtained specimens at the break-pressure tank at mile $\frac{11}{11}$ on the Mombasa pipe-line, and near the coral limestone at $\frac{12}{6}$. These Ammonites have been described by Mr. L. F. Spath (1920), and prove the age to be Bathonian.

The second variety is a light grey coral limestone so full of massive corals that it forms a true fossil coral reef. Some of the coral heads are 4 ft. in diameter. The corals are described in Chap. VII. Their affinities are Bathonian.

The third variety is oolitic and pisolitic, and is interstratified with both the unfossiliferous and coral limestones. The oolitic seams are interbedded with the coral limestone at $\frac{12}{6}$ on the pipe-line ; also N. of the Mwachi River, by the pipe-line crossing. This variety is abundant, with large pisolites, S. of the railway at the Kibiongoni pumping station (mile $\frac{11}{6}$), and it is there associated with a limestone containing corals and *Cidaris* spines. It also occurs interbedded with the coral limestone at Kambe.

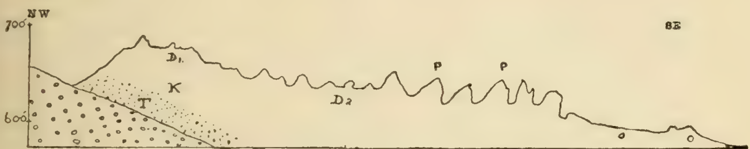
Pisolites have been described by Rothpletz (in Bornhardt, 1900, App. IV, pp. 483–485) from the Bathonian of the Mandawa River and Gongarogua in South-eastern G.E.A. ; he has identified in them various calcareous algæ, and the associated fossils are regarded as Bathonian. The pisolites in the specimens from the Uganda Railway, near the pumping station, are three-fifths of an inch in diameter ; microscopic sections show algal structures.

The reef limestone includes some layers rich in a large lamellibranch, with a fibrous texture and echinoid spines, and plates of

Cidaris. I saw one crinoid crown, as well as numerous ossicles. This limestone would yield a rich fauna.

The outcrop of limestone discovered by Mr. Hobley at Kambe is especially interesting. It is about a quarter of a mile wide; its dip is about 15° S.E.; and it is probably about 300 ft. thick. Its course is marked by crags and pinnacles of fantastic forms, including domes, towers, and natural arches. It gives rise to a rugged "Karst-land" topography. A section across the limestone, near the Kambe camping ground, is shown in Fig. 7. At the base the rock is very sandy and contains numerous mollusca, including ostreoid shells, and echinoid spines (Nos. 542–544).

The reef corals begin about 40 ft. above the base with masses of *Kobya rossi*, which is exposed in the pinnacles on the ridge. Down



O Oolitic Limestone
D1 Lowest Diplarea
T Sandy Limestone with large lamellibranchs, echinoids, etc.
D2 Main growths of Diplarea
K Kobya Limestone
Shimba grit

FIG. 7.—Section through the Kambe Limestone near Kaya Kambe.
Length, 1 inch = 420 ft.

the dip slope I observed the first *Diplarea northeyi*; the masses of that species increase in size and number until, about 200 ft. from the base of the limestone, it is the dominant fossil. The uppermost observed band consists of oolitic and shelly limestone.

S.E. of Jibana the limestone band is thinner; but it also begins with a layer crowded with quartz grains from the adjacent Shimba Grit and some fossil shells. Over this band is a flaggy limestone, dipping 20° S.E., with *Cidaris* spines and plates, *Montlivaltia*, and a cylindrical coral. Above follow more massive reef limestones with *Diplarea northeyi*.

The close association of the oolitic and shelly-coral limestone is shown at the pipe-line at $\frac{12}{5-6}$, where *Kobya rossi* occurs in the pisolitic limestone, and also at a small quarry near the railway pumping station, which exposes about 10 ft. of grey limestone, containing

Cidaris spines and shells and some oolitic bands. It is covered by brown shale. The relation of the two beds is obscured by slipping, which at first suggests a faulted junction; but the evidence rather favours the view that the shale was deposited on an uneven surface of limestone, and has subsequently slipped over it. Half a mile farther along the pipe-line, near the forester's hut, are heaps of pisolitic limestone, due to the breaking up of blocks that have weathered out.

In the hope of determining the relation of the limestones at the railway to those on the Mwachi River, Mr. Hobley and I made a hurried visit to the river where it is crossed by the pipe-line. Near the 18th mile-post along the pipe-line is a large slab of Diplarean coral (probably *D. northeyi*). The track descends to the floor of the valley, and at $\frac{17}{9}$ is an outcrop of limestone with many echinoid spines, which occurs at intervals along the track for about 300 yards. At the 17th milestone, near the mouth of the valley, are low hills of black shale. The pipe-line crosses the Mwachi River at $\frac{16}{12}$ miles, and here I collected Ammonites which Mr. Spath has described as *Phylloceras* cf. *kunthi* Neumayr, *Protetragonites* cf. *tripartitus* (Raspail), and *Hecticoceras*, and assigns to the Bathonian.

S. of this bed is a sandy, well-bedded limestone dipping 14° S.E.; below it is a compact grey limestone, beneath which is a coral limestone. Many simple corals are exposed on the limestone slabs; but it was impossible to collect them in the time available. Immediately beneath this coral limestone is a white sandstone in which Mr. Hobley found fragments of fossil wood. It is doubtless the Mazeras Sandstone.

5. *The Sequence N. of the Uganda Railway.*—The general sequence along the Uganda Railway is similar to that to the N. of Mombasa, between the head of Port Tudor and the Coast Range at Kambe (Fig. 8). Port Tudor breaks up into a series of shallow tidal creeks between ridges of the Changamwe Shale. At the head of the creek at Mwakirunge the Changamwe Shale includes a bed of limestone containing casts of Ammonites. The limestone dips 18° to 10° N. of W., showing a sharp local disturbance as the normal dip is gentle and in the opposite direction.

From the village the path crosses a wide tract of grey sands, so thick that the gullies crossed show no exposure of the shales which, however, no doubt underlie them and are exposed about 2 miles N. along the path. I could find no fossils in them, and they may represent the Miritini Shale. The exposures are better on the rising ground at the foot of the Rabai-Jibana range. The shales are succeeded, 3½ miles from Mwakirunge, by micaceous shales and sandstones, and, 1½ miles further, these by sandstones so cemented on the surface as to be quartzitic; then follow olive-green mudstones, often showing hexagonal shrinkage cracks. These beds represent the Kibiongoni beds; they rest on the Kambe Limestone, the pinnacles of which rise picturesquely above their western edge.

6. *The Sequence along the Mombasa Pipe-line.*—The sequence S. of the Uganda Railway may be illustrated by the section along the Mombasa pipe-line from Mteza Jetty to the intake on the Shimba Hills. In a traverse across this country I had the benefit of the guidance of Mr. W. McGregor Ross, Director of Public Works, and

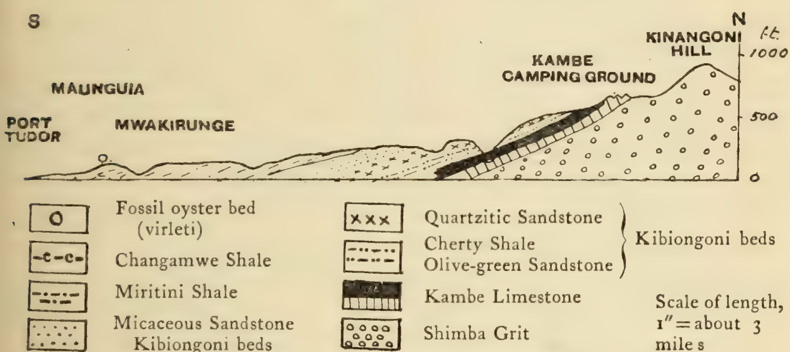


FIG. 8.—Section from Port Tudor to the Kambe Hills.

Mr. H. J. H. Stedman, Executive Engineer of the Mombasa district. We crossed from Mombasa to Mteza by boat along Port Reitz, which must have been formed when the land was at a higher level, for at present it is being silted up by the streams which discharge into its western end. The northern shore of this harbour consists of Changamwe Shale. We landed on the southern side at the "Red Earth Headland," Dongo Kundu, but failed to find there any Changamwe Shale; its rocks are decalcified shale, a blue earthy limestone, thin-bedded felspathic grits, and large quartzite pebbles. These rocks belong to a horizon lower than the Changamwe shale, which outcrops on the higher ground further to the S.E. The occurrence of these doubtless pre-Changamwe sandstones at sea-level opposite Changamwe Shale on the northern shore suggests that Port Reitz has been formed along a fault which probably skirts the straight southern shore. A fault along it would be in line with the straight course of the Shimba River through the Mombasa Gap. The hills beside the lower Shimba River, above Jimbo, consist of Changamwe Shale. The banks by Mteza Jetty are of dark black shale with calcareous bands and nodules, in which I could find no fossils. These black shales are also exposed along the track from about $\frac{1}{2}$ to $1\frac{1}{4}$ miles W. of the jetty. They represent the Miritini Shale. N. of the track from Mteza Jetty to the pipe-line, 13 miles from the intake, the country consists mainly of cherty mudstone, grits, and quartzites, with bands of false-bedded sandstone and coarse conglomerate, which contains pebbles of fossil wood apparently *Dadoxylon* from the Mazeras Sandstone. Farther W. in the same series occur sandstones with indeterminable casts of shells. This series represents the Kibiongoni beds. They end to the N.W. against the Kambe Limestone, which is here represented by its three normal types, viz. grey compact limestone with rare pyritic fossils including *Phylloceras kudernatschi* (Hauer), coral limestone, and oolitic and pisolitic bands. These limestones are shown along the pipe-line; the coral reef and interbedded pisolite are exposed beside $\frac{12}{6}$, and the grey limestone with *Phylloceras kudernatschi* and *Sowerbyceras aff. tortisulcatus* (Orb.) at the break-pressure tank at $\frac{1}{11}$. Thence the track goes inland over an undulating belt of sandstones, upon which the limestones occur in occasional patches or boulders. They are seen along the track at $\frac{11}{6}$, $\frac{10}{4}$, $\frac{9}{16}$, $\frac{2}{13\text{-}10}$, and they recur farther W. on the platform at the western foot of the Shimba Hills, where they are seen at $\frac{2}{3}$, $\frac{1}{12}$, $\frac{1}{9}$, and $\frac{1}{7}$.

The limestones observed along the western part of the pipe-line were only boulders, and the possibility of their having been carried up during the construction of the pipe-line had to be considered. Some of the men accompanying us had been engaged in that work, and in answer to enquiries by Mr. McGregor Ross and Mr. Stedman they declared that the limestone had not been carried there then. Their information is supported by the extremely weathered nature of the blocks and by the vegetation being richer around them than on the adjacent grits. Conclusive evidence is afforded by the presence at the same localities of efflorescent limestones in the form of concretionary nodules. This material, known in India as Kankar, is not present in the soil overlying the Shimba Grit. It seems clear that limestone was deposited on the plains at the northern and western foot of the Shimba Hills. That these limestones were laid down on a plane of marine denudation cut across the older Duruma sandstones is indicated by the differences in dip of the Kambe Limestone and the underlying sandstone, which dips 45° to the E.S.E. at $\frac{9}{16}$ and 12° to the S.S.E. at $\frac{12}{2}$. The evidence, therefore, indicates an unconformity of the limestones over uptilted, denuded Duruma Sandstone.

7. *The Relations of the Bathonian Limestones to the Duruma Sandstone and the Changamwe Shale.*—Maufe (1908, p. 10) regards the limestones as two distinct beds, of which the lower, a pisolitic limestone some 30 ft. thick, he describes as included in the upper part of the Mazeras Sandstone ;[3] the upper limestone, about 8 or 10 ft. thick, containing echinoderms, foraminifera, *Ostrea*, and other shells, he assigns to the lower part of the Changamwe Shale. According to this view, the Duruma Sandstone and Changamwe Shale would be conformable. I have not, however, been able to follow out this arrangement. The evidence beside the Uganda Railway is obscure, as the fault near the junction of the shales with the Mazeras Sandstone has thrown out some of the beds, and others are hidden by a valley caused by a high railway embankment.

The pisolitic and fossiliferous limestones appear to be on the same horizon and to be phases of the one formation. Mr. Hobley and Mr. Sikes, who both know the limestones well, consider that there is one limestone horizon. The evidence for this view seems strong, since I observed the interbedding of the oolitic and fossiliferous limestone at several localities, including the pipe-line at $\frac{12}{5}$ to $\frac{12}{6}$, the quarry at Kibiongoni near the railway at $\frac{11}{11}$, the Mwachi crossing, Kaya Kambe, and Jibana. Instead of the pisolitic limestone being the older, Mr. Sikes regards it as the upper part of the compact limestone, a view which I share. That certainly seems the position of the oolite at three localities where its relations are clear, viz. at Kambe, where it is the uppermost division of the limestone ; in the quarry near the railway at $\frac{11}{6}$, where it is directly overlain by the Kibiongoni beds ; and on the pipe-line E. of the break-pressure tank.

Instead of the Kambe Limestone forming a passage between the Duruma Sandstone and the Jurassic beds, it appears to occur at an unconformity between them. The evidence for this unconformity is as follows :—

(1) *The Overlap of the Limestones on to different Members of the Duruma Sandstones* (Figs. 5 and 6).

(*a*) The limestone W. of the break-pressure tank on the pipe-line rests on the Mazeras Sandstone; whereas the blocks of limestone beside the pipe-line in the Mreri Valley, to the W. of the Shimba Hills, lie on the Shimba Grit, as if the limestone had been deposited on a shelf which had been cut into the sandstones at about 400 ft. above present sea-level.

(*b*) At the Mwachi River the limestone rests on the Mazeras Sandstone.

(*c*) At Kambe and Jibana the limestone is in contact with the Shimba Grit. Careful search at several points along the junction failed to find any fossil wood in this district, so that the Mazeras Sandstone appears to be absent, and the limestones rest directly on the Shimba Grit.

(2) *The Apparent Unconformity at the Landani River.*

At the Landani River the limestones can be seen about 50 yards up stream from the Kambe-Jibana road, abutting against the sandstones; the base of the limestone is crowded with sand grains. The dip in the sandstones cannot be seen, as loose blocks of sandstone cover its outcrop, and the sandstone underlying the limestone is a massive rock which showed no bedding. The relations of the limestone can best be explained by its having been deposited on a worn surface of the sandstones.

(3) *The Independence of the Dips in the Jurassic and in the Duruma Sandstones.*

The dip of the Jurassic beds from Jibana to Shimba is to the S.E. or E. Thus the limestone to the S.E. of the Jibana camping ground has a dip of 20° to the S.E., which may, however, be partly a false dip, due to the beds having been laid down on a sloping surface of the Shimba Grit. Near the Jibana camping ground the dip is 14° in one place to E. by S., and in another to S.E.

The dip of the Duruma Sandstone is more variable; the main dip in the Shimba Hills is to the S.W., though on the south-eastern side Mr. Hobley's observations show a westerly dip at Kivumoni. N. of the railway the prevalent dip of the Shimba Grit is inland, westward and north-westward. Thus the hills from Mriali (S.E. of Rabai) past Ribe (dip 6° to N.W.) to Kambe and Jibana present an escarpment to the S.E. Jibana Hill presents a precipitous bluff to the E. and a dip slope inland. This inland dip explains why the hills in this part of the coastal range are highest on the seaward side; thus Mriali is 920 ft., and Rabai, inland from it, is 680 ft.; the Government Farm is 659 ft., and the hill to the N.W. 579 ft.; from both Ribe, 720 ft., and Kaye Kambe, 925 ft., the level falls to the N.W.

An unconformity would also best explain the very irregular western margin of the limestones near Kambe. On the north-eastern bank of the shallow valley beside the Kambe camping ground, the limestones run suddenly up-stream with so sharp a bend in their course that I at first suspected a fault. I could, however, find no evidence of faulting; the limestones were not shattered along the margin, which is very sandy. The limestone, as Mr. Hobley suggested, probably runs inland in bays along former depressions in the sandstone. One of these bay-like western extensions of the limestones occurs S. of the Landani River. Opposite Kaye Kambe, S. of the camping ground, the limestone is deflected to the S. by a rise of the sandstone; but a few low hummocks of the basal limestone occur in the shambas W. of the track to Ribe, about a quarter of a mile from the Kambe camping ground.

Further evidence of the unconformable relations of the beds in this area is given by the absence of the limestones near the Kombeni River, where some brown shales, lithologically identical with the Changamwe Shale, rest on the Duruma Sandstone; they occur on the north-eastern side of the Kombeni River at a height of about 200 ft. above sea-level, and appear to represent an overlap of the shales up the Kombeni Valley on to the sandstone. Moreover, the evidence of the fossils indicates a long interval of time between the limestone and the Duruma Sandstone, since the fauna of the limestone is Bathonian, whereas the latest date probable for the uppermost Duruma Sandstone is Rhaetic or Trias.

8. *Limestones at Coroa Mombasa.*—An interesting limestone from Coroa Mombasa, collected by Mr. Montague and given me by Mr. Hobley, consists of a block of *Thamnarea*. Mr. Hobley tells me that this limestone is reported to be interbedded in the Changamwe Shale. If so, it would be Corallian. At Mwakirunge, near Coroa Mombasa, is a bed of limestone dipping 18° westward; and it is possible that this *Thamnarea* limestone may be on the horizon of the Kambe Limestone and have been brought to the surface by the fold which has caused the steep dip at Mwakirunge.

The marine Jurassic divisions may be correlated as follows :—

Changamwe Shale . . .	Corallian.
Rabai Shale	Oxfordian.
Miritini Shale . . .	(?) Lower Oxfordian.
Kibiongoni Beds . . .	Callovian.
Kambe Limestone . . .	Bathonian.

The Thickness of the Jurassic Series.—The thickness as well as the classification of these beds has an important bearing on the problem of the deep well waters under Mombasa. The thickness is much less than might be expected from the width of the outcrop and the dip of the beds. The outcrop between the Kibiongoni pumping station and the shore of Port Tudor by the railway bridge is about 7 miles ; and if the average dip be only 5° the thickness would be almost 3000 ft. The thickness is probably much less than this, since the beds are repeated by a series of faults which trend approximately from N.E. to S.W. and throw down the beds to the S.E.

The thickness of the beds is no doubt considerable, but no reliable estimate is possible until the average dip from the pipe-line pumping station to the coast and the extent of the faulting have been determined.

CRETACEOUS

The evidence for marine Cretaceous beds in B.E.A. consists of two shells found by Hildebrandt N. of Freretown (*cf.* p. 59). The more important of the two, which had been identified by Beyrich as *Exogyra* cf. *couloni*, has been redetermined and figured by Müller (in Bornhardt, 1900, p. 549) as *Ostrea minos* Coqu., a middle Neocomian species. Further specimens of this important fossil and evidence as to the relations of the beds from which it came would be of special interest. Müller's decision renders it necessary provisionally to accept the conclusion that the Lower Cretaceous sea reached the coast N. of Mombasa.

[1] The existence of marine Cretaceous rocks where Hildebrandt's fossil was found is not inherently improbable, but has not been confirmed.

[2] Coral limestone associated with bluish clay and gypsum are reported by L. Aylmer (1911, p. 293) from the wells of El Wak ; the association suggests a lower Jurassic horizon.

[3] Accordingly, Dacqué (1910, p. 159) regards part of the Mazeras Sandstone as marine in origin and Bathonian in age. *V.* also Behrend, 1918, Table III.

CHAPTER VI

Kainozoic Geology of British East Africa

I. Eocene and Miocene

MARINE rocks of the Kainozoic Group are widely distributed along the eastern coasts of Africa. Eocene and Oligocene marine limestones occur in Mozambique and Madagascar; Eocene rocks are known both at low and high levels in northern Somaliland, and marine representatives of all the Kainozoic systems have been found in G.E.A. Hitherto, however, no marine rocks have been recorded from B.E.A. between the Lower Cretaceous and the recent raised reefs. Mr. J. A. G. Elliot, formerly Acting Commissioner of Melindi, found a few fossils about six miles inland from Fundi Isa, a coast town about half-way between the mouths of the Tana and Sabaki. Mr. Hobley subsequently collected two series of fossils in the same district (Fig. 9). The younger series were found in a river bed from five to seven miles west of Fundi Isa, on a platform about 120 ft. above sea-level. The second locality was about sixteen miles west of the coast, at a place S.S.E. of Hadu, at the elevation of about 250 ft., and near the eastern edge of the overlying Magarini Sands. The fossils of the eastern locality contain an oyster allied to the

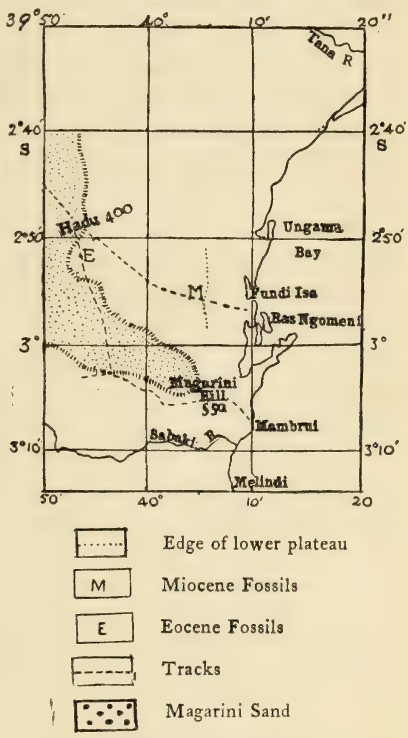


Fig. 9.—The fossiliferous localities west of Fundi Isa.

Scale, 1 inch = about 20 miles.

well-known Miocene species, *Ostrea crassissima ;* while the more inland series included the Eocene coral *Favia somaliensis*, a species which I had previously described from Somaliland. Mr. R. B. Newton has kindly examined the molluscs in this collection and identified five Miocene species (viz. *Ostrea gingensis* Schlot., *O. grypheoides* (?) Schlot. (=*crassissima* Lam.), *Lopha virleti* (?) Deshayes, *Amussium cristatum* Bronn, and *Æquipecten* cf. *malvinæ* Dubois) in those collected at the eastern locality; and a Campanile, the Middle Eocene *Volutilithes* cf. *sanarensis* Oppenheim, and some foraminifera from the western locality (cf. Appendix II, p. 384).

The addition of these two horizons to the geological succession in B.E.A. led me to re-examine some specimens of limestone which had been collected by the late Clifford H. Crauford from the north of Lake Deshek Wam, a large shallow lake about thirty miles N. of Kismayu, W. of the Juba. He referred to them as containing marine fossils in a report to the Foreign Office (5th September, 1896, 1567, a–1), in support of the view that the sea formerly extended inland to Abyssinia and the Masai highlands. The fossils, however, were so fragmentary that it did not then appear possible to make any reliable suggestion as to the age of these limestones ; but I have recently had sections cut from the Lake Deshek Wam limestone. They show some indeterminable corals, foraminifera and calcareous algæ. The limestone includes some shell casts, which have been kindly examined by Mr. R. B. Newton, who has had further sections prepared and reports that, in addition to the " indeterminable Corals and *Lithothamnium*, one of the shells is a *Semicassis* related to *saburon* Lam., which had its origin in Miocene times. The assemblage is suggestive of a Miocene (Vindobonian) age."

The occurrence of these Miocene limestones a few miles inland on the lower Juba suggests that they and the Fundi Isa fossils belong to a band which has or had a wide extension along the coast of Northern B.E.A.

The Maunguja Fossil Oysters.—At the village of Maunguja, on one of the northern branches of Port Tudor, occurs a litter of oyster shells like a village waste heap. My attention was called to this deposit by Mr. Hobley. Mr. Newton has determined the oyster as *Lopha virleti* (Deshayes), an extinct and Upper Miocene species. These shells may have been collected for use as lime from some Miocene shell bed beside the creeks which discharge into Mombasa harbour.

II. Pliocene—The North Mombasa Sands

One of the best known phenomena of coastal geology is the occurrence of marine beds above sea-level, and also of land deposits lying below sea-level. This association indicates either an alternate rise and fall of the land, or advance and retreat of the sea. The clearest evidence of one of these movements along the East African coast is that of a bore sunk for drinking water at Dar-es-Salaam, which reached clays containing wood below coral limestone and above a bed containing sea-shells. That the land at Mombasa was once relatively lower is obvious from coral rocks now 80 ft. above sea-level along the seaward cliffs of the island ; and that the land was once higher than now is shown by the valleys to the north of Mombasa which were once land valleys, but have been converted into creeks by submergence. Whether these changes of level along the East African coast were due to oscillation of the land or to variations in sea-level must be finally decided by their regularity around the Indian Ocean. If the movement was that of the land, it would probably be local and different in various places ; but if it were due to the rise and fall of sea-level, it should have affected simultaneously all the shores of the Indian Ocean. The evidence from East Africa is at present inadequate for a final opinion, but it suggests that most of the movements along the north-western coast of the Indian Ocean were local and irregular. At North Mombasa a Pliocene submergence formed some shelly crags or calcareous sands containing abundant fossils, amongst which Mr. R. B. Newton has identified the extinct *Spondylus* cf. *crassicostatus* Lam. and scollop *Pecten vasseli* Fuchs ; these are associated with the oysters *Lopha cristagalli* (L.) and *L. townsendi* (Melv.) and *Plicatula* cf. *ramosa*, species still living in the Indian Ocean. *P. vasseli* is the characteristic species of raised shell beds in Egypt, along the Persian Gulf, and on the coast of Baluchistan. It is the typical fossil of the Plio-Pleistocene beds of Egypt (Hume, 1916, p. 16), and Oppenheim (1916, p. 111) refers to it as Pleistocene. It has been previously found in East Africa at Tanga (Koert, 1908, pp. 326–328). These *Pecten vasseli* beds were formed by a widespread advance of the Indian Ocean upon the land.

The age of this movement is somewhat uncertain, and it is variously assigned to a date ranging from Miocene to Pleistocene. The *vasseli-cristagalli* beds of Egypt are referred by Dr. Hume (1916,

p. 16) to the Plio-Pleistocene ; Mr. Newton is disposed to regard them as Upper Miocene, or, as a compromise, Mio-Pliocene. If the Egyptian Geological Survey be correct in regarding the gypsum beds of South-eastern Egypt as Middle Miocene, the overlying oyster beds with *O. gingensis* are probably Upper Miocene. As the *vasseli-cristagalli* beds are later than *O. gingensis*, they cannot be earlier than Pliocene ; and the North Mombasa crag, which appears decidedly younger than the Miocene beds near Fundi Isa (*v.* p. 74), may be provisionally regarded as late Pliocene. The shells suggestive of an older age may be survivals of Miocene species. A couple of sea-urchins found in the North Mombasa crag are referable to *Echinolampas oviformis* (Lam.), the presence of which strengthens the case for the Pliocene age of the beds, as it is still living in the Indian Ocean.

The relations of the *P. vasseli* beds at Mombasa to the raised coral reefs along the southern coast of the island is not clear. It has been suggested that the North Mombasa sands were lagoon deposits formed at the same time as the coral limestone ; but they do not resemble ordinary lagoon beds, and it appears more probable that they were considerably older than the South Mombasa raised coral limestones and served as the foundation on which the corals grew as a fringing reef.

III. The Magarini Sand

Behind the coasts of B.E.A. rises a belt of sandhills, usually of bright red colour. The sand is sometimes unconsolidated, but some has the coherence of rocksand. It is interstratified with layers of pebbles of the harder sandstones, quartzites, and cherts of the Jurassic beds and Duruma Sandstone, and some pebbles from the Eozoic foundation. The grains were doubtless derived directly or indirectly from the Eozoic rocks. These sands form low hills in the Tana delta, as beside the river at Golbanti ; southward, they increase in width and height, rising to over 400 ft. W. of Fundi Isa, and 559 ft. at Magarini, W.N.W. of Mambrui, where they are so well developed that this formation was named the Magarini Sand (G.R.V., p. 229).

S. of the Sabaki they form the wide belt of the Sokoke Forest, between the Coast Range and the sea, and there also rise to over 500 ft. The Magarini Sand also extends up the Chalani River, a southern tributary to the Ndsovuni, between the hills of Makobeni

(Makongeni of the G.S., G.S. map) and of Kiwara ; the bed of the Chalani River is on the Duruma Sandstone, which also forms the upper part of the adjacent hills. S. of Mombasa they form the high ground between Port Reitz and the coast. Mr. Hobley has traced them through the ridge from Ziwani through Bombo (426 ft.) to Magajoni (*cf.* Fig. 4).

These sands are mainly siliceous, and the absence of shells may be explained by the removal of the calcareous material in solution ; but I saw no trace of shell casts in them. Their false bedding and the nature of the pebbly layers indicate that they were formed as sand-hills and river gravels between the foot of the inland plateau and the sea. In the northern district Jurassic rocks occur to the E. of them, and as the Duruma Sandstone on the western side in places weathers to similar sands, in 1893 I regarded the Magarini Sand as intermediate between those formations, and therefore as probably Trias ; and Fraas (1908, p. 650) has referred the Magarini Sand crossed by the Uganda Railway to the Cretaceous. This formation is certainly post-Jurassic, and Mr. Hobley's observations render it probable that it overlies the Eocene and Miocene limestones W. of Fundi Isa. It is probably older than the shelly crag of North Mombasa, though there is no conclusive evidence on this point.

Railway cuttings at Kilindini expose variegated sands above a limestone which probably belongs to the North Mombasa Series. The sands in these cuttings are traversed by vertical calcareous stems, which rise from horizontal stems and are no doubt calcifications around the stems of dune grasses. These structures indicate that the sands in the Kilindini cuttings were formed as calcareous dunes, and some of their material was probably derived from the Magarini beds. Judging by the denudation of the Magarini sandhills on the mainland S. of Mombasa, I am disposed to regard these calcareous dune sands of Kilindini and the Mombasa shelly crag as younger than the Magarini Sand.

On Magarini Hill I found, in 1893, a series of loose blocks of shell limestone at the level of about 300 ft. above the sea. The shells were examined by Mr. Edgar Smith, who reported that, as far as he could see, they were recent species. This limestone may have been carried up by man ; but if it were *in situ* it would be a further argument in favour of the Magarini Sand being older than the Mombasa crag and as probably Lower or Middle Pliocene in age.

In G.E.A. a chain of hills composed of similar sands occurs behind most of the coast. That formation has been described by Bornhardt (1900, p. 469), and named by him the Mikindani beds. He regarded them as of marine origin and as Pleistocene or Pliocene in age. Their marine origin he based partly on some marine shells associated with them, and he explains the rarity of such shells by their having been dissolved by percolating water. The shells found with the Mikindani beds are, however, attributed by Koert to native kitchen-middens. Most of the authorities on the geology of G.E.A. (e.g., Werth, 1901, pp. 297–298; Wolff, 1902, pp. 156–157; Dantz, 1903, p. 200; Koert, 1913, p. 182; Behrend, 1918, p. 127) regard these beds as of terrestrial and fluviatile origin. They appear to agree therefore, in origin as well as in position, with the Magarini Sand and to be its southern extension.

Later Pleistocene.—The recent earth movements along the East African coast appear to have been locally irregular. That faulting has happened later than the Mikindani beds is clear from evidence in G.E.A., and the variations in level of the coast in recent times indicate, although the evidence[1] is still fragmentary, that the emergence and submergence of the coastlands vary so greatly in different localities that they must have been due to movements of the land and not to a rise or fall of the ocean surface.

Thus in B.E.A. the land has risen in successive stages (*v.*, e.g., Hobley, 1916, pp. 5, 8) at least 80 ft., as shown by the raised coral reefs of the southern front of the island; and I am not aware of any greater submergence in B.E.A. at that date.

The last of these uplifts may have killed the corals in the still submerged reefs off Mombasa Harbour. Crossland (1902, p. 502) has shown that the reef edge along Zanzibar Island has ceased growing and that the fringing reefs along its eastern shore are dead reefs now being eroded by the waves. The killing of these reefs may be due, he suggests, to a general fall in sea-level.

The recent local changes in level have, however, been very irregular. Going N. from Mombasa, the raised reefs are lower at Melindi. Inland, W. of Mambrui, the highest that I saw were at about 40 ft. I do not recollect any near Lamu, where some sea cliffs, as at Ras Chagga, have been eroded out of dune formations. Further N. the uplift again becomes more marked, for, according to a report by Mr. W. M. MacClelland, near Kismayu the raised coral rock rises 200 ft. above sea-level; caves occur in it 70 ft. above sea-level.

S. of B.E.A. the recent submergences have in places exceeded that near Mombasa. Crossland (1902, p. 501) has found marine limestones—which may be Pliocene—on Zanzibar Island at the level of 250 ft., and he reports their probable occurrence still higher. In G.E.A. the Pliocene or Plio-Pleistocene beds at Dar-es-Salaam occur, with beds containing fossil wood, in a bore to the depth of nearly 500 ft. below sea-level (*v.* p. 285). The Mikindani beds occur to the height of 2700 ft., but are not now accepted as marine. The clearest evidence as to the Pleistocene oscillations of level in G.E.A. is that of Ortmann (1892, pp. 640–644), who records raised reefs at Dar-es-Salaam at 50 ft. above sea-level, in the islands near Zanzibar and the Mafia Channel up to 30 ft.; further S. their level rises to 130 ft. at Lindi and Mikindani (*ibid.*, p. 644). Further S., in Portuguese East Africa, the uplift appears to have been smaller, since the raised beaches at Mozambique are reported only to the height of 26 ft. by Wray (1915, p. 84).

The Pleistocene uplift appears to have been irregular and to have been greatest at Kismayu, Mombasa, and Lindi; and it was least near the Tana delta and the Mafia Channel.

[1] The general character of the reef limestones and their associated sandstones along the coast at Lamu, Malindi, Mombasa, Pemba, and Zanzibar has been described by Prof. Max Bauer (1911, pp. 3–14).

CHAPTER VII

Fossil Corals from British East Africa

I. SPECIAL FEATURES OF THE FAUNA

THE corals of the oldest division of fossiliferous rocks (Paleozoic) are so different from corals of later times that they have been separated as a distinct group, the Rugosa. The most striking feature in modern corals is their radial plan; each coral is strengthened by vertical plates (the septa), which radiate from the centre like the spokes of a wheel. The number of septa in modern corals is either six or some multiple of six. The coral is therefore composed of six similar sections. It is six-rayed. Each Rugose coral, on the other hand, like the great majority of animals, is built of two similar sections, right and left. In typical Rugosa the septa, instead of being radial, are arranged like the filaments or "barbs" of a feather on its axis or stem. This "pinnate" arrangement of the septa and the two-sided symmetry of the coral are illustrated in Fig. 10, *a* to *d*, in contrast with the six-sided radial symmetry of the modern coral.

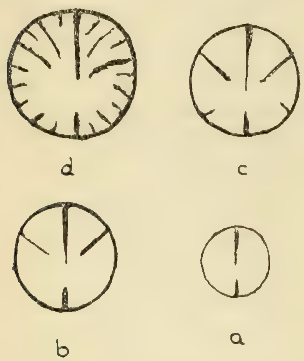


FIG. 10.—Cross-sections of the Jurassic Rugose Coral, Thecidiosmilia valvata Koby, from Switzerland, showing the development of the septa from two on the middle line, in the young stage, *a*; the bilateral symmetry in the intermediate stages, *b* and *c*; and the pinnate bilateral arrangement in the adult, *d*. (After Koby.)

The Rugose corals were long thought to have become extinct at the end of the Paleozoic Era; but the coral fauna which lived in Central Europe at the end of the Jurassic is remarkable for the reappearance of some Rugosa long after that group had elsewhere become extinct. This remnant of ancient corals ranged along the site of the Alps, through Moravia, across Switzerland, and as far W. as the upper valley of the Saône in Eastern France. These corals did not reach Northern France or England, and, what is still more significant, they are not known among the rich coral faunas of the same period in Portugal. It is interesting, therefore, to find a typical member of these Rip van Winkles among corals among the fossils of B.E.A. This coral, *Pleurophyllia hobleyi*, suggests that as the Jurassic Rugosa did not occur in Portugal, they entered Central Europe from South-western Asia, where they had found asylum long after the group had elsewhere been exterminated and replaced by corals of the modern type. In these later Rugosa the septa may be pinnate in one part and four-rayed in another (Fig. 11, *a* and *b*).

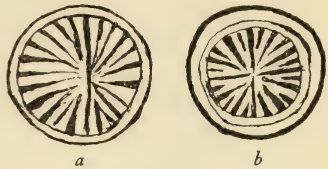
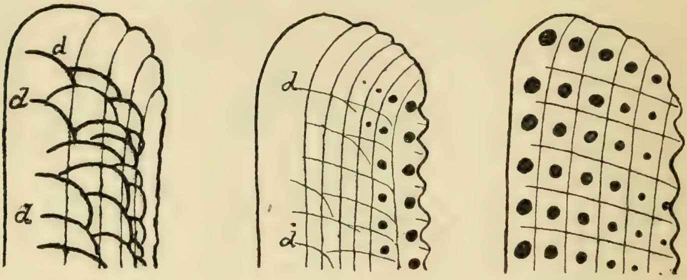


FIG. 11.—Cross-sections of the Jurassic Rugose Coral, Schizosmilia excelsa Koby, from Switzerland, showing variation between the bilateral symmetry and pinnate arrangement in Fig. *a*, and the 4-rayed symmetry of Fig. *b*. (After Koby.)

Another interesting member of this coral fauna is so different from ordinary corals that unless the origin of its structure had been traced it would have been regarded as some form of sponge. The aspect of the coral to the naked eye is that of an amorphous block of limestone. The specimen had been sent to Mombasa as a fossil tortoise, which it resembled owing to some veins of crystalline carbonate of lime. A transparent section shows that this limestone is composed of the skeleton of some massive calcareous animal. There are no regular septa and the structure is irregular, like a sponge. The radial plan characteristic of corals is, however, obscurely developed, and the study of allied fossils from Central Europe and Western India show that it is a true coral.

The septum of most corals is a continuous vertical plate, often bearing thin, more or less horizontal, curved shelves, which strengthen the septum and support the soft parts of the organism ; these shelf-like structures are known as " dissepiments " and they are shown in Fig. 12, *a*. The septum may also show lines which are vertical except near the upper edge. These lines may be faint striations or may be grooves, which indicate that the septum has been formed of a series of united pillars. In some septa, e.g. Fig. 12, *b*, which represents a Thamnastrean, the inner edge of the septum is perforated by a series of pores along the grooves separating the pillars. In some corals these pores occur throughout the septum, which is then sieve-like (Fig. 12, *c*), for instead of being a plate it is built up of a lattice-work of vertical pillars connected by cross bars. The pillars may be regularly arranged in vertical series like a palisade, as in the British East African coral, *Kobya rossi* (see Pl. VII, Figs. 3–4); such a palisade clearly corresponds to a septum. In some cases, as in *Thamnarea*, the rows of pillars become very irregular, for many of the rods are pierced by



a b c

a An Astrean septum with dissepiments (*d*), but no pores.
b A Thamnastrean septum with some pores near the inner margin.
c The perforated lattice-like septum of Kobya.

Fig. 12.—Side View of three types of Coral Septa.

horizontal pores, and are thus broken into short vertical lengths. An obscure radial plan may be recognized in places (see e.g. Pl. VII, Fig. 5); but the skeleton consists of an irregular spongy lattice-work, which is quite unlike the radial symmetry of an ordinary coral. This type of coral occurs in East Africa in *Thamnarea hobleyi.*

II. DESCRIPTION OF THE CORALS

The fossil corals of B.E.A. belong to four horizons—the Kambe Limestone of the country inland from Mombasa; the Changamwe Shale of Coroa Mombasa; the shell bed W. of Fundi Isa; and the raised reefs of Mombasa.

I. THE CORALS FROM THE KAMBE LIMESTONE

The Kambe Limestone includes some bands so crowded with corals as to be true fossil coral reefs. My time for collecting was, however, so short that I did not remove some of the specimens as they would probably have been spoilt. The material obtained includes five determinable species.

PLEUROPHYLLIA. De Fromentel, 1856. *Bull. Soc. Géol. Fr.* (2), XIII, p. 860.

Type species. *P. trichotoma* de Fromentel, 1856, *ibid.*, p. 860. Portlandian. Haute Saône, France.

PLEUROPHYLLIA HOBLEYI N.SP.

Diagnosis.—Corallum large and cæspitose with many crowded branches, which are usually in contact only at their bifurcations.

Corallites, in horizontal sections, circular when young; mostly oval when full grown. Walls thickened by concentric epithecal layers; walls up to 2 mm. thick.

Septa. A large cardinal septum extends about two-thirds across the calice; it is thickened at its free end and gives therefore the aspect of a lamellar columella fused to one septum; the central portion may be ½ mm. thick. Usually 18 to 20 well-developed septa and a few minute septa. The quadrant between the cardinal and alar septa includes two large adjacent curved septa, and four smaller septa. On each side of the counter septum are three sub-equal, short septa.

Endotheca sparse. Costæ indistinct.

Dimensions.—Corallum: dia. 130 by 120 mm. wide and 70 mm. high. Corallites: dia. from 3 by 5 to 5 by 8 mm.; walls, average thickness about .5 mm. Distance of calicinal centres, 5 to 8 mm.

Distribution.—Kambe Limestone–Mwachi River, just above the crossing of the Mombasa pipe-line.

Figures.—Pl. V, Fig. 1, *b*. The upper surface of the type specimen ($\frac{15}{17}$ nat. size). Fig. 1, *a*, section of the corallum showing both vertical and cross-sections ($\frac{3}{4}\frac{8}{1}$ nat. size). Fig. 1, *c*, a thin cross-section, ×2 dia.

Affinities.—This species differs from the type of the genus by its larger and more branched corallum, for in *P. trichotoma* From. the main stem bears only two or three branches. This difference at first suggests doubt whether the two species should enter the same genus; but the resemblance in the septal structure is more important than the prolificness of the branches, which may be due to the growth of *P. hobleyi* under more favourable conditions.

The nearest species is a Swiss coral described by Koby (1884, *Polyp. Jur. Suisse*, Pt. 4, p. 193, Pl. 56, Fig. 8) from an undetermined Jurassic horizon in the Mühlithal. The two species agree in their well-branched character, owing to which both of them form dendroid masses, and by the size and clavate form of the cardinal septum; but the growth of *P. alpina* is more open and loosely branched, the septa are more numerous, there being three instead of two large septa in each quadrant beside the cardinal septum ; the angle between the branches is larger (30°, according to Koby), and in the alpine species the corallites are larger and more regularly cylindrical, those of *P. hobleyi* being usually elliptical.

The form of corallum in *P. hobleyi* resembles that of *Diplocœnia bornhardti* Weissermel (in Bornhardt, 1900, p. 581, Pl. XXVI, Fig. 9), from the Upper Jurassic of Yumbulu, 20 miles N.W. of Kiswere ; but that species, as represented by Weissermel's figures, has a well-developed, isolated styliform columella, and large, distinct costæ ; the corallites are surrounded by a thick exothecal growth, and the septa are alternately larger and smaller.

The coral is more nearly related to *Pseudothecosmilia* Koby (*op. cit.*, Pt. 8, 1888, p. 428) and *Schizosmilia* Koby (*ibid.*, 1888, p. 435) ; in both the corallum is cæspitose, but in the former it grows as dendroid tufts ; in the latter it is submassive, as the branches are more or less united laterally. Both these Swiss genera differ in that the principal septum is hardly thicker and not always longer than the other primary septa ; whereas in *P. hobleyi* the cardinal septum is much thicker and stronger than the rest. In *Schizosmilia* the principal septum is sometimes much the longest, but the others are described by Koby as subequal. The species *S. corallina* Koby (from the Swiss Corallian, Koby, *op. cit.*, Pt. 8, 1888, p. 437, Pl. CXIV, Fig. 5) agrees with *P. hobleyi* in its tortuous corallites and the great extent of their lateral freedom ; but in *S. corallina* the corallites are only from 3–5 mm. in diameter, instead of from 5–8 mm., as in *P. hobleyi*.

Amongst the Paleozoic genera this coral most closely resembles *Schœnophyllum* Simpson,[1] which is so named from its long, thin, rush-like corallites. Its definite horizon is not mentioned in Simpson's paper, but as the specimen on which it was founded was labelled *Lithostrotion harmodites* it is presumably Carboniferous.

As it is natural to compare the Kambe Limestone corals with those of the Tithonian of Sicily, described by the Marquis de Gregorio, it may be noted that *Thecosmilia panormitana* de Gregorio (1884 ; and 1899, *Cœl. Tith. Sicilia, Ann. Géol. et Pal.*, Livr. 27, p. 19, Pl. III, Fig. 2) has a somewhat similar growth ; but the arrangement of the septa is essentially distinct, as they are more numerous and confluent at the centre ; so that to whatever genus *Thecosmilia panormitana* may belong it is not *Pleurophyllia*.

Fig. 1a.

Fig. 1b.

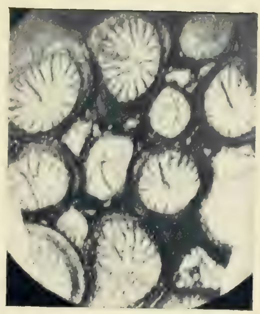


Fig. 1c.

Fig. 2.

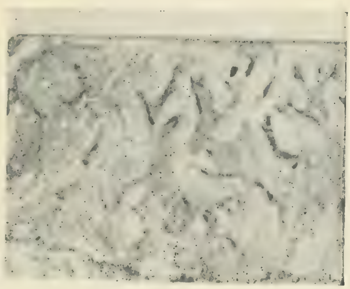


Fig. 3.

JURASSIC CORALS FROM EAST AFRICA.
PLEUROPHYLLIA AND DIPLAREA.

DIPLAREA, Milaschewitsch, 1876, *Kor. Natth.*, *Palæontogr.*, XXI, p. 229.

Type species.—*D. arbuscula* Milaschewitsch, 1876, *op. cit.*, p. 229, Pl. LI, Fig. 3. Corallian, Wurtemburg.

1. DIPLAREA NORTHEYI[2] N.SP., Pl. VI, Figs. 1, 2, Pl. V, Fig. 2

Diagnosis.—Large corallum with long, crowded, flexuous branches which subdivide repeatedly and form a massive cæspitose growth. The branches often subdivide at intervals of 10–20 mm.

Corallites circular; usually 8–9 mm. in dia.

Septa about four cycles—thin; those of the first three cycles join the columella. Intertrabicular spaces (or septal pores) numerous. Costæ faint. Columella large and loose.

Dimensions.—Corallum up to several feet in diameter. Corallites (in type) 8–9 mm. dia.

Distribution.—Kambe Limestone, Kambe, British East Africa. Probably also Buni Hill,[3] near Rabai.

Figures.—Pl. VI, Fig. 1. Part of a large corallum of the type specimen (No. 537), intergrown with *D. sikesi*, nat. size. Pl. V, Fig. 2. Part of a vertical section of the same specimen, to show the branching, nat. size. Pl. VI, Fig. 2. Part of a thin, transverse section of the same specimen, ×4 mm. dia.

Affinities.—This coral I regarded in the field from its mode of growth as probably a *Calamophyllia*; but thin sections show that it has perforate septa and therefore belongs to another family. Amongst *Diplarea* its corallum somewhat resembles that of *D. nobilis* Ogilvie (1897, *Kor. Stramb.*, p. 260, Pl. XI, Fig. 19), from the Portlandian of Moravia, by its large size and cæspitose, crowded growth; but the cross section of the corallites in *D. nobilis* is trigonal to irregularly elliptical, and the corallites are larger and more numerous. The new species agrees with *D. rugosa* (Koby, 1885, *Polyp. Jur. Suisse*, Pt. 4, p. 201, Pl. 52) in its circular calices and in the number of the septa; but *D. rugosa* has thicker corallites which are less branched. *Thecosmilia himerinicola* de Gregorio (1887; and 1899, *Cœl. Tith. Sicilia*, *Ann. Géol. et Pal.*, Livr. 27, p. 19, Pl. III, Fig. 4), from the Tithonian of Castello di Termini, Sicily, resembles this species externally; but its reference to *Thecosmilia* is doubtful, as its founder's generic determinations do not inspire confidence. The species is inadequately known, but its most distinct specific character is its well-developed, conspicuous costæ, which are very faint in *D. northeyi*.

2. DIPLAREA SIKESI N.SP.[4] Pl. V, Fig. 3, Pl. VI, Figs. 1 and 3

Diagnosis.—Corallum of small, repeatedly branched, crowded corallites.

Corallites average about 3 mm. in dia.; round to subquadrangular in horizontal sections.

Septa three complete cycles, with minute representatives of a fourth cycle in occasional loculi. The septa of the first and second cycles are subequal. Those of the third cycle are about two-thirds the length of the others and are usually free, but occasionally one of them unites with an adjacent septum.

Columella well developed and compact, united to the septa of the first two cycles. It is often obscured by the deposition around it of solid calcareous material, which gives the aspect of a large columella united to all three cycles of septa.

Dimensions.—Corallum: the type specimen (as reduced by section cutting) is a flat fragment, 35 by 20 mm., in horizontal diameter; and 35 mm. high. Corallites, 2½–4 mm. in diameter.

Distribution.—Kambe limestones. Kambe, near Mombasa. Mombasa pipe-line, at $\frac{12}{5}$ miles E. of the break-pressure tank.

Figures.—Pl. VI, Fig. 1. The small corallum in the upper part of the figure is a *D. sikesi* intergrown with *D. northeyi*: nat. size. Kambe (No. 537). Pl. VI, Fig. 3. Part of a transverse section of the type specimen (No. 16), ×4 dia. Mombasa pipe-line.

Affinities.—This species is characterized by the thinness of its corallites, and therefore grows in small coralla. The constancy of its distinctness in size from *D. northeyi* indicates that it is a distinct species and not the young of that species. The cylindrical form of corallites more than an inch long, show that they are full grown; young corallites of a larger species would increase more quickly to the diameter of the adult.

KOBYA, Gregory, 1900, *Jur. Cor. Cutch*, *Pal. Ind.* (9), II, pt. 2, p. 169.

Type species.—*K. crassolamellosa* Gregory, 1900, *op. cit.*, p. 170, Pl. XXI, Figs. 15–17, Pl. XXII, Figs. 2, 5–8, Pl. XXIII, 1, Pl. IIa, f. 7.

KOBYA ROSSI N.SP. Pl. VII, Figs. 1–4.

Diagnosis.—Corallum turbinate or with a nearly flat base ; elliptic or circular. The epitheca is thin and has low, concentric ridges. Corallites not concentrically arranged. Calices shallow. Septocostæ confluent. Septa 3–4 orders. The trabicular pillars in each septum are close and form a continuous plate, with occasional pores. The septa are subequal, and most of them join the columella, which is parietal and well developed. Synapticulæ usually hook-shaped ; vertically 1 mm. or .75 mm. apart.

Dimensions.—Corallum, diameter from 40–50 mm. up to probably three or four times as large. Calicinal centres, distance 3–8 mm. ; average 6 mm.

Distribution.—Kambe limestones, near Mteza, on the Mombasa pipe-line at $\frac{12}{5}$, and E. of the break-pressure tank.

Figures.—Pl. VII, Fig. 1. Base of a young corallum, covered by epitheca ; nat. size. Pl. VII, Fig. 2. Part of a thin horizontal section of another specimen, No. 12, ×4 dia. Pl. VII, Fig. 3. Horizontal section from a larger corallum (13, *b*), showing the septal structure and columella. Pl. VII, Fig. 4. Vertical section of 13, *a*, showing the septal trabiculæ and the hook-shaped synapticulæ, ×4 dia.

Affinities.—The genus in external characters is like *Microsolena*, but it differs therefrom by the greater continuity of the septa, which in horizontal sections (e.g., Pl. VII, Figs. 2, 3) appear lamellar, though perforate, and not as palisades of trabiculæ (*cf.*, e.g., *Microsolena stellata* Ogilvie, 1897, *Kor. Stramb.*, Pl. X, Fig. 6, or *M. tuberosa* Mich. in *ibid.*, Pl. X, Fig. 4, *b*).

Kobya occurs in the Bathonian rocks of Cutch, but the two species there are quite distinct from those of the Kambe Limestone. This new species agrees with *K. crassolamellosa* by the average size of the corallites, but differs by their irregular distribution and the wide spacing of the hook-shaped synapticulæ, which in *K. crassolamellosa* are about $\frac{1}{3}$ mm. apart.

K. lenticulata (Gregory, 1900, *op. cit.*, p. 172) differs by the concentric grouping of its corallites, its thin lenticular corallum, and larger corallites.

THECOSMILIA Edwards and Haime (1848, C.R., XXVII, p. 468). *Type species. Lithodendron trichotomum* Goldfuss (1827, Petref. Germany, p. 45, Pl. XIII, Fig. 6). Corallian. Germany.

THECOSMILIA SP.

Among the corals too imperfect for specific determination is a large, massive coral with corallites up to 90 mm. in diameter, with very spiny septa and many dissepiments and with apparently a parietal columella. It appears to be a *Thecosmilia*, of the group with the corallites united almost to the end, like *Th. truncata* Ogilvie (1897, *Kor. Stramb.*, p. 213, Pl. XIII, Fig. 16), which has corallites only about a third of the diameter ; another even-topped species, *Th. langi* Koby (1884, *Polyp. Jur. Suisse*, Pt. 4, p. 161, Pl. 49), has still smaller corallites.

In *Thecosmilia magna* Ét. (in Thurmann and Étallon, 1864, *Leth. Brunt.*, p. 385, Pl. 54, Fig. 11 ; Koby, 1884, *Polyp. Jur. Suisse*, Pt. 4, p. 166, Pl. XLIV, Figs. 1–3, from the Swiss Astartian) the corallum is also compact and has a similar subplane upper surface, but the diameter of the branches is only from 12 to 18 mm.

II. CORALS OF THE CORALLIAN

THAMNAREA Étallon (1864, in Thurmann and Étallon, *Leth. Brunt.*, p. 411).

Type species.—*T. arborescens* Étallon (1864, *op. cit.*, p. 412, Oxfordian and Corallian, Switzerland).

THAMNAREA HOBLEYI N.SP., Pl. VII, Fig. 5

Diagnosis.—Corallum massive ; an unpolished surface appearing as structureless limestone.

Corallites. 7 mm. in diameter ; confluent and margins indefinite. Septa obscure and developed as irregularly arranged trabiculæ, in which a radial plan is in places unrecognizable. Where the structure is more regular (as in Pl. VII, Fig. 5, *b*) the septa are numerous ; five orders are complete in full-grown corallites. The primary septa are thick and fusiform with strong, moderately sharp costæ ; the septa of the fourth and fifth orders are very thin and represented by faint lines of minute trabiculæ. Columella large and not clearly separated from the free trabicular ends of the septa.

Dimensions.—Corallum, part of a flattened, bun-shaped mass, 140 by 125 mm. in width, and 60 mm. thick. Corallites, diameter and usual distance of calicinal centres 6–8 mm.

Distribution.—Limestone, reported as interbedded in the Changamwe Shale, Coroa Mombasa.

Figures.—Pl. VII, Fig. 5, *a*. Part of a thin horizontal section, ×4 dia., showing the irregular, sponge-like aspect of the coral (No. 589). Fig. 5, *b:* part of one corallite from near the middle of Fig. 5, *a* × 16 dia., and showing the radial arrangement of the septal trabiculæ.

Affinities.—A large smooth, rounded block of limestone was collected by Captain Montagu and sent to Mr. Hobley as a fossil tortoise, the resemblance being due to its round surface and the plate-like aspect of some patches of veined calcite. The specimen had been bored by some circular pipes filled by oolitic limestone ; and in the hope of determining the nature of the organisms which had made these holes a section was cut and revealed the Thamnarean structure, which is remarkably irregular and sponge-like. So incomplete are the septa in this genus that Dr. Ogilvie placed it in the Madreporidæ.

The species of this genus are ill defined. This species differs from *Thamnarea amorpha* Gregory (1900, *Foss. Cor.*, Cutch, p. 194, Pl. XXVI, Figs. 1, 4–7, XXVII, Fig. 3) of the Bathonian of Cutch, which has much smaller corallites, their diameter being only 4 mm., and has three complete orders of septa. *T. tuberosa* Gregory (*ibid.*, p. 195, Pl. XXVII, Figs. 1, 2, 4, 5), also from the Bathonian of Cutch, has even narrower corallites, only 2½ to 3 mm. in diameter, and the surface of the corallum is humped and tubercular, a feature of which the internal structure of this Mombasa species gives no indication.

Thamnarea globosa Koby (1907, *Polyp. Bath. St. Gaultier. Abh. Schweiz. pal. Ges.*, XXXIII, p. 55, Pl. II, Figs. 15, 16) is worth comparison as a Bathonian species and as having moderately large calices ; but it is smaller, 10–40 mm. in dia., subpedunculate, and each corallite has only about twenty septa.

Th. pulchella (Ogilvie, 1897, *Kor. Stramb.*, p. 154, Pl. X, Fig. 14) has a small stem-shaped corallum from 8 to 10 mm. in dia., with calices only 1 to 1½ mm. in dia.

In some species of *Thamnarea* the structure is so obscure that the details have not been described by their founders or shown in their figures. Among such species *Th.* (?) *bacillaris* Koby (1888, *Pol. Jur. Suisse*, Pt. 8, XV, p. 413, Pl. CX, Figs. 9, 10) presents a general resemblance to this East African coral, but its septation is unknown ; the corallum, however, in *Th. bacillaris* has a mammilated surface and is built up of thin, concentric layers. In both these respects it differs from the Coroa Mombasa fossil.

In founding new species of *Thamnarea* it is necessary to consider some species of *Microsolena* which may be wrongly included in that genus, e.g., *Microsolena bruntrutana* Ét. (1864, in Thurmann and Étallon, *Leth. Brunt.*, p. 408, Pl. 57, Fig. 13) of the Swiss Corallian agrees closely with this coral in the size of the corallites, and by its apparently amorphous characters ; but as Koby left it in *Microsolena* it probably has the septal structure of that genus.

III. KAINOZOIC CORALS

FAVIA. Oken, 1815, *Lehrb. Naturg.*, III, 1, p. 67.

Type species.—*F. ananas* Oken. Recent. West Indies, etc.

FAVIA SOMALIENSIS Gregory (1900, *Quart. Journ. Geol. Soc.*, LVI, p. 35, Pl. I, Fig. 4). Pl. VI, Fig. 4.

Distribution.—Eocene beds, Uradu Limestone, Somaliland. Hadu, W. of Fundi Isa.

Affinities.—A small nodular coral, collected by Mr. Hobley N. of Mambrui, S.S.E. of Hadu, about 16 miles W. of Fundi Isa (which is a port S. of the mouth of the Tana), agrees in all essentials with that from Somaliland collected by Mrs. Lort Phillips. That species was assigned to the Cretaceous on the evidence of an associated mollusc. The corals of the Uradu Limestone indicated a higher horizon ; but it seemed possible that these corals might be due to the earlier appearance of these corals in the province of the Arabian Sea than in Western Europe. The other fossil has been redetermined as Eocene, with which age the fossil corals of the Uradu Limestone are fully consistent. In the specimen from W. of Fundi Isa the corallites are 4 mm. in diameter ; the multiplication of corallites by fission is shown toward the right-hand end of Pl. VI, Fig. 4.

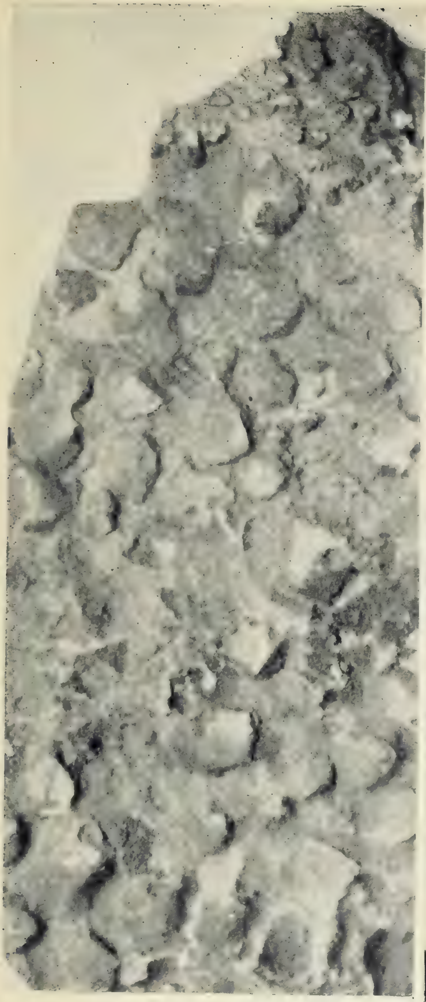
IV. PLEISTOCENE CORALS

A collection of corals from the Raised Reefs of Mombasa was made for comparison with those of the recent seas in order to test the length of time since the formation of the reefs.

The species collected and the regions they now inhabit are as follows :—

. *Mussa corymbosa* (Forsk.). Red Sea.

Fig. 1.



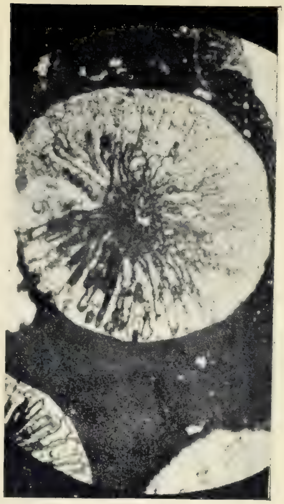
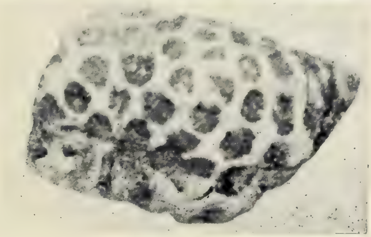


Fig. 2.

Fig. 3.

Fig. 4.



FOSSIL CORALS FROM EAST AFRICA.
DIPLAREA AND FAVIA.

2. *Cœloria arabica* Klunzinger. Red Sea. The valleys of the specimen collected are long and straight, and in this respect differ from those of both *C. sinensis* (Ed. and H.) and *C. leptoticha* Klz., both of which Ortmann[5] records from Dar-es-Salaam. He notes that his specimens determined as *leptoticha* have long calicinal valleys; they thus approximate to *C. arabica.*

3. *Prionastræa pentagona* (Esper.). Indian Seas. Corallites 5–8 mm. dia.; three cycles of thin septa, and a rudimentary fourth cycle; columella large and spongy; corallites irregular in size and shape.

4. *Prionastræa spinosa* Klunzinger. Red Sea; recorded from Dar-es-Salaam by Ortmann (1902, p. 662). This form has smaller corallites than the type, which is probably a variety of *P. tesserifera* Dana.

5. *Orbicella acropora* (L.). Indian Ocean.

6. *Orbicella laxa* Klunzinger. Red Sea. Possibly this species is only a thin-walled variety of *O. forskalana* (Ed. and H.)

7. *Solenastræa serailia* (Forsk.). The *S. forskalana* Ed. and H. Red Sea, Maldives, and Laccadives. This species is placed by Klunzinger in *Cyphastrea*, but it has solid septa. The Mombasa specimens agree exactly with that shown in a figure by Klunzinger.[6]

8. *Cyphastræa savignyi* Ed. and H. Red Sea, Indian Ocean. Probably *C. chalcidicum* (Forsk.) is the same species.

9. *Leptastræa solida* (Ed. and H.). Maldives and Laccadives. (Calices 1 to 1.5 mm. dia.)

10. *Porites solida* (Forsk.), = conglomerata, Esper., etc. Red Sea, Dar-es-Salaam, Mauritius, etc.

11. *Montipora* sp.

12. *Madrepora* spp. Numerous cylindrical branches.

These corals do not give any support to the idea that the raised reef which forms the southern margin of Mombasa Island is of any geological antiquity. They indicate no change in the general conditions, and represent the generic association and common living species of the East African coast.[7]

V. THE AFFINITIES AND AGE OF THE KAMBE CORAL FAUNA

It is natural first to compare the corals with those of G.E.A., where three Mesozoic faunas have been described by Weissermel (in Bornhardt, 1900, pp. 578–595, Pls. 26, 27).

The oldest of these faunas, which is determined as Callovian (*ibid.*,

p. 578, and explanation to Pl. 26), was obtained from Mamela, about 30 miles W. of Bagamoyo, and includes three species referred to *Isastrea* and *Thamnastrea*. The second fauna, of Upper Jurassic age, from 22 miles N.W. of Kiswere, includes *Diplocœnia*, *Calamophyllia*, and *Cladophyllia*, and from Mbinga, N.W. of Kilwa, *Cycloseris* and *Goniastrea*.

A lower Cretaceous fauna includes *Polyphylloseris*, *Thamnastrea*, *Montlivaltia*, and several species of *Astrocœnia*. Weissermel has also described some corals attributed to the early Kainozoic and Miocene, and some ranging from the Upper Kainozoic to sub-fossil.

The corals of the Kambe limestones belong to different genera from those of the Callovian and lower Cretaceous beds of "German" East Africa, since the faunas lived under different geographical conditions. The Upper Jurassic fauna presents a closer resemblance, as the characteristic corals grew under similar conditions.

Further from the Mombasa district Jurassic corals are known in North Madagascar, but they do not appear to have been described. The richest Mesozoic coral fauna of the western Indian Ocean is that of Cutch in India; but it appears to have lived in a different bathymetric zone from that of the Kambe Limestone. The feature of the Cutch coral fauna is the abundance of simple corals, especially *Montlivaltia*, and of small nodular species belonging to various genera; whereas the corals of the Kambe Limestone are branching reef corals which probably grew in a shallower zone than those of Cutch. The coral beds in the Kambe Limestone were probably formed as fringing reefs, while the Cutch corals lived in deeper water in the zone characterized by scattered nodular corals.

The most striking difference between the corals of the Kambe Limestone and those known from the Mesozoic rocks around the Indian Ocean is the presence of *Pleurophyllia*, which has the characteristics of a typical Rugose coral. The presence of this genus at once suggests comparison with that remarkable archaic coral fauna, found in the Upper Jurassic rocks of the Alpine area in Europe, of which some corals are obviously survivals from Paleozoic times.

The marked Rugose affinities of the septal characters of these corals is well shown in *Thecidiosmilia*, as shown by Koby's figures (Koby, 1889, Pt. 8, Pl. CXV, Fig. 4), reproduced as Fig. 10, which shows clear bilateral symmetry, as it starts with a pair of septa, and the later septa are definitely pinnate; and its resemblance to *Pleurophyllia hobleyi* is increased by the clavate form of the cardinal septum. This fauna was first described from the Portlandian and Kimmeridgian beds of Eastern France, adjacent to the Jura Mountains, by de Fromentel (1856, *Bull. Soc. Géol. Fr.* (2), XIII, pp. 851–865, and 1862, *Mon. Polyp. Jur. Sup.*, Pt. I, *Mém. Soc. Linn. Norm.*, XIII, No. 1). The existence of this Archaic fauna was confirmed and its range extended by Koby's monographs from the Jurassic and Lower Cretaceous corals of Switzerland, and later by Dr. Maria Ogilvie, from the Tithonian Stramberg beds of Moravia. This Alpine fauna is unrepresented in North-western France or in the British Isles, and appears to be absent from the Portuguese Jurassics, as its genera are not included in M. Koby's monograph thereon (1905, *Polypiers du Jurassique Supérieur*, in *Faune Jurassique Portugal*, *Commiss. Géol. Portugal*).

The presence of *Pleurophyllia* in B.E.A., therefore, strengthens the connection of the Jurassic of East Africa to the Mediterranean, and suggests that these Alpine Mesozoic Rugosa survived from Paleozoic to Jurassic times in a sea N. of Gondwanaland in South-western Asia, whence they spread north-westward through the Alpine Jurassic sea into Central Europe.

The Kambe corals accordingly give no precise evidence as to their age. The fact that the Rugose element in the fauna is most nearly allied to that of the Upper Jurassic and Lower Cretaceous of Mid-Europe is no evidence of their contemporaneity, for it must have lived on throughout the Jurassic and may have inhabited the seas of South-western Asia and Eastern Africa in any part of the Jurassic.

That these corals are pre-Corallian in age is indicated by their occurrence to the W. of the Changamwe Shale ; and they are probably pre-Callovian, as the limestones underlie a thick series of pre-Corallian sandstones.

Among the mollusca found with the coral bed Mr. R. B. Newton has identified a *Pecten* similar to *P. bipartitus* Futt., from the Corallian of Tanga (*Zeit. deut. geol. Ges.*, XLVI, p. 32, Pl. V, Fig. 4) ; others from the Mwachi River Crossing and Kaya Kambe, as *Gryphea aff. imbricata* (Krauss), from the Neocomian of South Africa and the Bathonian of Abyssinia ; from the limestone E.S.E. of the Jibana camping ground, *Exogyra aff. bruntrutana* Thurm., an Alpine Portlandian and Kimmeridgian species, which has been recorded from the Lagagima Limestone (Corallian to Kimmeridgian) of Shoa (*Zeit. deut. geol. Ges.*, XLIX, 1897, p. 582, Pl. 19, Fig. 1) and from the Kimmeridgian of G.E.A. (Bornhardt, 1900, Pl. XVIII, Figs. 11, 12) ;

and some fossils from the Mwachi River Crossing, as *Pseudomonotis echinata* (Sow.), a Bathonian species figured from G.E.A. by Müller (in Bornhardt, 1900, p. 518).

Mr. L. F. Spath (1920, pp. 311–320, 351–362) has identified the Ammonites collected from the Kambe Limestone as Bathonian, the age which seemed probable in the field. The Ammonites and corals therefore agree with the stratigraphical evidence as to the Bathonian horizon of the Kambe Limestone.

EXPLANATION OF PLATES

Plate V.

1. *Pleurophyllia hobleyi* n.sp. Kambe Limestone. Mwachi River crossing, Mombasa pipe-line.

Fig. 1, *a*. Section about nat. size ($\times\frac{3}{4}\frac{8}{1}$), showing both vertical and transverse sections.

Fig. 1, *b*. Part of upper surface of the same specimen, $\times\frac{1}{1}\frac{5}{7}$.

Fig. 1, *c*. Part of a thin section, ×2 dia.

2. *Diplarea northeyi* n.sp. Kambe Limestone. Kambe. Part of vertical section of the type specimen; nat. size. (No. 537.)

3. *Diplarea sikesi* n.sp. Kambe Limestone. Mombasa pipe-line. E. of the break-pressure tank. Part of a weathered surface of the type specimen, $\times\frac{1}{1}\frac{3}{4}$. (No. 16.)

Plate VI.

Fig. 1. Part of a specimen of *Diplarea northeyi*, with *D. sikesi* intergrown at 1, *a*. Kambe Limestone. Kambe; nat. size. (No. 537.)

Fig. 2. Transverse section of the type specimen of *D. northeyi*, ×4 dia. (No. 537.)

Fig. 3. Part of a transverse section of the type specimen of *D. sikesi*, ×4 dia. (No. 16.)

Fig. 4. *Favia somaliense* Greg. Eocene. Nr. Hadu, 16 miles W. of Fundi Isa (nat size). (No. 533.)

Plate VII.

Fig. 1. *Kobya rossi*, n.sp. Kambe Limestone, near Mteza, on the Mombasa pipe-line, $\frac{12}{5}$. Base of a young corallum, showing the thin concentric epitheca; nat. size.

Fig. 2. Part of a thin section, ×4 dia., showing the perforate, trabiculate septa. (No. 12.)

Fig. 3. Part of a thin horizontal section of another specimen (13, *b*), ×4 dia.

Fig. 4. Part of a vertical section of another specimen (13, *a*), showing the trabicular septa and hook-shaped synapticulæ, ×4 dia.

Fig. 5. *Thamnarea hobleyi* n.sp. Corallian Limestone. Coroa Mombasa.

Fig. 5, *a*. Part of a section of the type specimen, ×4 dia. The round

1.

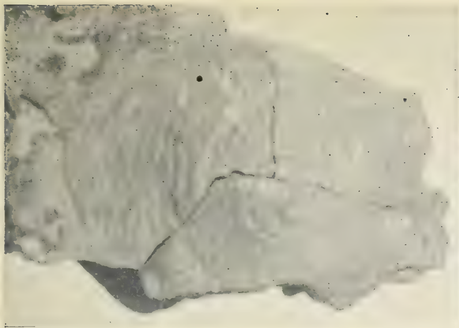


Fig. 2.

3.

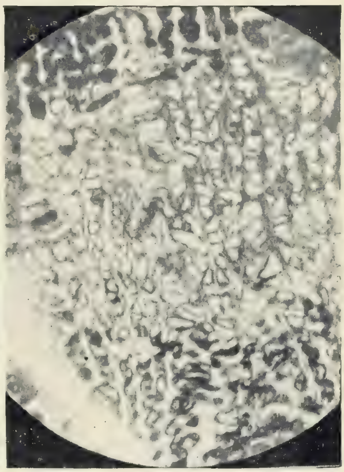
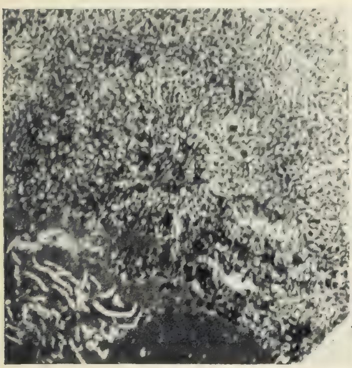


Fig. 4.

5a.



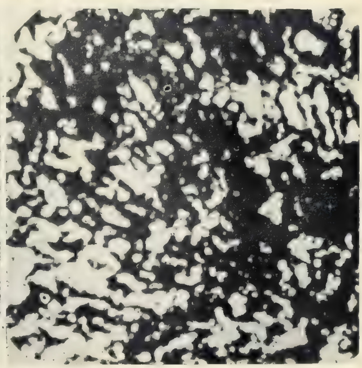


Fig. 5b.

JURASSIC CORALS FROM EAST AFRICA.
KOBYA AND THAMNAREA.

space at the base of the figure is the burrow of some mollusc. The irregular canals at the lower left-hand corner are probably fungal perforations.

Fig. 5, *b*. Part of the same section, × 16 dia., showing the radial arrangement of the septal trabiculæ.

[1] *Bull. N. York State Museum*, VIII, 1900, p. 214.

[2] Named after H.E. General Sir E. Northey, K.C.M.G., Governor of British East Africa.

[3] The coral collected by Mr. Hobley at Buni Hill, S.E. of Rabai, and described (Gregory, 1900, No. 2, p. 229), is probably this species. The specimen was poorly preserved, and as the perforate nature of the septa was not apparent, it was "provisionally determined" as an *Aplophyllia*.

[4] Named after H. L. Sikes, Esq., of the Water Supply Branch of the Public Works Department of British East Africa, and my companion in several journeys in the country in 1919.

[5] Ortmann (1892, p. 660).

[6] Klunzinger (1879, Pt. III, Pl. X, Fig. 12).

[7] The living corals of the Indian Ocean and Red Sea are described especially in C. B. Klunzinger, *Korallthiere Roth. Meeres*, 3 parts, 1877–1879; J. S. Gardiner, *Fauna Mald. and Laccad.*, II, 1904, pp. 755–790, Pls. 59–64, and Supp., pp. 933–957, Pls. 89–93; E. von Marenzeller, *Riff Kor. Roten Meeres*, *Denk. Akad. Wiss. Wien*, LXXX, App. 1907, pp. 27–97, Pl. 29; T. W. Vaughan, Madr. Fr. Somalil., *Proc. U.S. Nat. Mus.*, XXXII, 1907, pp. 249–266, Pls. XVII–XXVIII; G. Matthai, *Trans. Linn. Soc.* (2) *Zool.*, XVII, 1914, pp. 1–140, Pls. 1–38. Also A. Ortmann, "Koralriffe von Dar-es-Salaam und Umgegend," *Zool. Jahr.*, VI, 1892, pp. 631–670, Pl. XXIX.

CHAPTER VIII

The Volcanic History of British East Africa

VOLCANIC action is a natural result of extensive subsidences in the earth's crust. The outer crust is hard and rigid, and it bends by the opening of its joints or the formation of fissures, just as a roadway of granite blocks bends, when uplifted by a burst water-pipe, by the opening of the joints. The crust rests on a hot plastic material, which is displaced when a block of the overlying layer sinks into it. Some of the plastic material may be thereby forced up any opened joints, and if squeezed to the surface is discharged in a volcanic eruption. Hence foundering areas of the crust are usually bordered by lines of volcanos, while periods of only slight earth movements are times of volcanic peace. The Jurassic Period was characterized by world-wide volcanic rest, which continued into the Cretaceous; but by the end of that period the long, slow subsidence and shrinkage of the crust had established conditions of instability, which resulted in violent earth movements and the sinking of large areas. These Upper Cretaceous disturbances initiated one of the greatest volcanic periods in the earth's history, and volcanic activity of varying intensity lasted throughout the Kainozoic Era. Toward the middle of that era tumultuous upheavals of the crust raised many of the chief existing mountain systems, including the Alps, Pyrenees, the Atlas Mountains of North Africa, the mountain arc to the S. of Persia, the Himalayan System, the mountain systems of Western North America, and of the Andes. These mountain uplifts culminated in the Miocene, and were then coincident with world-wide volcanic eruptions.

Eastern Equatorial Africa, during the deposition of its Jurassic and Lower Cretaceous rocks, shared the world's general freedom from volcanic disturbance. At the end of this long rest eruptions burst out on a colossal scale. They deluged the country under floods of molten lava. The size of the area buried under volcanic material, the vast bulk of the ejecta, the variety of the lavas, and the prolonged duration of the eruptions make East Africa one of the great volcanic regions in the world.

B.E.A. lies in a volcanic zone which extends from Abyssinia to Nyasaland. The eruptions built up the two highest African mountains, Kilima Njaro and Kenya, and wide plateaus which, owing to their pleasant climate and fertile soil, are of all equatorial countries the most promising for European settlement.

The volcanic activity of this region is not yet at an end. The Western Branch of the Great Rift Valley includes several lofty craters (p. 270) which are in frequent eruption. In B.E.A. the Teleki Volcano was active in 1889, and, according to Cavendish (1898, p. 390), was blown to pieces in 1896, and a new vent, the Andrews Volcano, was opened 3 miles to the S.[1] Doinyo Ngai, "the Mountain of God," which lies a little S. of the British frontier, is apparently often in eruption, as the glow of molten lava in its crater upon the overhanging clouds is often seen at night from the soda works at Lake Magadi. Some of the volcanos within the Rift Valley in B.E.A. may be only dormant, for they contain active steam vents as well as sulphurous fumaroles, such as that in the Njorowa Gorge, a little to the W. of which Mr. Hobley found a bare volcanic cone that he estimates as not more than 100 years old.

In spite, however, of the recent date of some East African volcanos the country is now enjoying a quiet interval. Volcanic action is, however, dormant rather than extinct, and if fresh earth movements happen along the Rift Valley its renewal on a great scale is by no means improbable. Intervals of suspended volcanic activity have occurred occasionally, and it was most intense during the earlier and middle parts of the volcanic period.

Alkalic and Calcic Lavas.—The lavas discharged by the British East African volcanos, despite their great differences in age, have mostly one feature in common. They belong to the division of igneous rocks characterized by a high proportion of alkalies.

Igneous rocks are composed of four groups of constituents. The first group includes silica and alumina, and from their initials is derived its name of salic. The second group consists mainly of iron (Fe) and manganese; from their initials it is known as the femic. The third group includes the alkalies, potash and soda. Of the fourth group, the calcic, the essential constituent is lime. In the normal series of igneous rocks calcic material predominates over alkaline; but in the other series alkaline materials predominate over calcic. This fact was recognized by Prof. J. D. Iddings[2] in 1892, who called the division with predominant alkalies the alkalic, and that with predominant lime the sub-alkalic (it is also known as the calcic).

These two divisions may be distinguished by their constituent mineral species. The calcic division, in which lime is in excess, has none of the mineral species known as the felspathoids ; its felspars include species rich in lime, and its mineral species belonging to the groups of the pyroxenes and amphiboles are species containing lime or magnesia as the controlling constituent. The alkalic rocks, on the other hand, owing to the abundance of alkali, usually contain the felspathoids, such as nepheline, sodalite, analcite, or melilite. The pyroxenes are represented by species rich in soda, such as ægyrine and acmite ; and the amphiboles by the soda-charged species, such as barkevicite, riebeckite, and cossyrite. The microscopic examination of rock sections enables the alkali-rich and the alkali-poor igneous rocks to be easily distinguished by recognition of their constituent minerals.

The rocks rich in alkali are more abundant and widespread than was expected, and in 1897 Dr. A. Harker,[3] impressed by the frequency with which alkalic rocks occur in the Atlantic region and the calcic in the Pacific, referred to them provisionally as the Atlantic and Pacific " facies." He[4] used these terms more definitely in 1909, when he called the two types of rocks the Atlantic and Pacific " branches." This view had been meanwhile independently advanced by Dr. G. T. Prior (1903, pp. 261–262) and by Becke.[5]

So many alkalic lavas have, however, now been found in the Pacific region, and so many calcic in the Atlantic, that these geographical terms are no longer appropriate. The explanation offered of the association of these two divisions of rocks with the Atlantic and Pacific regions was that the calcic rocks are erupted in regions where the earth's crust is being folded into mountain chains, and the alkalic rocks through fault fissures beside subsiding areas. It has been further suggested that the high proportion of alkalies in the alkalic rocks was due to their having been enriched with soda from sediments that had been deposited on the ocean floors and were therefore charged with sea-salts. The volcanic rocks of B.E.A. belong to the alkalic division, and this explanation is not satisfactory in their case, since they occur far from the sea in regions exceptionally free from marine deposits. Deep-seated hot springs are generally alkaline, and the African lavas have probably come from the zone of alkali-rich material that feeds the alkaline springs. The alkali deposits of Lake

Magadi are probably fed from the same layer as that which produced the alkali-rich lavas of the adjacent country.

As many of the alkalic rocks are unfamiliar, a list of the igneous rocks referred to, stating their composition, is given in the Appendix, No. 8, pp. 415–417.

GEOGRAPHICAL TYPES

Volcanic activity has exercised a dominant influence on both the physical and political geography of B.E.A. It has built up the highest mountains and undulating uplands; it has spread out wide lava plains and, by undermining the crust, has led to great subsidences of the surface. It has controlled the political geography, since the volcanic districts, owing to the richness of their soils, are the main area of European settlement. The physical features directly due to volcanic action include five chief types: lava plains, volcanic uplands, volcanic necks, craters, and volcanic caldrons.

1. *The Lava Plains.*—The traveller by railway to Nairobi from the coast, after passing over the turfless wastes of the Nyika, finds a striking contrast in the aspect of the country when, at Magadi Junction Station, the line passes from the Eozoic gneiss to the lavas of the turf-clad Athi Plains. The lava plains, which are the chief home of the famous East African herds of game, are usually treeless but well-grassed downs; the total area of the lavas is about 7500 sq. miles.

The most important are the Kapiti Plains, of which the Athi Plains are the northern section, and the volcanic plateau of Laikipia, which extends northward from the western foot of Kenya and E. of Baringo nearly to Lake Rudolf. Lava plains with a less even surface occur between the south-western edge of the Kapiti Plains and Lake Magadi.

The common rock of the Kapiti Plains is a black lava with large white crystals of anorthoclase felspar and less frequent yellowish crystals of nepheline. These two minerals are both rich in soda, and their presence shows that the lava belongs to the soda-rich group. These plains are strikingly different from the lava fields around typical volcanos, such as Vesuvius and Etna. These mountains consist of a central pipe, from which has been discharged flows of lava and showers of fragmentary materials (tuff and agglomerate) that are due to some of the lava having been blown to pieces by explosions of steam. The lava streams solidify as they cool after their discharge; hence it is natural that the materials accumulate most abundantly immediately around the pipe, forming a ring-shaped hill with a central hollow known as the crater. From the crater radial lava sheets flow down the slopes of the mountain, becoming broader and thinner as they reach more level country.

This type of eruption therefore forms a conical hill, which slopes outwards with a graceful curve and encloses a deep central crater. In contrast to such volcanic cones are the lava plains of the Athi, beside the Uganda Railway and E. of Nairobi; they form vast, gently rolling downs; their surface is mainly of lava, and there are no conspicuous volcanic cones or beds of tuff.

Similar volcanic plains occur in the western states of America, as in Idaho, and in the Deccan of Western India, and they present the same three features—the vast expanse of lava, the absence of conspicuous volcanic vents, and the comparative rarity of tuffs. To explain these features it was suggested that these lava plains were not formed by eruptions from single vents, like Vesuvius, but by fissure-eruptions, the lava welling forth from fissures which might be hundreds of miles in length. Such long openings would allow the steam to escape quietly, and not with the explosive violence displayed where it rushes at high pressure through a narrow pipe. Fissure-eruptions would therefore deluge the adjacent country beneath floods of lava, while the fragmentary rocks (tuffs), due to explosive eruptions, would be scarce. The possibility of fissure-eruptions was supported by the occurrence, as in Scotland, of numerous dykes, which are long fissures filled with igneous rock; and these dykes, it was suggested, once reached the surface and discharged their molten rock in fissure-eruptions.

Further study, however, of the lava plains for which the fissure-eruption hypothesis seemed most suitable has not confirmed this attractive theory. Thus in Victoria, to the W. of Melbourne, extends a vast basalt plain; mining operations beneath the Victorian lava sheets have shown that they were not fed by fissures, but by numerous isolated vents, from which the flows overlapped, and thus formed continuous lava plains. Such evidence is not available from the East African lava plains; but if they had been fed through fissures the extension of the dykes should be exposed beyond the edges of the lava sheets. But I could find no adequate number of dykes, and I was therefore, in 1896, driven to the conclusion that the East

African lava plains were due to eruptions through numerous vents, of which the flows united as widespread lava sheets. The vents are probably arranged in a network at points of special weakness due to the intersection of fractures made during the uplift of the plateau. I there suggested (G.R.V., p. 219) that such lava sheets form the "plateau type" of volcanic eruption. They are the result of the rupture of the surface during the uplift of an area into a plateau, as that kind of uplift forms many scattered vents instead of comparatively few vents along a single line;[6] and the plateau structure is maintained by the resistance of the lavas to weathering and the greater excavating power of the rivers along the margin of the lava sheets. The craters and the beds of tuff would be swept away by wind and rain,[7] and the surface would thus be left as gently undulating plains of lava. The sites of the craters are marked by the low circular or elliptical rises, of which there are many on the lava plains, and which probably are due to the plugs of hard lava in the throats of the volcanos.

2. *The Volcanic Highlands.*—The great lava plains are obviously old; for denudation has swept away all but the base of the eruptions. The volcanic uplands of B.E.A. are also ancient, for their craters also have been destroyed and the country has been dissected by deep valleys, and the rocks have decomposed into thick sheets of rich soil. These volcanic uplands consist of rocks that are more varied in chemical composition and more easily weathered than the phonolites of the lava plains. They consist mainly of trachytes, rhyolites, and basalts, through which the streams have cut numerous valleys; and as the rich soils support rich vegetation and dense forests the streams are perennial. These rich-soiled, well-watered uplands form the most valuable agricultural land in the interior of B.E.A.; they include the Kikuyu Uplands, which extend from the southern foot of Kenya to the edge of the Rift Valley near Mount Ngong, the still forested highlands of Nandi and Lumbwa, and the grassy Guas Ngishu plateau on the western side of the Rift Valley.

3. *Volcanic Necks.*—The essential part of a volcano is the channel through which molten rock from the lower crust is raised to the surface. This passage is usually more or less circular in section, and is known as the "pipe"; its upper part is the "throat," which ends above at the "vent," or mouth. The materials discharged by the volcano accumulate around the vent and build up the volcanic cone; its central depression, which is kept clear by the explosive uprush of

steam, is the "crater." The volcanic cone may be built up either of lava or of beds of fragmentary volcanic materials, which are known as volcanic ash if fine-grained, as tuff if the fragments vary in size from that of a small nut to that of a coconut, and as agglomerate if many of the pieces are larger than coconuts. A volcanic cone, especially when largely composed of tuff or of a combination of lava and fragmentary material, is very easily destroyed by wind and rain, so that the life of a volcanic crater is brief. The most resistant part of a volcano is the plug of lava that has solidified in the throat; and when the crater walls and the tuff around the plug are swept away it remains as a pillar or hump raised above the general level of the country. From its formation in the pipe below the mouth such a plug is known as a volcanic neck. Volcanic necks are usually conspicuous surface features in districts of ancient volcanic activity.

The greatest volcanic neck in B.E.A. is Mount Kenya (Pl. VIII), which consists of a plug of nepheline-syenite and kenyte left exposed by the wearing down of the higher parts of the original mountain (Gregory, 1894 and 1900; *cf.* Chap. XII and the frontispiece).

The older peak of Kilima Njaro, known as Mawenzi, is a volcano in the same extreme stage of decay as Kenya. Many other mountains in the volcanic area of East Africa are necks of ancient volcanos; they include Mount Ol Gasalik, Ol Asagut, Ngong, Settima, Niandawara (Nandarua), Doinyo Nyuki Dogilani (Mount Shelford, N.E. of Lake Magadi), and numerous low hills on the Kapiti and other lava plains.

4. *The Volcanic Craters.*—Though the older East African volcanos have been reduced to the condition of volcanic necks, the latest volcanic eruptions have been so recent that the cones are still well preserved and retain their craters. Kibo, the modern peak of Kilima Njaro, which is seen rising majestically above the lava plains and the Nyika, has a well-preserved crater filled with snow and ice.

One of the most accessible of the well-preserved craters in B.E.A. is Longonot, beside the Uganda Railway, S. of Naivasha. This mountain has a large and perfect crater, and that it was formed at a comparatively modern date is further indicated by a powerful steam jet which was in action in 1893.[8]

Most of the volcanos with well-preserved craters occur in or beside the Rift Valley, such as the Teleki Volcano at the southern end of

Photo by] [*J. D. Melhuish, Esq.*

THE EASTERN FACE OF MOUNT KENYA,

showing the vertical structure of the rocks and a smoothed rock-surface—ice worn during the former extension of the glaciers.

Lake Rudolf, and Doinyo Ngai, near Lake Natron (S. of the British frontier). A well-developed linear series of craters form the Kyulu Chain, which may be seen from the Uganda Railway between Kibwezi and Simba stations. Kilima Njaro itself, the highest of African mountains, is one of a transverse lineal series which runs E. and W., and includes Mount Meru, Mondul, and Essimingor; while Doinyo Ngai, which is the most active volcano along the Rift Valley, is apparently the eastern vent on the same line.

Mount Suswa has a large circular cavity which can be well seen from the Kedong Scarp. In 1893 I interpreted this cavity as a normal crater, and the block in the middle as a secondary cone built up after the destruction of a higher cone of which the outer ridge is the remnant; but from information given me by Mr. McGregor Ross it appears that the inner peak may be part of an older cone which has been dropped by subsidence into the central depression.

5. *Volcanic Caldrons.*—The alternative explanations of Mount Suswa show that some crater-like hollows may be formed by subsidence and not by upbuilding, and are therefore not true craters. The typical representative of these subsidence hollows is that containing the famous lava lake of Kilauea in the Hawaiian or Sandwich Islands of the Central Pacific. This depression is large, relatively shallow, and flat-floored; it occurs at the summit of a dome-shaped mountain, of which the height is low in comparison to its width. This depression is known as a caldera, from the Spanish word for a caldron, and these formations are therefore known as volcanic caldera or caldrons.

The most remarkable volcanic caldron in B.E.A. is Menengai, on the floor of the Rift Valley, N. of Nakuru (Pl. IX, Fig. A). It has been described by Sir John Bland-Sutton (1911, p. 233); it consists of a low rim which in places rises gently above the plains and is bounded on the inner side by a precipitous wall surrounding a vast central basin, which from the view on the eastern margin appears to be a caldron. The floor is covered by lava flows, some of which are apparently of modern date. In the midst of the floor rises a hill of which the structure is unknown.

A magnificent series of volcanic caldrons occur S. of the British frontier in the highlands W. of Lake Manyara. These highlands have been built up by volcanic eruptions; while a series of infalls around some of the vents, due doubtless to the collapse of the foundations, has produced gigantic caldrons. The mountains are well known by the work of German explorers (see especially the fine monograph by Jaeger, 1913, pp. 135–157) as the Reisenkrater Gebirge; but as the largest and most remarkable are due to the subsidence of the floor and not to the upbuilding of the walls around the existing spaces (as was recognized by Jaeger, 1913, p. 125), the name of "The Giant Caldron Mountains" appears a suitable British rendering of the term. The greatest of these caldrons, Ngorongoro, is 14 miles across; Ol Olmoti is 5 miles across, and Elanairobi is slightly more than five. That Ngorongoro was not due to an explosion, but to a hollowing ("renforcement") of the magma, was the explanation adopted by Jaegar (1908, p. 264).

Dykes and Sills.—In most volcanic areas many of the igneous rocks occur as intrusive sheets, known as dykes when vertical or steeply inclined, and as sills when more horizontal. One of the remarkable features in the volcanic area of B.E.A. is the apparent scarcity of dykes and of intrusive rocks. Their fewness is doubtless due in part to the fact that they are of subterranean formation and in B.E.A. have not often been exposed at the surface. Abundant dykes are displayed in the Alpine zone of Kenya; on the walls of the Njorowa Gorge; and in the railway cuttings on the lower slopes of Tindaret. Near the coast where denudation is more effective, only the intrusive rocks remain, as at Jombo; but, as a rule in B.E.A., even where denudation has cut deeply into the volcanic foundations, dykes appear to be unusually few.

The volcanic eruptions of B.E.A. and the formation of the Rift Valley have been regarded by some authorities as comprised within one short chapter of geological history. Suess represented the Rift Valley as formed by earth movements confined to the two latest geological periods; a similar view has been adopted by other authors and recently expressed by Prof. Frech (1917, p. 280).

The Rift Valley, however, includes such a great variety of lavas, its walls give evidence of such long intervals of time between the successive series of eruptions, and of earth movements at such distant dates, that I was forced to the conclusion that the Rift Valley and its associated volcanic eruptions had a long and broken history. This view was adopted in a classification which divided the volcanic eruptions of B.E.A. into six chief series, of which the earliest happened in the Upper Cretaceous, contemporary with the Deccan traps of India and with the chief subsidences of the

Photo by] [*H. L. Sikes, Esq.*

(*a*) Lava-Terraced Inner Wall of Menengai.

Photo by] [*H. L. Sikes, Esq.*

(*b*) Upper Part of Njorowa Gorge,

where the floor is flat, at the foot of cliffs of comendite lavas.

Indian Ocean. This classification is summarized in the following table :—

Time Division	East African Representatives	Volcanos	Chief Lavas	Geographical Features
Pleistocene—Upper		Longonot ; D. Ngai, etc.	phonolitic trachyte and basalt.	Last R.V. faults and eruptions.
Pleistocene—Lower.		Suswa, Kilima Njaro, Kyulu Chain, etc.		
Pliocene.	Naivashan (including the Aden Series).	D. Buru ; Elgon.	Nephelinites and Comendite.	Second main series of R.V. faults.
Miocene.	Laikipian.	2nd Plateau eruptions.	Basalts and augitites.	
Oligocene.	Nyasan.			Great Lakes and 1st R. Valley faults.
Eocene.	Doinyan.	Kenya, Settima.	Kenyte and Phonolite.	
Cretaceous—Upper.	Kapitian.	Kapiti, etc., lava Plains.	Phonolite.	Beginning of the Volcanic Period.

The evidence for this classification will be considered in Chap. XVI, after an account of the volcanic areas and of the Rift Valley between Lakes Baringo and Magadi ; but it is convenient to include it here, as its nomenclature is used in the succeeding descriptive chapters.

[1] Doubt has been expressed as to this reported change in position. Wellby (1900, p. 298) refers to passing the Teleki Volcano in 1899. Mr. Hobley (1906, p. 473) quotes native accounts of boiling water and underground noises at the Andrew Volcano ; but they might have been based on reports from the Teleki Volcano.

[2] Iddings, *Bull. Phil. Soc. Washington*, XII, pp. 183–184.

[3] A. Harker, *Sci. Progr.*, VI, 1897, p. 26.

[4] A. Harker, *Nat. Hist. Igneous Rocks*, 1909, p. 90.

[5] Becke, *Tscherm. Min. Petrog. Mitt.*, XXII, 1903, pp. 248–250.

[6] Prof. C. Uhlig, of Tübingen (1912, p. 566), supports the explanation of the Kapitian lavas by plateau eruptions at intersecting fractures, which he says are sufficiently numerous; he agrees that the eruptions were through many small vents.

[7] In a traverse of part of the "Deccan Traps" in India, in 1917 and 1919, I found vents and tuffs more numerous than I had expected from the general descriptions of that volcanic formation.

[8] A sketch of it is given in the G.R.V. (Pl. X, p. 98). Subsequently either the steam vent ceased for a time or was not observed; recent visitors to the mountain have seen it again in operation. Mr. Hobley, in December, 1905, saw a dozen vents in action.

CHAPTER IX

The Baringo Basin

THE interpretation of the Rift Valley required a transverse geological section to show the structure of the walls and the relations of their rocks to those which form the floor, to compare the rocks on the opposite walls, and to determine whether the walls coincide with faults. I had intended, therefore, in 1893 to prepare a section near Lake Naivasha from the summit of the Mau Scarp across the Rift Valley to the eastern plateau. The Masai in that neighbourhood were, however, then so swarming and troublesome that geological survey was impracticable, and I hastened northward hoping to find more suitable conditions. A series of excursions from a camp S. of Lake Baringo and the examination of the Laikipia Scarp during the march towards Kenya supplied the necessary data for the section and gave clear evidence of faulting and of the sequence of most of the volcanic series.

The fame of Lake Baringo dates from the time when the interior of B.E.A. was known only from the reports of Swahili traders who used it as a base camp while dealing with the tribes of Karamojo, or resting their caravans before crossing the Elgeyo Mountains to Uganda or preparing for the arduous return march, burdened with slaves and ivory, through the wide, foodless tract between the lake and the plantations of Kikuyu-land. The name occurs in the Zanzibaris' marching song, " Hasten, hasten, as far as Baringo ; but a little further than you are at Uganda." Baringo is a much smaller lake than was represented on the maps based on these early reports, as they combined it with Lake Rudolf. It is roughly oblong, about 12 miles long by 5½ miles wide, and at the level of about 3200 ft.[1] It lies in an apparently shallow depression on the floor of the Rift Valley, which descends northward to the arid lowlands S. of Lake Rudolf. The lake has no visible outlet, yet its waters are quite fresh. As Joseph Thomson anticipated, it has a subterranean outlet ; for at several points along the north-eastern shore I observed in May, 1893, the water pouring freely into the lavas. This water, no doubt, flows northward and feeds the springs and water-holes of the Kogore, one of the head-streams of the Sugota The Kogore Valley, 5 miles from the lake, is 100 ft. lower and descends quickly to the N.

Baringo is situated in a swampy alluvial plain which extends as bays into the hills. The alluvium is bordered by terraces rising about 50 ft. above the present lake level; they consist of banks of sand and silt, with many lake-worn boulders and beds of shingle. The finer-grained beds contain numerous fresh-water shells, such as *Corbicula fluminalis*, which are not now living in the lake but still exist in the Nile basin. At various places in these old beaches (e.g., at the S.E. corner near the Guaso Arabel) mixed with the shells are fragments of pottery and obsidian flakes which mark the camps of neolithic man. The old greater Lake Baringo, judging from its

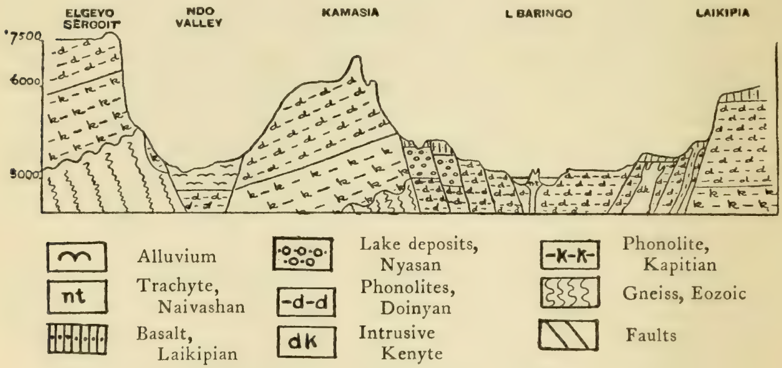


Fig. 13.—Section through the Baringo Basin from W. to E.
Scale of length, 1 inch = about 16 miles.

shells, was fresh water, and it probably discharged northward towards Lake Rudolf through the Lobat Pass. Its summit (according to my measurement, Gregory, 1894, p. 61, is 3310 ft.; according to the G.S., G.S. map, Baringo, 1912, it is 3307 ft.) is now above the level of the terraces; but it has probably been uplifted by a warping of the basin, which also led to the subsidence at the southern end. This tilting of the basin is indicated by the very different condition of the shore lines at the two ends of the lake; the northern shore is irregular and indented and has bare, rocky headlands; the southern shore has long, even lines and consists mainly of alluvium. The difference may be partly due to the three chief rivers entering the southern end and burying the irregularities of the shore beneath silt; but that fact does not explain the gradual southward fall in level of the rocky summits and their disappearance beneath the alluvium. The deposition of most of the silt there is, in fact, probably due to its being caught in the depression. Direct evidence of the sinking of the southern end of the lake is afforded by the southward dip of the lavas N. of the Ndau River.

The original drainage around Lake Baringo has been disturbed by earth movements. It was probably through two now riverless valleys N. of the lake. The main Baringo river flowed from the S. past Njemps across the site of the lake, and through the Lobat Pass (3307 ft.) to the Kogore. This river has been dismembered by the subsidence of the lake and the uprise of the Lobat Ridge. The second river, the Mukutan (the Mogodeni of von Höhnel, etc.), rises on Laikipia and flows N.W. until, E. of Baringo, it suddenly bends back and drains into the lake through the great swamp on the eastern shore. The Mukutan, however, must originally have continued to the N.N.W., through the pass (3336 ft.), between Korossa (4752 ft.) and Chebchuck (4543 ft.) into the valley of the Komall, a tributary of the Kogore. The subsidence of the southern part of the lake basin and uprise of the ridge to the N. diverted the Mukutan from the Komall into the lake.

The influence of earth movements in the Baringo basin is very See map p 212
conspicuous. The basin is bounded W. by successive platforms due to the faults of the Kamasia Range, and E. by the fault scarps of Laikipia and its foothills. The Laikipia Scarp forms a straight wall E. of the lake ; it trends almost due N. and S., and its fault is apparently continued N. by the narrow N.–S. block to the N.E. of Pakka. That mountain appears to be a volcanic neck on a vent close to the eastern boundary fault, and its eruptions have buried the southern end of this block and obscured the adjacent scarp.

E. of the main Laikipia Scarp and about 7 miles nearer Baringo is a lower fault scarp which forms the hill of Karau, and further S. the eastern front of the Laikipia foothills E. of Njemps, and at a still lower level the faulted hills of Lolbogo, about 4 miles E. of Njemps Ndogo. The older major fault scarps trend N. and S. ; they are cut across by younger faults which, where they strike the shores of Baringo, usually trend N. 15° E. The minor fault scarps are very numerous and break up the floor of the valley into a succession of minor rift valleys and fault blocks. I noted it at the time as the Clapham Junction type, from the resemblance to successive platforms separated by sunken railroads. This arrangement is well developed along the northern shore of the lake, where there are ten parallel faults. A group of six faults, also trending N. 15° E., occurs on the eastern shore, just S. of Logurdogi (Loroidok). That the N. 15° E. faults are the later is indicated on the north-western shore, where they cut across the scarps due to the N.–S. fault that forms the eastern boundary of the Lobat Pass.

On the western boundary of that pass is a conspicuous crag (3404 ft.) of phonolitic-trachyte, and the greater antiquity of these N.–S. scarps on both sides of the pass is shown by their having been cut through by the stream that excavated the valley between the 3404 ft. crag and its former southward continuation. Another series of faults, including at least three, cuts across the Lolbogo Hills, S. of the eastern side of the lake. The old volcanic hills of Korossa and Logurdogi are also cut across by the N. 15° E. faults, while they obscure the N.–S. faults ; so that their eruptions happened later than the N.–S. faults, but earlier than those trending N. 15° E.

The Volcanic Rocks.—The oldest lava near Baringo appears to be a phonolite, of which some varieties are spherulitic ; it outcrops at the foot of a hill which my guide called Doinyo Lersubugo, and is marked on the G.S., G.S. map as Karau. This rock has been described by Dr. Prior (1903, p. 241) as a phonolite of his group C, the other representatives of which occur on the Kapitian Plains. It appears that the Kapitian phonolite is exposed at the foot of the Laikipia Scarp, as it so often is on the margin of the volcanic area. Near the same place I collected (G. 321) an augite basalt. Further E., at the foot of the upper Laikipia Scarp, where the Mukutan River passes the old station of Baringo, Teleki collected a specimen determined by Rosiwal as an augite-andesite ; but as the felspar is labradorite and the rock contains some olivine, it is rather a basalt than andesite.

Rocks belonging to the older phonolites (which are broken by the N.–S. faults and earlier than the N. 15° E. faults) occur to the N. and N.E. of the lake at Logurdogi and its parasitic cone, and also W. of the Lobat Pass.

Teleki's basalt from the Mukutan was perhaps not *in situ*, but may have been a boulder washed down by the river or fallen from the basalt sheet on the summit of the upper scarp.

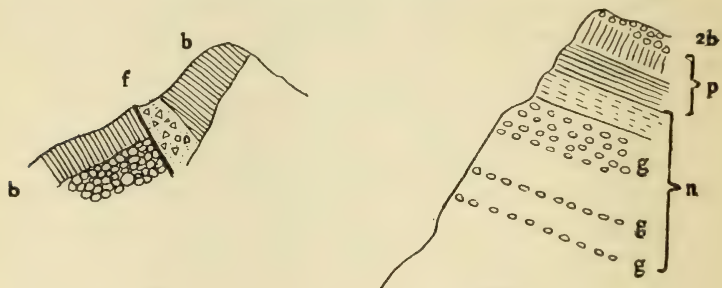
The later volcanic rocks around Baringo belong to the post-basaltic series and are mainly trachytic. A specimen (G. 311) from the crags to the S. side of the middle headland of the western shore has been described by Dr. Prior (1903, p. 241) as a phonolitic-trachyte. The same rock occurs at the faulted volcanic necks of Korossa—the Erri Mountains of the older maps.

The volcanic series represented on the shores of Baringo are (1) the Kapitian phonolite at the foot of the first or lower Laikipian Scarp; (2) the Laikipian basalts, unless the specimen described by Rosiwal was obtained from a fallen boulder; if it occurs *in situ* at Baringo Station, the basalt there probably rests on the older phonolites, as it does W. of Baringo on the upper Ndau River; (3) the phonolitic-trachytes which cover most of the floor of the valley; they are much faulted and probably belong to the same period (Laikipian) as those on the western plateau around Londiani; (4) a later series of phonolitic trachytes discharged by the last eruptions built up the disrupted volcano in the lake, and probably belong to the same stage as the Red Mountain (Doinyo Nyuki), i.e., to the earlier part of the Pleistocene.

I. From Baringo to Kamasia

Njemps Ndogo (3270 ft.) was in 1893 an important fortified village. It stands on an alluvial plain formed by three rivers—the Maji Moto, from the hot springs near Lake Losuguta or Hannington, the Tiggeri, and the Ndau, which discharge into the southern end of Lake Baringo. The clays and swamps of the later alluvium are bordered by raised terraces (*v.* p. 108) which mark a former extension of Lake Baringo; they consist of sands and loams, of which there is a section 15 ft. high by the ford of the Tiggeri, W. of Njemps Ndogo. Immediately W. of the ford (alt. 3430 ft.) the ground rises to a plateau, the dissected eastern edge of which is at about 3600 ft. The plateau is littered with large boulders, sometimes 20 in. in diameter; its foundation is a greyish lava, with distinct glassy felspars and dark specks of soda amphiboles. The rock has been described by Dr. Prior (1903, p. 238) as the type of the Kamasia phonolite, a variety characterized by the abundance of soda-pyroxene and small tufts of minute soda-amphiboles (riebeckite, cossyrite, etc.). One variety of this lava is a columnar flow a quarter of a mile up the Tiggeri from the ford, while at some places on the plateau the vesicular and ropy upper surface is exposed. This first plateau is bounded to the W. by a N. and S. ridge which forms the second fault scarp W. of Njemps—the edge of the 3600 ft. plateau being the first. At the base the rock is a fissile phonolite (G. 351), which is further exposed to the N.E., where it rests upon a spheroidal phonolite. This plateau is bounded to the N. by the valley of the Ndau River, which flows eastward from Kamasia into Lake Baringo.

On the floor of the Ndau Valley the phonolites are exposed until up-stream they are buried beneath lake clays and river gravels; these beds are covered by the sheet of basalt (G. 389) which forms the surface of the higher part of the second plateau. This basalt overlies a columnar phonolite, 20 ft. thick, which rests upon the spheroidal light grey phonolite also seen in the lower plateau. This spheroidal phonolite appears to have been a devitrified glassy lava, as it is traversed by perlitic cracks, and it corresponds with the spheroidal phonolite of the upper part of the scarp above Lake Hannington (*v.* p. 114). Following the Ndau westward, the columnar lava



A   B

A. Columnar phonolite resting on spheroidal phonolite and faulted at *f*.
B. Vesicular basalt, 2*b*; phonolite, *p*; *n* = Nyasan lake beds with gravels, *g*.

FIG. 14.—Sections in the Ndau Valley, W. of Lake Baringo.

thickens and forms a line of crags 80 to 100 ft. high along the southern bank of the river. The columns sometimes form radial masses. One instructive section shows the columnar lava broken across by a N.–S. fault (see Fig. 14, A). The rock on the western side has been downthrown and steeply tilted, apparently between two N.–S. faults. Sections along a tributary joining the Ndau from the S.W. show that the sedimentary beds below the basalt are baked at the contact. The top of the cliffs (Fig. 14, B) is formed of a vesicular basalt containing many zeolites; beneath this rock is a columnar phonolite which weathers into spheroids; the lowest layer is compact. Beneath this phonolite flow is a thick series of fine-grained, evenly bedded lake silts; interbedded with them are three beds of a coarse gravel containing large boulders; these gravels appear to have been formed as the delta fans of torrential rivers. In some of the sections along the Ndau the basalt rests upon a very fine white china clay which has been baked into a pure white porcellanite. Further up the Ndau the valley contracts, while the southern bank consists of a straight line of crags probably formed along an E.–W. fault. The lake clays and gravels continue to outcrop below the lava. The pebbles in the gravels include various types of phonolite similar to those which form the hills to the W. I examined a large number of pebbles from these gravels in the expectation of finding amongst them some of quartz, gneiss, or schist, since Thomson (1887, p. 272) had reported the range as composed of metamorphic rocks, and it was so represented on the sketch map by Toula (1891). I was unable to find any rock except volcanic.

The name given to the upper part of the Ndau Valley in 1893 was the Kamnye, which was also used in the time of Thomson. From the Kamnye, at the level of about 4000 ft., a track leads south-westward to a pass at 4450 ft., flanked on either side by the spheroidal pink weathering phonolite (G. 364). The hills around this pass are more rounded and less regular than the surface of the flat-topped basalt plateau S. of the Kamnye. W. of the pass is the valley of Mkuyuni, once an important camping-place on the Swahili caravan road to Uganda. Its stream flows northward, and the G.S., G.S. map, Sheet Uasin Gishu (1913), shows that its valley bends eastward to join the Kamnye-Ndau. W. of Mkuyuni is the summit of the Kamasia Plateau ; it consists of two main ridges. The eastern is crossed at the level of 6100 ft., S. of the hill known as Katura, which is the southern end of the mountain marked on the Guas Ngishu sheet as Marop. The summit of this plateau consists of a compact phonolite resting upon a grey earthy, fissile phonolite (G. 371), which rests upon a compact dark phonolite. These rocks are also shown descending the western slope into a valley, about 100 ft. deep, on the floor of which is a vesicular phonolite (G. 372). The western side of this valley rises to the western ridge (6600 ft.), the summit of which (G. 370) is a dark phonolite.

Neither on the summit of Kamasia nor among the eastern foothills could I find any exposures of metamorphic rocks or any indications of their presence, either in the soils or on the river beds.[2] Kamasia is a plateau of volcanic rocks with some contemporary sedimentary beds. It includes three chief series. The lowest belongs to the upper part of the phonolite series ; for I found amongst them no rocks similar to the Kapitian phonolite. These phonolites belong to the Doinyan Series and are covered by lake beds and torrential river gravels, the pebbles in which are derived from the older phonolitic series. These lake beds, from their extensive development in Kamasia, I regarded as formed in a Lake Kamasia, one of the lakes of the Nyasan Epoch. That the lake beds are shown to be earlier than the third series, the Laikipian, is proved by the evidence of super-position and by the baking of some of the clays into porcellanite where they were in contact with the basalt flows.

II. The Valley from Baringo to Naivasha

S. of Baringo the next significant area is beside Lake Hannington (Pl. X), known in the district in 1893 as Lake Losuguta, and in the basin of a small lake, which has been restored to the maps as Lake Solai.[3] This lake lies on the platform which rises in a precipitous scarp 1500 ft. high E. of Lake Hannington ; but, owing to the floor of the Rift Valley rising to the S., the scarp W. of Lake Solai is low. The platform is cut up by an elaborate series of N.–S. faults. It consists of the Kapitian phonolite. The associated phonolites are well exposed on the scarp E. of Lake Hannington, which shows the following section :

The crag E. of the scarp (at about 5800 ft.) belongs to a thick flow of coarse phonolite of the Kapitian type, of which the lower part is fine-grained and the base vesicular. An adjacent ravine shows the vesicular base of the plateau phonolite, resting on fine-grained, baked volcanic ash, which dips 15° E. Descending the main scarp to the lake, the upper edge is formed of a compact dark green rhyolitic-phonolite at 5500 ft., beneath which, at 5300 ft., is a spheroidal lava which when weathered is light grey and streaked with pink.[4] At 5250 ft. is a black, moderately coarse-grained phonolite with light green patches, beneath which, from 5225 ft. down to 5100 ft., is a flaggy black phonolite (G. 297). At about 5070 ft., forming a second terrace on the scarp, is a spherulitic rhyolitic-phonolite (G. 298), with well-marked flow structure. At 5000 ft. the rock (G. 299) is somewhat more massive and is spotted. At 4960 ft. (G. 301) is a bed of black phonolite which Dr. Prior (1903, p. 238) determined as his Losuguta type ; it becomes vesicular by weathering. Then follows a flow, about 100 ft. thick, of which the upper part is a compact rhyolitic-phonolite ; the middle band, 20 ft. thick (at about 4800 ft.),

Photo by] [*W. McGregor Ross, Esq.*

(*a*) THE SOUTHERN END OF LAKE HANNINGTON.

The Northern Wall of the Rift Valley is seen in the far distance.

Photo by] [*Dr. J. W. Arthur*

(*b*) THE OLD MORAINE OF THE LEWIS GLACIER KENYA.

Point Thomson is seen in the centre across the Lewis Glacier.

is coarsely crystalline, and the lower part, about 50 ft. in thickness, is again the compact rhyolitic-phonolite. At 4735 ft. the rock (G. 302) is of the Losuguta type of phonolite, like that at 4960 ft., and it rests on another thick flow of phonolite, some of which is coarsely crystalline. The compact variety occurs for 4430 ft. down to 4220 ft., below which, to the lowest lava seen *in situ* at the level of 3850 ft., the rock is a soda-analcite basalt (G. 304–305) with large black crystals of olivine. Below 3400 ft. I observed only loam and talus. Along the foot of the Hannington Scarp are interbedded gravels and loams which dip E. and are separated to the W. from a bouldery rubble by a sharp, almost vertical face. My first impression was that this junction was a landslip and that the boulder bed was talus; but the regular curvature of the beds on each side of the junction, the beds on the western side bending upward and the loams downward, the sharp, vertical nature of the junction, and its continuation in a straight line on the hill-side and across a further spur to the N., indicate that it is a fault.

The Kapitian phonolite is cut off to the W. by a series of down-faults; but I did not see any clear evidence as to the relation of the Kapitian phonolite to the Losuguta phonolite. Alternative explanations are possible. If the rocks in the lower part of the scarp underlie that of the plateau, the Losuguta phonolites would be the oldest lavas in the country. The more probable explanation is that the Losuguta phonolites are the younger and in the Solai platform have been faulted down against the Kapitian phonolite, which is not exposed at the base of the Hannington Scarp. It outcrops, however, further N. at the foot of the Laikipia Scarp (*v.* p. 110) in Doinyo Lersubugo.

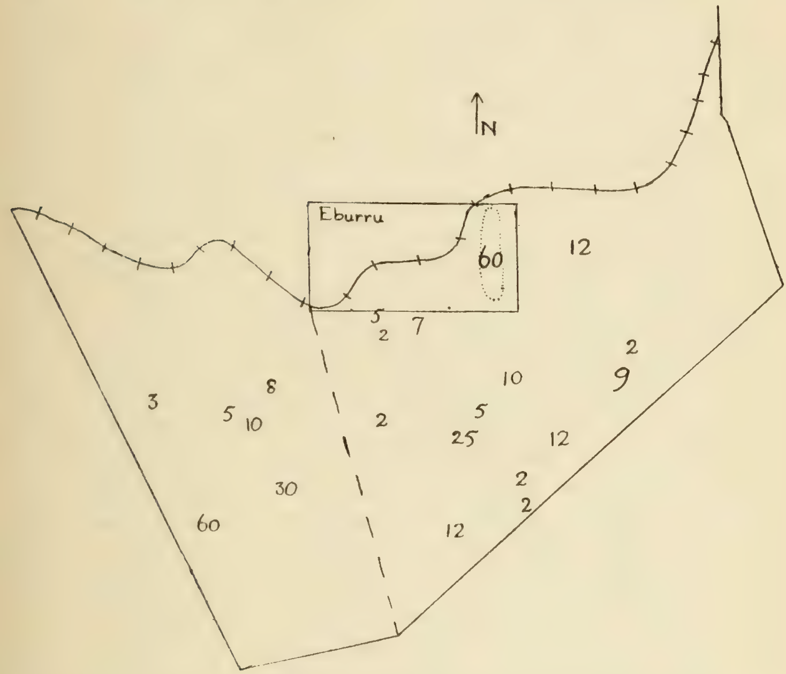
The Fault-blocks on the Floor of the Rift Valley.—On the floor of the valley to the W. of Lake Hannington and the Solai platform two distinct kinds of volcanic rock are exposed. The hill which I called Equator Peak, as its crest crosses the Equator, is composed of a phonolitic quartz-trachyte, which is similar to a rock on the platform E. of Lake Hannington; the same rock occurs N.W. of that lake and has been discharged during some of the later eruptions of the Baringo district. Along the floor of the valley is a series of fault-blocks which are tilted with a slope down to the E., but sometimes stand as blocks bounded by fault scarps on each side. The latter structure is clearly shown by the block (rising to 6877 ft.) which extends N. and S. on the eastern side of Lake Nakuru. This fault-block is cut through by a pair of minor faults, which have formed a depression along its middle line. Specimens from the block E. of Lake Nakuru, sent me by Mr. Sikes, are phonolites which resemble the older lavas of the Rift Valley.

The fault-blocks are mostly composed of kenyte and are due to eruptions intermediate between the phonolites and quartz-trachytes. The occurrence of kenytes in the fault-blocks to the W. of Lake Nakuru is proved by specimens recorded by Dr. Prior (1903, p. 245). These kenytes are covered to the E. by lake deposits which, E. of Elmentaita, have been faulted against the lavas of the Ol Bolossat platform, which continues the Solai platform southward.

The Elmentaita Scarp.—The swamps of Ol Bolossat rest on a platform which is the southern extension of the Solai Platform and lies between the Elmentaita and Laikipia scarps. The Elmentaita Scarp consists mainly of phonolitic quartz-trachyte with interbedded sheets of tuff. The scarp is broken into terraces by parallel faults; of these I recorded five during the ascent of a hill (7630 ft.) which is very conspicuous from the S., and owing to its flat top I called Kilima Mesa, or "Table Mountain." The ascent on to Laikipia due eastward from Elmentaita is very irregular, as the country has been broken across by over twenty faults, between which occur successive fault-blocks and intermediate fault-valleys.

The lake beds are extensively developed between the fault-block E. of Lake Nakuru and W. of Elmentaita; at the Kariandusi Valley they include diatomites or diatom clays, from which a list of sixty varieties of diatoms, identified by Mr. Thomas Comber, is recorded by Fergusson (1901, pp. 369–370). As the diatoms belong to living species, these clays are apparently of recent age; and that they are a younger series than those of Lake Kamasia is further indicated by their position, since the clays have been faulted against the Elmentaita phonolitic quartz-trachyte. To the W. and S.W. of Lake Nakuru the kenyte that forms the chain of blocks on the floor of the valley is exposed at the foot of the Mau Scarp near Makalia.

Doinyo Ol Buru.—Mount Ol Buru, which separates the Nakuru-Elmentaita basin from that of Naivasha, appears at first to be a volcano of very recent date, owing to the conspicuous steam vents from which it derives its name. They appear to be the most numerous and persistent in B.E.A. Their steam is now being condensed by Mr. Harvey to water his stock. One line of these vents occurs to the S. of the railway, close to the Eburru Station. The distribution of the steam vents is shown by Fig. 15 from a map by Mr. W. W. Gemmell (August, 1915); it appears to have been determined by recent faults, and is not directly connected with volcanic action. I failed to see any existing crater on the mountain, nor is there any suggestion of a crater on the G.S., G.S. map. Ol Buru consists of an E.–W. ridge which includes three chief summits, of which the highest is 9365 ft. Specimens collected from the Ol Buru flows at



Uganda Railway. The numbers mark the position of the groups of vents and the number in each group.

Fig. 15.—Plan and number of the steam vents near Eburru railway station. Scale, 1 inch = about 1,000 feet.

various points consist mainly of comendites very similar to those of the range S.W. of Lake Naivasha. Ol Buru appears to be a volcano of a stage considerably earlier than Longonot and to belong to the same period of eruption as those of Ol Gumi, and Ol Gane Aro to the S.W. of Naivasha, which are certainly no later than the Pliocene. The foundation of Ol Buru consists of kenyte, which is exposed at the northern foot and at the S.E. foot on the old caravan road between Gilgil and Naivasha, where it emerges from beneath the comendites and lake beds.

The Cross-Folds near Naivasha.—The occurrence of Kapitian phonolites at Lake Solai is probably due in part to the influence of folds crossing the valley at right angles to its main trend. E. of Lake Solai the beds on Laikipia have a gentle dip northward ;[5] further S., opposite the northern part of the Elmentaita basin, they dip southward, and opposite the southern part of that lake they again dip northward. These variations of dip indicate that the Nakuru-Elmentaita basin is due in part to a down-fold, of which the corresponding up-folds to the N. have brought up the kenyte along the floor of the valley, both N. and S. of the Nakuru-Elmentaita basin. S. of Lake Elmentaita the beds on the Laikipia front are horizontal; still further S., opposite Longonot, an up-fold with its axis trending from the western foot of Kenya, where it is marked by the outcrop of the Kapitian phonolites, extends south-westward and forms the highest ridge across the Rift Valley (7000 ft. at the Longonot Saddle), and may explain the formation of the Lolaita Plateau and the Loongaya Scarp. The fall in level of the Kapitian phonolites from Laikipia to the Kapiti Plains and the descent of the Rift Valley from 7000 ft. at the Longonot Saddle and 6250 ft. at Naivasha to 2035 ft. at Magadi may be due to the southern limb of this N.E.–S.W. fold.

The Basalt Craters S. of Elmentaita.—At the north-eastern foot of the Ol Buru Ridge and rising from the Elmentaita alluvium is a group of broken basalt craters. These volcanos are comparatively young, and are probably of the same date as that of the islands in Lake Baringo. They have been broken across by N.–S. faults, which are probably of the same age as those which have thrown the Elmentaita clays against the quartz-trachytes and formed a parallel scarp just N.E. of Eburru Station. Another fault of this series occurs along the steam vents near the railway station.

The steam vents, young craters, and still more recent faults give this locality the aspect of one of the least stable in the Rift Valley—at least, S. of Lake Baringo.

[1] In 1912, at the time of the survey for the G.S., G.S. map, sheet Baringo, 1914, the surface must have been slightly under 3190 ft., as that height is marked on the shore. The height which I determined in 1893 was 3200 ft. (Gregory, 1894, p. 61); that the water was then somewhat higher than in 1912 is suggested by some differences in shape and in the relations of the islands.

[2] These were subsequently found by E. E. Barchard in 1902 and later by Walker (1903, p. 7) to the W. of Kamasia at the base of the Elgeyo Scarp.

[3] The only name I could obtain was Lake Kibibi—probably given it by the Swahili, owing to the plague of mosquitoes.

[4] The same rock occurs on the scarp W. of Baringo.

[5] This fact was also observed by Walker (1903, p. 6).

CHAPTER X

The Highlands West of the Rift Valley near the Uganda Railway

I. Kavirondo

THE traverse of the highlands between the Rift Valley and the Victoria Nyanza by the Uganda Railway has been facilitated by two geographical incidents. The volcanic eruptions of Menengai have built up against the Mau Scarp[1] a sloping bank which affords an easy gradient through forest and moorland to the summit. The descent westward is into an E.–W. rift valley, of which the eastern part is occupied by the Nyando River and the western part is submerged as the Kavirondo Gulf. An easy descent from the summit of Mau (8321 ft.) to the plains on the floor of this valley, which are reached at Koru (4609 ft.), has been rendered possible by the eruptions which filled its eastern end.

The importance of faults in determining the geological structure of this country was clearly recognized by Mr. Hobley and expressed in his map (1918, p. 287).

B.E.A., W. of the Rift Valley, consists of a foundation of granite, gneiss, and schist, which, in the descent along the railway, outcrops between Koru and Muhoroni and also at the western end of the Kibos-Kibigori Plain. The same rocks form the Nandi Scarp, which runs E.–W. to the N. of the railway and forms most of north-western Kavirondo. To the E. the ancient rocks are buried by the volcanic rocks of the Uasin Gishu Plateau, which extends N. and S. between the Elgeyo and Kakamega Scarps and bounds the view eastward from the country between Elgon and Kisumu. The Kisumu District forms a natural separation between the districts of North and South Kavirondo ; it follows the Nyando Valley, which continues westward as the Kavirondo Gulf. South Kavirondo includes the Kisii highlands, which are composed of gneiss and quartzite ; they are covered to the W. by the nephelinites of the Gwasi Plateau, which are proved by the underlying Miocene lake beds to be later than Lower Miocene. Between the eastern part of

South Kavirondo and the Rift Valley is the Lumbwa District, an irregularly dissected lava plateau, with terraced slopes rising above the Uganda Railway.

Excluding the igneous rocks associated with the pre-Paleozoic foundation of the country, the oldest volcanic rock is apparently the phonolite of the Lumbwa Plateau and around Kisumu. This lava is exposed in many places on the Uganda Railway, as about mile 491 W. of the Mau summit, around Londiani Station, at about mile 508 N.W. of Kedowa Station, near "the Tunnel"—the only one on the Uganda Railway—about mile 525 W. of Lumbwa Station (which is 515½ miles), overlying the gneiss E. of Koru (513 miles), and about mile 538 near Kisumu. The phonolites are also exposed on the lower parts of the Nandi Plateau, and some flows near Kisumu have covered parts of the scarp. The character of the rock is identical with that of the typical Kapitian phonolite. Künzli (1901, p. 147) justly declares that the rocks of the two areas are indistinguishable either in hand specimens or under the microscope.

These phonolites are extensively developed on the Lumbwa Plateau, where numerous caves (Chap. XIX) have been excavated in a sheet of soft decomposed phonolite with minute quartz veins underlying the harder lava.

The phonolites are only seen at intervals along the Uganda Railway, as they have been covered by later eruptions; but on the western border of the volcanic area the phonolites are widely exposed around Kisumu. Further W., as described by Dr. Oswald (1914, pp. 156, 158), beside the Kavirondo Gulf, are younger volcanic rocks, some of which are post-Miocene and some post-Pliocene; while the tradition that Homa Crater was formed about eighty years ago suggests that subsidences, secondary to volcanic action, happened there in recent times.

Elgon.—Elgon (alt. 14,140 ft.), on the boundary between B.E.A. and Uganda, was, after Kenya, the greatest volcano in British Africa. The first European to see it was Stanley in 1875 (*Through the Dark Continent*, I, p. 185); he recorded it as Marsawa, which, according to Hobley (1897, p. 185), is its real name, Elgon being that of the El Goni, the cave dwellers of its southern slopes. The mountain was visited by Joseph Thomson (1887, p. 300), who discovered its caves (Chap. XIX) and recognized its volcanic nature. Photographs taken in 1890 by Sir F. J. Jackson and E. Gedge proved that around the summit are cliffs with the characteristic weathering of agglomerate. Mr. Hobley explored the mountain in 1896 and showed that it has a well-marked crater, the walls of which have been cut through by two rivers ; one of these, the Shwam, is the head-stream of the Turquell, and its origin within the crater indicates that the eruptions have been extinct for a considerable period. In the classification advanced in 1896 (G.R.V., p. 235) I included Elgon among the Pleistocene volcanos as from the descriptions then available its crater seemed as perfect and almost as recent as that of Longonot. Mr. Hobley's map (1897, opp. p. 248), however, showed that though the crater wall is still well developed, the mountain has undergone great denudation since the last eruption ; for not only is the crater wall cut through by rivers, but its northern rim is lower than the floor in the southern part of the crater. Dr. Prior has identified its chief lava as nephelinite.[2]

The nephelinites of Gwasi, though so denuded that they are probably older than those of Elgon, are clearly Pliocene or Upper Miocene, since they are intermediate between the Miocene lake beds of Karungu and the late Pliocene bone beds of Homa (Oswald, 1914, pp. 157–158). The dome of Elgon is the last great centre of the nephelinite eruptions, and may be late Pliocene. It was probably the last great volcano in action in north-western B.E.A.

Information as to the geology of the country between Elgon and the Rift Valley is scanty, and is due mainly to the identification by Dr. Prior of specimens collected by the officers of the Uganda Protectorate and forwarded by Sir Harry Johnston. Dr. Prior (1902, pp. 304, 305) has thus identified phonolite at the Seget Valley and Sigowet Hills, both in Nandi ; on the southern slopes of Tindaret ; at Mount Manava, 12 miles W. of Fort Ternan ; also in the Korando Hills, at 2 and 4½ miles N. of old Kisumu ; at Kisumu ¾ mile from the lake ; and N. of the railway at the Ravine. He also announced (*ibid.*, p. 304) the occurrence in this district of nephelinite, at the Nyando and lower Kedowa rivers and on Elgon at 7000 ft. He (*ibid.*, pp. 305–306) recorded basalt at Mumias and on Elgon, and granite 10 miles W. of Fort Ternan and at Awichina, 8 miles N. of Kisumu. The widespread distribution of gneiss and of quartz (which usually indicates the existence of the metamorphic rocks) is shown by records from the Nyando Valley, 10 miles W. of Fort Ternan, at Tindi, Kabaresi, Marama, Nzoia River, Ketosh in the Upper Nzoio River, Kakamega, Nyala, the Sio River, the Lego subdistrict, and the Samia Hills. This information has been supplemented by specimens collected by Mr. McGregor Ross, now in the Public Works Department at Nairobi, fragments of some of which he kindly gave me for microscopic determination. The chief distribution of the rocks in North-western B.E.A., as shown on Fig. 1, p. 26, is mainly based on the records of collections investigated by Dr. Prior and that of Mr. McGregor Ross, supplemented for the country north and north-east of Elgon by the observations of Mr. Barchard, as recorded on a sketch map kindly shown me by the East African Lands Development Co.

II. Kisumu

The Uganda Railway ends at the head of the Kavirondo Gulf, at the port of Kisumu. The gulf is very shallow, and lies along a valley due to the subsidence of a belt of country between faults trending approximately E.–W. (Lyons, 1908, p. 390). The shores of the Gulf are irregular, and the fault scarps beside it have been dressed down into irregular slopes; but E. of Kisumu the northern face of the valley is formed by the long straight Nandi Scarp.[3] That this scarp is of considerable antiquity is shown by the fact that the Kibos River has cut through it to the level of the floor of the main valley. The unbroken character of the scarp for most of its length is due to the resistant character of its rocks, and to the drainage being mainly northward away from the edge into the Kibosi River. The Nandi Scarp is the northern wall of a rift valley about 20 miles wide, of which the southern wall, S. of the Nyando River, continues along the shore of the Gulf from the mouth of the Nyando to Homa Point. Both northern and southern walls become increasingly dissected and irregular W. of the longitude of Kisumu. The very denuded tectonic valley of the Kavirondo Gulf was made by faults parallel to those that made Speke Gulf. These E.–W. tectonic valleys end E. against the highlands on the western side of the Rift Valley; and the eastern end of the valley that continues the Kavirondo Gulf has been buried by the volcanic eruptions of Tindaret and Lumbwa.

The town of Kisumu stands on a hill of which the northern slope, as at the workshops of the Public Works Department, consists of black phonolite of the Kenya type. It is a variety characterized by somewhat feathery growths of ægerine and cossyrite around crystals of nepheline. On the southern slope of the hill, in a hasty traverse, I collected a granophyric quartz dolerite, as well as a lava with ropy surface. The relations of these rocks were not apparent, but the dolerite is clearly intrusive, and may belong to the Kisii dolerites described by Oswald (1914, p. 148), though that at Kisumu is a much coarser-grained rock than that of Kisii.

North of Kisumu an alluvial plain, about two miles wide, extends to the foot of the western extension of the Nandi Scarp. The rock at the foot of the scarp (4¼ miles from Kisumu) is a black porphyritic kapitian phonolite which weathers into spheroids (Fig. 16). The phonolite is sometimes well banded, as near the top of the ascent at about 5½ miles from Kisumu, and upon the plateau along the

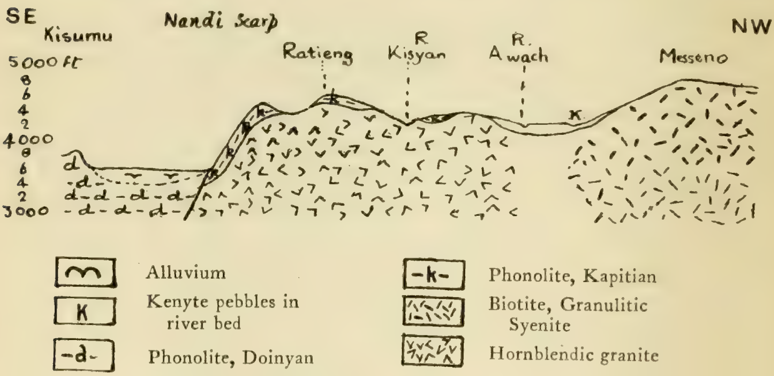


Fig. 16.—Section from Kisumu across the Nandi Scarp and along the road to Messeno.

Scale of length, 1 inch = about 4 miles.

Messeno road. At 7 miles from Kisumu the phonolite rests directly on hornblende-granite.

The Messeno Granulites and Syenites.—About 12 miles N.W. of Kisumu is a series of intrusive igneous rocks to which my attention was directed by Mr. H. L. Sikes. On the chance of these rocks throwing light on the relations of the pre-Miocene volcanic rocks of Metamala and near the Karungu bone beds—as I had not time to visit both districts—I went to Messeno to compare its rocks with those collected by Dr. Oswald at Metamala.

The road to Messeno passes over gneiss and granite, with outliers of phonolite on the higher ground between the valleys. Mr. Sikes tells me that the hills to the E. of the road are composed partly of phonolite resting against granite. The phonolites N. of Kisumu, as on the Athi Plains, appear to have been poured out over the undulating surface of the pre-Paleozoic rocks. Somewhere beneath the lavas may be preserved fossiliferous deposits which may definitely settle the date of the eruptions. At 14 miles from Kisumu (Fig. 16) the road crosses a stream littered with phonolite, metamorphic quartzite and a rock which Miss Neilson has determined as kenyte. North of this ford rise the hills of Messeno. These rocks were first examined by Mr. Sikes, and my observations and collections confirm his conclusions. The rocks are intrusive and now greatly altered; their microscopic characters have been investigated by Miss Neilson, who

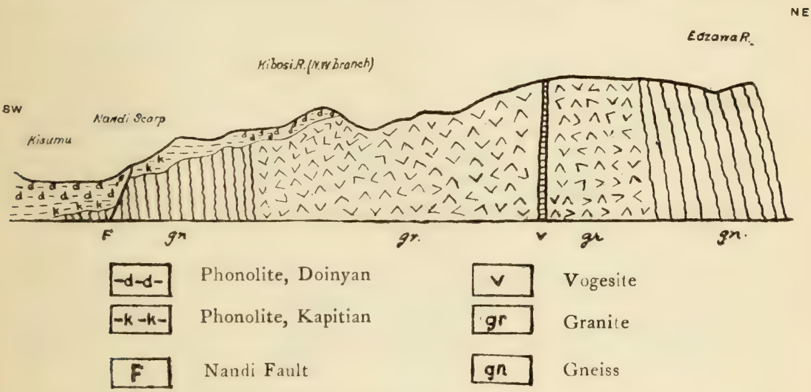


FIG. 17.—Geological Section along the road from Kisumu to Kaimosi.
Scale: length, 1 inch = 4 miles: vertical, 1 inch = about 3000 feet.

identifies the intrusive rock as an anorthoclase syenite, which has been partly rendered granulitic; it is intrusive into a biotite-granulite.

So far as I saw, there are no agglomerates in this complex or anything to connect them with the volcanic series of Metamala. Mr. Sikes has found, about 8 miles further N. on the Yala River, some slates which appear to belong to the Karagwe Series, and the Messeno syenites may be intrusive into the Archeozoic slates.

Kisumu to Kaimosi.—In the hope of finding exposures which would show the relations of the phonolite to the nephelinites—owing to the great kindness of Mr. Tyler-Smith, who, although very unwell, drove me by motor for two days over rough tracks—I examined the rocks N.E. of Kisumu. The section along the road to Kaimosi shows that the plateau consists of a foundation of Eozoic gneiss with some granite and vogesite. The gneiss, according to information given me by Mr. O'Mara, extends about 3½ miles E. of the Mission Station at Kaimosi, when it is succeeded by granite. The gneiss by the Itsavo or Edzawa River, 2 miles S.W. of Kaimosi, is partly a quartzose gneiss and partly a metamorphic quartzite; its strike there varies within a few degrees of due E.–W., and the foliation dips 70° N. The granite, as near the brickyard, contains quartz veins which trend N.–S. The surface of the plateau occurs at two chief levels, a platform on the southern margin at the level of about 4600 ft., and an old peneplane at the level of about 5600 ft., of which the higher hills are the remnant. On the lower surface lies the remains of a sheet of phonolite, which occurs at different levels but

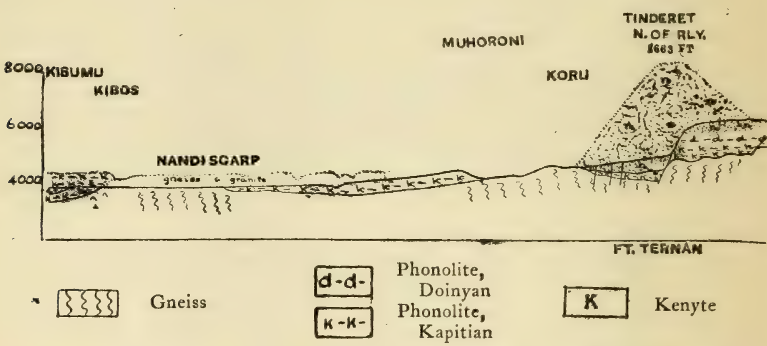


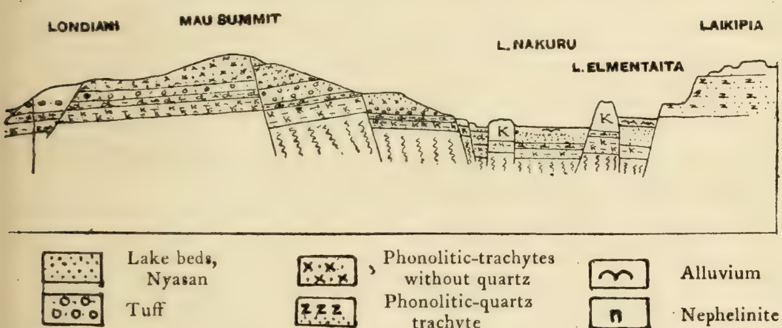
Fig. 18.—Section from the Kavirondo Gulf to
Scale of length,

never reaches the higher summits. It was poured out over an irregular area of gneiss and granite, and most of it has been removed by denudation. The phonolite, for example, forms the ridge at the height of 5100 ft. above the brickyard in the valley of the western branch of the Kibosi River, 10 miles N.E. of Kisumu. The phonolite there of the Kenya type is identical in character with that beside the Public Works Department workshops at almost lake level at Kisumu, and it forms a mantle over most of the southern slope of the plateau. This phonolite is clearly of considerable antiquity, for it has been greatly dissected, and there are no remnants of craters, though some of the phonolite hills may be volcanic necks. The contrast between the phonolite and nephelinite is therefore very marked. The contrast between the denuded condition of the phonolite and the comparatively perfect preservation of the immense dome of

Elgon, as seen from the Kaimosi Road, and of its crater, as shown on the G.S., G.S. map (Elgon, 1913), indicates that the Kisumu phonolites belong to a much older series than the nephelinites.

The nephelinites of Karungu are shown by Dr. Oswald's observations to be certainly later than the Lower Miocene; the phonolites were in all probability discharged long before the Miocene, though I am not aware of any section in which their relations to the Miocene lake beds is actually shown.[4]

Lumbwa.—The western stage of the journey by railway from the Victoria Nyanza to the Rift Valley is over the level plain at the foot of the Nandi Scarp. The railway rests on phonolite, gneiss, and alluvium, and the rocks are so planed down that their boundaries



Laikipia, mostly along the Uganda Railway.
1 inch = about 18 miles.

are indefinite. So level is the ground that the railway rises with a grade of only 1 in 350; for 16 miles the gradient is only 1 in 926, and the line is often straight for miles together. E. of Koru the conditions change; the ascent is steeper and the course very sinuous as the railway winds round the southern slopes of Tindaret and skirts the northern foot of the plateau of Lumbwa. Between Koru and the summit of Mau the rocks seen on the railway line are all volcanic, the lowest being the phonolite, which is exposed occasionally. The later volcanic rocks belong to two groups, the nephelinites, including the melilite-nephelinite of Tindaret, and the phonolitic-trachytes around Londiani. The cone of Tindaret, 8563 ft., is allied by composition and date with Elgon. It is probably Upper Pliocene whereas the phonolitic-trachytes around Londiani are probably older Pliocene.

The nephelinite of the Nyando Valley was first identified by Prior (1902, p. 304); its distribution along the Uganda Railway has been described by Maufe (1908, pp. 47–49). Elaborate petrographic descriptions and analyses (see Appendix IX, pp. 418–420) of the rocks collected along the railway by Prof. Uhlig have been published by Dr. Goldschlag (1912), who has described pantellerite allied to the paisanite of Naivasha (1912, p. 587) at Lumbwa Station; nepheline-tephrit, also at Lumbwa Station (*ibid.*, p. 591); phonolite tuff at Lumbwa Station (*ibid.*, p. 597); nephelinite and nepheline-basalt near the shore of the Victoria Nyanza at Karungu (*ibid.*, p. 595); phonolitic tuff and palagonite tuff at Molo Station (*ibid.*, pp. 597, 598).

The denuded lower slopes of Tindaret between Koru and Lumbwa Station and numerous railway cuttings show volcanic tuffs intruded by dykes and covered by nephelinite flows. Dr. Prior (1904, p. xxxv) has recorded kenyte from the lower slopes of Tindaret, which may indicate a lava lying between the phonolite and the nephelinite. For specimens of the rocks at various selected points along the railway I am indebted to the courtesy of the District Inspector of the Uganda Railway at Nakuru; I am much indebted to his staff for the care with which they collected the material.

The Tindaret eruptions were clearly later than the formation of the faults which made the Nyando Valley; they are probably of the same age as the Gwasi nephelinite which (Oswald, 1914, pp. 140–142) overlies the Miocene lake beds near Karungu.

The railway cuttings about mile 495 near Londiani Station expose sheets of phonolitic-trachyte, similar to that extensively developed further north in Kamasia. That these trachytes are later than the phonolite is shown at mile 506, just N. of Kedowa Station, where trachyte is intrusive into phonolite. One of the most conspicuous dykes along the line is a conspicuous black columnar boss at 512 miles (W. of Kedowa); a limburgite is recorded there by Maufe (1908, p. 48), but a specimen (No. 576), which the District Inspector of the Railway kindly had collected for me, is much less basic than a limburgite; it has phenocrysts of andesine and yellow-green augite, and a ground mass of felspars which are probably oligoclase.

Miss Neilson has examined the rock (Appendix, p. 400) and regards it as a kenyte of the basic variety.

Fossil Wood.—The only direct palæontological evidence as to the age of the volcanic rocks of the Lumbwa-Nandi district is given by some fossil wood, specimens of which have been kindly examined by Prof. Seward. The late P. L. Deacon sent Mr. Hobley from Northern Nandi (No. 567) as fossil ivory, a piece of whitened altered tree-stem ; Prof. Seward remarks in it the presence of broad medullary rays and pith, and says it is dicotyledonous but otherwise indeterminable. Mr. G. R. Chesnaye sent Mr. Hobley (No. 611) a cast of a stem from the Miocene bed near Muhoroni, which is probably the eastern extension of the Miocene lake beds of the Victoria Nyanza ; Prof. Seward has determined this specimen as dicotyledonous and as either Cretaceous or Tertiary in age. Mr. Maufe (1908, p. 49) has recorded fossil wood from the agglomerate of Fort Ternan.

The Railway Ascent of Mau.—From the summit of Mau to the foot of the Mau Scarp there are few rock exposures, and the long railway cuttings (as at $\frac{467}{14}$, $\frac{469}{1}$, $\frac{470}{6}$, $\frac{470}{17}$, and $\frac{471}{11}$) expose thick beds of a red earth which is probably decomposed volcanic tuff ; a few cuttings (as $\frac{453}{15}$ and $\frac{454}{18}$) show trachytic tuff. The slopes are gentle and present no resemblance to a fault scarp ; but that the boundary fault of the Rift Valley must pass beneath this bank of volcanic debris is shown between the Molo and Bissoi Rivers, where the ground falls abruptly over 2000 ft. in a straight steep scarp which is clearly marked on the G.S., G.S. map (sheet Kericho) by crowded parallel contours. At the deep ravine of the Molo River, at $\frac{475}{7}$ above Elburgon Station, 7941 ft., the viaduct rests on a sheet of lava (No. 568), a riebeckite-trachyte,[5] or orthophyric-trachyte.

Nearer the summit, above the station, 8157 ft., at Turi Mill (477) the river at $\frac{480}{1}$ (7997 ft.) exposes lava (No. 569), of which a specimen kindly collected for me by the District Inspector at Nakuru is also orthophyric-riebeckite-trachyte. Between the summit and that valley the only exposures beside the railway are of tuff, but at a little distance on each side occur hills resembling volcanic necks. Between the forests at the foot of Mau and Nakuru Station the line crosses or passes various kenyte ridges. Nakuru Station stands at the S. foot of Menengai, of which the last lavas, including some collected by Mr. Sikes from the floor of the crater, are phonolitic-trachyte and phonolitic-rhyolite ; the older lavas of the crater wall include phonolite of the Kenya type.

Summary of the Sequence in the N.W. Districts.—Some of the records appeared to suggest that the phonolites and nephelinites were so closely associated or even interbedded that they belonged to the same division of the volcanic succession. The nephelinites are, however, later than the Lower Miocene beds with *Dinotherium hobleyi*. As the Kapitian phonolites must be older, it appeared probable that there were two phonolitic series of very different dates. One object of my visit to the Kisumu area was to test this hypothesis. The result failed to confirm the reported interbedding of the Kisumu and Lumbwa phonolites with the nephelinites.

The sequence in the north-western districts may be summarized as follows :—

Naivashan.	Upper Pliocene.	Homa Bone beds. Nephelinites of Elgon, Tindaret, Gwasi, etc.
Laikipian.	Lower Pliocene to Upper Miocene.	Phonolitic-trachytes of Londiani and orthophyric-trachytes of Mau.
Nyasan.	Lower Miocene.	Lake beds of Karungu, etc.
unconformity		
Doinyan.		(?) Metamala agglomerate and andesites E. of Kikongo.
Kapitian.	Upper Cretaceous (? Eocene).	Phonolites of Kisumu, Nandi, Lumbwa, etc.
unconformity		
Post-Archeozoic.		Messeno syenite.
Archeozoic.		Yala Slates.
Eozoic.		Gneiss, granite, schist.

[1] Mau is the Masai word for twin. Its applicability to the Mau Escarpment has been finally explained by Mr. Rupert Hemsted in answer to an enquiry by Mr. Hobley. The Masai distinguish between two Maus, the Mau Narok or Black Mau, and Mau Nyuki, the Red Mau. Mr. Hemsted remarks that the same root occurs in Mau Enzi, the name of the lower peak of Kilima Njaro.

[2] Ejected blocks found in its agglomerate have been described by Dr. Prior (1904, pp. xxxiv, xxxv) as jacupirangite, an augite-magnetite-perofskite rock of Brazil, and as a nepheline-melanite rock resembling the borolanite of Sutherland.

[3] The term Nandi Scarp was originally used for the N.–S. scarp from the Nzoya River near the Brodick Falls southward to the Yala River. Mr. Hobley recommends that this scarp should be called the Kakamega Scarp.

[4] This evidence may be given by the bone bed discovered by Mr. Chesnaye near Muhoroni.

[5] Mr. Tyrrell remarks that the texture of this rock is orthophyric and not trachytic. The name orthophyre was originally applied, and is generally restricted to intrusive rocks, e.g., Hatch, *Petrology*, 5th edit., 1909, p. 218.

CHAPTER XI

The Succession at Laikipia

I. Traverse from Baringo to N. Kikuyu-land

LAIKIPIA is the high plateau which rises in precipitous scarps from the Great Rift Valley from the Kedong northward to beyond Baringo ; it extends eastward to Kenya and the Guaso Nyiro and descends gradually to the Nyika. It is bounded to the S. by the forest-clad Kikuyu Uplands, to which it descends through a belt of down and park-like country ; to the N. its boundary is indefinite, as it passes through the plains of Lorogi into the arid wastes E. of Lake Rudolf. The general level of the plateau ranges from 5000 to 7000 ft. A section represents Southern Laikipia as an open valley between the Settima Range to the W. and Kenya to the E. The north-western margin is known as the Subukia or Subugo, which, according to Karl Peters (1891, p. 252), means " a fringe of mountains," but according to my Masai interpreter is a wood-covered mountain. Either definition would be applicable, for it is the western rim of Laikipia and is well wooded ; the range reaches its greatest heights, 12,715 ft. on Settima, and 12,816 ft. on Niandarawa.

The first European traveller to reach Laikipia was Joseph Thomson during his adventurous journey in 1883–1884 ; he tried to cross the plateau to Kenya, but, owing to persecution by the Masai, he only reached the Guaso Nyiro, whence he was glad to escape back to the Rift Valley. He recognized (1887, pp. 224, 221) that Kenya is an old dissected volcano, and that Laikipia consists mainly of lava. Thomson was followed in 1887 by von Teleki and von Höhnel ; they kept along the Guaso Nyiro from the western foot of Kenya northward through Eastern Laikipia, and crossed Northern Laikipia to Baringo. The rock specimens they collected were described by Rosiwal (1891), who identified them as phonolite, trachyte, and basalt, with some augite-andesite at the foot of the Laikipia Scarp. Von Höhnel's collection also showed that gneiss is exposed to the N.W. of Kenya and along the Guaso Nyiro.

In 1889 Karl Peters, in command of the German Emin Pasha Relief Expedition, fought his way through the Laikipian Masai, followed Teleki's route down the Guaso Nyiro, and descended to Baringo by the lower part of the Arabel River. The next traverse of the plateau was in 1893, when I crossed from Baringo to the S.W. foot of Kenya along a route W. of those previously used and near the foot of Settima, since along that line evidence could be determined as to the geological nature of both Settima and Laikipia. It seemed possible that Settima might be a block or horst of Eozoic gneiss standing above the level of the lava plains. Some of the specimens then collected have been described by Dr. G. T. Prior (1903, pp. 238, 240, 247, 248) as varieties of phonolite and basalt. The same two groups of rocks were found by Mr. H. B. Maufe, who, in 1906, visited Laikipia from the Rift Valley.

In 1919 I had the privilege of traversing Laikipia from Naivasha to Nyeri and South-western Kenya in company with Mr. H. L. Sikes, and was then able to collect better rock specimens ; for the traverse in 1893 was under conditions which rendered any branch excursions impossible and limited collections to the minimum necessary for a section to show the general structure of the western part of the plateau.

From Njemps Mdogo, S. of Lake Baringo, my route in 1893 crossed the alluvial plains to the foothills (Fig. 19, p. 133), which were entered through a narrow gorge cut across the lowest of the parallel fault scarps that form there the western front of Laikipia. The rocks on the sides of this gorge are fissile phonolite, which weathers dark grey and is lustrous owing to the parallel arrangement of the felspars. On the dry bed of the stream lie boulders of basalt. This gorge, which the natives called the "Domo Larabwal," was probably formed as the outlet of the stream that drained the valley between the first and second Laikipian fault scarps ; it has now been captured by the "Arabel" river which enters the south-eastern corner of Baringo. The name of this river was given as the Guaso Boli by von Höhnel ; as Guaso Tin by Karl Peters. My men called its lower part the Guaso Larabwal, and its upper the Guaso el Narua ; the former name, spelt Ol Arabel, is used on the G.S., G.S. map, Baringo, 1914, and that spelling is here adopted.

From the portal into this tributary of the Arabel we continued eastward over or around a series of spurs from the hills to the S. Our Dorobo guide then led us southward up a tributary valley at

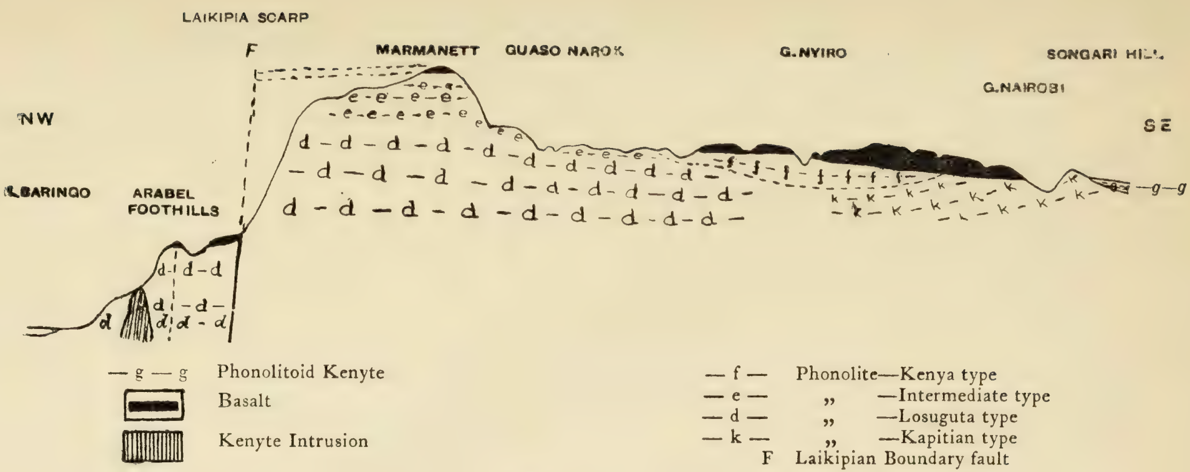


Fig. 19.—Section across Laikipia from Baringo to near the western foot of Mount Kenya.

Scale in length : 1 inch = 15 miles horizontal ; about 4000 feet to 1 inch vertical.

the foot of the third main fault scarp, which forms the western front of a high ridge on the western side of the Arabel ; in this valley we camped beside some springs known as Lanjoro Arabel. The foothills between the Domo Arabel and the springs consist of compact magma-basalt, resting upon a flow of phonolite, in which is an intrusion of a glassy kenyte (Fig. 19) identical with that of the plug of Kenya. The high hill face, Doinyo Nalesha or Ngalesha, E. of the Arabel Valley, is the fourth main scarp, and forms the western edge of Laikipia. The surface of the plateau, according to the specimens collected by von Teleki (Rosiwal, 1891, p. 504), is formed of basalts, including a variety rich in augite and olivine-basalt. The specimens collected at the foot of the Nalesha scarp are of phonolite similar to that in the foothills at a level 2000 ft. or more lower. The phonolite of the Domo Arabel has therefore been downthrown by faulting, so that the basalts, which are at the height of from 6500 to 7400 ft. on the plateau, occur at the level of 4500 to 4700 ft. on the Arabel foothills. That the Arabel basalts are later than the phonolite is indicated not only by their superposition, but by their intrusion into the phonolite. The high ridge W. of the Arabel consists of fissile phonolite, and the same rock occurs at the head of the Arabel Valley, from which a specimen (G. 421) was determined by Dr. Prior as phonolite of the Losuguta type. This rock is overlain by another variety of the Losuguta type of phonolite, which is dark grey in colour and weathers into large spheroids.

From the head of the Arabel Valley a high pass at the eastern foot of Marmanet (8558 ft.), the highest summit on the Laikipian Scarp, gives access to the northern tributaries of the Guaso Narok, which discharge north-eastward through deep valleys between thinly wooded hills. These valleys give clear sections showing that the plateau consists of spheroidally weathering phonolite of the Losuguta type which is found E. of Lake Hannington and W. of Baringo ; this rock is covered by a compact porphyritic phonolite, which Dr. Prior has described as intermediate between the Losuguta and Kamasia types. This intermediate variety differs from the Losuguta type, as the flow structure is ill-defined.

In the hope that if we came across game with which to supplement our scanty food supply we should have time for an excursion to Settima, we kept along the high ground W. of the open country. We crossed many head-streams of the Guaso Narok, and their valleys showed exposures of phonolite mainly of the Losuguta type ; this rock is covered in places, as near Doinyo Subugo Lal Mwari, by a phonolite (G. 423) of Dr. Prior's intermediate type, which, when weathered, has a spotted appearance. Further S. the Losuguta type for a time disappeared beneath the intermediate type, which forms the floor of the ravines in the country (known to my guide as Gopo Lal Mwari and Alngaria) S. and S.W. of Pesi Swamp. The Losuguta type was found again beneath the intermediate type in the deep ravines S. of Lari Lol Morjo. The phonolite at the Pesi River weathers into enormous spheroids, the outer part of which is decomposed, but from the core of one I obtained a fresh specimen (G. 429) of the Losuguta phonolite. Near by a flow of basalt down from the hills to the S. overlies the phonolites.

On the bed of a river which my guide called the Guaso Lashau, and which is marked on the G.S., G.S. map as the River Suguroi, are more outcrops of the Kenya type of phonolite ; it is there covered by vesicular phonolite (G. 436), above which is a bed of phonolitic tuff (G. 437), and in the river beds below these is a sheet of phonolite like that of "Phonolite Cwm," high on the S.W. slope of Kenya (Gregory, 1900, No. 3, Pl. X). S. of the Suguroi the country consists of a plateau of tuffs through which the streams, then all dry, had cut their valleys down to the Kenya phonolite. This lava sheet had come from Settima, and I could find in the river beds no quartz pebbles, quartz sand, or flakes of muscovite mica, as would be expected if there were any exposures of gneiss or schist on this flank of Settima. I concluded that Settima, at least in the north-eastern part, is wholly composed of volcanic rocks. The views of the mountain suggested that its structure is similar to Kenya, but without the central peak.

The country at the time had very little water. Some Dorobo hunters whom we met said that the country had been stricken by a severe drought, which had exterminated the game. The ravenous condition of some lions which, in spite of our circle of fires, rushed the camp one night to get the donkeys, also indicated that game in the district was scanty. Hence I felt bound to be content with the evidence of the river gravels as to the structure of Settima and turn aside into more open country across which we could make longer marches to reach food in Kikuyu-land. We therefore went eastward to the Ongobit River, a tributary of the Upper Guaso Nyiro, and beyond it passed from the phonolites to wide plains of basalt between the Nairobi River and the main branch of the Guaso Nyiro, The phonolite continues under the basalt and is exposed on the floors of the deeper valleys. That the basalt overlies the phonolite is proved, for example, by the sections in the Rangata Nado, where the branches of the Engare Berisha, of the G.S., G.S. map, flow over phonolite, while the plateau between the valleys consists of wide sheets of basalt. The basalts also form the plateau between the last tributary to the Guaso Nyiro and the Guaso Nairobi, which rises on Lake Hohnel in Western Kenya and is the highest tributary to the Tana. The basalts end at the foot of a high down-like hill, Songari, which consists of coarse phonolite with large crystals of anorthoclase and nepheline and rare olivine; this rock belongs to the Kapitian phonolites of the Kapiti Plains, but is a more basic variety. This rock disappears to the S. beneath phonolitoid-kenyte, which forms a very rich soil, and was then covered by dense forest maintained by the Kikuyu as their rampart against the Masai.

The oldest volcanic rocks seen in this traverse of Laikipia were phonolites of the Kapitian type ; they are covered by a fine-grained fissile phonolite, which is Dr. Prior's Losuguta type ; above it is phonolite of the Kenya type which contains soda-amphiboles. These minerals are still more abundant in the Kamasia type, which I did not find on this route across Laikipia. The Kenyan phonolite seen on Laikipia had clearly flowed from Settima. It is covered by wide sheets of basalt which occupy nearly all the upper part of the Guaso Nyiro and most of the Nyeri basin, while specimens collected by Teleki show that it is widespread in Northern Laikipia.

The characteristic feature, then, of the Laikipian sequence is the superposition of basalt over a varied series of phonolites. The basalt, with the associated quartz-trachyte and phonolitoid-kenyte of the southern border of Laikipia, were selected as the typical representatives of the third volcanic series, the Laikipian ; and the traverse of Laikipia in 1893 showed that the Laikipian lavas are younger than the phonolites of the Kapitian and Doinyan Series.

II. Naivasha to Nyeri and along the Meru Road

In order to compare the sequence in Southern Laikipia with that seen in the march from Baringo to the Kikuyu country I was glad of an opportunity in 1919 to cross from Naivasha to the Kapitian phonolite at Songari, near the S.W. foot of Kenya. In this journey I had the privilege of the company of Mr. H. L. Sikes and also, for the first part of the way, of Mr. A. G. Bush, District Engineer of the Public Works Department, who organized the Safari. At Naivasha I enjoyed the hospitality of Mrs. McLellan and Mr. McLellan, the District Commissioner.

The general structure of the country is illustrated by the section Fig. 20, pp. 138–139. It begins 3 miles N. of Naivasha along the Gilgil road, at a low block of lava, which rises above the alluvial plain on the line of the first Naivasha fault-scarp ; it has a low scarp to the W. and dip slope to the E. The rock is the same phonolitic trachyte as in the cliff below the Commissioner's house at Naivasha, which exposes three rocks. The top of the cliff is a fissile black phonolitic trachyte in which Miss Neilson has determined the felspar as anorthoclase ; below it is a soft freestone, like that of Nairobi, and is a devitrified glassy phonolitic trachyte ; the base of the section is a banded porphyritic, phonolitic trachyte, with streaks of pitchstone and porphyritic felspars. E. of the railway station is a quarry in the second fault scarp, in rhyolitic tuff beneath a columnar tuff and a red weathering phonolitic rhyolite (89) with porphyritic anorthoclase.

As the rock at the beginning of the traverse (Fig. 20) has a slight dip to the S., it may be on a lower horizon than that in the Commissioner's cliff. To the E. of this block a gorge through the second fault leads to the summit of the second platform ; the gorge is cut through a columnar phonolitic rhyolite, which dips slightly northward, so that it has been tilted in the opposite direction to the block just W. of it. The base of the columnar lava in the gorge is at the level of 6700 ft. ; it is a platy fissile, non-porphyritic rhyolite, with a ropy, vesicular lower surface (No. 371). This lava flow forms a wide platform, covered by gray tuff with rhyolitic fragments, and rising from about 6900 ft. at its western edge to the level of 7400 ft. The ground then descends gently down a dip slope to an alluvial flat at Nunjoro. Behind Mr. Mervyn Rae's house rises a fault scarp, which forms the western front of the Kinangop platform. It rises steeply from about 7400 to 8000 ft. The lower part of the scarp consists of gray tuffs ; at 7600 ft. occur blocks of dark rhyolite with well-marked flow banding, but they are perhaps not in situ and may have fallen down the hill-side. The track we had followed joins the Nyeri road at 7500 ft. below a conspicuous horizontal band of coarse agglomerate with columnar jointing. This bed is covered by tuffs in which, at the height of 7900 ft., is a thin flow or a sill of banded rhyolite. A similar rhyolite, 18 ins. thick, occurs at 8000 ft., and above it is a coarse agglomerate, with an intrusive vein of obsidian 2 ins. thick. This agglomerate contains many fragments of compact trachyte, of rhyolite similar to that seen on the hill-side at 7600 ft., and lumps of a fibrous pumice which resembles fossil coniferous wood. It appears, however, to be pumice composed of very fine parallel tubes, which give the material its fibrous structure. The agglomerate, which dips 4° N.E., is exposed on the western edge of the Kinangop platform, a tract of moorland about 8 to 10 miles wide. Near the western edge the surface descends slightly to the E., down a dip slope of tuff, below which the first river, the Muruaki, exposes the underlying agglomerate. The surface descends a little further to the Mogotiu, whence the level rises to the foot of the main scarp of

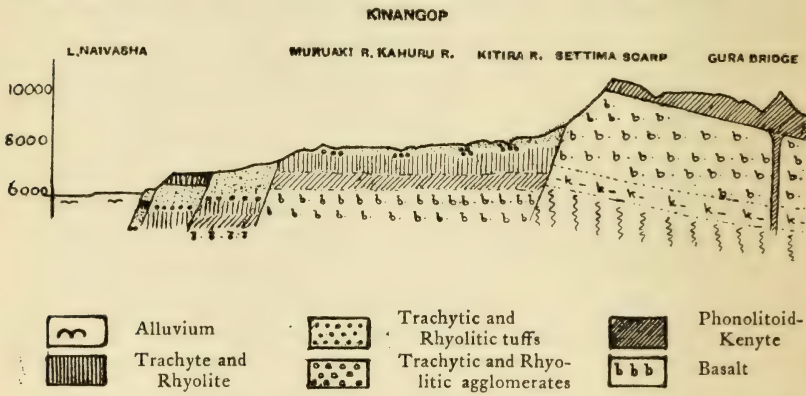


FIG. 20.—Section from Lake Naivasha

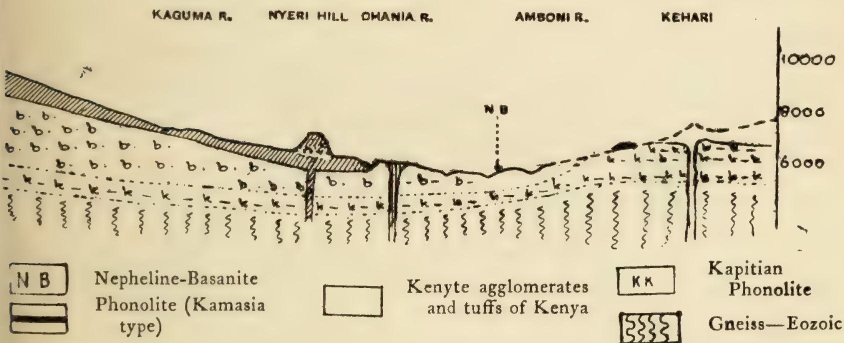
Scale in length :

Laikipia. The surface of the platform consists mainly of rhyolitic tuff, beneath which is a bed of agglomerate exposed in the Kahuru River and in the river bed beside Medhursts, where a fine-grained gray ash rests on the agglomerate. A low hill, Loronyo (8151 ft.), N. of the track, resembles a volcanic neck. The Kitira, or Cotter's River, flows through a deep ravine, showing good sections of the tuffs. On the river bed are soft gray and buff tuffs, covered by a hard, dark tuff with numerous fragments of plagioclase ; this bed is covered by soft, earthy black tuff. Above this bed, 200 ft. above the river, is a bar of gray tuff, as hard as a lava and undercut in places to form caves. Above this hard band is soft, gray tuff, about 80 ft. thick.

E. of the Kitira River the surface rises more rapidly over the tuffs to the foot of the main Laikipian fault-scarp. The fault is buried beneath a huge talus fan, and further S., the hill of Isanga (10,063 ft.) appears to be a volcano on the Laikipian fault. Examination of this hill through field-glasses showed a central tuff cone surrounded by a crater-like depression and an outer rim. Isanga is an example of the volcanos which have contributed to the irregularities of the boundary fault scarps by building a volcanic buttress against the plateau front.

N. of the track, a little in front of the fault scarp, is Kipipiri (10,897 ft.), which was doubtless due to eruptions of the same epoch as Isanga, but its vent was W. of the main fault. Opposite Kipipiri the fault-scarp turns W. of N., and the spurs from Settima in the valley between it and Kipipiri are faceted along a straight line; the facets probably mark the exact line of the fault.

The first rock exposed *in situ* on the scarp above the talus fan



across Southern Laikipia to Mount Kenya.
1 inch = about 8 miles.

occurs at the height of about 9100 ft. and is an augite-basalt with large porphyritic augites. This rock is abundantly exposed for over 500 ft. This basalt is a thick porphyritic lava flow, of which the upper part is compact.

The rock is in places considerably altered, as near 9480 ft. At 9650 ft. it weathers light gray, like an andesite; but only 30 ft. above this (No. 387) the rock contains distinct olivine. At 10,000 ft. the basalt is compact (No. 389); at 10,270 ft. it is again porphyritic and banded, and contains conspicuous phenocrysts of olivine (No. 390); at 10,400 ft. it is of finer grain, with only small phenocrysts, some of which are olivine (No. 391).

On the summit of the pass, at 10,500 ft., the rock is a fine-grained, flaggy (No. 392) olivine-basalt. Just E. of the summit, at 10,450 ft., is a gray weathering basalt with porphyritic augite and distinct olivine.

The abundant rock exposures leave no doubt that the scarp is a fault face, and there is nothing on it corresponding to the rhyolites and tuffs of the Kinangop platform. The coarse porphyritic basalt probably underlies the tuffs, which have been removed by denudation from the summit of the pass, but would probably be found above the basalt on the higher ground to N. and S., as they do further E. down the slope towards Nyeri.

From the summit of the pass a forest-clad plateau, diversified by flat-topped hills, numerous volcanic necks, and a complex system of valleys, extends eastward to the plains of Laikipia, beyond which can be seen the massive dome of Kenya crowned by its towering peak and glaciers.

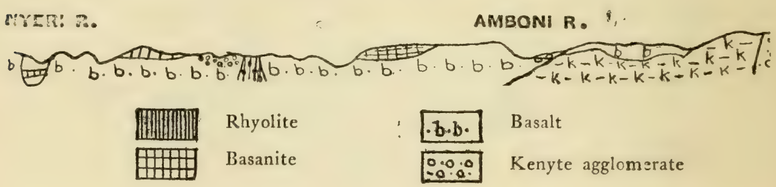
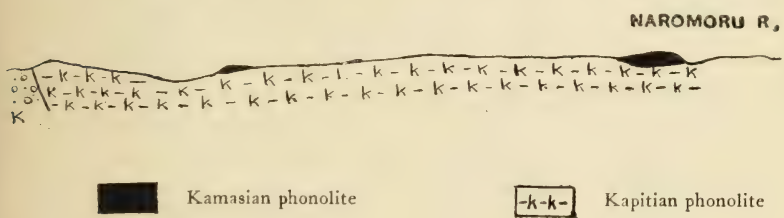


FIG. 21.—Section along the road om Nyeri
Scale : Inch

The upper part of the eastern slope from the pass towards Nyeri is covered by gray tuffs, similar to those on the Kinangop platform near the Kitira. Associated with these tuffs, the most distinctive rock is a fissile dark blue lava (No. 394), which is exposed a little E. of the first bridge. It is fissile, and its surfaces are lustrous owing to the parallel arrangement of its felspars; the rock is a phonolitoid kenyte. The same rock is well exposed around the fish-breeding station, near which the Gura River has a picturesque fall over the lava. The descent continues eastward over undulating country with few rock exposures along the track. The surface is composed mainly of soft, weathered tuff; while lavas, such as the phonolitoid kenyte (399 A) at Gura Bridge, are exposed in the valleys. After crossing the Gura the track rises over slopes of gray tuff to the ridge (9950 ft.), which rises N. to a peak (10,600 ft.) which looks like a volcanic neck. The ridge consists of gray spheroidal phonolitoid kenyte. At the eastern foot of this ridge is a bed of a bauxitic clay, probably an altered volcanic ash. Thence follows a long, even descent towards Nyeri, through bamboo jungle and forest with a thick red soil, probably derived from volcanic ash. The banks of the Kagumo River, at about 7400 ft., expose the same phonolitoid kenyte as that near the summit, which indicates that the surface is a dip slope. Where the Nyeri track crosses the Kagumo River the rocks exposed are gray and red tuff with trachyte (No. 402). Hence a motor carried me swiftly on to Nyeri, past the southern side of Nyeri Hill (7210 ft.), with a crater breached by a flow to the S.E. Mr. Field-Jones kindly obtained specimens from this hill which show that it is a fine-grained phonolitoid kenyte. The ridge S. of it along the Nyeri road consists of a gray rhyolitic tuff interstratified with flows of a trachytic lava. The deep gorge of the Chania River at Nyeri has cut through the



towards Meru, at the west foot of Mount Kenya.
2·6 miles, horizontal ; 2000 feet, vertical.

loose upper tuffs to a columnar volcanic tuff crowded with flat wisps and fragments of rhyolite, some of which, 3 ins. long, are standing vertical. Below the columnar bed is a massive dark gray tuff, which is worked as a freestone in the Public Works Department quarry. The columnar tuff is also well shown on the opposite bank of the river.

To extend the Naivasha-Nyeri section north-eastward Mr. Sikes drove me by motor 25 miles along the Meru road (Fig. 21). The first noteworthy section is just E. of the Nyeri bridge, where basaltic agglomerates are cut through by a basalt dyke and interstratified with a light gray volcanic ash. Above the agglomerates is a flow of vesicular, irregular, olivine-basalt. The road to Meru then climbs on to a plateau between the Chania and Muriagato Rivers. The plateau itself is covered with a very thick chocolate-red soil suggestive of decomposed basaltic ash. Descending to the Muriagato River, beyond the Government Nursery, the red soil is seen to rest on gray rhyolitic tuff, which is like that in the Nyeri quarry and is also worked as freestone ; beneath this bed is a phonolitic-trachyte agglomerate containing abundant fragments of coarse porphyritic pyroxene-basalt, which resembles the Markle basalt of Southern Scotland. On the northern side of this valley the road section exposes a long section of varied agglomerates and tuffs, which are succeeded on the plateau by decomposed basalt. Just N. of the Muiga River a road section has been cut through a columnar lava which Miss Neilson has determined as nepheline basanite ; it is covered by a spheroidally weathering basalt which is seen on both sides of the Amboni River. The road rises from this river to the height of about 6400 ft., and there the basalt is finer grained and spherulitic ; then from beneath this spherulitic basalt appears a coarse porphyritic phonolite with large crystals of anorthoclase and nepheline and scarce olivine. It is an olivine-bearing variety of the Kapitian phonolite. As this rock appears abruptly, and presents neither overlying tuffs nor vesicular upper surface, the spherulitic basalt appears to have flowed over a denuded surface of phonolite.

The phonolite continues eastward till it is buried by the volcanic tuffs of Kenya ; W. of the Meru road it forms the down-like hills of Songari (6536 ft.), on the western face of which, in 1893, I had noticed the emergence of the Kapiti lavas from beneath the Laikipian basalts.

The phonolite, 3½ miles N. of the Amboni River, is broken through by a coarse agglomerate with large boulders of kenyte, similar to that of Mount Hohnel on Kenya ; and the presence of a pebble of gneiss indicates that the Eozoic foundation is comparatively near the surface. This agglomerate is apparently in one of the marginal vents of Kenya.

The bridge over the next river to the N., the Rongai, is built partly of a glassy and felspathic trachyte, apparently derived from the hill (6404 ft.) to the E. of the road.

Eight miles further N., along the Meru road, the descent to the Naromoru River, which rises on the Lewis Glacier on Kenya, shows a compact blue trachytic-phonolite with small phenocrysts of riebeckite, nepheline, and anorthoclase ; on the floor of this valley an agglomerate contains boulders, 8 and 10 ft. in diameter, of the porphyritic Kapitian phonolite. The adjacent gravels include specimens of nepheline-syenite, similar to that of the central core of Kenya ; these pebbles indicate the probable existence up the valley of a kenyte vent.

The combined observations of the two traverses across Laikipia indicate that the Laikipian succession is as follows :—

Naivashan .	Phonolitoid-kenyte of Nyeri, etc.
Laikipian .	Quartz-trachyte and rhyolite. Phonolitic trachytes. Basalts and basanites, and lower phonolitoid kenyte.
Nyasan . .	Unconformity.
Doinyan .	Kenya type of phonolite and kenyte intrusions (Domo Arabel). Losuguta type of phonolite.
Kapitian .	Coarse porphyritic phonolite.

The position of the chief kenyte eruptions, as determined on Kenya, is shown in the following chapter.

CHAPTER XII

Mount Kenya

I. Its Volcanic Geology and Structure

MOUNT KENYA, discovered by that noble missionary pioneer Ludwig Krapf on the 3rd of December, 1849, is the greatest mountain in B.E.A. Its volcanic nature was first proved by specimens collected by von Teleki in 1887, and determined by Rosiwal (1891) as andesites and phonolites. Teleki, misled by the rounded form of the valley in which he reached his highest point and by the corries in the central peak, represented Kenya as a volcano with a still existing crater, and that view has been re-expressed by Capt. Orde Brown (1918, p. 392). In 1893 I visited the mountain and climbed to the height of about 600 ft. below the summit,[1] and found[2] that the central peak is a plug of nepheline-syenite and kenyte filling the vent of an old volcano, of which the crater had been destroyed by at latest the Pliocene. Kenya was a volcanic neck in much its present stage of decay in pre-glacial times.

The mountain consists of three parts : a central rocky peak (Pl. XI) with glaciers and snow-fields ; an Alpine zone of moorland and valleys with tree-lobelias (Pl. XI, B) surrounding the peak ; and a vast gently sloping dome, which is covered by dense forests and bamboo jungle. Seen from a distance, Kenya appears as a gently sloping mound, above which rises a rocky peak with snow fields and glaciers in its valleys and corries.

The central peak consists of a plug of igneous rock, which choked the pipe of the volcano. This rock consists of nepheline-syenite, which is a deep-seated rock and not a lava ; it is associated with the lavas and agglomerates of the walls of the pipe, and that it forms the summit[2] was proved by specimens collected there by Sir Halford Mackinder. He thus confirmed the view that the existing summit stands far below the floor of the original crater. The interpretation of the central peak as the plug of a volcanic neck is also supported by the photographs of Mr. McGregor Ross, Dr. Arthur, and Dr.

Photo by] [*C. J. Blackburne-Maze, Esq.*

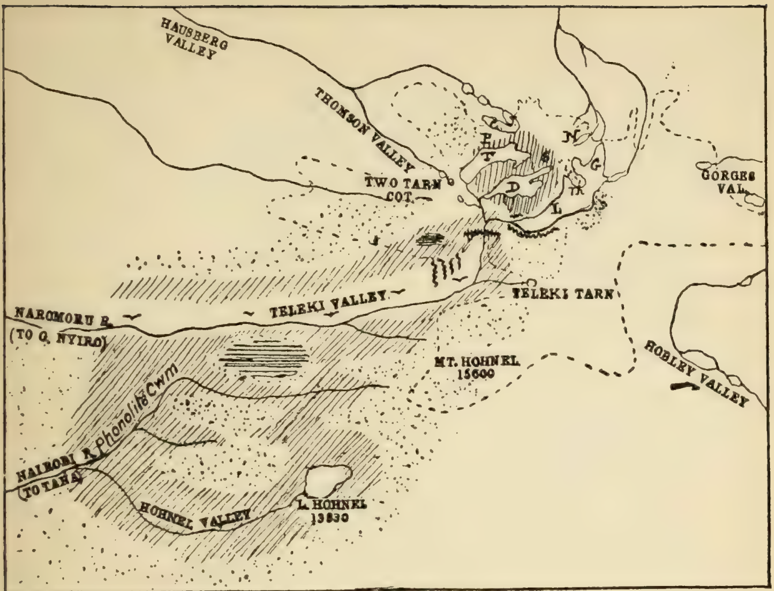
(*a*) MOUNT KENYA, THE SOUTH-WEST FACE.

The Tyndal Glacier to the left ; the Darwin Glacier to the right.

Photo by] [*C. J. Blackburne-Maze, Esq.*

(*b*) THE VEGETATION OF THE ALPINE ZONE OF KENYA.

Including young giant groundsels (*Senecio kenyense, Bak. f.ls*) ; to the right are two *Lobelia Gregoriana Baker fil :* tree heaths in the background.



Alluvium

Moraines

Old ice-wall across Teleki Valley

Basalt

Kenyte (lavas and agglomerate)

Phonolite

Nepheline-Syenite

Contour 15,000 feet

S Summit of Kenya

P Point Piggott

Th. Point Thomson

Glaciers:

T	Tyndall	South side
D	Darwin	
L	Lewis	
C	Cesar	North side
J	Josef	
N	Northey	
G	Gregory	

FIG. 22.—Geological sketch map of the south-western quadrant of Mount Kenya.

Scale: 1 inch = 1·8 miles.

Melhuish in Pls. VIII, XII–XIV; they show that the structural lines are vertical (*cf.* Pl. VIII, opp. p. 102) and not horizontal, as they are in the rocks which built up the crater (*cf.* Pl. XII, B).

The rock which forms the nucleus of the plug is an olivine-bearing nepheline-syenite (Gregory, 1900, pp. 208, 209, and Pl. XI, Fig. 4). It consists of anorthoclase,[3] barkevicitic hornblende, long prisms of nepheline, a pale purplish augite fringed by ægerine, small crystals of cossyrite, and a constituent which is probably sodalite. It contains a little olivine.

The lavas which form the outer part of the central plug are chemically allied to this nepheline-syenite, but instead of being composed wholly of crystalline constituents, they contain much

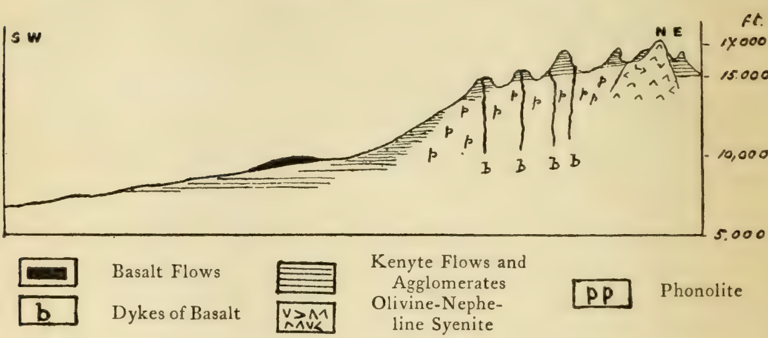


FIG. 23.—Diagrammatic Section of the south-western quadrant of Mount Kenya.
Scale: 1 inch = about 6 miles.

black glass. In hand specimens, the most conspicuous materials are a black glass and crystals of anorthoclase felspar up to an inch in length; under the microscope can be seen corroded crystals of olivine, which are often altered to serpentine. Around the central plug is a zone of agglomerate, volcanic tuff, and lava, which is part of the foundation of the crater walls. This zone is dissected by radial valleys, the sides of which show the characteristic weathering of agglomerate into rough crags and pinnacles (*cf.* Pl. XIV); the horizontal bedding lines are conspicuous and are shown in Dr. Melhuish's photograph, Pl. XII, Fig. B. The typical lava in this zone consists of a black glass, which becomes gelatinous and yields crystals of common salt when treated by acid; it is largely a nepheline glass. The felspars are anorthoclase; the

Photo by] [*J. D. Melhuish, Esq.*

(*a*) THE UPPER PART OF THE LEWIS GLACIER WITH POINT THOMSON.

The foot of the central peak of Kenya is seen to the left.

Photo by] (*b*) POINT THOMSON. [*J. D. Melhuish, Esq.*

Showing the horizontal layers of its lava (keynte) and tuffs in contrast to the vertical structure of the central peak (cf. Plate VIII.).

dark-coloured constituents are microscopic crystals or larger grains of a pale green ægerine which has often been altered into a decomposition product known from its opaqueness as opacite. The other important constituent is olivine, which is often much altered.

This rock is the typical component of Kenya. It is closely allied to the alkaline-lava of the island of Pantelleria, S. of Sicily, which is known as pantellerite. That rock is, however, more acid than that of Kenya ; it contains many amphiboles but no olivine. The Kenya lavas could only be included in pantellerite by adopting for that rock a definition which Rosenbüsch emphatically repudiated for it. I therefore proposed for the lavas of Kenya the name of kenyte, which may be defined as an igneous rock which consists of anorthoclase and ægerine, which typically contains glass and olivine, and is the lava or dyke representative of olivine-bearing nepheline-syenite. Kenyte belongs to the family for which Rosenbusch adopted the name of trachy-dolerite, which suggests a rock intermediate between a trachyte and a dolerite. Both of these rocks are of the normal or calcic igneous division, whereas the kenyte belongs to the division rich in soda. The term trachy-dolerite is therefore inappropriate as it overlooks that essential difference between these alkaline rocks and the trachytes and dolerites.

The rock kenyte has been subsequently found to have a wide extension in Antarctica, where it has been described from Mount Erebus by Dr. G. T. Prior, who has commented on the striking resemblance of the East African and Antarctic kenytes. Dr. Jensen (1916, *Brit. Antarctic Exped.* 1907–1909, Geol., Vol. II, pp. 103–111) has divided the allied rocks from Mount Erebus into three types, acid kenyte, basic kenyte, and trachy-dolerite ; both these kenytes have phenocrysts of anorthoclase and ægerine ; the main difference between the three types is that acid kenyte has the composition and ground-mass of an alkaline trachyte, basic kenyte has the composition and ground-mass of basic phonolites and tephrites, trachy-dolerite has the ground-mass of a basanite.

Finck has adopted kenyte as a special type of trachy-dolerite (1903, p. 14). In a later memoir (1906, p. 394) he identifies it as the extreme member of the trachy-dolerite family, and says (*ibid.*, p. 397) that the kenyte of Kenya is the eruptive form of the laurdalitic magma. He shows the presence of the same rock on Kibo, and makes a new type, the Vasvik type, in which he includes some of the specimens from N.E. Kibo (table of analyses, *ibid.*, p. 392).

The kenyte lavas of the Alpine zone of Kenya are associated with a series of phonolitic lavas, which are well exposed along the sides of the Teleki Valley, one branch of which I called the Phonolite Cwm. Prior (1903, p. 239) has adopted this rock as the typical representative of his Kenya type of phonolite. This phonolite underlies the kenyte lavas and agglomerates, and is the oldest rock known in the mountain.

In addition to kenyte and phonolite the chief rock present on Kenya is basalt, of which there are two varieties; one, the massive olivine-basalt of the Alpine zone, is often columnar, as in the crags S. of the Teleki Valley; the other is a fissile olivine-basalt and occurs in the forest zone. Olivine-basalt dykes cut across both the kenytes and the phonolites, and are therefore the latest of the three series of igneous rocks; whether the fissile basalt of the forest zone is of the same age as the basalt dykes of the Alpine zone is uncertain; they probably belong to the same eruptive stage, so that the lavas of Kenya were discharged in the order, first phonolite, then kenyte, and lastly basalt.

Kilima Njaro is a mountain with a much longer volcanic history than Kenya, and includes a much greater variety of igneous rocks. They range from sub-acid rocks, as trachytes and phonolitic obsidians, to the ultra-basic limburgite (1906, p. 90). Prof. Lacroix shows that in this range the Kilima Njaro rocks include kenyte at the foot of the Kibo Glacier and phonolitic-trachytes, augitic-trachytes, which often contain olivine (Lacroix, 1906, p. 90), nepheline-phonolite, and nephelinites; and according to Lacroix, ijolite (a garnetiferous-nepheline-ægerine gabbro) plays on Kilima Njaro the rôle of the olivine-nepheline-syenite of Kenya (p. 95). Mauritz (1908) shows the predominance of the alkaline lavas and kenyte around Mount Meru, W. of Kilima Njaro. He describes there (*ibid.*, p. 316) nephelinite, with nephelines $\frac{1}{8}$ in. long, from tuffs at Elduroto Ebor, between Kilima Njaro and Meru; also kenyte (trachy-dolerite) at 4250 ft. at the southern foot of Meru (*ibid.*, p. 319). At Meru, as often elsewhere, the later lavas are especially alkaline, and include the phonolitic kenyte of the Meruni crater and Towaila at the height of 4900–5200 ft. S.E. of Meru, and a leucit-nepheline-tephrite tuff at 5900 ft. E. of Meru (*ibid.*, pp. 324–326).

The exact sequence of the lavas of Kilima Njaro has not yet been fully established; but Jaeger (1909, p. 129) has shown that on the Hans Meyer Ridge, S.W. of the crater, the kenyte (basic " rhombenporphyr") is covered unconformably by nepheline-phonolite, showing that, as in B.E.A., the kenyte eruptions long preceded those of the later phonolites.

II. The Glaciation of Kenya and its Evidence as to the Age of the Eruptions

Although Kenya stands actually on the Equator, the summit being 8 miles S. of it, the peak bears a system of about fifteen glaciers. On the S.W. side of the mountain there are five glaciers, which I discovered and named in 1893; the Lewis glacier (Pls. I, XII, XIII), which was named after the brilliant American glacial geologist, Carvill Lewis, is the largest on the mountain, and is a little over a mile long. The other four on the same side are the Tyndal (Pl. XIII, B), Darwin, Heim, and Forel Glaciers, named after European men of science who advanced glacial geology. On the northern face of the mountain further series were discovered by Sir Halford Mackinder, Dr. Arthur and Dr. Melhuish, and named the Gregory, Kolb, Krapf, Northey, Cesar, and Josef glaciers. Five smaller glaciers lie in corries on the peak. The northern glaciers now end, according to Sir Halford Mackinder's determinations, between the levels of 14,900 and 14,450 ft. (Mackinder, 1903, p. 483).

The most remarkable fact concerning the glaciation discovered in 1893 was its former great extension. The peak was once covered by an ice-cap, from which glaciers flowed outwards and descended about 5000 ft. lower than the existing glaciers. This fact appeared the more surprising because at that date no evidence had been discovered in tropical Africa of a greater expansion of the existing glaciers or reliable evidence of any glaciation simultaneous with the Great Ice Age of Europe. Chaper (1886) had reported evidence of glaciation in Equatorial West Africa, but on the quite inadequate evidence of unrolled boulders, and Drummond had reported glacial traces from Nyasaland on equally unreliable grounds. The glaciers on Kilima Njaro had been carefully examined by Meyer, and though he reported (*Across East African Glaciers*, 1891, pp. 312–313) moraine-like ridges, he explained them as banks of talus.

At the height of about 9800 ft., in the upper forests of Kenya, I came across a boulder-strewn bank which was suggestive of a moraine; it was too densely covered by vegetation for its nature to be determinable, but on emerging from the forests a few hundred feet higher I at once recognized typical moraines. They afforded clear evidence that glaciers had once existed at the level of about 10,000 ft., and other moraines were seen from that height up to those of the existing glaciers. Confirmatory evidence was obtained from glacial scratches, which I found in several places by stripping off the turf and exposing a fresh rock surface. The corries, some of which have a small lake on their floors, were evidence of a formerly severer climate, for they were probably due to the shattering action of frost; and that the corries had been occupied by ice was clear from the glaciated condition of their floors. One of the striking features in the scenery of Kenya is the contrast between the rounded summits once covered by the glaciers and the jagged crests (as shown in the Frontispiece) and rock pinnacles known as gendarmes (as at Point Thomson and the Twins, Pl. XIV) on the ridges that rose above the ice zone. The ice-worn forms of the valleys and rock surfaces are also striking evidence of the former extension of the glaciers; they are illustrated in the photographs of the Hobley Valley, Pl. XIV, B, and by that of the rounded glaciated rock surfaces above the Lewis glacier shown in Pl. VIII, opp. p. 102.

The Lewis glacier, according to the altitudes adopted on the unpublished G.S., G.S. map of Kenya, ends at 15,400 ft.[4] above sea-level. Sir Halford Mackinder (1900, p. 483) records old moraines down to the level of 12,000 ft. and scattered boulders, which may be erratics, down to the level of 9000 ft. Evidence of the former extension of the ice has also been observed by Mr. McGregor Ross, Dr. Arthur, and Dr. Melhuish.

The evidence is clear that the ice once extended on Kenya about 5000 ft. below its present limits; this cannot be explained by a general refrigeration of tropical Africa, because the contemporary deposits along the coast showed no indications of colder conditions. Nevertheless, the plant distribution shows that the change must have been widespread in the interior; for the higher mountains are inhabited by a flora quite different from that on the lower country around them. The two most remarkable members of this Alpine flora are the tree groundsels and tree lobelias, which are represented by nearly allied species on the mountains of Abyssinia, on Elgon, Ruwenzori, Settima, Niandarawa, Kenya, Kilima Njaro, and Meru. The ancestors of these trees probably spread through eastern tropical Africa at a time when owing to the severer climate they lived far below their present limit; as the climate became warmer they were

Photo by] [*J. D. Melhuish, Esq.*

THE UPPER PART OF THE TYNDAL GLACIER
and the western Arete of the central peak.

Photo by] [*J. D. Melhuish, Esq.*

THE UPPER PART OF THE LEWIS GLACIER.
A long crevasse seen to the right.

exterminated except on the highest mountains; there they have been isolated so long that they have developed into different species on different mountains; thus the tree groundsel of Kenya was described by Mr. E. G. Baker as a new species, *Senecio Keniense*, and the tree lobelias are two species known only from the mountain, as *Lobelia Telekei* Schweinf.,[5] and *L. Gregoriana* Baker, for a photograph of which (Pl. XI, Fig. B) I am indebted to Mr. C. J. Blackburne-Maze. The period of the glaciation, during which the ancestors of these trees lived at lower levels, was therefore probably tens of thousands of years ago, and contemporaneous with the Great Ice Age of Europe. It was probably the meteorological changes connected with the glaciation of Europe which forced the cyclone-track that now lies along the Mediterranean farther south, and thereby gave Equatorial Africa a moister and colder climate. As the glacial conditions waned in Europe, the track of the storms returned northward, Equatorial Africa became warmer and more arid, producing the areas of local desiccation, to which in B.E.A. attention has been specially called by Mr. Hobley.

The fact that the greater glaciation of Kenya was approximately contemporaneous with that of Europe has an important bearing on the date of the volcanic period of B.E.A. The glaciers of Kenya at their greatest extension flowed down valleys which had been excavated previously. As remarked in 1894 (Gregory, 1894, p. 526), "The fact, moreover, that the valleys are glaciated to their bottoms and that perched blocks still surmount the crests shows that there has been no very great denudation in the Alpine zone since the maximum glaciation. Thus, though there may have been a considerable lowering of the central plug which now forms the summit since the time of maximum glaciation, in the later stages, as when the glaciers were depositing the terminal moraines of the Teleki Valley, the entire crater-walls had disappeared."

The existing glaciers were once much larger; the greater thickness of the Lewis glacier at its present end is shown by the ice-worn rock surfaces above its western bank (Pl. VIII) and the great moraine which forms its opposite bank (Pl. X, Fig. B). The glaciers used and enlarged pre-existing valleys, which had been formed in pre-glacial times. The crater of Kenya must once have risen at least 3000 ft. above the present summit; and during the pre-glacial excavation of the valleys around the central peak the crater was completely destroyed. As Kenya had been worn down to essentially its present condition in pre-glacial times, the upbuilding of its crater obviously happened long before that date. The last eruptions were probably pre-Pliocene; the volcano was in its prime long before the Pliocene. The lavas of Kenya were not the earliest in B.E.A., so the pre-glacial denudation of Kenya indicates that the older lavas of East Africa must date from at least early Kainozoic times.

That the other highest East African mountains shared in the greater glaciation has since been proved. Kilima Njaro has a series of glaciers which were once much longer (Meyer, 1901, p. 770). As on Kenya, they extend lowest on the S.W. side, where, according to Jaeger (1909, map No. II), the chief western glaciers end at the levels of 14,750 ft., 15,350 ft., 15,500 ft., and 15,550 ft. Below the western glaciers Jaeger (1909, p. 191) reports that the rocks are glaciated to 14,100 ft.; he does not admit glaciation below that level as though a cirque (or corrie) occurs as low as 13,100 ft., he considers that it was not glacial in origin. On the southern side Uhlig (1904, p. 641) records glacial traces at 13,450 ft. The greatest extension of the glaciers of Kilima Njaro has been claimed by Meyer (1900, p. 370) at from 11,800 ft. on the northern slopes, and at 12,450 ft. (*ibid.*, p. 372) on the southern and south-eastern sides. Uhlig and Jaeger (1909, p. 192) regard the rounded rock surfaces upon which these lowest records are based, as desert-formations and not glacial. On Mawenzi, the peak of Kilima Njaro in the Kenya stage, there appears to be no traces of former glacial action (Meyer, 1900, p. 374).

The most surprising glacial advance in Equatorial Africa is that of Ruwenzori, where Scott Elliot (1895, p. 310; and in Scott Elliot and Gregory, 1895, p. 676) discovered old moraines in the Mubuku Valley at the height of only 5000 ft. above sea-level. Mr. Scott Elliot's observations on this question have been fully confirmed during the expedition of the Duc of the Abruzzi (Roccati, 1907).

The Kenyan Succession.—The geological history of Kenya and its correlation from the evidence of its structure and glaciation may be summarized in the following table :—

Early Pleistocene .	Maximum Glaciation.
Pliocene . . .	Long interval of denudation, destruction of the crater and excavation of existing valleys.
Laikipian . . .	Third eruptive stage; olivine-basalt.

Photo by] (*a*) THE TWINS. [*J. D. Melhuish, Esq.*

Two lava pinnacles on Kenya above the formerly ice-covered zone.

Photo by] (*b*) THE HOBLEY VALLEY, KENYA. [*J. D. Melhuish, Esq.*

One of the valleys in the Alpine Zone which have been rounded by glaciers during their former extension.

Nyasan . . .	Probable long interval.
Doinyan . . .	First eruptions, the Kenyan phonolite; second, the main eruptive stage—kenyte and olivine-nepheline-syenite.

[1] The accepted height is 17,040 ft. Thomson (1887, p. 224) gave it as 18,400 ft. In 1893 I estimated it, from an observation with an Abney's level from the Teleki Valley, as 18,370 ft. (Gregory, 1894 (1), map). I subsequently accepted the height as determined trigonometrically by von Höhnel (Gregory, 1900 No. 3, p. 207). He raised the estimated height to 19,600 ft. after his later expedition (Chanler, 1896, map). Karl Peters (*New Light on Dark Africa*, 1891) gave the height as 23,000 ft.

[2] The Glacial geology was described in a paper in 1894, No. 2; the igneous rocks in 1900, No. 3.

[3] The most remarkable constituent of the kenyte rocks of East Africa is their large felspar, which is anorthoclase. Attention was first directed to its peculiarities by Prof. Bonney (1886, p. 684) when describing a lava from the height of 14,700 ft. on Mawenzi, the peak of Kilima Njaro in the same condition as that of Kenya. These felspars from Kilima Njaro were investigated by Sir H. A. Miers (1886, pp. 10–11), who compared them to those in the Norwegian rhomb-porphyry. A subsequent note by Sir Lazarus Fletcher and Sir H. A. Miers (1887, pp. 131–132) proved their composition as An_1 $Or_{0.94}$, $Ab_{2.11}$.

[4] My determination in 1893 was 15,580 ft. (Gregory, 1894, No. 1, p. 513; 1900, No. 3, Pl. X).

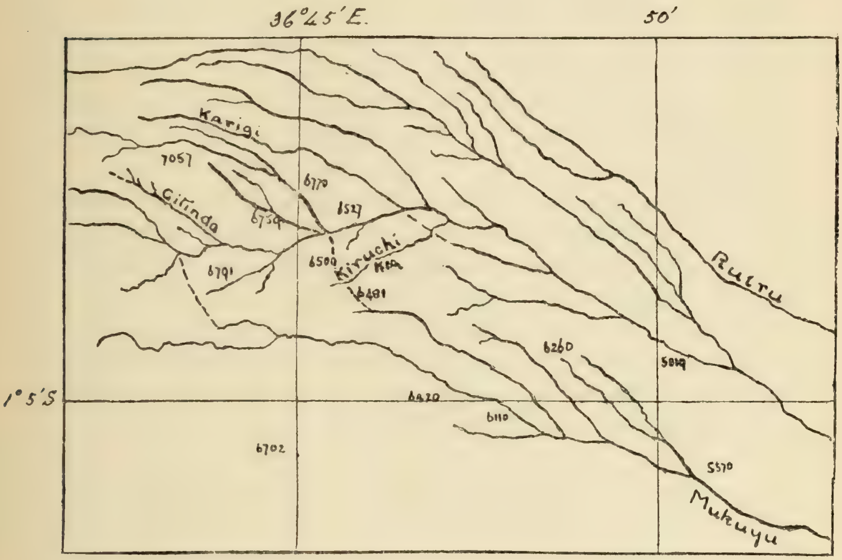
[5] E. G. Baker, *Journ. Bot.*, Mar., 1894, Pl. 340. The distinctness of the species is accepted by Engler. Photographs of both Kenya tree-lobelias have been published in the *Gardener's Chronicle*, LIX, 1916, pp. 126, 127.

CHAPTER XIII

The Volcanic Belt of Kikuyu-land

KIKUYU-LAND is a belt of hilly upland which is furrowed by closely set valleys and extends from Mount Kenya S.S.W. to the Rift Valley W. of Nairobi. Two marches across this country in 1893, one through the southern districts between Nairobi and the Rift Valley and the other through the northern districts from Laikipia to the Tana, showed that the country consisted originally of a long down-slope from Laikipia to the Kapiti plains. The country, especially in northern Kikuyu-land, was then covered by such dense forest that it was rarely possible to obtain a general view of the country ;[1] but occasional glimpses from a hill-top or down a valley revealed the fact that the country had once been a peneplane (i.e. almost a plain—analogous to the term peninsula) with a long gentle south-eastward slope, of an average, based on several traverses, of about 75 ft. in the mile. Most of the original surface has been removed, for the country consists largely of soft volcanic tuffs. Their decay has produced a thick rich soil, which is one of the most fertile in East Africa, and used to support dense forest, until it was cleared in recent years. This ground slopes downward to the E. and S.E. from 6000 ft. in Laikipia or 8000 ft. on the edge of the Rift Valley (as above Escarpment Station and at Mount Ngong), in a long and originally gentle decline, in which numerous streams have cut valleys that often run parallel for miles, separated by long narrow flat-topped ridges. The drainage is of the type known as consequential, as it is directly consequent on the original slope of the ground. That the rivers are of considerable antiquity is shown not only by the depth to which they have cut their valleys, but by the fact that some of the tributaries have cut valleys across the slope, and have thus captured the head-streams of the neighbouring rivers. The beheaded lower sections can still be recognized below the capturing stream (see Fig. 24). Such river capture has happened near Kiawairera (6579 ft.), where the Kiruchi River and a parallel river N.W of it, by cutting a valley across the slope, have diverted into the Upper Ruiru the Karigi and Gitinda Rivers, and the Kimaiti River, which were doubtless originally the head-streams of tributaries of the Mukuyu (Fig. 24).

The special character of the Kikuyu drainage is due to the rain-water easily cutting runnels in the soft tuffs ; and the valleys have maintained the direction of the original runnels owing to the general uniformity of the tuffs. The interbedded lava sheets are more



Kia = Kiawairera

---- Probable original course of rivers before the development of the cross valleys of the Gitinda and Kiruchi

Fig. 24.—Kikuyu rivers, illustrating their approximately parallel course and the early stages of river capture by the Kiruchi and Gitinda, near Kiawairera.

Scale : 2 miles to 1 inch.

resistant, but the rivers undermine them at waterfalls or drill into them innumerable pot-holes and thus slowly cut valleys through them.

The widespread agglomerates show that Kikuyu-land lies along a series of volcanic vents. The Kapitian phonolite forms the high plateau of Laikipia to the N. and the lower Kapitian Plains to the S.E. ; and the Kikuyu volcanic chain was probably formed along the fractures, by which the Kapitian phonolite was lowered to the S.E.

Swamp-Pits.—The Kikuyu vents were in eruption after those which discharged the Kapitian phonolite; but I saw no volcanic crater in Kikuyu-land, and, so far as I know, none has been discovered. Some depressions, of which the best known is the Niakumu swamp, two miles W. of Kikuyu Railway Station, have been regarded as craters. Those which I have seen do not, however, present any of the essential features of a crater; one, N.E. of Tumu-tumu, in northern Kikuyu-land, which I inspected in 1893, seemed due to the collapse of the surface where it had been undermined by volcanic action. The Kikuyu eruptions happened so long ago that the craters have been destroyed, the volcanic hills worn down into a peneplane, and this plane has been dissected by rivers into a grid-like system of valleys and ridges.

The Kikuyu Volcanic Sequence.—The volcanic history of Kikuyu-land includes three different series of eruptions, later than the out-pouring of the Kapitian phonolites and the main upbuilding of Kenya. The first of the Kikuyu volcanic series includes basalt and basaltic tuffs; they were followed by phonolitic trachytes; the Kikuyu eruptions closed with the discharge of quartz-trachytes and rhyolites. All these eruptions were earlier than the last main faulting of the Rift Valley.

I. The Traverse from Kenya to the Thika-thika

The above sequence is well shown by the traverse across northern Kikuyu-land; but in the traverse from Kenya to the Tana in 1893 I had little opportunity of determining the relations of the rocks, for, unfortunately, I passed through the country just after the sugar cane was ripe, and the warriors were drunk and so quarrelsome that it was impossible for me to leave the caravan on the march or make excursions from camp. I had therefore to pass excellent river sections unexamined, and had to be content with the evidence that the basaltic series intervenes between the rhyolite-trachyte series and the phonolites.

In 1919, thanks to the kindness of Mr. McGregor Ross and Mr. Sikes, I had the opportunity of motoring from Nyeri to Nairobi via Fort Hall on a line to the S.W. of the traverse of 1893; and I could examine the country with no other restriction than that of time, which, however, was limited.

The observations made during these three traverses establish the general succession of the Kikuyu volcanic series. The most northerly traverse was from the western foot of Kenya to the Tana near its junction with the Thika-thika. The line of march mainly followed the watershed between the Sagana or upper Tana to the W., and the Murabara-Thiba River to the E. It began at the south-eastern corner of Laikipia on the Kapitian phonolite, which disappears beneath the agglomerates and tuffs of the south-western slopes of Kenya. These rocks were succeeded by the Kikuyu volcanic series, which around Tumu-tumu and Itiati (Geitati) weather to a deep red prolific soil. The associated lavas are exposed at Itiati, and also at Tumu-tumu, from the summit of which specimens were collected by Mr. Sikes (406). The rock is a compact dark blue phonolitoid-kenyte; it somewhat resembles a basalt by its red weathering, denseness, and black colour; but its weight is lighter, as can be judged from hand specimens. (I have recently received from Mr. Sikes a specimen from Tumu-tumu of a more basic rock, which Miss Neilson identifies as an alkali-basalt or tephrite.) As we followed the slope south-eastward the river valleys became deeper, and thus exposed broad sheets of tuff and basalt; a section W. of the Ramusambe River, 7 miles N. of its junction with the Tana, shows the phonolitoid-kenyte overlying basalt. Near the foot of the main slope of the country, near the village then known as Marungu (the unnamed 3837 ft. hill, at 37° 19′ E., 0° 46′ S., on the G.S., G.S. map, sheet Kenya, 1912) are numerous exposures of olivine-basalt and tuffs; and at a still lower level, on the plains on the northern bank of the Tana, the Kapitian phonolite rests on the gneiss which is exposed on the valley floors and on the bed of the Tana.

The sequence seen in this traverse is then gneiss, Kapitian phonolite, the kenytes of Kenya, basalt, and finally phonolitoid-kenyte. The relations of the lavas of Kenya to the basalt were not seen; but the horizon of its kenyte is clearly between the Kapitian phonolite and the phonolitoid-kenyte; and the exposures on Laikipia indicate that the older kenyte is earlier than the basalt, if the Kikuyu and Laikipian basalts be on the same horizon.

II. Traverse from Nyeri to the Kapiti Plains (Fig. 25)

The traverse from Nyeri to the Thika and thence on to Nairobi was made in 1919 with the luxury of a motor-car and the guidance of Mr. H. L. Sikes, who knows parts of the country intimately, and to whom I owe most helpful information. In the neighbourhood of Nyeri the plateau is dissected by the deep valleys of the Chania River and its tributaries. In the view north-eastward from S. of Nyeri the Kapitian phonolite is seen emerging as a plateau from beneath the volcanic dome of Kenya; and at the foot of that plateau lies the Nyeri basalt, that has obviously been discharged down a valley eroded in the phonolite. The road sections on the long descent to the Suta River are cut in agglomerate, which is pierced by basalt dykes. The basalt at the Chania Falls, according to Mr. Sikes, is a thick columnar sheet resting on agglomerate, beneath which gneiss is exposed on the river bed. From the plateau north of the Suta we descended to the Chania River, crossing thick beds of tuff and agglomerate cut through by a basalt dyke. The road from the Chania bridge to the Mission Station rises over tuff capped by basalt, that is covered by trachytic tuff and the phonolitoid-kenyte of Tumu-tumu hill.

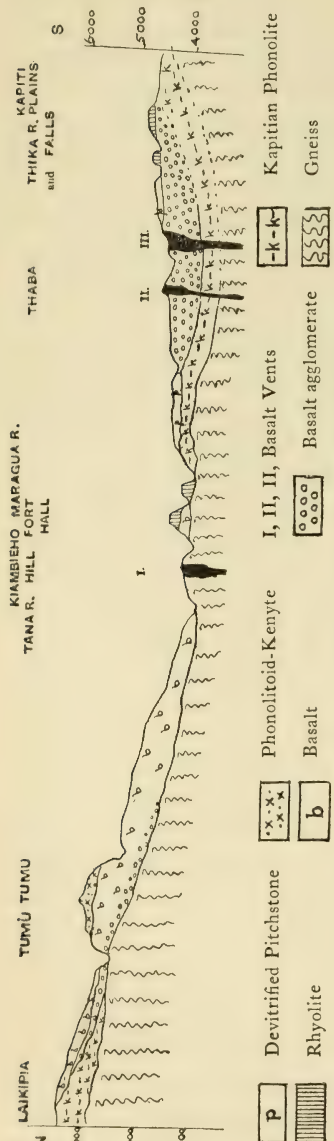


FIG. 25.—Section across N. Kikuyu-land.
Scale: 1 inch = 9 miles.

The road from the Mission Station southward to the suspension bridge over the Tana passes first through the plantations in the native reserve, from which there is an instructive panoramic view down the dissected Kikuyu peneplane to the rugged gneiss hills of

Ithanga and Kiambicho, and the distant Kapiti Plains, above which rises the gneiss mountain of Doinyo Sapuk. At the foot of the steep descent from the Tumu-tumu plateau, beside the bridge over the Rogati River (4680 ft.), is a sheet of vesicular olivine-basalt that Mr. Sikes tells me is identical with the rock at the Tumu-tumu Falls. The road continues down the valley of the Rogati, over basaltic soils and past hills terraced by basalt flows, to the Tana, where the foundation of the suspension bridge on the northern bank is a coarse fresh olivine-basalt, and on the opposite bank is gneiss. The gneiss (No. 429) is mainly light-coloured biotite-gneiss, of which the foliation trends from between N. by W. to N. by ½ E., and dips 70° E. Kiambicho Hill, S. of the Tana, consists of gneiss. The next Kikuyu ridge to the W. appears, from the weathering of the rocks, to consist

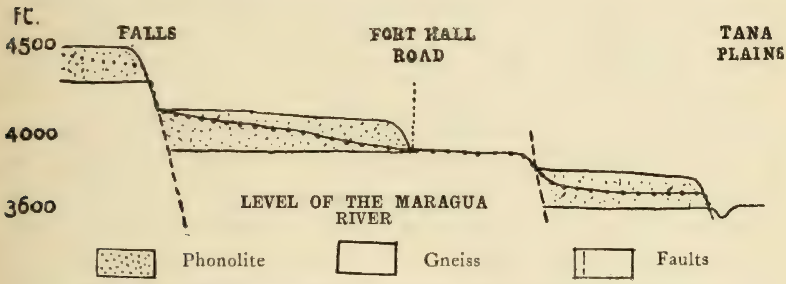


Fig. 26.—Diagrammatic Section showing the faulted descent along the Maragua River.
Scale: Length, 1 inch = about 5·7 miles.

of gneiss which is exposed at the southern end of a cap of rhyolite further N., and with low hills of basalt lying at its foot. On the southern side of Kiambicho Hill the gneiss is interrupted near the bridge over the Mathioya River by agglomerate containing large boulders of porphyritic-basalt and many fragments of gneiss. From the Mathioya Bridge a long steep ascent leads to Fort Hall; up to the height of about 4000 ft. the road crosses basaltic agglomerate; a road section has cut through a lenticular flow of basalt, which has filled up a stream channel in the agglomerate. The top of the plateau near Fort Hall is a sheet of brecciated rhyolite, which has been worked in a small quarry (4300 ft.). The rhyolite is devitrified and so full of fragments that it is not easy in the field to distinguish the lava from the tuffs. The Merali, the first stream S. of Fort Hall, has cut its valley through the rhyolite to the agglomerate; in the next valley, the Kithambia River, the rhyolitic series rests on the basalt agglomerate, which overlies gneiss. The road winds round a spur and reaches the Maragua River ; its banks near the bridge give instructive sections. The gneiss is exposed at the bridge (4000 ft.), and on the northern bank is overlain by agglomerate covered by phonolitic-rhyolite (Pl. XIX, Fig. 1, No. 435) and rhyolitic tuff with abundant fossil wood ; about 230 ft. above the river is the base of a cliff of columnar tuff that from the bridge appeared basic owing to its rich red colour ; but the rock is a rhyolitic tuff coloured by a thin film of red clay that has been washed on to it from the soil on the hill-top. On the southern bank of the river above the gneiss is a sheet of Kapitian phonolite. The position of this rock directly opposite the rhyolite in the northern bank suggested a fault ; but as the rhyolite and tuff overlie the phonolite, this explanation is inadmissible. The rhyolite series has been deposited on an irregularly dissected surface and so rests sometimes on phonolite and elsewhere on gneiss.

Mr. Sikes, who has examined the Maragua River in connection with the electric utilization of its power, has found that the phonolite occurs at three successive levels, viz. 4500 ft., 4000 ft. at the Fort Hall Road, 3800 ft. at the descent to the Tana plains (Fig. 26). At each level the phonolite rests upon gneiss, and is bounded by a cliff over which the river leaps in a waterfall. Mr. Sikes explains the change of level as due to the sheet of phonolite having been displaced by two faults, each with a downthrow to the E. These faults happened before the discharge of the rhyolite. This important evidence therefore shows that there was a long interval of time between the phonolitic and rhyolitic eruptions, and that during this interval the country was faulted.

South of the Maragua River the phonolites extend for some distance. The plateau between the Maragua and the Itherui Rivers is covered by rhyolite and tuff capped by a pale gray devitrified rhyolite. The Kapitian phonolites are exposed beside the Itherui River and S. of it to the Indian village of Thaba-thaba. The hill S. of that settlement is composed of very coarse basaltic agglomerate. Just S. of the Kachi River (the southernmost tributary of the Thaba River crossed by the road) is the base of a volcanic vent, of which the agglomerate includes enormous blocks of basalt. Rising again southward to the plateau of Mukuyu, the agglomerates are covered by a devitrified axiolitic phonolitic rhyolite, containing small fragments of fossil wood. It resembles the Nairobi freestone. Microscopic examination of this rhyolite shows that it is certainly a lava; for it has a regular flow-banding; it includes vesicles formed by escaping steam, and some of its included crystals of quartz and felspar have been deeply corroded by the glass. This rock extends S. of the Kabuko River, where it is succeeded by a red soil probably formed from decomposed tuff; this material extends southward nearly to the Samuru River; here basaltic agglomerates are again exposed on the northern bank. The plateau between this river and the Thika consists of a quartz-free rhyolite with streaks of obsidian. At the Thika Falls the river leaps over a bar of rhyolite, which is covered by rhyolitic tuff, into a gorge deep cut into agglomerate.

At the Thika Falls the road to Nairobi turns to the S.W. and descends a long slope of devitrified rhyolite, resting at the Thuriga River upon obsidian tuff. Thence the road continues for 20 miles to Nairobi across a plain of rhyolitic and trachytic tuff, through which the river valleys are cut down to sheets of lava. Approaching Nairobi the rhyolitic tuffs are succeeded N. of the Ruiruaka River by the underlying Nairobi quartzless phonolitic trachyte. Then follows a series of sections in agglomerate, trachyte, and the Nairobi freestone. At Muthaiga, a suburb of Nairobi, the road descends over agglomerate and the Kikuyu volcanic series ends by the appearance from beneath it of the Kapitian phonolite.

From the Thika Falls a route to the S.E. soon descends to the Kapiti plain, about 12 miles from the line followed in 1893 from the Thika-thika to Machakos.

III. The Traverse of Southern Kikuyu-land

The traverse between Nairobi and the Kedong, near the Uganda Railway, crosses lavas and tuffs which are sloping south-westward at about the same gradient as the country, so that the summits of the ridges keep for long distances on the same sheet of rock. Hence the sections along the Uganda Railway are few and not very helpful. They have been described by Maufe (1908, p. 36). The old caravan track between the site of Nairobi and the Kedong through Fort Smith kept mostly on lower ground and crossed numerous valleys, and was thus geologically a more instructive route. The scarp of the Rift Valley above the Kedong shows the succession of rocks that form the western part of southern Kikuyu-land. The summit of the plateau near the pass used by Sclater's Road for the descent to the Kedong, consists of a thick series of quartz-trachytes resting upon kenyte.

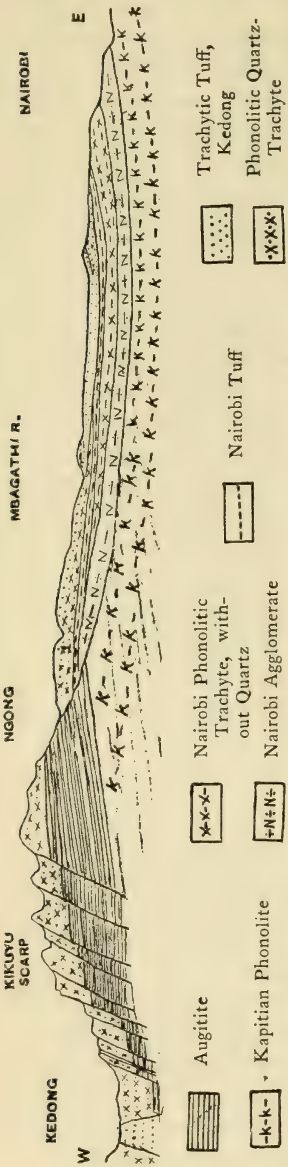


Fig. 27.—Section across Southern Kikuyu-land from Rift Valley to Nairobi.
Scale: Length, 1 inch = $3\frac{1}{8}$ miles; vertical, 1 inch = 3300 feet.

This quartz-trachyte occurs down the main slope to the camping ground, known as the "Second Swamp," and as it occurs to the E. of this track, in the Limuru district, it may be conveniently referred to as the Limuru trachyte. The surface of the country is broken into a series of ridges and valleys by faults trending from about N. by E. to S. by W. The scarps of the fault blocks face W., and have a dip slope to the E. The parallel faults were doubtless due to the yielding of the ground in consequence of the infall of the Rift Valley.

At the Second Swamp, kenyte comes to the surface and is again exposed at the First Swamp, 7 miles further S. Beside Fort Smith outcrop two varieties of phonolite. The upper is of the Kenya type, the lower is of the Kapitian type and it no doubt underlies the country from Fort Smith to Nairobi. It is not, however, so far as I know, exposed there on the surface, which consists of two series of trachytes; the upper is a quartz-trachyte similar to that of Limuru, while the lower trachyte is free from quartz. A variety of the more basic trachyte is worked in the quarries at the Kikuyu Mission; it is a coarse-grained rock with only obscure flow-structure; it contains large crystals determined by Miss Neilson as kataphorite; the rock may be described as an orthophyric soda-trachyte.

This traverse also shows the Kapitian phonolite as the lowest member of the volcanic series; it is covered by a Kenyan phonolite, which is associated with the kenytes; the phonolites were succeeded, after a considerable interval of time, by the Nairobi trachyte without quartz, and the eruptions ended with the quartz-trachyte of Limuru. The basalts are not represented, but the Nairobi and Limuru trachytes were deposited upon phonolites after a long interval of time, during which were discharged the basalts of northern Kikuyu-land and the augitites of the Ngong.

IV. The Traverse from Nairobi to the Ngong

As Nairobi lies at the junction of the Kapitian phonolites and of the Kikuyu volcanic series, it is a convenient locality for the determination of their relations. From observations in 1893, at my camp on the site of Nairobi, I felt no doubt that the phonolites continued westward under the Kikuyu volcanic series. This conclusion has been proved by a bore in the railway station yard at Nairobi which passed through the tuffs into the phonolites, and by Mr. H. L. Sikes' examination of the geology of Nairobi.

The phonolites are covered in eastern Nairobi and S. of the racecourse, by a sheet of tuff which is also exposed on the bank of the Nairobi River, beside Ainsworth's Bridge. The tuff there contains boulders so large that it is almost an agglomerate; it is stratified, iron-stained, and dips below the devitrified lava which is worked as a freestone and known as the Nairobi "claystone." This freestone has been quarried just above Ainsworth's Bridge; it (e.g. No. 292) is a devitrified trachytic pitchstone. The upper surface of this rock is smooth and planed, and was obviously an old land surface, covered unconformably by the second series of tuffs and agglomerates (No. 293). The devitrified pitchstone—the Nairobi freestone—is also exposed in a long quarry on the road to the Government Farm, E. of the bridge over the Mathari River[2]; in that quarry it consists of two divisions, the lower of which is more tuff-like (No. 296), but the position of some large vesicular fragments lying oblique to the fluxion banding around them indicates that the rock is a lava. The upper part (No. 295) is clearly a phonolitic rhyolite. The upper division at this quarry is cut off above by a land surface which has planed down the original top of the lava flow, and in one place excavated a stream channel in it. This surface is covered unconformably by a second agglomeratic tuff, containing fragments of pumice, obsidian, rhyolite, and the freestone.

The hills of South-western Nairobi consist of flows of a phonolitic quartz-free trachyte which, according to Mr. Maufe, succeeded the freestone series ; I did not see any clear exposure of the relations of these two series, but the alternative to Mr. Maufe's conclusion involves long interval and great denudation between the trachytes and the phonolitic rhyolites. The quartz-free trachyte is followed by a third bed of tuff, which is seen along the road towards Ngong, and according to Mr. Sikes overlies the trachytes in the Kirichwa Valley, N.E. of the divergence of the Dagoreti and Ngong Roads 4½ miles due W. of Nairobi Station. Around Dagoreti the tuffs are covered by quartz-trachyte and by coarse-grained orthophyric trachyte quarried at the Kikuyu Mission ; but as the Dagoreti road keeps along high ground, deeply covered by decomposed material, exposures of the rocks could only be found in the river valleys, which I had no time to visit. Along the Uganda Railway (*cf.* p. 161) the cuttings are mainly in decomposed tuff, and it is rarely that any fresh rock is exposed, the first observed being a quartz-trachyte in the bend east of Kikuyu Station. The volcanic sequence near Nairobi—accepting on Mr. Maufe's authority the superposition of the Nairobi trachyte to the Nairobi tuff and freestone[3]—may be summarized as follows :—

Quartz-trachyte of Limuru.
Tuff of the Kirichwa Valley.
Nairobi trachyte.
Nairobi tuff.
Unconformity.
Nairobi devitrified pitchstone—the Nairobi freestone.
The Ainsworth Bridge agglomeratic tuff.
Unconformity.
Kapitian phonolite.

This sequence includes no representative of the basalts of northern Kikuyu and the eastern walls of the Rift Valley, or of the Ngong augitites. In order to examine the relations of the basic rocks nearest Nairobi to the trachyte and rhyolitic series, Mr. Sikes kindly motored me to Ngong Bagas, and thence S. along a track at the eastern foot of Lamwia, better known as Ngong Mountain, to the Keserian River.

The Ngong road, after leaving that to Dagoreti, goes W., past pits 6 to 10 ft. deep in "murram," or surface ironstone, through forest and beside a shallow swampy depression of the kind known in South Africa as a "Vlei," and past the Government Nursery. The first rock exposure is at the crossing of the Mbagathi (alt. 6157 ft.); the river flows over trachyte and riebeckite-trachyte. These lavas are covered on the eastern bank by a tuff with large fragments of very coarse pumice. The trachyte shows clear fluxion structure with the surfaces dipping N.W. West of the Mbagathi are further exposures of trachyte and trachytic tuff, until at the crossing of the Ngong branch of the Mbagathi, E.N.E. of the Boma, the trachytic tuffs are seen resting on porphyritic nepheline-augitite. The relations of the augitite to the trachytic tuffs is shown on the eastern and northern slope of the Boma Hill. At the bridge on the Nairobi Road at the north-eastern foot of that hill the augitite outcrops on the river bed at 6290 ft. and in both banks. It is covered on the eastern bank by a basic tuff wherein I found neither trachyte nor pumice. The augitite series is covered beside the road S.W. of the bridge by trachytic tuff including mainly a very vesicular pumiceous rhyolite, fragments of obsidian, small pebbles of fine-grained soda-trachyte, and grains of augite. Further up the hill, to the N. of the road, at 6380 ft. is a quarry in decomposed augitite, and the hill-top at the Boma appears to be composed of porphyritic augitite, which is strewn over it. This rock also forms the northern and north-western slopes of the hill. The southern side, however, consists of trachyte tuff, which is there quarried.

The evidence of the Boma Hill is that the trachytic tuff was deposited upon an irregular and denuded surface of the augitites, for the junction between them is very variable in level. The presence of the associated tuffs shows that the augitite is not intrusive; moreover, there is no sign of any alteration in the trachyte tuff at the junction. The tuff contains grains of augite which have probably been derived from the underlying augitite; but there is no trace of the trachytic rocks in the basic tuffs. The augitite is older than the trachytes, and the two series of eruptions were separated by a long interval of time.

From Ngong we followed a track going at first generally to E.S.E. and then S. to the Keserian River over the lower slopes of Ngong

Mountain. The trachytic tuffs are well exposed in quarries at the foot of the Ngong Hill and continue for over a mile from the Boma. Then successive rivers expose porphyritic augitite, and this rock is also seen forming the tops of some of the ridges. Just S. of the N. branch of the Choro River is basalt with augitite (No. 83), long-bladed augites, while at the most southerly point reached on this traverse the water-tank of the Magadi Water Works beside the Keserian River was excavated in basalt and tephrite (No. 84).

The evidence at Ngong Hill seems conclusive that the trachytic tuffs were deposited on an irregular, denuded surface, above the Ngong augitite. The augitite was probably discharged during the interval represented by the unconformity at Nairobi between the Kapitian phonolite and the overlying lower Nairobi tuffs and trachyte.

One discovery which may ultimately prove helpful is a bed with fossil leaves, found by Mr. Sikes in the volcanic tuffs on the western side of Ngong Mountain. It is uncertain whether the bed rests on the side of the mountain or is interbedded with the volcanic series. Prof. Seward has kindly examined those leaves and says they are Cretaceous or Kainozoic, probably the latter. A more extensive collection from this locality might yield evidence that would fix a precise age for the Ngong eruptions.

Summary of the Kikuyu Sequence.—These four traverses show the following sequence of the Kikuyu-land rocks :—

Naivashan . .	Phonolitoid-kenyte of Nyeri.
Laikipian Series .	Phonolitic-quartz-trachyte of Limuru and Rhyolites of the Fort Hall District.
	More basic quartzless phonolitic trachyte of Nairobi, phonolitoid-kenyte of Southern Laikipia.
	Basalts and basaltic-agglomerates ; and Ngong augitites.[4]
Doinyan . . .	Kenyte and phonolite.
Kapitian . . .	Phonolite.
Eozoic . . .	Gneiss.

[1] One of the most startling changes between the conditions of 1893 and 1919 was that observed from the hills above Nyeri over a wide range of open downs which had replaced formerly impenetrable Kikuyu forest.

[2] This is the river followed by the road N. of the railway to the Govern-

ment farm; by an accident in the G.S., G.S. map, Nairobi, 1/125,000, 1910, it is marked as the Getathura, which is the next river to the N.

[3] Mr. H. L. Sikes tells me in a recent letter that his further study of the geology of Nairobi renders it probable that the Nairobi freestone is younger than the Nairobi trachyte. The probability of this view is supported by the resemblance of the Nairobi freestone to rocks belonging to a later horizon, as at Naivasha and at Mukuyu in North Kikuyu (p. 160). According to Mr. Sikes' view, the bed marked on Fig. 27, p. 162, as the Nairobi Tuff (which includes the freestone) lies in a valley in the trachyte hills; the eruptions of the two rocks must have been separated by a long interval of time during which a large valley had been excavated in the trachyte.

[4] Mr. Sikes has sent me a specimen of felspathic lava from the southern end of the Ngong Hills which is rich in plagioclase, and is identified by Miss Neilson as a basic kenyte. This suggests that the Ngong eruptions were begun in the Doinyan.

CHAPTER XIV

The Rift Valley between Lakes Naivasha & Magadi

I. The Njorowa Gorge

THE Naivasha basin is bounded to the S. by a plateau which is the highest part of the floor of the Rift Valley. This plateau is about 6 miles broad, and supports the cone of Longonot, the best preserved and most recent great volcano in B.E.A. Evidence of recent activity further W. on the Sub-Longonot Plateau was obtained during our visit by Mr. Hobley, who discovered W. of the Njorowa Gorge a pumice cone, Orengingnai (apparently the 7087 ft. point N. of Ol Orugo on the G.S., G.S. map, Nakuru-Nyeri), which is so bare that he regards it as certainly not more than a century old. Steam vents are still active in and near the gorge. This plateau consists of lavas and tuffs of which the vents are recognizable though the craters have been swept away. The highest, Donyo Ongoswaishwi (the 7986 ft. peak), is situated on a fault that runs due S. from the south-western corner of Naivasha and is now a volcanic neck. Some of the lava flows, such as that beside the entrances to the Njorowa Gorge, have been cut through by passages which are now wind-gaps, but through which once discharged the overflow from Lake Naivasha to the Suswa plain. The plateau ends northward in spurs between the bays of Naivasha. To the S. it is bounded by a scarp which was doubtless formed by a fault trending from E.N.E. to W.S.W.; this scarp is recognizable, though greatly dissected, at the western half, but its eastern end is buried under the lava flows from Longonot. The extension of this line passes under the crater.

The structure of this Sub-Longonot Plateau is shown by the Njorowa Gorge, which cuts a deep section across it, in the district marked on the G.S., G.S. map Nakuru-Nyeri, as Ol lol bu tot.

The Njorowa Gorge was traversed in June, 1883, by G. L. Fischer, the first European explorer of Masailand. His journal (1885, p. 205) records his march from Naivasha down the gorge as follows:—

Photo by] [*W. McGregor Ross, Esq.*

LAVA FLOW OF COLUMNAR COMENDITE.

At the Western entrance to the Njorowa Gorge.

Photo by] FISCHER'S TOWER. *W. McGregor Ross, Esq.*

A pinnacle of lava (comendite) in the Eastern entrance to the Njorowa Gorge.

"12th June. To the Ssussua district, near the hot springs; camp 1800 m. (5900 ft.) in a water course; the water of an insipid taste. About nine o'clock we reached the group of mountains which thrust out into the lake; a broad gap, some 300 paces wide, led through the same, the rock walls were very steep, as though cut off; an isolated tower-like mass of rock stands in the gap; at first the ground was very even, then the way descended sharply to a broad, deep, water course; and the erosive activity of the flood water was highly marked. High walls of different coloured clay masses rose to 300 ft.; on the summit was pumice stone; here and there were reddish masses which the natives use for paint. Volcanic tuffs, breccia, pitch-stone, and andesite build up the high, rocky masses of these districts. A fresh S.W. wind blew.

"13th June. Camp 5250 ft. by stream. Half an hour's march to the hot springs, clouds of steam from which were already in sight yesterday. They lie on the western side of the gorge at a height of 5873 ft. In the highest basin [p. 206] bubbled hot water with a full red-brown colour. The air was full of the pungent smell of smouldering sulphur. Until the opening of the gorge small clouds of steam were still visible on the brow of the hill."

Subsequently the gorge was independently discovered by Mr. Hobley, who guided us down it in May, 1919. Its canyon scenery and isolated rock pillars present a dramatic contrast to the usual open plains of East Africa. There are two entrances at the northern end, each at the height of about 6400 ft. above sea-level.[1] The western entrance is beside a cliff of columnar lava (comendite), about 200 ft. high, of which the lower part is a banded obsidian. This cliff (Pl. XV, Fig. B) reminded me of Blanford's description of a similar alkali-lava, with columns 300 ft. high, at Kishyat, W. by S. of Senafe, in Abyssinia (Blanford, 1870, p. 42; it has been described by Prior, 1899, pp. 94–95, as a paisanite, on the assumption that it is intrusive; but if the Kishyat rock be a lava, it would be a comendite). On the southern side the flow rests against a slope of horizontally bedded tuffs which formed the bank of a valley filled by the lava stream. The tuffs on the opposite side of the western entrance have been undercut along the former outflow of Lake Naivasha; and a line of cliffs and beaches made by the lake at the same time occurs along the northern hill-sides. The eastern entrance is cut through the same lava flow, and in it stands Fischer's tower—a pillar of irregularly columnar lava (comendite) (Pl. XV, Fig. A). Both entrances lead to a broad flat-floored valley (Pl. IX, B, opp. p. 104), which was formed between a pair of faults. This valley descends gently southward, while the plateau is nearly level, so that its cliffs of tuff and comendite increase in height. After two right-angled bends, as Fischer remarked, a deep gorge has been cut by the flood waters on the floor of the valley. This gorge rapidly deepens; and after passing a second high tower of comendite, known to the Masai as El Barta or "the horse," the valley suddenly changes in character from a fault-trough to a river-cut ravine. The descent is abrupt, for the lower beds are quickly worn away by the stream. The upper part of the valley consists of the sheet of comendite and tuff, beneath which occur horizontally bedded clays, in places stained

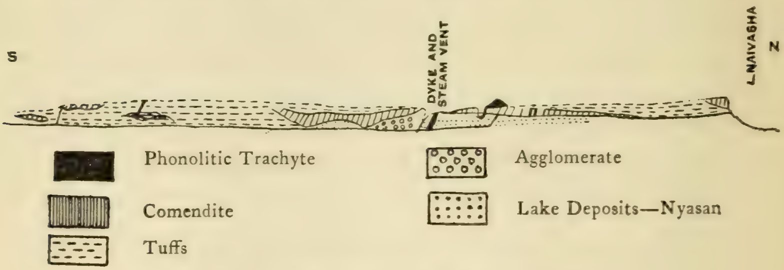


Fig. 28.—Section along the Njorowa Gorge.
Scale: Length, 1 inch = 2 miles; vertical, 1 inch = 4000 feet.

and altered by former steam vents. The lake silts are interbedded with thin layers of pumice and scoria, often only a couple of inches thick. About half a mile S. of the steep fall in the valley a powerful steam vent discharges beside a columnar dyke, which has disturbed and altered the tuffs beside it. An analysis of the water from this steam vent has been published by Fischer (see Appendix X, No. 45). For a short distance below this dyke dense vegetation obscures the view of the walls; but on the eastern side is a cliff of comendite (No. 132) with beautiful blue patches of riebeckite. The base of the western wall consists of tuffs, which in places contain such large boulders as to become an agglomerate. This bed is covered by a columnar lava sheet with a very irregular base; above, the lava is vesicular and covered by tuff. The lava on the eastern wall is cut off to the S. by a fault which has thrown it against tuffs, the junction being marked by a band of conglomerate, apparently fault-rock, probably due to the fault. In line with this fault is a third high rock pinnacle which is a part of a steeply tilted sheet of igneous rock. It is composed of two layers, of which the upper is columnar and the lower flaggy. Hence, in spite of its dyke-like appearance, its structure indicates that it is part of a lava flow; it has doubtless been thrown into its present position by the fault that forms the southern margin of the lava on the eastern wall. I did not notice the western continuation of this fault, but it may run up the branch valley near the steam vent. The lava on the western wall thickens rapidly southward, till it nearly reaches the floor of the valley; it rises again over a low hill of tuff, on the southern slope of which the columns are curved, and it then thins out. The lower part of the flow is of banded obsidian, similar to that at the base of the comendite flow at the western portal of the gorge. A little further S. a columnar lava—the columns of which are 150 ft. high—appears in the eastern wall, where the cliff is about 300 ft. high. This lava is covered by tuff, and it occupies an old valley in the lower tuffs; a lower lava forms the base of the cliffs. Unfortunately, as we made a forced march through the gorge, my notes were hasty and had to be partly completed from memory in camp, and some structures at the southern end of the gorge had to be left unexamined, including some apparently intrusive igneous rocks on the western wall. On the eastern side above the tuffs lies a sheet of columnar lava which at one place thickens like a lens with radial columns where it has filled a river valley.

The geological section through the gorge, as far as could be seen during our traverse, includes five or six main lava sheets, which are apparently all comendites (riebeckite-trachyte). The latest is apparently that at the northern entrance to the gorge. The lava flows are interbedded with tuffs, and rest on lake beds which are exposed for about three-quarters of a mile along the gorge above the large steam vent. The lake beds probably belong to the Nyasan series, and are the oldest rocks seen in the foundation of the Sub-Longonot Plateau. Otherwise the rocks traversed by the gorge have been discharged by Pliocene eruptions, with the exception of some recent flows, such as those from the cinder cone (Oringengnai) discovered by Mr. Hobley.

That the plateau and its comendites are not later than the Pliocene is evident since they had been formed and cut through by valleys which were used as the overflow channel from Lake Naivasha in the beginning of the Pleistocene.

II. Doinyo Nyuki—The Red Mountain, or Doinyo Morijo—the Mountain of the Poison Tree

On the floor of the Kedong Basin, a little W. of the great angle in the Kikuyu Scarp, is the base of an old volcano to which the Masai of the nearest kraal gave the appropriate name of Doinyo Nyuki or Red Mountain.[2]

Doinyo Nyuki is mainly composed of volcanic tuff dipping outwards on all sides. A stream section in the southern side of the mountain has cut through a mass of agglomerate 25 ft. across, that has filled a parasitic vent, towards which the ashes on the southern side dip inward at an angle of 50°. Above the tuff is a sheet of lava which forms the summit; it has been worn into an undulating surface with a central depression which probably marks the site of the original crater. The rock is a phonolitic trachytic, which is sometimes black; but the typical representative on this mountain is a compact, spherulitic, banded phonolitic-rhyolite, brick-red in colour with bands of vermilion. Doinyo Nyuki is a worn-down volcano, of which the actual crater has either been destroyed by denudation or possibly by an explosion that blew away the tuffs above the funnel-shaped sheet of phonolitic-rhyolite. The black, more crystalline lava is similar to that of Longonot, so the two vents probably belong to the same volcanic series. Doinyo Nyuki was perhaps somewhat earlier than either Longonot or Suswa, and was formed near the boundary fault of the Rift Valley, nearly contemporary with the formation of that fault, and before the main stresses were relieved by the eruptions which upbuilt Suswa and Longonot.

III. The Scarp above the Kedong

The sections around the Kedong basin illustrate the relations of the Kikuyu trachytes to the down-faulting of the Rift Valley. The Kikuyu Plateau is traversed near its edge by numerous secondary faults parallel to the eastern boundary of the Rift Valley; and along these secondary faults occur parallel scarps and valleys which break up the surface of the plateau between Limuru Station and the Kedong Scarp. The scarps trend from between N.N.E.–S.S.W. and N.N.W.–S.S.E. The Kedong Scarp descends in two steps separated by the platform used by Sclater's Road. The scarp exposes a series of lava flows and beds of tuff. The lavas have ropy surfaces and sometimes concentric curved flow banding, whereby some blocks resemble fossil wood. The rocks are varieties of trachyte, often with porphyritic felspars. On the platform at the foot of the upper scarp is a more basic rock ; but owing to a misadventure that evening, the specimens collected were lost. The platform and scarp repeat the trachytes of the upper scarp. At the foot of the lower scarp lie the wide plains of the Kedong Basin, of which the final levelling has been by wind erosion. The rocks exposed on the plains are mainly tuffs, flows of trachyte, and agglomerates filling volcanic vents which have been worn flush with the general surface. The agglomerates include volcanic bombs 6 ft. in diameter. West of the Lower Kedong at Nartje's, lava streams of phonolitic and often spherulitic pitchstone from Suswa have flowed over the older volcanic rocks ; the Suswa flows have there been cut by faults trending N.N.W.

From Nartje's we crossed the Kedong Basin to its south-eastern corner, whence a native track leads up to the Kikuyu Plateau. The plains E. of the Lower Kedong River consist mainly of tuffs with some flows of phonolitic trachyte, of a vesicular trachyte (No. 483) which though black in fresh specimens, weathers bright red, and fissile trachyte. The most conspicuous constituents of the tuffs are phonolitic pitchstone, phonolite, and orthophyric-phonolitic-trachyte. Some varieties are more acid, such as a spherulitic rhyolite (No. 487). Two long cliffs of lava, doubtless formed as fault scarps, rise W. of the Lower Kedong ; their weathered faces are bright red, and the rock thus resembles the phonolitic-trachyte. Near the northern foot of the Cathedral Bastion a block of phonolitic-quartz-trachyte (No. 488) rises through the floor of the valley. The bay between it and the main scarp is littered with obsidian flakes, as if this had been a favourite camping ground of neolithic man.

The foot of the main Kikuyu scarp at the S.E. corner of the Kedong basin consists of spherulitic trachyte alternating with porphyritic trachyte. The track to the plateau climbs the scarp to the E. over a succession of secondary scarps and intervening platforms. The chief rocks exposed are spherulitic trachyte and banded obsidian (with spherulites half an inch in diameter and layers divided into hexagonal joints) ; some of the rock dips 24° W., probably having been tilted by faults. High on the scarp is an outcrop of phonolitic-quartz-trachyte similar to that of the northward projection from the Cathedral Bastion. E. of the scarp the plateau is broken by a succession of fault valleys, in which as the opposite scarps are more equal in height, the resulting ascent to the Ngong Plateau is slow. The rocks are trachytes, till N.W. of the Ngong Boma the augitites appear from beneath them.

IV. From Longonot to Magadi

Between the Sub-Longonot Plateau and Lake Magadi the floor of the Rift Valley is divided into three well-marked divisions. The northern division, between Longonot and Suswa, includes the level plains from the Kedong on the E., along the Guaso Narok Road and Weikei River to the foot of the Mau Scarp. The second division extends from Suswa southward to Ol Gasalik and south-eastward to the northern face of Ol Asagut (Lasagut) and Ol Esayet which appears to have been determined by a fault crossing the valley from E.N.E. to W.S.W. This area is occupied by blocks of lava and many old lake basins ; it falls to the S. in a succession of steps and banks. The third division extends from the southern foot of Ol Gasalik to the southern boundary of B.E.A. Both the middle and the southern of these three divisions are characterized by numerous N.–S. fault-blocks, separated by tracks of alluvium in secondary rift valleys—the largest and lowest of which is the basin of Lake Magadi.

From our camp in the plains N.W. of Suswa, at a place known as Lemosilla, which, according to our Masai guide, means the place whence the Masai were driven by lions, Mr. Ross and I made an excursion westward to obtain a nearer view of the Mau Scarp and examine its foot-hills. The first rock exposed W. of the camp is a scarp of vesicular trachyte (No. 139). It disappears westward under tuffs that form a belt of undulating hills rising to a N. and S. ridge, which is separated by a broad valley from the foot of the western scarp. The Mau Scarp here shows no horizontal lines due to sheets of lava ; its slopes are gentle, indicating that its beds are easily denuded ; it probably consists wholly of lake beds and tuffs, of which the dip southward is indicated by the long southward slope of the spurs and structural lines. The crest of the ridge which commanded this view appears to be determined by a dip slope of 4° S. ; we followed it northward to the foot of Ol Setian, a steep conical lava hill, with sides rising at the angle of 38° ; it is of a brown comendite, partly vesicular, glassy, and porphyritic, and partly banded and micro-granular. On the summit is a slight depression which marks the site of the crater. At the eastern foot are beds of tuff. The Ol Setian cone and ridge are bounded to the E. by a fault scarp, and a section S.E. of the mountain exposes five parallel faults breaking through the tuffs.

To the E. of Lemosilla the hill of Doinyo Mungan is composed of an extremely rough blocky lava which from the distance looks like lava of the Aa type. Weikei Hill to the S. of the Weikei River appears to consist of the same material.

Suswa to Ol Gasalik.—The geological structure of this part of the Rift Valley is complex, and includes a great variety of volcanic rocks; To the S. the volcanic rocks are less recent, and the predominant phonolitic quartz-trachytes and rhyolites give place to more basic rocks, though rocks of the trachyte series still occur where they have been faulted down into the Rift Valley. The northern part of this section is dominated by the great volcano Suswa, which consists of a massive dome, trenched at the summit by a circular depression around a central hill. Views of the mountain in 1893 suggested that this inner hill was a new cone built up on the floor of the crater; but Mr. Ross's exploration of Suswa shows that this explanation is too simple, for the central hill, which he has named the "Lost Land" owing to its inaccessibility, is apparently a block of old lava. The northern and western slopes of the mountain consist mainly of phonolitic tuffs, while on the southern and eastern slopes lava is more abundant. Flows of spherulitic phonolitic-pitchstone have reached Nartje's by the Kedong River (No. 479), where they are cut through by faults trending to about N.N.W. Similar flows, down the southern slopes, form flat-topped ridges with lobed edges; some of the latest have come from a secondary crater high on the southern slope of Suswa. One conspicuous L-shaped flow begins as a narrow band to the S.S.W., and then beside a powerful steam vent turns sharply eastward and forms the rocky forest-covered ground known as Ewetut, which is said to be a special haunt of buffalo.

The flows from Suswa are mainly of phonolitic-trachyte, which also forms the conspicuous landmark, the volcano of Soit Amut, S.S.E. of the summit of Suswa. This crater is breached to the S.E. and its rim is very denuded. S.E. of this locality, near the margin of the Rift Valley, the Nderiki has cut a deep trench to the west of the Kedong Valley. We descended into the northern part of the Nderiki Valley at Tiridik, where the lower rocks are phonolitic quartz-trachyte; but beside a water-hole at the southern end of the valley the rocks belong to a variety which Miss Neilson describes as a pantelleritic or orthophyric phonolitic-trachyte (179).

The Nderiki Valley shows evidence of marked oscillations of climate in recent geological times. The floor of the original valley has been buried under a thick sheet of loess, deposited mainly by the wind; this material is now being attacked by the river which flows in the rains, and has cut a deep ravine through the loess (see Gregory, 1919, Fig. 5), indicating that the discharge of this river has become greater since the deposition of the loess.

S. of the Nderiki the ground falls abruptly to a plain, while to the E. on the Lower Kedong is Nkobiri, the best permanent water-hole of this district. It was visited by Mr. McGregor Ross and Mr. Sikes who found that the water drains from a mass of agglomerate, and probably up a fault, as on the western side the rocks dip 30° to 40° W., while those on the eastern side, 300 yds. away, are horizontal. The water at the time was a pool 100 ft. by 30 ft. across, lying in a depression, about 15 ft. deep, in the agglomerate.

Between the Nderiki Valley and the eastern wall of the Rift Valley the floor is broken into a series of fault blocks and valleys by about eight parallel faults. The chief valley is that of the Kedong River, which sometimes flows as far S. as the foot of a high scarp, which from its jagged crest we referred to as the "castellated ridge." It is composed (No. 193) of two sheets of phonolitic-trachyte with porphyritic crystals of anorthoclase, separated by a bed of red volcanic ash which dips 13° southward. The trachyte is similar to that found near the summit of the Kedong Scarp, and it appears to have been faulted down to the floor of the valley.

Further S. the mountains Ol Asagut and Ol Esayet project from the eastern plateau along an E.–W. line which is probably a fault. Where our route crossed this line the rock (No. 195) is a dark gray lava crowded with large crystals of anorthoclase. Miss Neilson has determined it as an orthophyric-phonolitic-trachyte. To the S. of this line are old lake basins with extensive deposits of diatomite, and above them rises Ol Gasalik (5765 ft.), which continues the chain of great volcanos on the floor of the Rift Valley; it is intensely dissected, and three large corrie-like depressions, when seen from a distance, resemble craters; but they have probably been made by denudation in the tuffs around the central plug. Mr. McGregor Ross climbed the mountain, and his specimens show that the upper part (e.g. No. 183, about 500 ft. below the summit on the W. side) consists of nepheline-phonolite, while the lower flows and spurs on the north-western and western sides of the mountain are of kenyte.

The kenyte foundation of western Ol Gasalik is shown by the view northward from our camp at the S.W. foot of the mountain to have come from the ridge which lies to the W. and rises northward to the 4400 ft. peak marked on the G.S., G.S. map, sheet Magadi, as Shayamu. Mr. Hobley tells me it should be Shanau. This ridge is now separated from Ol Gasalik by a fault valley, which provides an easy pass from the basin of Ol Keju Nero to the Koora Plain.

In the Ol Gasalik district the most conspicuous rock is a red weathering phonolitic-trachyte, which is often columnar and forms wide horizontal sheets. It rises in terraces to the E. and appears to be continuous with the rock of the plateau immediately E. of Lake Magadi and with that of the ridge between Shanau and the mountain, N.W. of Koora Station, marked on the G.S., G.S. map (sheet Magadi) as Ol Doinyo Nyegi,[3] 3835 ft. The structure of this ridge we observed during the traverse from the northern end of the Koora Plain to Lake Magadi. Its eastern front is a fault scarp, at the foot of which, beside the alluvium of the Koora Plain, is a gray porphyritic-phonolitic-trachyte with coarse anorthoclase (No. 226). It is overlain by a vesicular trachyte. The plateau above this scarp (No. 229) is formed of fine-grained black basalt of an andesitic variety. The ascent to the upper plateau is up a steep scarp capped by red weathering orthophyric-phonolitic-trachyte (No. 230). This rock, including some beautiful spherulitic varieties, extends southward to the descent to the valley N. of Doinyo Nyuki el Dogilani and the plain W. of the Shanau-Nyuki ridge. This Doinyo Nyuki (Red Mountain) is a volcanic neck, which has been truncated both to W. and E. by faults, on the western of which at the foot of the mountain two small volcanic cones have been built up by its last eruptions. The chief rock in the descent opposite Doinyo Nyuki (Nos. 232–236) is phonolitic rhyolite. W. of the mountain lies a lake basin with well-marked beaches, one of which is in places littered with obsidian flakes marking the site of camps occupied when the lake was in existence. From this lake basin we crossed the ridge E. of Lake Magadi, descending to the lake down a scarp composed of a compact glassy phonolitic-rhyolite (No. 240), some of which rings like a clinkstone. This rhyolite is so black and dense that further to the S. it has been recorded as basalt. It has been in places coated by incrustations of chalcedonic quartz and carbonate of lime, but I saw none of soda until within a few feet of the lake level.

The Section Across the Basin of Lake Magadi

The section E. and W. through Lake Magadi, near the southern frontier of B.E.A., shows the relations of the various lower volcanic rocks to one another and to the gneiss. The eastern part of the section is easy of access, as it is traversed by the Magadi Railway, which descends from the Kapiti Plains to the floor of the Rift Valley down a succession of fault scarps that have been mapped by Mr. Parkinson (1914). Lake Magadi yields, moreover, one of the most interesting mineral deposits in Africa. Its trona (sesquicarbonate of soda) is the largest natural supply of the salt known ; and, as a mining field, it is unique, since the mineral is being renewed as fast as it is removed. The source of the trona has given rise to much discussion. Beside the lake are numerous springs, some of which, as at the southern end, discharge hot alkaline waters. That of the spring at the foot of the Hospital scarp near the Magadi works is rich in sodium salts (2.276 per cent) as shown by the analysis quoted in App. X, No. 1. A group of mud-volcanos on the eastern shore, a few miles N. of the Hospital, indicates the ascent of hot water under pressure. These facts support the view that the soda is brought up in solution from some underlying source. The alternative view is that the lake is a great evaporating pan in which is deposited soda leached out of the adjacent lavas by percolating water. According to this view the silt on the lake bed, having been deposited while this evaporation was in progress, is impregnated with soda and is the reservoir which renews the surface crust. The view of the deep-seated origin of the soda is supported by the absence of any comparable deposits of trona around the other East African lake basins where evaporation has also been going on for a long time. It is true that there is no other lake so favourably situated for the formation of soda by evaporation as Lake Magadi. Lake Natron to the S. would be as suitable were not its waters diluted by floods from the Nyiro River. Lake Rudolf at the northern end of the B.E.A. lake chain is surrounded mainly by metamorphic rocks, which would yield less soda. There are, however, in East Africa dried lake basins which are surrounded by alkali-rich lavas and nevertheless contain little or no carbonate of soda.

The probabilities therefore seem in favour of the deep-seated origin of the alkaline waters. For the elucidation of this problem it was necessary to consider whether the rocks underlying the lake would yield soda to waters rising through them from the lower parts of the earth's crust.

Soda-rich lavas are widespread E. of the lake; if they also occur on the Nguruman Scarp W. of it they probably underlie the lake, and might be the source of its alkalies. As I had no time to visit that scarp, Mr. A. L. Lawley, then General Manager of the Magadi Soda Company, kindly arranged for an expedition under Mr. Gerald St. Claire, to collect samples along a line between the lake and the summit of the plateau on the western side of the Rift Valley. I am much obliged to Mr. St. Claire for the care with which he carried out this mission.

The evidence previously available as to the rocks W. of Magadi was collected during the journeys by Fischer (1882–1883) and Schöller (1896–1897) along the Guaso Nyiro, but they gave little help in the construction of a transverse section. Fischer, who was the first European to visit this district, passed along the foot of the Nguruman Scarp in April, 1883, and remarked (1884, pp. 58, 60, 75, 76; and 1885, p. 199) its parallel lines, abrupt cliffs, and banded terraces; but the only specimens he collected there were gneiss and basalt (Mügge, 1885, pp. 577, 605). Kaiser (1898, p. 322), the geologist with the Schöller expedition, recorded great melaphyr (i.e. basalt) eruptions in the Nguruman district, and their extension northward to the upper Guaso Nyiro; his collections were investigated by Künzli (1901, pp. 158–160, 163–164), who has identified in them from the Nguruman district varieties of basalt, including olivine and amygdaloidal basalt; the basic character of the rocks is shown by his description of one rock (1901, p. 159) which he identified as an amygdaloidal pikrite-porphyrite. Künzli's specimens represent only the lower part of the Nguruman Scarp.

The western wall of the Rift Valley is about 14 miles W. of Lake Magadi and rises steeply to the plateau at the height of about 6000 ft. at Dunbol and Lazur. The whole scarp is generally known as the Nguruman Scarp; it is divided into two steps by a platform on which is a Masai kraal and the river Kirikiti. Mr. St. Claire informs me that the Masai restrict the term "Nguruman" to the scarp below this platform. The plateau W. of the scarp appears to consist wholly of metamorphic rocks, of which the specimens collected by

Mr. St. Claire are granulitic quartzites, which are sometimes micaceous and flaggy. They are members of the Eozoic series, and have been formed by the intense alteration of sandstones. Pebbles from the Nyiro River include normal gneiss.

Five hundred feet down the scarp occur dark heavy lavas which Miss Neilson has determined as nepheline-augitites; they are similar to those on the eastern wall of the Rift Valley at Ngong Mountain. The quartzites are exposed at intervals beneath the augitite. Below the Kirikiti platform the rocks collected by Mr. St. Claire on the face of the plateau are olivine-basalts; but the

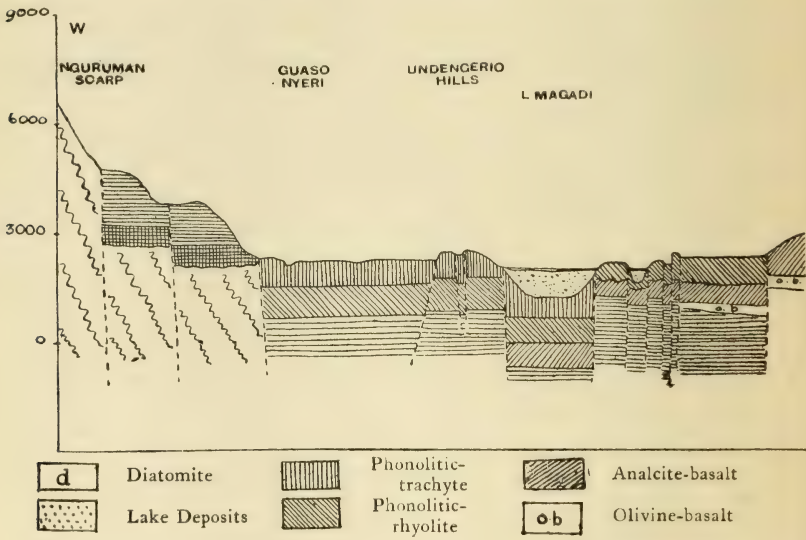
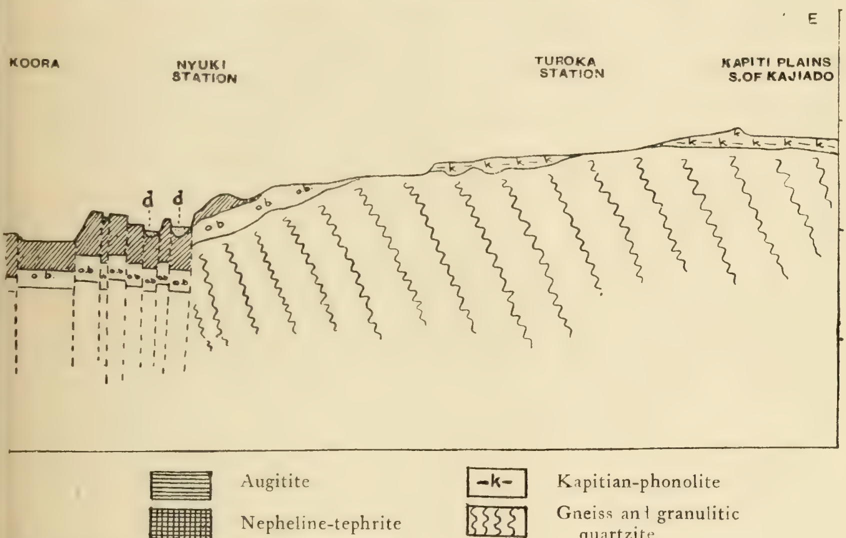


FIG. 29 —Section across
Scale: Length, 1 inch

gneissose-quartzite is again exposed at the base of the scarp beside the Sambu River, associated with nepheline-tephrite. Thence eastward extends the plain of the Guaso Nyiro at the height of about 2200 ft.; the specimens collected in the river bed include pebbles of the normal gneiss of B.E.A. E. of the Guaso Nyiro is the Undongerio Range, a plateau which rises at the northern end to 3273 ft.; it is broken across by four fault scarps, which Mr. St. Claire remarks "die out into a more or less even plain when they reach the extreme S. end of the lake." The rock of the Undongerio Range, as shown by the samples from the western shore of the lake and from the second scarp W. of the lake, is phonolitic-trachyte. It is covered at places by limestone deposited on the surface by the evaporation of water which has dissolved lime from the underlying lavas. The Nguruman Scarp is probably formed by two distinct faults, and by them and those further E., the nepheline-augitite and nepheline-tephrite have fallen below the level of Lake Magadi. These two nepheline-bearing rocks would yield an ample supply of soda to hot ascending waters ; and as Mr. St. Claire's collection gives no evidence of the occurrence of the Kapitian phonolite on the Nguruman Scarp, it may not extend so far to the S.W.



the Magadi Basin.
=6 miles.

The continuation of the section eastward to the Kapiti Plain has been described by Mr. Parkinson, and I was able to collect some supplementary information as, by the kindness of Mr. Lawley, our train was stopped at several localities. The map by Mr. Parkinson (1914, p. 37) marks twenty-five N.–S. faults, by which the country is broken up into an alternation of fault blocks and secondary rift valleys. The structure is similar to that E. of Lake Elmentaita, but on a greater scale. The general geological structure is illustrated by the section Fig. 29. From the lake to about mile 45 the country is occupied by sheets of phonolitic-trachyte. The railway climbs by steep grades up successive fault scarps, and between them rises gently over sloping plains. The last fault scarp is a low bank at mile 48, after which the railway winds up the valley of the Turoka River for an ascent of another 1000 ft. on to the Kapiti Plains. The rock from the lake to mile 47 was recorded as basalt, and so we did not stop to collect much from it; but most of the lower platforms consist of a black compact phonolitic-trachyte. The rock from the Nyuki Scarp at $\frac{55}{7}$ miles is identified by Miss Neilson as an analcite-basalt; and this soda-rich basalt appears to be widespread between Nyuki and Koora. Further E., at miles $48\frac{1}{2}$ and 47, occurs olivine-basalt, which is probably the oldest of the basalt series.

In the basins and valleys between the scarps are various drift and lake deposits, of which the most interesting are the diatomite beds at the level of about 3680 ft. at the foot of the Nyuki Scarp, between miles 62 and 60 (i.e. from Magadi Junction Station). These diatomites have been investigated by Mr. V. H. Kirkham; they were doubtless deposited in lakes which were fed by alkaline water from the lavas, and were therefore rich in silica and supported an abundant growth of diatoms. These lakes were in existence after the basaltic eruptions and probably after the faulting.

East of the olivine-basalts of mile 47 is a plain without rock exposures; but beside the break-pressure tank on the water-pipe at 46 miles were loose blocks of the Kapitian phonolite, and this rock occurs *in situ* further along the line, as at $\frac{43}{4}$ miles; at $\frac{42}{8}$ miles it forms a thin cap resting on gneiss. Mr. Sikes tells me that this phonolite forms the plateau 5 miles N. of the railway at mile 45, and extends thence northward to Ngong Mountain. Gneiss is exposed along the railway up the valley of the Turoka River, and eastward to Kajiado (mile 26), beyond which, though it forms the country to the S. of the line, it is covered, except for narrow outcrops, under the phonolitic lavas of the Kapiti Plains.

The volcanic sequence, as shown by the section across Magadi, begins with the phonolites of the high Kapiti Plains to the east; they were directly succeeded by a long series of basalts, beginning with olivine-basalt, followed by analcite-basalt. The black compact lavas nearer the lake are phonolitic-trachytes. The relation of the volcanic group including the nepheline-tephrite and the nepheline-augitites of the Kuruman Scarp is uncertain. It is probably on approximately the same horizon as the basalts, and belongs either to the base of the Laikipian or possibly to the upper part of the Doinyan

Series. The eruptions of the Magadi lavas ended with the discharge of the phonolitic-trachyte of the orthophyric variety of the Undongerio Hills. The quartz-trachytes, rhyolites, and comendites of Kikuyu-land and around Naivasha do not, so far as is yet known, enter into the composition of this part of the country.

[1] According to the contours on the G.S., G.S. map, the height would be about 6800 ft. The level of 6400 ft. was determined by levelling, by instructions of Mr. McGregor Ross.

[2] This term is, however, often used, as it was by Thomson and Fischer, for the great mountain further S., which was known to both the local Masai and my Swahili as Suswa. The Masai at the present time, however, use the term Suswa for the plains at its northern foot. Mr. Holles suggests that it may be the old Wanderobbo name of the mountain, which the Masai, being more concerned with grazing, applied to the plains. As the word Nyuki means red, it is more appropriate for the hill of brilliant red phonolitic-rhyolite than for the mountain of gray ash.

[3] Mr. Ross tells me its name should be Doinyo Nyuki el Dogilani ; it is also known as Mount Shelford.

CHAPTER XV

The Volcanos & Intrusions of the Nyika Borders

I. The Yatta Plateau

THE suggestion that the Kapitian lavas are approximately of the same age as the Deccan Traps is faced by one obvious difficulty. The impression given by the first view across the Kapiti Plains is that they have undergone comparatively little denudation. As I walked down the valley from Machakos on to the Athi plains I found to my surprise instead of the wide sheet of alluvium represented on the existing map an undulating prairie of hard dark lava. " Its extent also was greater than I had expected. Here and there in the foreground bosses and ridges of gneiss, such as Lukenya and Koma, rose above the surface ; a few dark lines of trees marked the courses of the rivers. Except for these we could see only a vast expanse of rolling grass-land, extending westward and southward as far as the eye could follow it. The rock of this prairie ended abruptly at the foot of the old gneiss ridge on which I stood, but it followed its outline, running up the valleys, round the spurs, and into the hollows of the mountains, just as the water of a lake adapts itself to the irregularities of its shore " (G.R.V., pp. 88–89).

The apparently undenuded condition of the Kapiti Plains is strikingly different from the intensely dissected western edge of the Deccan Traps where Europeans usually first see them during the ascent by railway from Bombay to Poona or on the way to Calcutta, or among the stupendous precipices of Mahableshwar with their projecting buttresses and isolated outliers. In each of these districts ravines have been cut into the Deccan Traps compared with which the valleys of the Kapiti Plains are slight and shallow. The Deccan Traps therefore give the impression of greater geological age than the Kapitian phonolites. But this comparison is misleading as it contrasts the middle with the margin of a plateau. Deep trenches are quickly cut along the edge of a plateau by waterfalls and cascades. For any reliable indication as to relative age a comparison of the

Kapiti Plains with the lava sheets of India should not be with the face of the plateau along the Western Ghauts, but with the heart of the Deccan Trap country, as around Jalgaon or in the western parts of the Central Provinces; and in these districts the dissection is not essentially different from that of the Kapiti Plains.

Closer acquaintance with the Kapiti Plains soon modified the impression that they were comparatively undenuded. They have been cut through by the valley of the Athi, the bed of which at Athi Plain Station is 250 ft. below the surface of the adjacent plains. Still more significant is the complete absence of any crater on these lava plains. Here and there, as just north of the railway line between Magadi Junction and Kajiado, some low rises probably mark plugs of lava in old volcanic pipes, but the craters from which the lavas were poured have all been swept away.

The most striking evidence of the antiquity of the Kapitian lavas is, however, that since their eruption the slow action of rain, rivers, and wind has produced profound geographical changes in the structure of the country. Evidence to this effect is given by the Yatta Plateau. This plateau is a south-eastern extension of the Kapiti Plains. It begins E. of Doinyo Sapuk as a broad phonolite plateau, and after passing the Ulu Mountains continues as a flat-topped ridge, which is well seen from the railway near Kibwezi and Tsavo. Its width E. of Masongaleni is between 3 and 4 miles, and it is bounded eastward by the valley of the Tiva River, of which the upper part is parallel to the Athi. Opposite Tsavo the Yatta Plateau suddenly bends from its course to the S.S.E. to almost due E.; it forms the northern bank of the Sabaki, and finally ends in long. 38° 51′, about 12 miles E. of Lugard's Falls.

The base of this plateau consists of gneiss; its summit is a sheet of phonolite which reaches to the very edge of the plateau, although it must have been discharged as a sheet of molten lava. The position of this fluid sheet as the cap of a long, high ridge is as unexpected as would be a lake at the summit of a hill. A lake may occur in a depression on the top of a plateau, but on Yatta the lava stands higher than the rim on both sides. It may be suggested that the lava was discharged from a fissure, on each side of which it soon solidified; but even if the lava came from a fissure, if it reached the edge of the plateau, it should have poured in fiery cataracts down the sides to the low ground. I watched along the southern bank of the Sabaki for any trace of the phonolite *in situ*. A dyke of phonolite cuts through the gneiss of the plain E. of Tsavo; and in one place, close to the foot of the plateau, the ground is strewn with fallen blocks of phonolite; but none of the lava seems to have flowed over the plain at the foot of the plateau. It is therefore clear that either the existing band of lava is the remnant of a wider sheet or it must have been confined like a stream between the banks of a valley. Either alternative involves extensive denudation of the country beside the plateau. If the lava sheet had formerly been much broader and had been reduced by denudation, fragments of the phonolite should occur scattered over the adjacent plains.

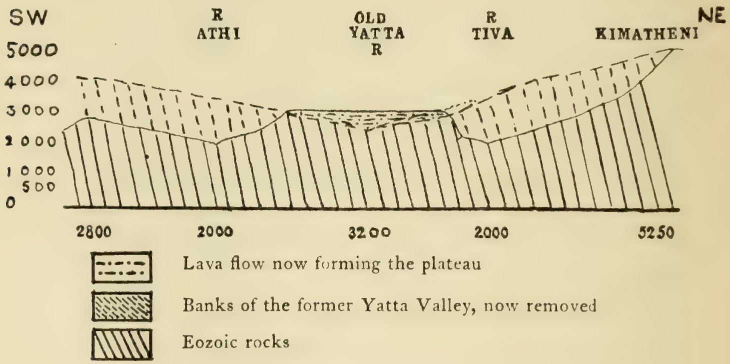


FIG. 30.—Diagrammatic Section across the Yatta while the lava flow lay in the valley.
Scale: Length, 1 inch = about 30 miles.

The interpretation of the Yatta Plateau which seems to me best to explain its origin is that before the volcanic period a great valley, parallel to the present course of the Athi, extended from Kikuyu-land near Doinyo Sapuk south-eastward past the Ulu Mountains to Tsavo, and thence eastward along the valley of the old Tsavo-Sabaki River. The volcanic eruptions poured a stream of lava down this valley to beyond Lugard's Falls. This lava stream would have been bounded on both sides by the banks of the valley, which were composed of gneiss and schist. The phonolite, as usual with lava streams, would have formed a hog-backed ridge, on each side of which a new river would be formed. Each of these rivers would flow at the junction of the gneiss and lava; and as the gneiss would be worn away by river action more easily than the lava, the streams would wear away the gneiss and leave the lava as a ridge between two marginal rivers. The original Yatta River would have been thus replaced by the Athi and Tiva, which, continuing to wear away the gneiss and schist, have in the course of ages cut down the hills that bounded the valley, and left the lava on its floor as the cap of the Yatta Plateau. The gneiss hills between the Athi River and the Uganda Railway, which rise to the level of 6000 ft. at Nzawi, are probably remnants of the western bank of the Yatta Valley; and the gneiss range of Lingithia, which rises to 4920 ft. opposite the level of 3200 ft. on the Yatta Plateau, is a fragment of the eastern bank of the pre-volcanic valley.

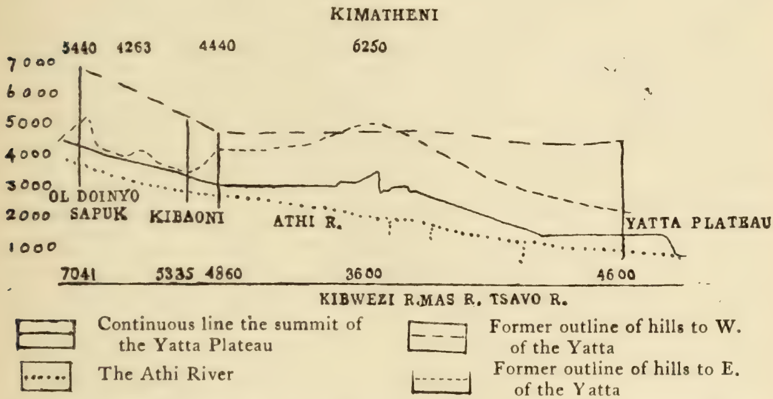


FIG. 31.—Section along the Yatta Plateau and Athi Valley and through the hills left from the demolition of the banks of the original Yatta Valley.

Scale: Length, 1 inch = about 65 miles.

This hypothesis explains the gradual fall of the Yatta Plateau from its source in the Kapiti Plains to its end above the Sabaki. It begins near Doinyo Sapuk at the level of about 4600 ft.; during the next 6 miles to the S.E. the surface falls about 30 ft. to the mile; during the next 40 miles further S.E. to the track (at just over 4000 ft.) from Machakos to Kitui, the gradient is only 10 ft. to the mile; for 30 miles further to the S.S.E. (to the latitude of Nzawi at 3200 ft.) the fall is 26 ft. to the mile; thence for 80 miles to the bend opposite Tsavo (2200 ft.) the fall is about 12 ft. to the mile. From Tsavo to its end at 1600 ft., about 24 miles E., the gradient is again steeper, and is about 30 ft. to the mile. Some undulations in the surface level occur,[1] but may be due to denudation; and differences in the structure of the lava may be expected, for if the stream happened to pass over swamps or lakes their evaporation would inject the rock with steam and render it locally vesicular. Differences in the rate of cooling may render it in places columnar. The local irregularities in gradient, however, are insignificant compared to the persistence of its downward slope for its length of 180 miles. This fact, combined with its narrowness, indicate that the lava of the Yatta Plateau flowed down a river valley.

Plateaus left by the lowering of a country by rivers working along the edge of a lava stream are well known in the goldfields of Victoria. They have been studied there in detail, as the underlying gravels are rich in gold, and have been worked by Deep Lead mines. The basalt plateaus in the Loddon Valley of north-western Victoria have the origin suggested for the Yatta Plateau ; and in the Loddon, deep boring has demonstrated the truth of the theory by discovery of the buried river channels, which have been fully explored while mining.

According to this explanation of the Yatta Plateau, since the discharge of its lavas the country beside it has been lowered 2500 ft. by slow denudation. The geography of the whole country has been altered since the Kapitian eruptions, and the time required for these changes would be comparable to that which has elapsed since the eruption of the Deccan Traps.

The Sabaki Valley, on this view, is an older valley than the present Athi, and some of the W.–E. tributaries of the Athi may follow the courses of rivers that flowed eastward across the site of the Yatta into the deserts N. of the Sabaki. Thus the rivers Keite-Thwaki may be the original head-streams of the Thowa ; the drainage from the southern Ulu Mountains may have discharged through the Nthangi River eastward past Ikutha and continued along the line of the Nquati and Itito Rivers into the plains E. of the upper Tiva ; the Kibwezi and Masongaleni Rivers may have been similarly continued as the part of the Tiva which flows eastward S. of the range at Masia ; while the Mtito Andei may have been the upper section of the southernmost portion of the Tiva, which flows eastward, S. of Ngilo, towards the Lower Tana. The map by Aylmer (1908, opp. p. 120) represents the drainage of the area N. of the Sabaki as a W.–E. river system including the Thowa and the Tiva. These rivers must be older than the original N.W.–S.E. valley which diverted their drainage through the Lower Athi to the Sabaki, and has been preserved by the phonolite flow that buried its floor, and has been left upraised as the Yatta Plateau. The denudation which destroyed its banks left remnants of them as the line of isolated tors (*cf.* p. 36) along the Uganda Road from Nzawi to Tsavo, and along the western margin of the deserts between the Tana and Sabaki.

II. The Kyulu Volcanos

Opposite the ancient Yatta lavas rises a chain of young volcanic cones which are seen from the Uganda Railway, between Tsavo and the Ulu Mountains. These Kyulu volcanos consist of well-preserved cones and craters surrounded by radial lava streams. Some of them are arranged in line as if formed along a volcanic fissure trending N.W.–S.E., and on a parallel line are the two volcanos of Mwani and Kelembwani, visible to the N.E. of the railway near Sultan Hamud. Some of the Kyulu lava flows are crossed by the caravan route to Uganda, for, on the march in 1893, I noted volcanic rocks at least ten times between the Tsavo and Nzawi. They were best seen at Kibwezi, where the lava is very fresh and has ropy surfaces. Dr. Charters of the Kibwezi Mission described the country to the W. as resembling a vast foundry by the slag-like appearance of the rocks. The Kibwezi River, owing to the cavernous nature of the lava, disappears underground to re-emerge further E.

Excellent views of the Kyulu chain are obtained from both the Uganda Road and Railway, which traverses the lava from Kibwezi to Sultan Hamud, and passes close to some of the craters.[2]

The chief lava is olivine-basalt, poor in augite. Some of the thinner flows and the tuffs near Tsavo have been altered into a limestone, the silicates of lime having been weathered into carbonates. The undenuded condition of the cones, and the freshness of the lava surfaces at Kibwezi show that the flows are comparatively young; but as I have not heard of any signs of recent volcanic activity or of existing steam vents the eruptions may be assigned to the Lower Pleistocene.

The Origin of Lava Plains.—The Kyulu volcanic field well illustrates the origin of some of the earlier volcanic formations of B.E.A. The north-western part of the area is dotted with many small volcanos. Thus from the hills above the mica lodes near Kulu, although part of the ground was hidden, I counted thirty-four distinct volcanic vents in view at one time. The total number must amount to scores.[3] The eruptions have formed a lava plain similar, though on a smaller scale, to the Kapitian; and it has clearly been formed, not by fissure eruptions, but by the flows from many scattered vents coalescing into a continuous lava sheet.

The Formation of Lava Plateaus.—The Kyulu volcanic field also shows an early stage in the formation of a narrow lava plateau like that of Yatta. The railway from Sultan Hamud passes towards Kiu

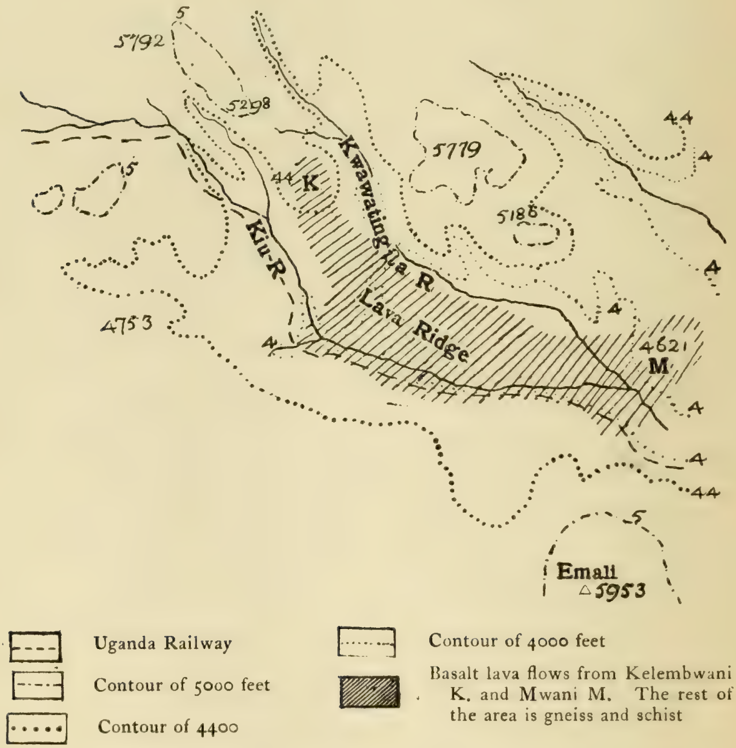


FIG. 32.—The beginning of a lava plateau.
Scale: 1 inch = 4 miles.

Station along the southern side of a lava flow from Kelembwani (5141 ft.) which joined the lavas from Mwani, the volcanic vent (4621 ft.) close to Sultan Hamud Station. This lava stream occupies the valley floor, and the original Kiu River has been replaced by two streams (the Kiu and Kwawatingila), one on each side of the basalt flow, where they are now cutting fresh valleys into the gneiss. The set given to the drainage by the eruptions will probably persist, and in the course of ages the two sections of the original river will probably excavate deep valleys in the more easily destroyed gneiss, and leave the Kelembwani basalt upraised as a plateau. The traveller, from the railway, may therefore observe above Sultan Hamud the preliminary stages in the formation of such a lava plateau as Yatta.

III. The Jombo Intrusion

The igneous nature of Mount Jombo, or Jomvu (39° 13′ E., 4° 28′ S.), in the Wadigo country, about 37 miles S.W. of Mombasa, was discovered by Mr. Hobley, who, in his map (1895, p. 559; also pp. 560–561), marked it and a dyke at the foot of Jombo as intrusive into the coastal sandstones. He kindly gave me specimens of the rocks which were described in 1900 (Gregory, 1900, No. 4, pp. 224–225, Pl. XII, Figs. 3–5). The chief rock of Mount Jombo is a coarse-grained nepheline-syenite with large crystals of anorthoclase, prismatic crystals of nepheline, and radial nests of ægirine. The associated dykes are camptonites, containing analcite, oligoclase, augite, and brown hornblende.

Mr. Hobley has recently given me further specimens from the Jombo district which were collected by Mr. C. B. Thompson (Nos. 595–599), and also a specimen of the rock of Kiruku Hill. The most important of the new specimens (No. 597) is from half-way up Mount Jombo; it has been identified by Miss Neilson as an ijolite tending towards jacupirangite. Ijolite was originally described from Finland, and differs from nepheline-syenite by the dark mineral being ægirine (or ægirine-augite) instead of hornblende. Its occurrence at Jombo is the more interesting as it appears to be the chief plutonic rock of Kilima Njaro (Lacroix, 1906, p. 91).

The rock from Kiruku Hill (No. 600) is probably an altered Duruma Sandstone; but it is now in the condition of a granulite composed of fretted grains of quartz and clinozoisite, and it is possibly an outcrop of the Eozoic floor upon which the coastal sandstones have been deposited. The Jombo nepheline-syenite is so similar to that of the central core of Kenya that they are probably of the same age. At Jombo no lavas have been preserved since, being near the coast, it has been subjected to such extreme denudation that only the base of the volcanic neck is left.

The Jombo igneous rocks are intrusive into the coastal sandstones. Mr. Hobley (1895, p. 561) states that similar dykes may be seen "in many places" in the Duruma Sandstone, so that they are certainly later than the Permian or Trias. According to information received in 1896, the Jombo syenite itself was regarded as intrusive in the Jurassic beds, and would therefore be upper or post-Jurassic; whether the sandstone into which it is intruded is the Duruma or Jurassic Sandstone is uncertain. Until the age of the sandstone is determined the direct evidence only proves that the Jombo nepheline-syenite and ijolite are certainly post-Permian; if, as is probable, the sandstone belongs to the Shimba Grit division, the igneous rocks would be post-Triassic; if the adjacent sandstone is part of the Jurassic which has extended westward S. of the Shimba Hills, the age of the intrusion may be post-Jurassic. That it is not earlier than Cretaceous is probable from the similarity of these rocks to those of Madagascar and Kilima Njaro.

The Jombo nepheline rocks probably belong to the same igneous series as the nepheline-syenites of northern Madagascar described by Prof. Lacroix (1902, pp. 167–171), of which the age is post-Jurassic (Lemoine, 1906, pp. 156, 166–167), and probably not earlier than Upper Cretaceous. A similar rock associated with the Deccan Traps in Kathiawar in western India is approximately Upper Cretaceous (Evans, 1900, *Q.J.G.S.*, LVII, p. 42). Mount Jombo belongs to the eruptions which in various parts of Africa and around the Indian Ocean marked the beginning of the Upper Cretaceous—Kainozoic volcanic period.

[1] Near the crossing of the Kitui track is the only marked break in the slow fall of the plateau (see Fig. 31). That break in the gradient is suggestive of a cross-fault.

[2] The G.S., G.S. map, Makindu, marks the position of the chain; but its contouring represents a massive ridge rather than a series of cones.

[3] The plan of their arrangement, when determined by a fuller survey, may be expected to yield interesting evidence.

CHAPTER XVI

The Volcanic Succession

THE absence of fossiliferous marine deposits in the interior of B.E.A. renders its geographical history mainly dependent upon the volcanic rocks. Whereas in most countries geological time can be dated by using fossils as medals, in B.E.A. the chief dates have to be fixed by correlating the eruptive periods and earth movements with those of adjacent regions.

The oldest fossiliferous rocks in B.E.A. are the Permo-Carboniferous and Jurassic sandstones of the coast zone; and these have been intruded by nepheline-syenites and ijolite at Jombo, the only locality where the igneous rocks are known in contact with the coastal sedimentary series. Mr. Hobley tells me that the country around Mount Jombo is so overgrown that sections are few and obscure, and the exact horizon of the sandstone in contact with the Jombo syenite is undetermined. The evidence available shows that volcanic action in B.E.A. began later than the Duruma Sandstone, and from analogy with allied rocks in Madagascar not earlier than Upper Cretaceous and probably not much if any later than that date.

The eruptions lasted on until modern times, since some have been seen by European travellers and some craters are in excellent preservation. The volcanic history of B.E.A. must have covered a long period of time. In 1893 there was no direct evidence to fix the age of the East African volcanic rocks between the Cretaceous and historic times; but from the indirect evidence, I proposed the classification into seven successive series, which are summarized in the table on p. 105.

It will be convenient in this chapter to consider how far the evidence recorded in the preceding descriptions of the volcanic districts establishes this succession, and to state the chief characteristics of the different volcanic series.

I. The Kapitian Series[1]

The outbreak of East African volcanic activity appears to have begun with the discharge, through a large number of small vents, of the flows of phonolite that have given rise to the great lava plains of B.E.A. The typical area is that of the Kapiti Plains, which occupy an area of about 1500 sq. miles, extending from Nairobi on the N.W. to Magadi Junction Station on the S.E., and from the neighbourhood of Doinyo Sapuk on the N.E. to the Turoka Valley below Kajiado to the S.W.

The predominant Kapitian rock is a black phonolite which contains large white crystals of felspar (anorthoclase) an inch or more in length, with scarcer and usually smaller yellowish crystals of the soda-rich felspathoid mineral, nepheline. Owing to the presence of the large crystals of these two minerals set in a compact black base this rock has a very distinctive appearance and is easily distinguished

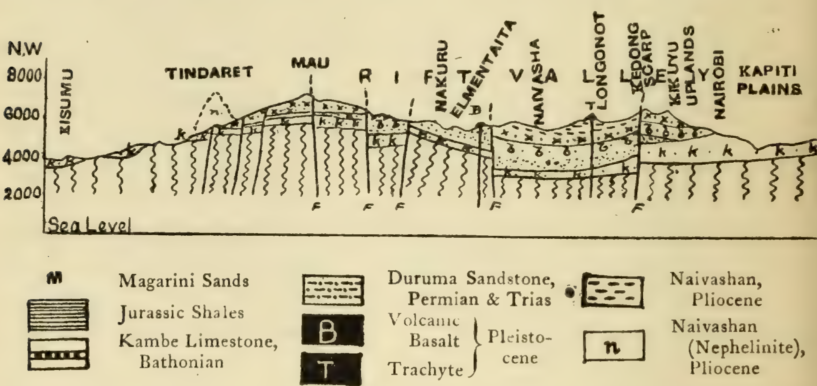


FIG. 33.—Diagrammatic Section

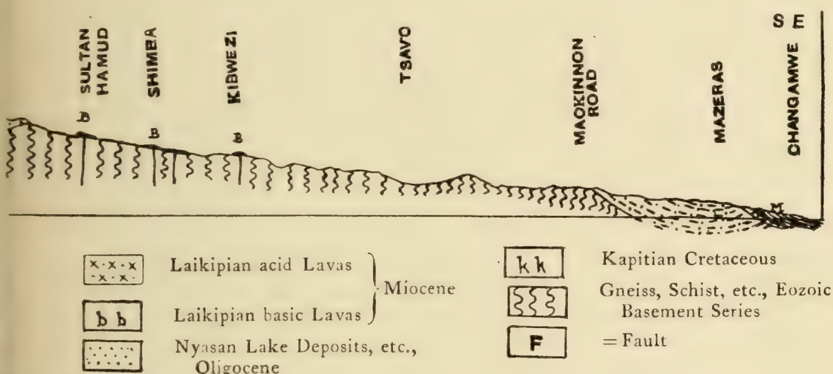
Scale : 1 inch =

from any other East African lava. Its microscopic characters have been described by Dr. Prior (1903, p. 247). It weathers into rich black soil, which is very heavy, and forms such a thick tenacious mud that it is almost impossible to work in the wet season.

Interbedded with the lavas are beds of volcanic tuff and agglomerate, which are exposed in the valleys that have been cut by the rivers deep below the general level of the plains. The widespread distribution of these tuffs shows that the discharge of the phonolite was accompanied by numerous volcanic explosions. The craters have been entirely swept away.

Distribution.—These lavas are the oldest in East Africa except possibly altered volcanic rocks in the pre-Paleozoic system. They overlie the gneiss at various places, and no other volcanic rock is known to occur between this phonolite and the gneiss; whereas though the basalts and trachytes in places rest directly on gneiss, in others phonolite occurs between them and the Eozoic foundation. The direct superposition of the phonolite on the gneiss is well shown around Kisumu and also in the valley of the Thika-thika, the lower part of which consists wholly of gneiss and schist; they extend up the valley past the Lower to the Second Falls; near them, S. of Kakuzi Hill (5440 ft.), the gneiss is covered by a thin sheet of phonolite, which occupies the angle near the Second Falls, between the river and its tributary. Further W. the phonolite thickens and the gneiss disappears beneath it.

From the Athi-Thika outlet, N. of Doinyo Sapuk, the eastern



along the Uganda Railway.
about 70 miles.

margin of the phonolite continues southward at the western foot of Doinyo Sapuk (7041 ft.), from which it is separated by a deep valley cut along the edge of the lava. The phonolite boundary also passes W. of Koma rock (5261 ft.), then goes S.W. to round the Lukenya Hills, turns E. at the foot of the great bluff which forms the southern face of Lukenya, runs N.E. as a bay between that hill and the Mua Hills; it turns S.W. again, passing W. of Chumbi and Wami, and crossing the Uganda Railway between the Kapiti Plains and the Magadi Junction Stations; it runs westward N. of the Magadi Railway line, which it crosses near Kajiado. Its extension S. of the Magadi Railway is unknown.

The Kapitian phonolites are occasionally exposed on the Kikuyu Uplands from beneath the later lavas; they occur for example on the Maragua River S. of Fort Hall, where they lie above the gneiss and below the basalt-rhyolite series; also near Thaba-thaba, and near Fort Smith, N.W. of Nairobi.

N. of the Kikuyu Uplands a variety of the Kapitian phonolite containing a little olivine outcrops from beneath the basalts on the road from Nyeri to Meru at the western foot of Kenya. They first appear there N. of the Amboni River, 7 miles N.N.E. of Nyeri, and extend thence northward along the road nearly to the Naromoru River. The same rock is exposed in Laikipia, where I found it in 1893 on the banks of the Engare Berisha and other branches of the Guaso Nyiro, and in the plains W. of Songari Hill. It there appears to occupy a considerable tract of country resting upon gneiss, as it does along the eastern and southern borders of the Kapiti Plains. In the far N. a phonolite, which, from the description by Weber (1906, p. 648), appears to be similar to the Kapitian, rests on the gneisses of western Somaliland in the Gillett Mountains. On the floor of the Rift Valley the Kapitian phonolite is mostly covered by later rocks, but it occurs occasionally, e.g. as the surface of the Hannington-Solai platform, and at the foot of Karau, E. of Baringo; west of the Rift Valley it also outcrops from beneath the younger lavas at intervals along the railway line from the Mau summit to Muhoroni; it forms the Lumbwa Plateau; and along the western and north-western edge of the volcanic area it is widespread around Kisumu, and E. and N.E. of Elgon.

Age.—These Kapitian phonolites always present features indicating considerable geological antiquity. They are always in a greatly denuded condition. The vents through which they were discharged have been worn down into low rises, some of which have been so denuded that they are hardly even marked by volcanic necks; the beds of volcanic tuff which probably once lay on the lavas have been swept away and the surface is left as wide, gently undulating down-like country, with the richest game-fields in East Africa. That they are the oldest lavas in the country is proved by abundant evidence; where their base is exposed they always rest upon gneiss or schist, which sometimes, like Lukenya, rises through the phonolite of the plains like an island. They often form the margin of the volcanic area, as the base of the series is naturally there laid bare by denudation.

Wherever the Kapitian phonolite is seen in relation with other volcanic rocks, it is the oldest. The evidence at Nairobi shows that it is earlier than the Kikuyu trachytes ; and this fact is proved conclusively by the clear sections along the Maragua River near Fort Hall, which show that it underlies the basalts and the rhyolites. The phonolite rests on gneiss on the southern bank above the bridge over the Maragua ; and further up the hill-side the phonolite is succeeded by rhyolitic tuff and rhyolite. The hill-side on the northern bank consists of rhyolitic agglomerate containing fossil wood, above which is a flow of dark glassy rhyolite, about 250 ft. higher than the road ; but on this bank the agglomerate rests directly on the gneiss, as if a valley had been cut through the phonolite to the underlying rocks before the eruption of the rhyolites. Mr. Sikes tells me, moreover, that the phonolites further up the Maragua River are not only covered by the basalts, but were faulted before the basaltic eruptions, for, ascending the river, the phonolite sheet occurs at three levels, apparently separated by fault scarps, which have moved the phonolites but neither the neighbouring basalts nor rhyolites. On the Nyeri-Meru road, W. of Kenya, the phonolite clearly underlies the basalt ; the base of the basalt sheet is spherulitic, as if it had been quickly cooled by contact with an old surface of phonolite.

These coarsely porphyritic Kapitian phonolites appear in fact to form the northern, eastern, and southern margins of the volcanic area, and to pass westward beneath the later lavas. How far they extend underneath the volcanic area is uncertain. Apparently they do not underlie the whole of it as in places the later basalts and nephelinites rest directly upon the gneiss—possibly because the phonolites had been locally removed by denudation. Thus basalt occurs over gneiss at the Tana bridge N. of Fort Hall.

Along the western margin of the volcanic area the phonolite is also the basal lava, as around Kisumu. In the S.W. part of the volcanic area of B.E.A. the augitites rest directly on the gneisses and the phonolites appear to be absent ; for the collections from the Nguruman Scarp W. of Lake Magadi, made by Mr. Gerald St. Claire on instructions from Mr. Lawley, include no phonolite. Further S., in G.E.A., the lava plains of Zerengeti, the oldest volcanic rocks of the Giant Caldron Mountains, appear from the descriptions of Jaeger (1913, p. 98) very similar in physical features to the phonolite plains ; but they are formed of basalt (Jaeger, 1913, p. 101), and appear to be later than the Kapitian.

II. The Doinyan Series

The term "Doinyo," the Masai word for mountain, was adopted for the next volcanic division because instead of forming widespread lava plains its eruptions built up lofty volcanic mountains, including Kenya, and probably also Settima, Niandarawa (Nandarua), and the older peak of Kilima Njaro. Mount Kenya is the typical representative of this group.

That its eruptions were somewhat later than the Kapitian is shown by two facts : (1) the tuff slopes of the south-western part of the mountain appear to rest upon the phonolite plains N.E. of Nyeri ; (2) the phonolite plains there have been cut through by vents parasitic to Kenya and containing nepheline-syenite and kenyte ; (3) the oldest lava of Kenya, the phonolite of the Kenyan type, occurs on Laikipia and near Kisumu, and in those places is clearly younger than the Kapitian phonolite.

On the western side of Laikipia rise the two deeply dissected mountains of Settima and Niandarawa or Kinangop. As to their geological structure I have no certain evidence ;[2] but the view of Niandarawa from the N. which I enjoyed in 1919, showed east of the summit a magnificent series of crags, that have the characteristic weathering of agglomerates and are strikingly like the kenyte agglomerates of Kenya. A photograph by Mr. McGregor Ross well shows this feature. Though the evidence is still inferential, I am inclined to regard my former suggestion, that Settima and Niandarawa are worn-down volcanos of about the same period as Kenya, as probably correct.

The third great mountain which appears to belong to this period is Mawenzi, the older vent of Kilima Njaro. It is strikingly similar in appearance to Kenya (see e.g. the photograph and plate in Meyer, 1891, pp. 165, 175). I am not aware of the discovery of nepheline-syenite in this plug, which is mainly built up of flows and agglomerates of kenyte. It is a mountain in the same stage of decay as Kenya, and probably belongs to the same eruptive epoch.[3]

The Doinyan series includes flows of phonolite which ally it to the Kapitian lavas ; but the kenyte which is the prevalent rock of the Doinyan is of a more basic character and of a different chemical composition, though it belongs, like the phonolite, to the alkalic division. The olivine-bearing Kapitian phonolite near Songari is an intermediate variety between those phonolites and kenyte,

III. The Nyasan Series

The third series in the East African volcanic succession includes the one horizon in the interior of B.E.A. of which the age is definitely fixed by fossils. It therefore furnishes the most reliable evidence as to the age of the other series. This series was called Nyasan, from Nyasa, the Yao word for lake, because its chief feature was the development of a series of large lakes of which Lake Nyasa is a typical example. The Nyasan trough appears to have been formed then, and reached by an arm of the sea through the Zambezi Valley.

The most important deposits of this period are lacustrine. In the journey along the Rift Valley from the Kedong to Baringo I had seen the remains of extensive ancient fresh-water deposits, as to the relations of which I obtained no definite evidence; but in Kamasia, about 11 miles W. of Lake Baringo, exposures of these lake-bed deposits are clearer and show that they were deposited during an interval in the volcanic eruptions. As these Nyasan deposits form the lower part of the Kamasia range I suggested for the lake in which they were formed the name of Lake Kamasia.

The deposits include fine-grained pure clays and silts, that could only have been dropped in the still, stagnant waters of a lake. They are interbedded with coarse gravels and some boulder beds, which were probably formed where torrential rivers discharged into the lake and spread out deltas of stones swept down from the adjacent hills. The pebbles in the gravels are derived from the older lavas; and the lake beds are covered by flows of basalt and trachyte, by some of which the clays have been baked into a natural snow-white porcelain.

Lake Kamasia was therefore in existence after the older lavas, and after faults had formed steep-walled lake basins; but it was earlier than the younger volcanic series.

The Njorowa Gorge cuts through a similar series of lake deposits, which were probably formed either in the southern part of Lake Kamasia or in a contemporary independent lake. The lake deposits are shown in the walls of the gorge S. of the great step that bounds the upper part of the valley; they consist of fine-grained regularly bedded clays, layers of sands which contain so much volcanic material that they resemble tuffs, and gravel composed of pebbles of the older lavas. These lake deposits rest upon kenyte lavas, and they are covered by comendites, the alkalic acid lavas that form the great columnar flows near the picturesque entrances to the gorge.

These Njorowa lake beds therefore correspond in position to those in the foot-hills of Kamasia.

In the basin of Lake Elmentaita is a thick series of lake deposits which appear to be of two ages, some are quite modern, but some of the older, as around Soit-Sambu and E. of Lake Elmentaita, may belong to the Nyasan series.

In 1893 there was no direct evidence from B.E.A. as to the exact age of the Nyasan deposits. Physiographic evidence indicated that they must be either Miocene or somewhat earlier. This age was supported by the evidence of a fossil sea-urchin from Lake Nyasa in the British Museum of Natural History. At that time it seemed inadvisable to use the term Oligocene in East African Geology, and the Nyasan was therefore placed at the top of the Eocene, as the horizon of this fossil sea-urchin (*Echinolampas discoideus*) in India was then included in the Eocene. Since then the Oligocene System has been universally accepted for the beds previously included in the Upper Eocene and Lower Miocene; and indeed, if the course adopted by R. Douvillé (1908, p. 323) in regard to the beds in Madagascar were followed, the Burdigalian horizon (that of the *Dinotherium hobleyi* beds) and the Nyasan beds would be included in the Oligocene. The Burdigalian appears, however, to be conveniently regarded as Lower Miocene.

If these Nyasan lakes of the Rift Valley are on the same horizon as those of Kavirondo their age is precisely determined by the fossil bones found near Karungu on the eastern shore of the Victoria Nyanza. This discovery was first made by Mr. G. R. Chesnaye in 1909; he showed the bones to Mr. Hobley, who immediately recognized their importance and induced D. B. Pigott to look for further specimens. His search was rewarded by the discovery of the lower jaw of a primitive form of elephant, which was described by Dr. C. W. Andrews in 1911 as *Dinotherium hobleyi*. As Mr. Pigott shortly after his discovery of these bones was eaten by a crocodile, the information as to the mode of occurrence of the fossils was lost. Dr. Felix Oswald visited the area in 1911–1912, made a valuable collection of fossils and a detailed survey of the bone beds. Dr. Oswald found that the bones are scattered in lake beds which have a narrow outcrop from beneath widespread sheets of lava. He divided the lake beds into three divisions:—

3. (Uppermost) 70 ft. of clays with occasional sandstones, containing tree stems, land shells, and remains of crocodiles.

2. 30 ft. of red and gray clays such as may have been formed on the floor of a muddy lagoon, with white sandstone and beds of calcareous tufa, with remains of turtles, crocodiles, and fresh-water shells (*Ampullaria*, etc.), and bones of mammals.

1. The lowest division, about 55 ft. thick, consists of buff-coloured sandstones and torrential gravels passing down into clay and marl; it contains *Dinotherium hobleyi* and other mammals. The gravels in the lower division include pebbles of gneiss and various volcanic rocks including andesite and fragments from the volcanic agglomerate of Metamala.

The lake beds are shown by the pebbles in the gravels to be younger than the older volcanic series, while they are older than the local nephelinites overlying them. That a considerable interval elapsed between the formation of the lake beds and the discharge of the nephelinites is shown by the fact that these lavas filled up valleys which had been excavated in the lake series (Oswald, 1913, p. 7).

The Karungu lake deposits occur near the eastern shore of the Victoria Nyanza around Karungu Bay, a little less than 30 miles S. of Kavirondo Gulf and N. of the mouth of the Kuja River. Their extension inland is hidden by lavas. They were formed at a period when the lake stood at a level over 300 ft. above its present level (Oswald, 1914, pp. 138, 146). Lake gravels and water-worn caves are reported at over 330 ft. above the present lake level on the western shore of the Victoria Nyanza, beside the fault N. of the Kagera River as recorded by Sir William Garstin (1904, p. 32). They also apparently extend further E. than the exposures near Karungu and to a level at least 500 ft. above that of the Victoria Nyanza, as Mr. G. R. Chesnaye has discovered a new bone bed near Muhoroni.

The age of the lake beds is definitely fixed by their fossil vertebrates, which have been described by Dr. Andrews. The title of his memoir states their age as Lower Miocene which the text defines more explicitly as Burdigalian. The vertebrate fauna is as follows:—

MAMMALS

Proboscidea—

Dinotherium hobleyi Andrews.
Dinotherium; a larger species.

Hyracoidea—

Myohyrax oswaldi Andrews (n. gen.).

Artiodactyla—

Merycops africanus Andrews.
Large Anthracothere ; aff. *Brachyodus.*

Perissodactyla—

Rhinoceros schleiermacheri Kaup.

Rodentia—

Paraphiomys pigotti Andrews.

Carnivora—

Pseudælurus africanus Andrews.
Large Creodont ?

REPTILES

CHELONIA—

Testudo crassa Andrews.
Podocnemis ægyptiaca Andrews.
Cycloderma victoriæ Andrews.

Crocodilia—

Pristichampsa sp.

These vertebrates are accompanied by fossil shells, which have been described by Mr. R. B. Newton (1914, pp. 187–198). They are mainly of value as elucidating the geographical conditions under which the beds were deposited, for they give no precise evidence as to age. All the species still live in Africa, though not in the Victoria Nyanza. The shell fauna is as follows :—

Fresh-Water—

Ampullaria ovata Olivier.
Lanistes carinatus (Olivier).
Cleopatra bulimoides (Olivier).
Cleopatra exarata (E. von Martens).

Terrestrial—

Tropidophora nyasana (E. A. Smith).
Achatina sp.
Burtoa cf. *nilotica* (Pfeiffer).
Cerastus cf. *moellendorffi* Kobelt.
Cerastus sp.
Limicolaria sp.

The species determined are mostly found living in the Nile basin; one is known only from Lake Nyasa, and one only in the Mombasa region. The shells show that the lower beds were formed on the floor of a lake, while the upper division was formed on land.

Unfortunately no fossils have yet been found in the Nyasan beds of Kamasia or of the Njorowa Gorge; so that their correlation with the Karungu beds is unproved. But the lake beds of Karungu, Kamasia, and the Njorowa agree closely in general character; they all contain fine-grained lake deposits associated with coarse torrential gravels, and they were all deposited in an interval between an older series of sub-basic eruptions and the discharge of the comendites and nephelinites. The probability is that they occur on the same horizon, and if so, all the volcanic rocks in B.E.A., which are pre-Nyasan, are pre-Miocene.

A more definite opinion on this question would be possible if the nature of the volcanic pebbles in the Miocene gravels, of the pre-Miocene agglomerate of Metamala, and of the rock determined by Dr. Oswald as the augite-andesite of Kikongo were better known. These pre-Miocene volcanic rocks occupy a considerable tract of ground E. of the Miocene bone beds in the valleys of the Riana River, the upper part of the Kuja, and near Kiwa to the S.E. of Homa Bay, a branch of the Kavirondo Gulf. Dr. Oswald described these volcanic rocks as "ancient," and his references to them suggest that he regarded them as dating from some early geological period. The feature in them which at first might suggest that their age is long pre-Miocene is their intersection by quartz veins; but as quartz veins also intersect the Miocene lake beds (Oswald, 1914, p. 134) they are no evidence of a pre-Miocene age.[4] The locality was probably saturated by hot waters during the post-Miocene eruptions and the quartz veins formed then. Dr. Oswald has kindly lent me his specimens of these rocks, and they have been examined by Miss Neilson, Dr. G. T. Prior, and Mr. Campbell Smith. The rocks are so much altered that no satisfactory correlation with the lavas of the Rift Valley can be based on them. Dr. Prior, Mr. Campbell Smith, and Miss Neilson point out the determinable felspar in the andesite is andesine, which, however, occurs also among the older lavas of the Rift Valley (e.g. Künzli, 1901, p. 160, from E. of Elmentaita). Miss Neilson is disposed to regard some fragments in the Metamala agglomerate as decomposed kenyte; but the material is too poorly preserved for this suggestion to be more than tentative. The microscopic examination of Dr. Oswald's specimens shows nothing inconsistent with their correlation with the pre-Nyasan volcanic series of B.E.A. The rocks are no doubt much altered, the pyroxenes, as Dr. Oswald remarks, are uralitised; but equal alteration occurs in the Kenyan lavas where the olivine is altered to serpentine and some of the pyroxenes altered to opacite. The probabilities appear to me in favour of the view that the pre-Miocene volcanic rocks of the Karungu district belong to one of the older volcanic series of the Rift Valley. If so they are probably Doinyan. If further study of the Karungu older volcanic rocks confirms this suggestion, it would conclusively establish the pre-Miocene age of the Doinyan and Kapitian volcanic series.

The Oligocene Age of the First Rift Valley Faults.—The lake deposits of the Nyasan series were in existence after the first series of Rift Valley faults which are therefore no later in age than the Oligocene. This view is consistent with the age of the Rift Valley at its two ends, where its faults cut across marine rocks of which the age is fixed by fossils. Thus the Red Sea trough was certainly formed by the Oligocene (p. 352), while at the southern end the same date is established by the faults cutting across the Eocene limestones of Sheringoma and by the evidence of the fossil Sea-Urchin (*v.* p. 298) that part of the Nyasa basin was covered by an Oligocene sea.

IV. The Laikipian Series

The disappearance of the Nyasan lakes was probably due to earth movements which led to eruptions, and thus to the preservation of some of the lake deposits beneath sheets of basalt. The eruptions of this division discharged a varied series of lavas, which may be divided into three sections. The Lower Laikipian lavas were more basic than those of the lower divisions and are mainly basalts and basanites. The Middle Laikipian consists mainly of phonolitic-trachytes; and the Upper Laikipian of phonolitic-quartz-trachytes and rhyolites.

The superposition of the Lower Laikipian lavas on the Nyasan is proved at several localities; thus W. of Lake Baringo the basalts have overflowed and baked the clays of Lake Kamasia. It was the widespread distribution of these basalts above the phonolites on Laikipia that suggested the name for the division. The basalts of Kenya, which are later than phonolites, suggest that the last of the

Kenyan eruptions were Laikipian in date. In North-eastern Kikuyu-land the basalts do not rest on any known Nyasan deposits ; but their discharge on eroded and faulted Kapitian phonolites indicates an interval of time between them that renders probable the correlation of these basalts with the Laikipian series. If the leaf beds on the lower slopes of Mount Ngong are Nyasan, then the augitites of that mountain and consequently those of the Nguruman Scarp also belong to the basic lower section of the Laikipian.

The Middle Laikipian consists mainly of phonolitic-trachyte, which occurs as wide sheets with no traces of the craters. To this division may be assigned the phonolitic-trachytes of Mau (*v.* p. 128), of Londiani, Western Baringo, Laikipia, Kikuyu-land, Magadi, the Shanau Ridge, the base of Ol Gasalik, and the lower part of the Kedong and Kikuyu Scarps.

The Upper Laikipian lavas are more acid in composition, and are mainly quartz-trachytes and rhyolites, which are shown to be later than the phonolitic and quartz-free trachyte at Nairobi, and in the Kedong and Kikuyu Scarps.

V. The Naivashan Series

The quartz-trachytes and rhyolites of West Kikuyu-land are certainly older than the Kedong and Kikuyu Scarps. These scarps were due to the second or Naivashan series of Rift Valley faults, which date from the last great infall of the floor of the Rift Valley. The age of that infall is proved by three bone beds—that of the Omo, N. of Lake Rudolf (*v.* p. 342) ; that of Homa beside the Kavirondo Gulf, which lies in a transverse tectonic valley probably of the same age as that of the Naivashan Faults of the Rift Valley ; and that of the Oldowai Gorge in the Giant Caldron Mountains. Each of these three localities has yielded a mammalian fauna which is either Upper Pliocene or Lower Pleistocene in age. That of Homa was determined as Upper Pliocene by Andrews (1916) ; that of the Omo Valley is referred to the Pliocene (Haug, *Traité Géol.*, Vol. II, p. 1727) ; the Oldowai Gorge has yielded a series of fossils which are referred by Reck (1914 (1), p. 95) and Dietrich (1916) to the early Pleistocene ; the fossil elephant found there is a local variety of the extinct species of *Elephas antiquus* (named by Dietrich *E. antiquus recki*, and it is associated with a fossil baboon and a three-toed horse allied to *Hipparion*. The lowest but one of the bone beds contained a human skeleton which Reck (1914 (1), p. 93) insists is not due to burial but was that of a contemporary man drowned in the lake. Dr. Andrews (1916, p. 417) has identified the same or a closely allied elephant from Homa in Kavirondo, where it is associated with an extinct genus of baboon; hence he regards this fauna as Pliocene and the human skeleton as later and due to burial by man. These bone beds were laid down on the floor of the Rift Valley after its formation had been practically completed by the Naivashan faults, which are therefore earlier than the Upper Pliocene.

The foundering of the floor of the Rift Valley by this faulting led to fresh eruptions along its course. Some of these were probably on or close to the boundary faults, such as D. Nyuki at the foot of Kikuyu Scarp, Menengai near the foot of Mau, and Isanga on the Boundary Fault W. of Niandarawa.

About the same date, judging by their condition of preservation, were the last eruptions on Laikipia and in Kikuyu-land, such as the eruptions of phonolitoid-kenyte of Nyeri and Tumu-tumu.

The most powerful eruptions of the Naivashan were those along the middle of the Rift Valley. These included the discharge of the comendites which built up the Sub-Longonot ridge S. of Naivasha. Others built up a chain of great volcanic hills including Ol Gasalik, the chief part of Suswa, the volcanic hills S.W. of Naivasha, D. Buru, and the volcanic hills N. of Baringo. These eruptions were largely of kenyte. This return to more basic lavas helps to correlate the Rift Valley eruptions with those of the later lavas of the N.W. province of B.E.A. The nephelinites S. of Kavirondo Gulf are later than Lower Miocene, as they overlie the lake beds (*v.* p. 201), and in all probability Elgon and Tindaret, which consist mainly of nephelinite, are also Naivashan in age. That Elgon was pre-Pleistocene is assumed by the view that its caves were partly made by stream action under the glacial conditions of the Lower Pleistocene. The late age of the nephelinites is consistent with the evidence from G.E.A., where they are still being discharged by the active volcanos of Kiringa and Doinyo Ngai.

The late Pliocene eruptions included the group of faulted basalt craters S. of Lake Elmentaita, since they were older than the extension of its lake deposits; also the crater of which the remnants form the islands in Lake Baringo.

VI. Pleistocene

The demarcation between Pliocene and Pleistocene is not well defined. The eruptions of Suswa and Menengai were doubtless continued, and many of the phonolitic-trachytes with well-preserved craters are due to this period. The Lower Pleistocene was characterized by the climatic change which increased the rainfall and led to the great development of the glaciers of Kenya and Kilima Njaro, and to the great extension of the lakes, such as the greater Baringo, the greater Naivasha, and to the formation of Lake Suess, a former lake which once covered the plains around Suswa and Longonot. The overflow from Lake Naivasha through the Njorowa Gorge was doubtless Lower Pleistocene, and it shows that the comendite flows of the Sub-Longonot ridge were not later than the Pliocene.

The Upper Pleistocene eruptions built up the volcanos with perfect craters, such as Longonot and the caldron of Menengai. The Kyulu volcanos began somewhat earlier, probably in the Lower Pleistocene, for though in Mwani and Kalembwani the craters are still recognizable, they have been much denuded since the discharge of their lavas.

VII. Comparison with the Earth-Movements and Volcanic Sequence in G.E.A.

In G.E.A. there is clear evidence that the earth movements and eruptions have lasted throughout most if not the whole of the Kainozoic Era, and according to some authorities the faults of the Rift Valley date back even to the Paleozoic. The neighbourhood of the Giant Caldron Mountains (Riesenkrater-gebirge), S. of the British border and W. of the Rift Valley, has been the subject of illuminating investigations, especially by Jaeger and Obst, and the petrographic studies by Finckh (1911). They have shown that the country has been broken by faults that date back at least to the early Kainozoic ; and this faulting, according to Obst, was a continuation of that which, in the later Paleozoic, initiated the formation of the Wembere Sunkland. The sequence of faults and eruptions has been carefully investigated by Jaeger in the Rift Valley of Lake Eyasi, which is a branch of the Rift Valley trending to the S.W. Its basin is now separated from the main Rift Valley, as its north-eastern end has been buried by the eruptions of the Giant Caldron Mountains.

The oldest of these eruptions formed the widespread basalts and tuffs of the Zerengeti Plains, and at about the same date built up the volcano of Lemagrut. This mountain has been cut through by the Eyasi faults, so that it was certainly earlier than the formation of the Eyasi Rift Valley. Lemagrut consists of a cone bordered by an older rim which has been described as its Somma, in analogy with the older rim of Vesuvius. A section in the Duwai or Oldowai Gorge near Lemagrut furnished Jaeger with clear evidence that successive eruptions in the district were separated by intervals during which the country was faulted.

The sequence of geographical events after the beginning of the Zerengeti eruptions may be divided into eight episodes. (1) The eruptions began with the discharge of a doleritic basalt with but little olivine. (2) This lava was covered by basaltic tuffs after the deposition of which (3) some faults dislocated both basalt and tuff. (4) The surface was then planed down. (5) Upon this level surface was spread out a wide sheet of red or lateritic tuff. (6) The country was again disturbed by faults, which affected the lateritic tuffs, as well as the earlier beds. (7) The depressions formed by the faults were then partially filled by trachytic tuffs, which were laid down irregularly on the tilted surface of the older volcanic series. After an unknown interval these earth movements were followed by (8) the subsidence which produced the caldron of Balbal. (9) The sides of this caldron were attacked by streams which cut a series of gorges, one of which, Oldowai, has yielded some fossil mammals which are probably Pliocene (*v.* p. 206) and a human skeleton.

Since the deposition of the tuffs some of the caldrons have subsided and the country has been again faulted (see Reck, 1914 (1)), and these faults are of very recent geological date.

The foregoing evidence proves that after the discharge of the Zerengeti lavas the country has undergone four distinct series of earth movements, separated by four eruptive periods; the last of these eruptive periods was early Pleistocene or Pliocene; the oldest volcanic period was clearly of much greater geological antiquity and is probably at least middle Kainozoic.

The Zerengeti Plains, as remarked (p. 197), appear to be very similar as regards denudation to the older lava plains of B.E.A. There is no evidence in the Zerengeti area of a Kapitian phonolite; the eruptions began with an olivine-basalt which it is natural to correlate with the Laikipian basalts. The later sequence, according to Jaeger (1913, p. 144), was nephelinite; then melilite-basalt tuff; then nepheline phonolite; then came kenyte (trachy-dolerite). Jaeger is emphatic that in the Zerengeti Plains and other localities in the Giant Caldron Mountains the kenytes overlie the nephelinites. As the Eyasi fault happened at the end of this volcanic sequence, it was later than the kenytes. On Kilima Njaro, on the contrary, the kenytes are earlier than the lavas of the nephelinite and basanite series. The sequence is therefore reported as reversed between Kilima Njaro and the western end of its volcanic line. Further evidence as to the correlation of the Kilima Njaro and Giant Caldron lavas, and as to the position between them where the reversal of the eruptions took place, is desirable before confidence can be felt in the correlation of the eruptive sequence in G.E.A. with that in B.E.A. The nephelinites and melilite-nepheline-basalt series of the Giant Caldron Mountains may correspond to those of Tindaret and Elgon which are post-Miocene, and the kenytes of the summit of Lemagrut would appear to correspond to those of Ol Gasalik and be of Pliocene age. The older part of Lemagrut is, however, earlier than the Eyasi faults, and its basalts are probably contemporary with the Laikipian basalts of B.E.A.

[1] As the accepted spelling is now Kapiti instead of Kapte, the name of the series is modified accordingly.

[2] A detailed account of an ascent of Niandarawa has been published by Bishop Perlo (1908). One of his photographs represents rocks with the weathering of agglomerate.

[3] H. Meyer (1900, p. 334) remarks of Mawenzi that its age may be Pliocene. He says: "In no case (keinesfalls) is it younger."

[4] Small quartz veins also occur in the cave earth at Kebrasi; *v.* p. 225.

CHAPTER XVII

The Tectonic Structure of the Rift Valley

THE travellers who early in the nineteenth century began the scientific exploration of the Jordan and Dead Sea Valley were convinced that it had been formed as a rift or crevasse in the earth's crust. The long straight course of the Red Sea is geographically so remarkable that it was also attributed to earth movements. This view was strengthened when von Höhnel's work during the Teleki expedition proved the extension of the Jordan-Red Sea valley across the high plateaus in eastern Africa. The valley is continuous, although its floor in the Red Sea sinks more than 6000 ft. below sea-level and at Naivasha rises more than 6000 ft. above sea-level.

The volume of instructive sketches by von Höhnel (1890), published by von Teleki, showed that B.E.A. is crossed by a flat-floored steep-walled trough. Suess, in an illuminating memoir (1891), attributed the formation of the valley to faulting and its age to the Pleistocene—the latest epoch of geological time. The study of this valley during the journey from the Kedong past Naivasha to Baringo afforded ample evidence of its tectonic origin; but the volcanic rocks that it intersects are so varied, and their eruptions were separated by such long intervals of time, that I was driven to the conclusion that the formation of the valley must have taken much longer than Suess considered, and was due to earth-movements at very different geological dates. The classification of these earth-movements summarized in the table on p. 105 (from G.R.V., p. 235) was based on the study of the Rift Valley between Naivasha and Baringo; and especially on a geological section across the Rift Valley through Lake Baringo.

That this valley cannot have been excavated by rivers is obvious. As remarked by Collie (1912, p. 312), "There are no through streams which could have made it." The natural drainage is often at right angles to its course. Rivers occur on its floor and have cut meandering valleys that illustrate the difference between river-made and fault-formed valleys.

The Rift Valley rivers are due to the pre-existing valley, and have no more made it than a railway train has made the cutting through which it runs. River action is in fact rapidly destroying the Rift Valley, by attacking its straight steep walls and converting them into sinuous sloping banks. Fault scarps are inevitably short-lived; the rock beside them is shattered by the fault movement; so it readily falls before the attack of the agencies of denudation and the upper part of the cliff is quickly worn back. This process is especially rapid in tropical valleys with walls facing E. and W., and therefore subject to the disruptive effect of sudden changes of temperature at sunrise and sunset. The fallen material covers the fault line at the base of the scarp. As is usual with faults, the evidence for their existence is more often indirect than direct; but when the tributary gullies are carefully examined, many of the faults will doubtless be detected; for in spite of having only time for hasty search, I have found them in many places, as at the eastern foot of Ol Setian, on the eastern scarp of Lake Elmentaita, beside Lake Hannington, in the fault-cut gashes through the basalt craters S. of Elmentaita, in the truncated eastern and western sides of Doinyo Nyuki el Dogilani (Mount Shelford), and in the faceted western spurs of Settima. Indirect evidence is, however, generally more conspicuous. It is shown by the displacement in level of the rocks; by the breaking of a sheet of lava into a series of steps; by the parallel-sided blocks or horsts, which are separated by straight-sided valleys and occur on the floor of the Rift Valley, where no erosional agents could explain their formation; and by the absence from the younger walls of the spurs and outliers characteristic of escarpments made by rivers, rain, and wind.

Valleys due to erosion are common in East Africa. From the summit of Mau the river-moulded landscape of Lumbwa offers a striking contrast to the Rift Valley which lies to the E.; and there is a similar contrast between the high wall above the Kedong Basin and the neighbouring river-cut valleys of Kikuyu-land.

The origin of the Rift Valley by direct subsidence has been remarked by G. L. Collie (1912, p. 312): "The Rift Valley must be regarded as a vast graben or tectonic trough; the undulations of the floor, and the absence of through trunk streams forbid the supposition that it is a valley of erosion." So far from the valley having been made by erosion, it is being rapidly destroyed thereby. Collie, for example, remarks that erosion is rapidly removing the divide between the Rift Valley and the Victoria Nyanza, and that in time the drainage of the Rift Valley will be thus added to that of the Nile. He writes: "By that time the Rift will largely disappear, perhaps leaving no trace of its existence. All that may be left to tell the story of its greatness and uniqueness will be the records of those who saw it in its pristine days."

The Rift Valley Faults

The scarps along the boundary faults vary in accordance with their age, the composition of the rocks beside them, and the structure of the plateaus which they traverse. The boundary faults may be grouped into four main varieties. (1) Steep scarps composed of rocks which yield but slowly to weathering; these scarps may consist of a single cliff, but when high they are usually divided into one or more cliffs separated by platforms, owing to the splitting of the fault. (2) Scarps which weather into gentle slopes; they are usually composed of thick beds of tuff, but are sometimes due to the building up of buttresses by volcanic eruptions along the fault, or to the flow of lava over the scarp. (3) A succession of steps with comparatively wide treads, due to the subsidence happening along a parallel series of widely separated faults. (4) Ancient dissected scarps which are so old that they have been cut away by streams; very little of the original scarp is left, and the country looks like an irregular mountain range, and its formation as a fault scarp may only be recognizable by the spurs ending along a straight line and by the absence of outlying foot-hills.

The eastern boundary scarp of the Rift Valley in B.E.A. may be divided into five chief sections which, from N. to S., are those of Laikipia, Settima, Kikuyu, the Kapiti Plains, and the Magadi steps.

The Laikipian Scarp extends past Baringo and Lake Hannington; it is in places at its northern end a single lofty scarp, but E. of Baringo a branch scarp results, opposite Nalesha, in two scarps with a band of foot-hills, the Arabel Platform, between them. This platform continues southward above Lake Hannington and around Lake Solai. The height of the scarp which forms the western front of this platform decreases gradually southward owing to the rise in level of the floor W. of it. A convenient southern boundary for the Laikipian Scarp is the valley of the Guaso Narok; this river rises on the Ol Bolossat Platform, which is the southern continuation of the Arabel-Solai Platform, and crosses the eastern boundary

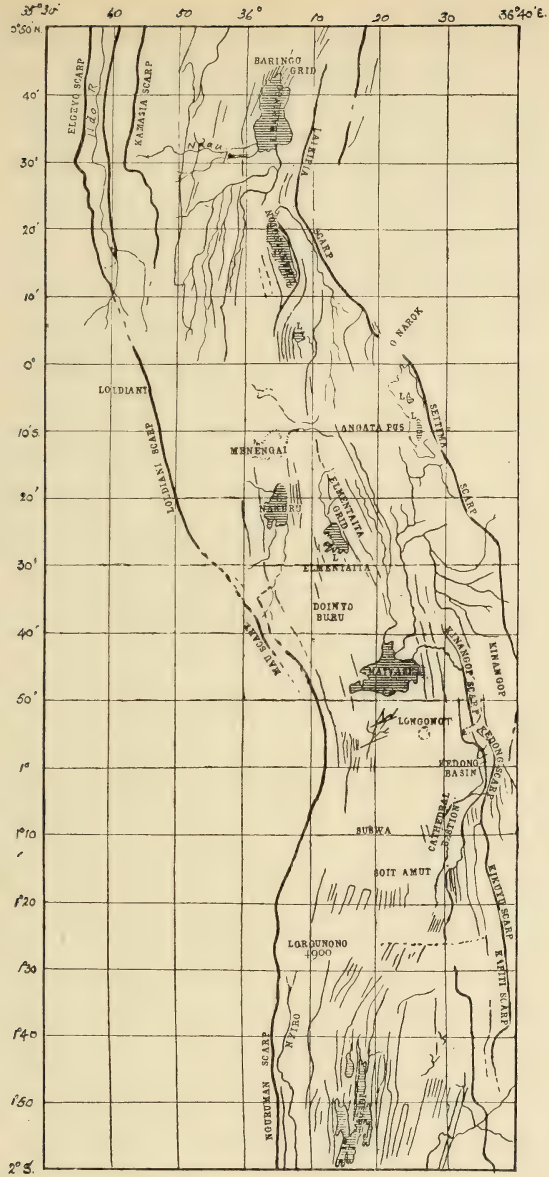


FIG. 34.—The Fault Systems of the Rift Valley in B.E.A.

Scale, 1 inch = 33 miles.

scarp. The Guaso Narok was therefore older than the boundary scarp. The Laikipian Scarp is continued as the Settima Scarp, which truncates the western slopes of Settima and Niandarawa. This scarp has been buried opposite Niandarawa by the volcano Isanga, which has been piled up over the fault plane ; further N. the volcano of Kipipiri arose E. of the fault, that lies in the valley between the volcano and Settima.

The western front of the Hannington-Solai Platform is continued as the Kinangop Scarp, which bounds the western edge of Kinangop. In places it consists of one chief scarp, with three or four minor parallel scarps in front, as near Lake Naivasha ; near Elmentaita the platform is traversed by many parallel faults, which break up the surface into a complex series of horsts and valleys. Opposite Lake Naivasha the different branches of the Kinangop Fault come together or die out, and they are joined by the Settima Fault, which there bends westward. Opposite Longonot the Kikuyu Plateau projects as the Kijabe buttress, due to the trachytic flows from the Kijabe vent having overflowed the scarp. The Kijabe buttress appears to have buried the southern continuation of the Settima Fault. South of Kijabe, the Kikuyu Scarp is in places one sheer cliff ; but it is mostly double, the two sections being separated by the narrow platform which is used by the railway beside Kijabe Station, and further S. by Sclater's Road between the floor of the Rift Valley and the Kikuyu Plateau. The floor of the Rift Valley extends eastward in a bay which is bounded to the S. by an intensely broken block E. of Cathedral Hill which may be described as the Cathedral Bastion. The northern front of this bastion, as shown by Mr. Sikes' photograph (in Gregory, 1919, p. 430, Fig. 1), is a part of the Kikuyu Plateau, which has been left projecting owing to the subsidence of the Kedong basin to the N. and of the Rift Valley to the W. ; the projecting block having been left laterally unsupported, it has been broken through by a series of about six N.–S. faults, between which the rocks have been tilted with a slope eastward. In the views of the Cathedral Bastion from the W. the rocks appear to have been tilted steeply southward ; but as I was only able to see this section from a distance, it is possible the inclination of the beds may be due to lava and volcanic ash having been laid down on the sloping sides of a volcanic hill. S. of the Cathedral Bastion the Kikuyu Scarp is continued as the western front of Ngong Mountain, and the continuations of the Cathedral faults have formed a series of steps between Ngong and the Kedong River. S. of Ngong a second great westward projection of the eastern plateau is formed at Esayet and Asagut, probably by a cross fault parallel to that of the northern face of the Cathedral Bastion.

South of those mountains the main eastern boundary fault is the Kapiti Scarp, which there forms the western front of the Kapiti Plain. To the W. of this plateau the level falls by successive steps to Lake Magadi, by the subdivision of the main fault into many parallel faults, of which Mr. Parkinson (1914, p. 37) marks twenty-five. The eastern boundary scarp of the Rift Valley is thus broken up into the Magadi steps, and the further development of this change leads in northern G.E.A. to the elimination of the eastern wall and its replacement by a gentle weathered slope.

The western boundary fault in B.E.A. bifurcates at its northern end, and between the two branches stands the plateau of Kamasia, which is separated from the main western plateau of Elgeyo by the deep trench of the Ndo Valley. S. of the Eldoma ravine the western boundary fault is single, forming the steep eastern face of Loldiani, which is succeeded southward by the Mau Scarp, the best-known section of the western wall of the Rift Valley. Mau is the Masai word for "twin," and was applied to two parts of the western wall of the Rift Valley (see p. 130). The Mau Scarp consists mainly of volcanic tuffs which weather into gentle slopes. The gradient is further eased opposite Lake Nakuru by the banks of later tuffs ejected from Menengai. The Mau Scarp retains these characteristics from the crossing of the Uganda Railway southward past Naivasha and Suswa; but S. of the Narok track the scarp passes from tuffs to gneiss and lava, and is again developed as a high rocky wall. As the Nguruman Scarp, W. of Lake Magadi, it is one of the most striking scarps in B.E.A.; the boundary fault there is double, the scarp being divided by the Kirikiti Platform, and in front of it are numerous minor faults that break up the floor of the Rift Valley into the Ndongerio Hills, which are bounded by plains as the faults die out to the S.

Between the two Boundary-Faults are numerous crowded parallel faults, arranged like a grid. Thus at the northern end of Baringo the shore at one of these fault-grids produces a structure like a series of quays separated by bays of alluvium (*cf.* p. 109). Another fault-grid occurs W. of the Lower Kedong, where eight parallel faults occur in a width of little over a mile. The same structure occurs on a much larger scale S. of Suswa and Soit Amut. The ending of the fault-grids is sometimes due to the gradual diminution in the throw of the faults, and sometimes to the faulted ground having been buried by tuff or alluvium.

The floor of the Rift Valley is also interrupted by long fault-blocks or horsts, left upstanding by the subsidence of the ground around them. A chain of these horsts occurs, for example, east of Lake Nakuru and Menengai. Striking examples of them, especially long and narrow, rise above the alluvium around Lake Magadi, and form the long N. to S. peninsulas on the shores of that lake. The ridge occupied by the offices and works of the Magadi Soda Company is one of these horsts.

The chief faults within the Rift Valley trend N. and S.; but it is also intersected by transverse movements that divide the valley into basins, of which the chief are those of Lake Rudolf, Losuguta, Baringo-Hannington, Nakuru-Elmentaita, Naivasha, the Kedong, and Suswa Plains, the plains N. of Ol Gasalik and Magadi. These basins are separated by high ground left in relief by the subsidence of the country to the N. and S.; but sometimes, as at Longonot, the barrier has been heightened by later volcanic eruptions. These cross barriers are sometimes due to folding, as indicated by the dip in the adjacent walls of the Rift Valley. This folding was mainly earlier than the Rift Valley faults. Africa had been previously corrugated by folds trending approximately E. and W.; and in the early periods of the volcanic history of B.E.A., especially during the resettlement of the country after the Kapitian eruptions, fresh movements occurred along the same general lines as the older folding. The areas of weakness thus pre-determined have guided the subsidences along the Rift Valley, which have divided it into successive basins of internal drainage.

Age of the Faults and Possible Renewal of Volcanic Activity.—The meridional faults of the Rift Valley belong, in respect to age, to three main groups—Oligocene (pre-Nyasan), Pliocene (or Naivashan), and Pleistocene.

The dominant fault scarps, such as the Kikuyu, Kedong, and Laikipian Scarps, are Naivashan in age, as they are earlier than the Upper Pliocene bone beds; they are post-Laikipian, since they cut across the quartz-trachytes and rhyolites, as e.g. at the Kikuyu Scarp. The pre-Nyasan faults in B.E.A. are comparatively inconspicuous. They are seen W. of Baringo and near Lake Solai as fault blocks with very denuded scarps, apparently much older than the main scarp of Kamasia. In G.E.A. the evidence of the older series of the pre-Nyasan is clearer; they formed the Wembere Sunkland and are still recognizable in the diagonal hill fronts near Kilimatinde and in the Eyasi basin. Further away the intensely dissected scarps of the Red Sea are clearly much older than such scarps as that of the Kedong. In places fresh movements have happened along the old fault lines and reformed the scarps; thus the eastern wall of the Nyasa Basin has been revived by refaulting, and its features are much younger than those of the western wall, which has been undergoing denudation since the Nyasan.

The third group of faults is of very recent date, and some may be quite modern. They have broken across the comparatively young craters S. of Lake Elmentaita, across the younger lava flows from Suswa near Nartje's, and even across alluvial plains. Some of the slight steps on the floor of the Rift Valley, as S. of Suswa, look as if they were only a few years old, and they may be still in progress.

Contemporary earth-movements should be recognizable by earthquakes along the Rift Valley. Many earthquakes have been recorded along the tectonic lines of East Africa, and Stigand (1916) reports their prevalence along the Rift Valley of the White Nile. They are frequent and strong along the coasts of Tanganyika and Nyasa (Koert, 1913, pp. 236). Meyer (1900, pp. 336–337) has recorded eight earthquakes in the Kilima Njaro district between 1891 and 1897. The most serious along the Rift Valley in recent years devastated New Langenburg on 1st May, 1919 (Field, 9th Aug., 1919), which, according to the *Beira News*, behind that town "split one hill in two, as though it was cut with a chopper."

The East African coast is well known as one of the great seismic zones of the world. But along the Rift Valley in B.E.A. earthquakes appear to be slight and infrequent. Mr. Hobley has set a useful example of recording (1918, pp. 349–350) some of the small earthquakes, two of which happened on 16th May and 17th May at Voi and Masongeleni, and were strong enough to damage the stationmaster's house and the dak bungalow. Mr. Hobley (1895, p. 548) himself experienced a slight earthquake in the same district 20th October, 1892.

Small earthquakes are now reported as often felt near the Rift Valley between the Kedong and Nakuru. Captain Caldwell has kindly told me of a reported displacement of the railway line between the Longonot saddle and Kijabe Station. There seems to be no definite evidence on this point; Mr. Griess of the Uganda Railway tells me that differences in level have been detected near Naivasha too large to be dismissed as errors in the first survey, and he has kindly arranged to have accurate levels taken along the line near Kijabe and to have them retested in a few years' time. These observations would show if any movements of the Kijabe faults are still in process.

The re-outbreak of volcanic activity along the Rift Valley would depend upon the renewal of earth-movements. At present the country appears to be in a stage of comparative rest, and the existing earth-movements are slight; but if extensive subsidence of the floor of the valley were resumed a renewal of powerful volcanic eruptions might be expected.

CHAPTER XVIII

Prehistoric Man in British East Africa

EVIDENCE of recent geographical changes along the Rift Valley is abundant and conspicuous. Volcanic eruptions and earth-movements have taken place at a date which, geologically speaking, is quite modern; and that some of the changes have happened during the human occupation of the area is shown by the stone implements, which are widely scattered through the district and are buried in the beaches of the ancient lakes. The first prehistoric stone implement found in B.E.A. was apparently a chipped flake of obsidian which I picked up in the Ulu Mountains in 1893. The adjacent rock was gneiss, so that the piece of obsidian had been clearly carried there artificially; but it seemed possible that this might have been made for use as a gun-flint, as the main Suahili caravan route to Uganda passed a few miles away. Subsequently, however, I found obsidian flakes of a Neolithic type on the Athi Plains; on the summit of the Kikuyu Uplands; on the beaches of the extinct Lake Suess; on the plateau S. of Lake Hannington; on the lake terraces around Lake Baringo; on the Lobat Pass leading from Baringo northward to the Sugota; on the summit of the pass from Baringo on to Laikipia; and at numerous places on that plateau. The best collection was obtained on the floor of the Rift Valley beside the Gilgil River from an ancient camp where the implements were made; for I obtained there numerous flakes and scrapers as well as the cores and lumps of obsidian from which the implements had been struck. Many of the flakes were of the shape useful as skin-scrapers, and for scraping wood to be used as spear and arrow shafts; others were of forms suitable for knives, arrow- and spear-heads. A series of these implements is figured in "Great Rift Valley" (Fig. 19, p. 234).

These obsidian implements were clearly of considerable antiquity, for they were found buried in the soil on the platform above the Kedong Basin, and in the high level beaches of Lake Baringo, where they were associated with broken pottery at a camp site inhabited when the lake was much larger than at present. None of the Masai, or the people of Njemps, or the Kikuyu, whom I asked about them, had any traditions of these implements having been used or made by man. They were of the Neolithic type[1]—that of the Newer Stone Age. During recent years they have been found abundantly and widely distributed through the interior of B.E.A. Some of the most perfect were collected by Mr. Tunstall at an old obsidian implement factory at Njoro, W. of Lake Nakuru.

Hobley (1912, p. 21) has figured an obsidian implement from Kisumu, and (*ibid.*, Figs. I and II) a series of those from Njoro that were found by Mr. Tunstall; also beautiful pointed arrow-heads from Kinobop, and from Kyambu, and more roughly chipped flakes from near Kikuyu Station (*ibid.*, Fig. III). Obsidian flakes of a crude type made of chert, sandstone, quartzite, and quartz-porphyry were found by Dr. Oswald near Karungu (Appendix, Hobley, 1912, pp. 27–28).

To the Neolithic age probably also belong some stone bowls and rings which have been found in Western B.E.A. Mr. Hobley in his book on the Akamba (1910–1911, Pl. XXVI) has figured a stone hollowed into a bowl, found 4 ft. deep at Naivasha. A similar stone ring and a bowl were found in Sotik and described by Mr. C. M. Dobbs (1914, pp. 145–146) covered over with a few inches of loose soil; they are regarded by Mr. Hobley as Neolithic. A similar bowl found at the depth of 10–12 ft. in a salt cave near the Government Bungalow at Sotik has been described by Mr. Dobbs (1918, pp. 265–266).

Conclusive evidence of the Neolithic character of the obsidian implements is given by the discovery of two ground stone axes. The first, which has a weather-roughened surface, was found by Major C. Ross in 1913 at the depth of 3 ft. at the Eldoma Ravine. It has been described by Mr. Hobley (1913, pp. 60–61), who regards it as the same age as the obsidian implements found at Njoro, only 25 miles distant.

In 1919 I found an obsidian axe with a ground front edge on a raised beach near the south-western end of Lake Naivasha, where it was associated with chipped flakes of the type common in the district. Its ground edge is clear evidence of Neolithic workmanship.

This Neolithic axe helps to fix the date when Lake Naivasha was at its greatest extension; it was found at a camp 50 ft. above the present level of the lake, so that Neolithic man was living beside

Lake Naivasha after its waters had fallen about 100 ft. below their highest level,[2] and long after the end of the overflow down the Njorowa Gorge. This axe shows that the maximum extension of Lake Naivasha was pre-Neolithic.

Though implements of the Paleolithic or Older Stone Age are widely distributed in Africa, none appears to have been found in B.E.A. until 1913, when a settler named Harrison took a series of roughly flaked axes to the Nairobi Museum. He was told that they were worth a good price, so he refused to say where he had obtained them, as he thought the discovery would be as valuable as a gold mine. He left the collection on loan at the Museum, went to the war where he was killed, and the secret of the locality was lost. The circumstance of their deposit at the Nairobi Museum and a plate illustrating five of them have been published by Mr. Hobley (1917, p. 189), who suggests that the stone is like the phonolite of the Yatta Plateau.

During our journey from Naivasha to Magadi Mr. Hobley and I found independently near our camp at the Ol Kejo Nyiro, at the northern foot of Mount Ol Gasalik, some large roughly chipped axes similar in size and character to those found by Harrison. The specimens collected (Pl. IV, Fig. C, reduced $\frac{1}{3}$ dia.) were lying on a bank of white diatomaceous earth which seemed to have been dug by such implements. The earth was probably used as a paint, and these thin stone axes would make effective hand hoes in digging it. One specimen was in two pieces lying 4 ft. apart, showing that it had been broken at the place. These flakes are certainly suggestive of Paleolithic workmanship. They are not to be explained as unfinished implements which were to be ground and used elsewhere, since no ground stones of this type have been found in the country. They indicate the occupation of the Rift Valley N. of Magadi by Paleolithic man.

Further evidence of the presence of men of the Older Stone Age in the Rift Valley is given by an implement from the Murendat River near the Government Farm N. of Naivasha. Mr. Dowson there found a series of rough flakes of amber-coloured chert in gravels beside the Murendat River, in the same bed as a fossil bone, identified by Dr. Smith Woodward as that of some species of rhinoceros. They came from the same gravels as part of the lower jaw of a fossil zebra, which Prof. Ridgeway (1909, pp. 586–588) has described as an extinct species, *Equus hollisi*, and as more nearly related to Grevy's zebra than to the species now living in B.E.A. At the same locality

Mr. H. J. H. Stedman found an implement, also of amber-coloured chert, similar to that of the flakes collected by Mr. Dowson. Mr. Stedman's specimen may have been made for use as a spear-head; it is three-ridged and triangular, 3 ins. long, 1¾ ins. wide at the lower end, and ¾ in. thick. The chert may have come from the beds beside Lake Magadi. The implement strikingly resembles those of the Magdalenian, the uppermost division of the Paleolithic (exclusive of the Azilian). This specimen indicates the existence in East Africa of late Paleolithic man, for in addition to the difference in workmanship, it, and Mr. Dowson's flakes, came from a lower horizon than that of the Neolithic implements which are numerous on the surface.

Modern Stone Articles.—Stone implements of the modern period, which are used for various purposes but not as cutting tools, are also found. They include rounded stones which were used by the Masai as the weights of throwing sticks; and rounded perforated stones similar to those which are known in South Africa as Kwe; they are there abundant, and they range northward to Khartum. They have been recorded from Mwatate in the Taita Hills by Mr. Hobley (1910–1911, Pl. XXVI, and 1912, pp. 21–22), and have been found near Fort Hall by Mr. H. R. Tate (1918, pp. 261–265), who has described and figured them. The South African Kwe were seen by the earlier travellers in use for clubs and for weighting sticks. Mr. Tate, however, shows (1918, p. 263) that the Kikuyu, to whom they were known as Ithathi, used them for ceremonial purposes.

[1] H. Meyer (1900, p. 404) remarks that, judging from the figures, G.R.V., p. 234, the implements are probably Paleolithic; he may have overlooked the fact that they were made of obsidian and would not require grinding. The specimens were submitted to the late Sir John Evans, and reported by him to be Neolithic. His authority appears conclusive.

[2] This level was determined by the outlet through the Njorowa gorge, which, according to a survey by the officers of the Public Works Department, communicated to me by Mr. McGregor Ross, was 6400 ft., or about 150 ft. above the lake. According to the contours on the G.S., G.S. map, Nakuyu-Nyeri, the height would appear to be about 6800 ft. The P.W.D. result is no doubt reliable.

CHAPTER XIX

Man & the Origin of the British East African Caves

I. The Elgon Caves

THE existence of a prehistoric race in B.E.A. has been asserted on the evidence of the caves, as is well known from the use of this hypothesis in Sir Rider Haggard's novel *Allan Quatermain*. Caves were discovered on S. Elgon by Joseph Thomson (1887, pp. 300–302), who described them as occurring in beds of agglomerate, as being from 12 to 15 ft. high and of great length, and as branching in various directions. He concluded that they were excavated by some early race—possibly, he suggests, the ancient Egyptians—as mines of precious stones or precious metal; of their artificial origin he had no doubt. "They must," he said (1887, p. 301), "have been excavated by the hand of man. That was a fact about which there could absolutely be no two opinions."

Mr. Hobley (1897, p. 184) visited them in 1897, and in his account of them expressed the opinion that they were "due to natural causes and excavated by water." He gave an instructive account of the caves, in which he made some excavations. He found the caves very dry and formed in material so fine and soft that the passage of the bare human feet produced a "fine floury dust in which one sinks nearly ankle-deep." This description is suggestive of loess, which in so many parts of the world is used for underground dwellings owing to the ease with which it is excavated and its power of standing in vertical walls; but I know of no case in which the artificial dwellings in loess resemble those of the branching Elgon caves. The probabilities seem to be with Mr. Hobley's view, and the caves may have been formed at a period of a heavier rainfall before the existing surface channels had been cut large enough to discharge the rainfall.

Sir Harry Johnston (1902, I, pp. 52–58), who has published photographs of the caves, is also inclined to the view of their natural origin. He remarks, "I am unable to throw much more light on the origin of these curious recesses," but he noted their occurrence always in the same material, an agglomerate, at the foot of high precipices, and usually under waterfalls which act as a screen to the entrance; he suggests that they were made by streams of which the former underground channels have become blocked, so that they now flow over the surface and leap over the cliffs in waterfalls. Some features in the cave-walls shown by the photographs suggest that they were made by man and tool marks have been observed on them, but these may be due to the enlargement of natural caves. Thomson's view that they were ancient mines worked by foreign miners is improbable, since the agglomerates are not known to contain either precious stones or precious metal. Caves are common incidents in volcanic areas, and the evidence available gives no sufficient reason for rejecting their origin as ordinary natural caverns, though they may have been artificially enlarged and modified.

II. The Lumbwa Caves and Edible Cave Earth

In the Lumbwa district is a series of remarkable caves which have been carefully investigated. These caves have been described at length in a series of papers in the *Journal of the East Africa and Uganda Natural History Society* by Mr. Hobley (1918), Mr. C. M. Dobbs (1918), Mr. A. Knight-Bruce (1918), and by Messrs. Hobley, Kirkham, and Colet Birch (1919). The rocks and earths of the caves have been chemically investigated by Messrs. Kirkham and Birch. Some caves in the granites of the Nandi escarpment were also described by the late P. L. Deacon in 1918.

The Lumbwa caves occur in decomposed phonolite and phonolitic tuff beneath a flow of hard phonolite on the Lumbwa plateau both N. and S. of Kericho. The natives reported one of these caves to be a mile or so long, but the actual investigation by Hobley and Kirkham proved this to be an exaggeration—the greatest length measured was 180 yds. They are in places 60 ft. wide and from 3 ft. to 12 ft. in height, but many of the passages are so low as to be only traversed by crawling. There is direct evidence of the artificial and comparatively modern origin of at least most of them,[1] for although work on some has been abandoned, others are still in process of excavation for the soft earth which is greedily eaten by cattle and goats and is believed by the natives to be of medicinal value to these animals. Mr. Hobley describes the bed as underlying the phonolite, and ranging up to 7 ft. in thickness. Elsewhere the bed may be 10 ft. thick, and Mr. Hobley estimates that it underlies the phonolite through an area of about 160 sq. miles. The rock below the cave earth at Kebrasi has been identified as rhyolite ; but the specimen has been given me (No. 254), and it is a very decomposed fine-grained phonolite with microscopic secondary quartz veins.

At the time of Hobley and Kirkham's visit to the Kibroise cave on the Chemungnet River, the end of one branch was about 180 yds. from the entrance, and at its farthest point some twenty to thirty natives were excavating the soft rock, which they called " ngenda," by the aid of rude iron picks. The excavated material was placed in wooden troughs which were slid along the floor of the cave to the entrance ; some of it was placed in long wooden troughs and there eaten by the cattle, and some was carried in creels to distant villages.

The fact that the Lumbwa caves are undoubtedly artificial, and are still being excavated, encourages belief in the artificial nature of the Elgon caves, especially as the people inhabiting Elgon are of the same race as the Lumbwa. The immigration of this group into B.E.A. does not, as far as we know, date back more than a few hundred years. The caves on Elgon are numerous, some occur above the zone of present habitation and some are situated on the eastern side which is at present entirely uninhabited.

Information about the structure and geology of the Elgon Caves is less detailed than for those of Lumbwa, and without having seen them my opinion as to their origin is tentative. But it appears probable that the caves were originally due to natural causes, and were made when the climate was colder and the ground often frozen. Subterranean erosion may then have been more active, and subsequently, after man entered the district, some of the caves were probably enlarged artificially for shelter, residence, and possibly also by the excavation of the earth for domestic animals. There appears no evidence that the people of Elgon gave their cattle a ration of cave earth ; but it is possible that this Lumbwa custom originated on Elgon. The natives may have seen their livestock munching the cave earth and considered that it improved their condition ; when, therefore, the people abandoned the caves for villages in the open country they may have mined the earth and carried it to their new residences.

Some generations ago one section of the tribe migrated southwards and occupied the Nandi Highlands ; and another section went still further S. and occupied Lumbwa; the withdrawal of these sections reduced the population on the mountain and left parts of it uninhabited and the caves deserted.

The Cave Earth.—Several suggestions have been made as to the useful constituent in this earth. The material was reported to contain occasionally as much as 13% of phosphate of lime; and though animals cannot use the phosphorus in raw phosphate of lime, it was suggested that the material was mined for the sake of that constituent.

A report by Messrs. Kirkham and Birch states the percentage of calcium phosphate in twenty samples from the caves. The maximum is 5·35% in a sample from the Gitoi Cave, whereas the material selected by the natives at that cave yielded only ·28%, and another sample of the crushed material excavated by the natives gave only ·13%. Phosphoric acid in such amounts can be of no appreciable food value to animals. Many of the samples contain less than ordinary igneous rock, in which the average is about ·6%. Mr. Hobley's report shows, however, that the cave earth is eagerly eaten by animals. "The deposit found in this cave is stated to be especially suited for cattle, and large numbers of cattle were munching it with avidity at long wooden troughs placed in a clearing about 100 yds. from the cave at the top of the hill. A number of natives were working away outside at the entrance to the cave, crushing this soft rock with stones. The rock is undoubtedly very attractive to domestic animals, for when we approached these troughs my mule, who had never been to Lumbwa before, whinnied and rushed to one of the troughs and commenced to munch the powdered rock without hesitation; the native goats were also nibbling at the rock exposures in the vicinity of the caves. The natives stated that they brought their cattle to this place about three times a month if possible." As the phosphate cannot be the cause of this craving, Messrs. Kirkham and Birch suggest that the earth acts as an ant-acid and neutralizes the acids in the digestive track. The amount of lime, however, is too small to have any considerable neutralizing effect. An alternative explanation that seemed possible was based on the fact that as the earth is a decomposed phonolitic ash it is naturally rich in soda, and the carbon dioxide in percolating water would readily convert this soda into bicarbonate of soda, which cattle could assimilate and enjoy. A sample of which a full analysis was made by Messrs. Kirkham and Birch contained, however, practically no carbonate, and this view has therefore to be set aside.

The sample from the Gitoi cave analysed by Messrs. Kirkham and Birch was from material obtained by the native miners; its composition is as follows:—

	Per cent.
Silica	47·76
Aluminium oxide	22·03
Sodium oxide	4·87
Potassium oxide	2·88
Ferric oxide	4·98
Manganese oxide	·32
Calcium oxide	2·97
Magnesium oxide	1·08
Phosphoric oxide	·13
Carbon dioxide	trace
Water	13·95
	100·97

This analysis, on the assumption that all the soda is in nepheline and all the potash in sanidine felspar, would indicate that the mineral composition of the earth is as follows:—

	Per cent.
Ordinary clay, hydrated silicate of aluminium	28
Nepheline	19
Quartz flour	18⅓
Sanidine	12⅓
Oxide of iron	5
Silicate of magnesium (e.g. enstatite)	2¾
Lime, present as an accessory constituent in one of the silicates	2¾
Phosphate of lime	2
Oxide of manganese	⅓

This interpretation is approximate, for some of the soda may occur in the felspar. That the useful material is not carbonate is, however, proved by this analysis.

The useful constituent in the cave earth is probably its soda. The special chemical peculiarity of phonolite is its richness in soda; for example, the analysis in Appendix X, shows that East African phonolites and kenytes contain about 8 per cent; it would therefore *a priori* appear probable that it is the soda in the earth which is so attractive to animals. The earth in which the caves are excavated is a phonolitic tuff or decomposed phonolite, and contains particles of nepheline, the chief soda-rich constituent of phonolite. This mineral is easily attacked and rendered gelatinous by acid. In the cave earth it is already partially decomposed, and occurs in particles so minute that they would be attacked by the hydrochloric acid in the gastric juices and their silicate of soda converted into sodium chloride. That this reaction would certainly take place in the stomach of the cattle I am assured by so high an authority on physiological chemistry as Prof. E. P. Cathcart, F.R.S., in a report (Appendix I).

The bulk of the material in the edible earth is ordinary clay which would be innocuous or have perhaps some slight mechanical effect; but if clay were the desired material it could be obtained more easily than by mining this phonolitic bed. The fact that this particular stratum is worked for cattle "food" indicates that its soda is the useful constituent.

III. The "Cave of God" near Lake Naivasha

Whatever purpose this Lumbwa cave earth serves in the digestive system of cattle, the Lumbwa caves are unquestionably artificial; but the same conclusion is not necessarily true for the markedly dissimilar caves of Elgon, light on the origin of which is thrown by a cave W. of Lake Naivasha that happens to be of special interest from the traditions connected with it. It is probably the cave referred to by Sir Rider Haggard in *Allan Quatermain.*

This cave is situated near the foot of the Mau Scarp. It is known as Ngumut Ngai, or the "Cave of God." It is regarded as sacred by the natives, and according to a local report the cave ends at a great cleft down which is heard the roar of rushing water. I had an opportunity of visiting the cave by the courtesy of Mr. A. G. Bush, the District Engineer of Naivasha, in company with Mr. McGregor Ross and Mr. H. L. Sikes. The present entrance is 80 yds. from the original mouth, and is due to the collapse of the roof. The northern section included the largest chamber, which is about 160 yds. long and in places 30 ft. high; it is far too large to have been excavated without scaffolding. At the northern end of this chamber the cave narrows and becomes so low that we had to crawl through ; it then descends steeply for about 15 ft. through a shaft, the walls of which show clear evidence of its formation as a pothole by a stream. At the foot of this steep descent the cave widens again and forks. The main branch ends at a vertical joint fissure, while the branch to the E. descends steeply, but is closed by a fall of the roof. In this part of the cave were the dried remains of a hyena and of a hartebeest (Kongoni).

The cave is excavated entirely through beds of water-deposited volcanic tuffs, which may belong to the Nyasan series. The lowest bed of the large chamber consists of sand interbedded with a pumiceous gravel. This layer is about 10 ft. thick, and is covered by stratified clayey loams, containing layers, about 2 in. thick, full of black pumice. These loams are also 10 ft. in thickness ; they are covered by tuffs and soft flaggy sandstones in which occur two small branch caves. The southern entrance to the cave is 10 ft. high, and there the upper part consists of 7 ft. of flaggy sandstone resting on 3 ft. of sand which is so soft that it has been worn away and the flaggy bed undercut. The cave therefore grows by the fall of the undercut sides and then of the roof. The cave has probably been enlarged by man as a shelter for himself and cattle ; but it appears to have had a natural origin. It occurs along a joint fissure which runs approximately N. and S. The level falls steadily northward except where interrupted by falls of the roof and by the sudden descent at the pothole-drilled shaft. The cave was probably formed by a stream of water finding its way through a joint in the lake beds, and washing away the soft sand below the flaggy sandstone and then sweeping away the fallen material. Falls of the roof and the erosion of the walls and floor by the stream led to the gradual growth of the cave. On this explanation the original outlet was through the now closed branch at the north-eastern end. This may have been kept clear when the stream flowed through the cave. The cave stream may have been diverted by the deepening of the valley S. of the cave. If the caves had been made by man like the Lumbwa caves, the excavation would probably have followed one particular horizon ; but it starts in the flaggy beds and works downward till at the N. ends it occurs only in the underlying bedded tuffs.

At the time of our visit there was no water falling in the fissure at the northern end ; but a noise, which could easily have been mistaken for that of water, was made by the whirling of myriads of bats.

They were disturbed by our visit, and made the descent through the pothole disagreeable by flying into our faces and crawling under the projecting rims of our hats. Possibly after heavy rain, water may still fall in the fissure ; but I saw no signs of any recent flow of water, and the flying bats may have caused the sound reported by European visitors as falling water, and by Masai as the voice of " Ngai."

[1] The Gitoi Cave, which has been described and figured by Mr. Dobbs, 1916 (for identification, see Knight-Bruce, 1918, p. 299), is traversed by a stream of water and may have originated as a natural cave. The caves described by Deacon on the Nandi Scarp, according to Hobley (1918, p. 284), are fault-caves.

CHAPTER XX

Water Supply & Wells

I. General Problem

BRITISH East Africa presents the vexatious anomaly of a country with a generous rainfall but with vast plains covered by soil rich indeed, but useless through lack of water. During a journey (April, 1919) from Lake Naivasha to Lake Magadi we marched for days through grass which was often up to our waists and sometimes up to our shoulders ; yet this prodigal growth of cattle food is wasted since there is not enough water for the Masai to water their herds. The inconvenient irregularity of the water supply we realized as we sat one night in heavy rain awaiting the tents which had not arrived as we had been compelled to go beyond our intended camp as the waterhole there was dry. A few days later we had to send back drinking water to the porters, who were exhausted by the steamy heat beside the brine of Lake Magadi.

The value to B.E.A. of its considerable rainfall is reduced by three limitations : (1) the rainy seasons are separated, in most parts of the colony, by long dry seasons during which the country is parched and arid ; (2) the rains are abnormally irregular and uncertain, and vary greatly from year to year both in amount and date ; (3) the evaporation is high, so that the water of the pools is soon dissipated and shallow reservoirs lose a high proportion of their contents.

Under these conditions, wells, where geologically possible, are particularly useful as they recover water that has sunk underground and is protected from evaporation by a cover of heat-proof soil and rock.

Wells, however, in B.E.A. have hitherto been disappointing. Preliminary failures are natural. A house is built on the summit of a hill owing to the attractions of a dry site, a cool position, and a commanding view ; but there may be no permanent water supply. A well sunk in such a situation is probably useless. The temptation is also to sink wells in the more arid areas as in them water would be most useful, though it may there be least likely to be found. It may therefore be useful to consider the general conditions that govern the supply of well waters under such climatic conditions as prevail in B.E.A.

The essential requirements for wells are (1) an adequate supply of water, which is usually received from the rain ; (2) adequate storage underground for the water collected ; (3) and this storage must be in beds or rocks that will give up their water readily to wells or through natural or artificial channels.

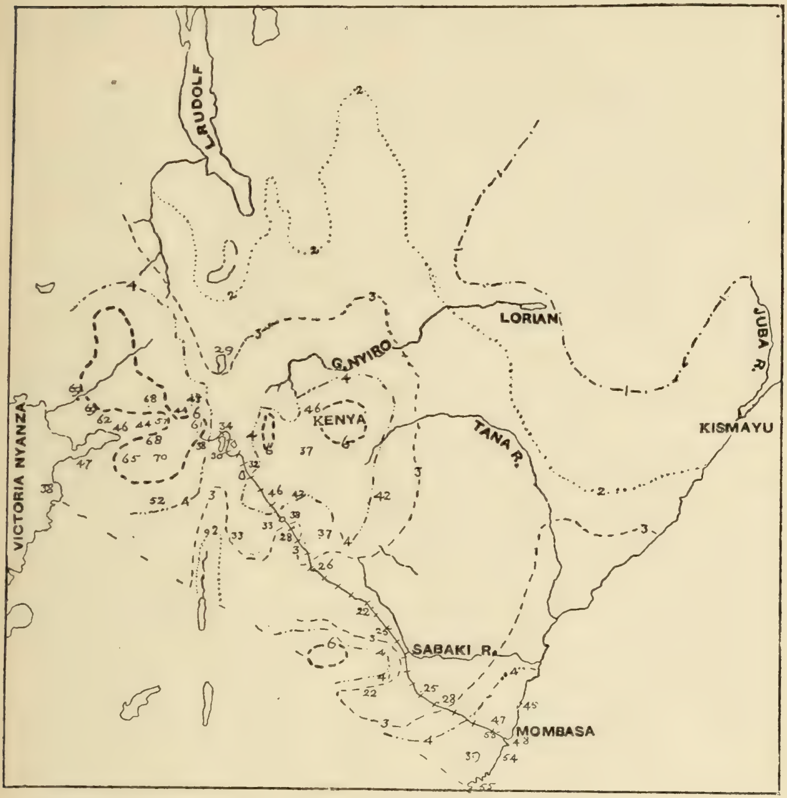
II. Water Supply and Rainfall

Most of the water which feeds wells and springs falls on the earth as rain or snow ; it is therefore called " meteoric water " in contradistinction to " plutonic water " which arises from the interior of the earth. Some of the hot springs of the Rift Valley and some of the soda-charged waters which feed Lake Magadi may be plutonic waters making their first appearance on the earth's surface ; but the information available as to these East African hot springs and alkaline waters is inadequate for a definite conclusion as to their source.

Wells often draw upon old stores of water ; the rocks act as a cistern and the wells run dry when they have drawn off this " water of cisternage." Yet in spite of plutonic waters and waters of cisternage, the bulk of that drawn from wells is derived from contemporary rain.

The rainfall records of B.E.A. are inevitably still so incomplete that only general and tentative conclusions can be based on them. The last complete records published (E.A.P., Agric. Dep., Bull. No. 3, Meterological, 1914) include those up to 1913 ; and though I have received through the kindness of Mr. Hobley and Mr. McGregor Ross the results from some stations for later years, the following remarks deal only with those up to the last year (1913) for which all the observations have been published.

In 1913 there were 114 rainfall stations ; of these only ninety-two gave complete returns for the year. The rain in 1913 was below the average ; for the Bulletin includes observations for ten years or more at twenty-two stations, and of these (table opposite p. 5) six stations gave above the annual average and sixteen below it. The rainfall at many of the eastern and coastal stations was above or but slightly below the average, whereas that at the western stations was deficient ; at Muhoroni, for example, the total for 1913 was 39·8 ins. against an average for ten years of 68·4 ins.



1	Line bounding the area of less than 10-inch rainfall	
2	" " " under 20 " "	
3	" " " " 30 " "	Uganda Railway
4	" " " " 40 " "	
	" " with more than 60 " "	

Fig. 35.—Rainfall Map of B.E.A., based on record to the end of 1913.

The distribution of rainfall through B.E.A. may be judged from the following list. Of the seventy-five stations of which returns are available for two or more years :—

The number with more than	10	and less than	20	ins. a year was	2
” ” ”	20	” ”	30	” ”	13
” ” ”	30	” ”	40	” ”	18
” ” ”	40	” ”	50	” ”	25
” ” ”	50	” ”	60	” ”	9
” ” ”	60	” ”	70	” ”	8

The two stations with less than 20 ins. are Kismayu on the northern coast and the District Commissioner's office at Voi, where the average for three years is 18·14 ins.; but at Voi railway station, where the results are available for nine years, the annual average has been 25 ins. An average of less than 20 ins. is exceptional and is confined to the north-eastern part of the colony. The general rainfall is from 30 to 50 ins. a year, and in one year some stations received over 100 ins. No doubt the rainfall records come mainly from the settled and better-watered districts; but those on the arid Nyika, such as Kitui, Kiu, and Masongaleni, give average annual returns respectively of 42 ins., 26 ins., and 25 ins.

The rainfall of B.E.A. as a whole is therefore generous and above the average. The sketch map (Fig. 35), based on observations at seventy-two stations (though at some of them the records are only for two years), shows the outlines of its distribution as known up till 1913.

The rainfall is heavy along the southern coast, decreasing from about 60 ins. at Shimoni, and from between 40 and 50 ins. between Mombasa and Melindi, to less than 20 ins. approaching Kismayu, where it is only 15 ins. Behind the plentifully watered coastal belt lies the wide zone of the Nyika; here the rains are low and uncertain in the N., and increase southward to 42 ins. near Kitui and 25 ins. at Mackinnon Road Station. This zone has many desert features; in the dry season the ground is bare and largely covered by loose sand, the vegetation consists of scattered tufts of grass; its trees are thorny acacias with spiny leaves, or huge, soft-trunked baobabs, or fleshy euphorbias. Despite, however, the arid aspect of the country in the dry season, it receives at other times a fair rainfall borne by winds which sweep across the plains from the Indian Ocean. Probably none of the southern part receives less than 20 ins.; but the northern part may have less than 10 ins. The lowest recorded average is 15 ins., but no continuous records have been taken in the driest areas. Mr. Finch-Hatton tells me that the country between the Juba and Lake Lorian cannot in normal years receive more than

6 or 8 ins. That estimate seems probable, for the rain decreases northward along the coast until at Kismayu it is less than one-third of the amount at Mombasa; and if the Nyika W. of Kismayu similarly receives only a third of that in the Nyika W. of Mombasa, it would have a mean rainfall of about 8 ins.

Considering the power of the S.W. monsoon and of the N.E. trades and the source of the air they carry across B.E.A. it would appear improbable that any considerable area should receive less than 8 or 10 ins., especially as the country which appears to have the lowest rainfall is covered with thick scrub. The travellers who have crossed the plains between the Lorian swamp and the Juba report as one of their difficulties the denseness of the thorn trees; it is difficult to explain so abundant a growth as that described of even thorn-leaved acacias—on less than a 10 in. rainfall.

Kismayu may be about the minimum on the coast, since at Gosha, Alexandria, about 40 miles up the Juba Valley, the average for the year is 25 ins., and this may be largely due to the N.E. trades, since in 1913 41% fell in October and November.

This arid belt ends westward against the central highlands, which uplift the S.E. winds and precipitate their moisture as rain. The highlands and mountains on both sides of the Rift Valley receive a heavy rainfall, increasing from the plain stations, such as the Athi River Station with 28½ ins. and Nairobi with 35 ins., to the Lari escarpment with 55 ins. Similarly in the highlands W. of the Rift Valley, Mola, a station on the Uganda Railway, has 61 ins.

The floor of the Rift Valley, owing to the hot air which fills it, has a lower rainfall; thus at Naivasha it is about 32 ins., at Nakuru about 34 ins., at Elmentaita 30 ins., and at Baringo 29 ins. Further N. the amount doubtless falls rapidly.

W. of the Rift Valley the precipitation from the moist air which drifts eastward from the Victoria Nyanza against the highlands produces another area of high rainfall—45 ins. near the lake shore, 60–70 ins. on the plateaus, and 100 ins. or more at some stations. At some localities in this area there is no well-marked dry season. Thus at Mumias in 1905 no month had a less rainfall than 2 ins., while only four had less than 5 ins., and the maximum for any month was under 10 ins.[1]

Usually, however, there are two distinct rainy seasons—spring rains in March to May, and smaller rains for about six weeks between October and December.[2]

The most serious defect of the B.E.A. rainfall is its uncertainty both as to quantity and season. The irregularity in the quantity of its rainfall is unusual. Sir Alexander Binnie in a famous paper maintained that the deviation of the minimum and maximum rainfall from the average is remarkably small: where the average rainfall is 100 ins. the minimum is not less than 60 ins., and the maximum not more than 151 ins.[3] But this rule is not confirmed by the East African records:—

	Min.	Max.	Mean.	Ratios. Min. Mean. Max.
Machakos	21·37	56·11	36·61	
Athi River	15·23 in 1904	41·70 in 1905	28·49	
Kismayu	6·68	29·53	15·14	44 : 100 : 195
Kisumu	30·43	71·24	45·67	
Makindu Station	16·20	38·27	22·27	42 : 100 : 172
Mazeras	35·86	100·21	55·12	
Muhoroni	36·86	96·28	68·40	
Shimoni	27·30	81·10	55·24	
Mombasa	22·10	73·36	47·80	46 : 100 : 153

Hence at Mombasa, taking the mean up to 1913 as 100 the minimum is 46 instead of 60, as it should be according to Binnie's rule; at Kismayu the range instead of being from 60 to 151 is from 44 to 195; and at Makindu Station the range is from 42 to 172.

The rainfall is also very uncertain as to date; it may disturb agricultural arrangements by coming a month or more earlier or later than normally, while the autumn rains may fail altogether.

The districts of B.E.A. which are in process of settlement receive rainfalls of from 25 ins. to 70 ins., while some stations in wet years receive over 100 ins. No definite minimum rainfall for agriculture can be fixed, as the amount necessary depends on labour and the certainty of transport to a market. In South Australia the limit of wheat cultivation was formerly regarded as Goyder's line, which defined the area with a 14 in. rainfall; but it is expected that by improved agriculture and transport the land can be profitably worked with as low a rainfall as 10 ins. This estimate represents the possibility with white labour and reliable transport; but with negro labour, the uncertain transport that may prevail in East Africa, and the extreme irregularity in the annual rainfall, 25 ins. may for some years to come be the limit necessary for profitable cultivation.

III. The Disposal of the Rainfall

B.E.A., with its rainfall of from 20 to 70 ins., receives a colossal quantity of water from the rain. A rainfall of an inch amounts to over 14 million gallons for every square mile. An annual rainfall of 24 ins. yields 540,000 gallons per acre, and only a very thirsty farmer needs more. The rainfall is disposed of in three ways: by "run-off" over the surface, by percolation underground, and by evaporation into the air.

1. *Run-off.*—The run-off is the part that flows over the ground and passes directly into streams and rivers, and is discharged by them into lakes, swamps, or the sea. The amount of the run-off depends on various factors, including the steepness of the slopes, the porosity of the soil, the nature of the vegetation, and the intensity of the rainfall. The proportion of rain which runs off is heavier from persistent rains which saturate the ground than from isolated storms or showers.

2. *Percolation.*—The second section of the rainfall percolates underground, and after the available storage is full the excess discharges through springs, or drains directly into lakes or the sea. The water that has sunk by percolation forms the "ground water," and its upper surface is known as the "water-table." The problem of well sinking is that of reaching the water-table in rocks or beds of sand that will yield their water to a well. The depth of the water-table is very variable. It rises and falls with the general undulations of the country, but with smaller variations in height. The water-table reaches the surface along the seashore, on lake shores, and at springs; it is deepest below high peaks, and in regions drained by deep canyons. The water-table in such places may be hundreds or even thousands of feet below the surface. In countries, however, with a moderate rainfall and gentle slopes the water-table is usually from a few feet to 150 ft. deep.

The water that has sunk underground flows in the direction of the slope of the water-table. Its flow is usually very slow; water is practically stagnant in clays; its rate may be a few feet a day in sands.

In B.E.A. then rain is the source of a very large water supply; the run-off is small, since the only perennial rivers that reach the sea are the Juba, Tana, Sabaki, Shimba (or Pecuba), Umba, and a few smaller rivers, and their total discharge is insignificant compared with the rainfall. The amount of evaporation, as tested by the distribution of efflorescent rocks, does not seem unusually high. From these facts it is natural to conclude that the amount which percolates underground must be large.

3. *Water Storage in Rocks.*—The water storage depends on the porosity of the rocks and the extent of cracks, fissures, and joint planes. The sandstones, like those of the coastal series, contain as a rule from 10–15% of pore spaces; they can absorb from one-sixth to one-tenth of their volume of water; a layer of sandstone 10 ft. thick, with a 10% porosity, will hold about 270,000 gallons of water per acre. Some of the lower members of the coastal sandstones will hold this amount; the Magarini Sands will probably hold 30% of their volume, and every layer in them 1 foot in thickness will hold 81,000 gallons per acre. But in some of the sandstones further inland the original interstices have been filled with cement and the rock will probably hold only about 1% of its volume. Granites, metamorphic rocks, and dense lavas probably also absorb about 1% of their bulk. These hard rocks, however, are broken by joints and fissures, which hold considerable stores of water; their water capacity depends on these fissures and not on the pore-spaces in the rock itself.

Lavas often contain large numbers of cavities formed by bubbles of gas and steam; such lavas as, e.g., pumice stone are called "vesicular." Gas cavities enclosed in water-tight rock do not increase the water absorption of a rock; but when a vesicular lava decays its cavities are connected by cracks, and it may then hold and transmit water readily.

Many non-vesicular volcanic rocks are traversed by fissures due to the shrinkage of the rock during cooling, and these fissures serve as abundant water spaces; and beds of loose volcanic material (scoria and tuff) which have been shot out in fragments may hold large quantities of water.

Wells, however, require to reach rocks which will not only store water but will readily give it up. Clay and shale may absorb 50% of their bulk of water; but they yield little or no water to wells, since they have such high powers of imbibition that the water absorbed is held firmly within them.

The value of clay beds in relation to water supply is that they act as impermeable layers that uphold water or form a cap beneath which water may collect under high pressure.

4. *Evaporation.*—The water not removed by the run-off or percolation is returned to the air by evaporation from the sheets of water, from vegetation, or from the soil. In England evaporation amounts on an average from one-third to one-half the rainfall; from constant water surfaces, such as lakes and reservoirs, it is on an average probably from 12–20 ins. a year. In arid tropical regions evaporation may amount to 150 ins. a year.

The amount is determined by evaporation meters, but its measurement is difficult except where a gauge can be maintained on a platform floating on a lake or reservoir.

Where evaporation from the ground is about or nearly equal to the total local rainfall, the fact is usually manifest by the occurrence of a superficial crust of some "efflorescent rock" deposited by the evaporating water. The composition of this crust depends on the soluble constituents in the ground and on the solvent power of the percolating water. If the water is charged with carbonic acid and the ground contains lime the efflorescent layer is a concretionary or banded limestone of the kind known in India as "kankar"; if the waters be alkaline, they dissolve silica and precipitate it as layers of chert; if the rocks contain iron, the deposit is likely to be the superficial ironstone known as laterite or murram.

If, however, as in some black cotton soils, the ground contains no lime, alkali, or iron, but consists of insoluble sand and clay, no efflorescent crust will be formed.

The presence or absence of efflorescent rocks is therefore usually a ready test of the extent of local evaporation.

Ultimate estimates of the amount of water available for wells are based on the amount of rainfall left after deduction of the run-off and evaporation; but the information about the amounts removed by these two factors in B.E.A. is too limited for any definite conclusions to be based on it. Nor can any final conclusion be drawn by analogy with other parts of the world; for the factors which control these processes are so complex and variable that each country must measure them for itself. The results in other tropical localities and parts of Africa are, however, useful illustrations of the extent of these agencies.

In India the average rainfall over the whole country is 42 ins. a year,[4] while the total run-off is estimated as discharging 41·6%[5] of the total rainfall; and according to Blanford,[6] evaporation varies in the dry season from an average of one-ninth of an inch in

Bombay to one-third of an inch in the Deccan. According to B. Tripp,[7] the annual rainfall of South Africa, based on measurements for nineteen rivers S. of the Orange and Vaal Rivers, varies from 3 to 34 ins., and the run-off varies from 5 to 10% of the rainfall. In the Transvaal the normal mean rainfall is estimated at 20–35 ins., and the run-off as varying from 7½ to 12% of the rainfall.[8]

Evaporation in the Nile Valley N. of Khartum according to Keeling (1909, p. 15) amounts to as much as 13 ft. per annum; in the Central Sudan to over 10 ft.; but he estimates it as only 3 mm. a day or about 3½ ft. a year (*ibid.*, p. 23) in the Victoria Nyanza.

Col. Lyons (1906, p. 51) estimates evaporation into the moist atmosphere of the Victoria Nyanza as about 49½ ins. a year, with a run-off of 30% on the eastern and from 12 to 15% on the western side of the lake.

Mr. McGregor Ross tells me that evaporation at Kisumu is reported as about 7 ft. a year; at Nairobi it is 4 ft., and at Naivasha about 5 ft.; though the first of these figures appears high, the two last seem the rates that would be expected.

5. *Summary of Conditions in British East Africa.*—In B.E.A. the rainfall, excluding a few limited areas, is probably between 20 and 70 ins. a year. The run-off is probably fairly high from the areas of heavy rainfall near the Victoria Nyanza, but for the country as a whole it is low, as there is no outlet from the Rift Valley, and from the country to the E. of it flow only a few relatively small permanent rivers; so the total run-off is probably nearer to the 10% of the Transvaal than the 41·6% of India. Though evaporation can remove all the rainfall from the areas where it is low, and though no large contribution to the underground supplies penetrates through the "black cotton soil" (except where it is not more than a few feet thick), considerable percolation underground must occur in many parts of the country.

IV. Prospects of Wells in British East Africa

Application of the foregoing principles to B.E.A. requires separate consideration of four chief types of structure: (1) the bedded rocks and drift deposits along the coast; (2) the metamorphic rocks of the Nyika; (3) the volcanic rocks of the plateaus and highlands; (4) the floor of the Rift Valley.

1. *The Coast Zone.*—The coastal area with its rainfall varying from 15 ins. per annum at Kismayu to 60 ins. S. of Mombasa has a large water supply, and the rocks consist of belts of sandstones, clays, limestones, and sands, in belts approximately parallel to the shore.

The sands and limestones along the coast support numerous wells; they yield abundant water if sunk below sea-level or below the water-table which has a slow rise inland from the sea-level. (Analyses are given in East Africa Prot., Nairobi Lab. Rep., I, pp. 93–120). The water is derived from the rain which soaks into the porous dunes and limestones, and as usual along coasts, it contains sea salts which have been blown inland from evaporated spray. The escape of this water seaward is retarded by the resistance of the heavy sea-water

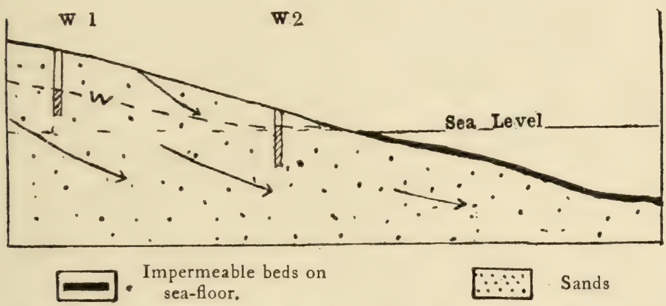


Fig. 36.—Diagram illustrating the formation of fresh-water wells going below sea-level on a sandy shore.

and often of the relatively impermeable beds on the sea-floor; hence if a well be sunk on the shore below sea-level it is filled by the land water flowing seawards down the water-table and not from the sea. Thus is explained the common occurrence of wells on the seashore yielding fresh water. The nature of such wells may be illustrated by Fig. 36.

The same conditions give rise to wells of fresh water beside salt lakes, such as Lake Nakuru; beside fresh-water lakes, such as Naivasha and Victoria Nyanza, there is no inducement to sink wells close to the shore; but some distance back from the lake wells are more useful, and they may be successful if they reach a water-yielding bed below the water-table.

Fig. 37 illustrates the conditions that determine the prospects of deep wells in the coast zone. They are controlled by essentially the same conditions as shallow wells on the shore. The diagram illustrates the conditions on a much smaller scale. Thus the coastal range from Shimba to Mangea consists of jointed and often porous sandstones which slope seaward, and probably extend beyond the Jurassic beds until they outcrop on the sea floor. The water-table must rise inland and away from the floors of the valleys which cut through the coastal series.

The water which percolates seaward through the Duruma Sandstone must be blocked at its exit by the resistance of the heavier sea-water and by the silts on the sea-floor. Hence it will accumulate there under pressure. A bore through the Changamwe Shale and Miritini Shale (the thickness of which may, however, be consider-

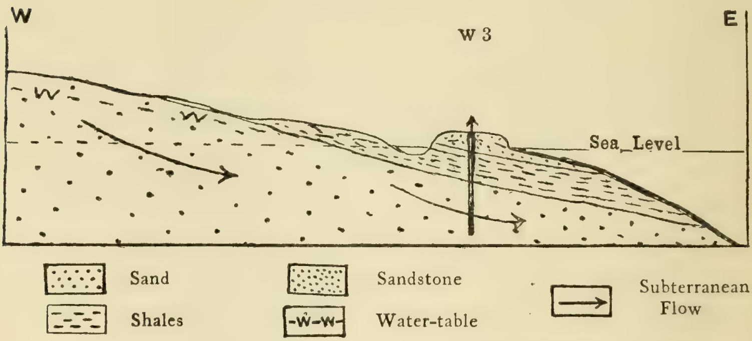


Fig. 37.—Diagram illustrating the possibility of flowing wells at Mombasa Island

able) may be expected to find water in the fissures and pores of the underlying sandstones.

The Duruma Sandstone near the western margin of the Jurassic Shales might, at suitable localities, yield wells, but the prospect of obtaining water from these sandstones above sea-level is limited by the deep valleys which have been cut through them. These valleys will have drained the sandstone to a level determined by its resistance to the flow of water through it. The Mwatchi and Kombeni Rivers have cut their valleys through the Mazeras Sandstone down to sea-level ; and a well could not be expected to strike any large supply of water in the sandstone between those rivers except at only a moderate height above sea-level. Where the Duruma Sandstone is not drained by deep valleys, the water-table should stand at considerable heights above sea-level and yield water to wells which go below the water-table.

2. *The Nyika.*—Wells would be particularly useful in the plains of the Nyika, as they often have a rich soil and after rain produce luxuriant growths of cattle food ; but the land cannot be permanently occupied without an artificial supply of water.

The conditions governing wells in this area are as follows : Large parts of the Nyika consist of gently undulating plains, which have been levelled by long-continued wind erosion. The soil is sandy, often pebbly, and usually very porous ; hence much of the rain on it is readily absorbed ; but the soil, though sandy, has usually a basis of clay derived from the decomposed felspars of the gneiss. This clay has strong powers of imbibition. It absorbs water greedily and gives it up slowly ; in the long dry season the water is sucked up to the surface and there evaporated. The extent of evaporation is indicated by the development of efflorescent rocks. Where the evaporation is large the chances of recovering water in the Nyika by wells appears small. If evaporation be 50 ins. and the rainfall 20 ins., even if all the rainwater in the first instance percolate into the ground, evaporation may dispose of it all.

In some parts of the Nyika the metamorphic rocks may be greatly fissured and collect large quantities of water ; and if such a place be covered by coarse sand or gravel which separates the water-table from the surface, evaporation may be small, and a well in such a place may be successful. As there may be many sites in the Nyika with this association of conditions, the whole Nyika cannot be condemned as hopeless as regards wells. Such conditions, however, would be exceptional. In many parts of the world wells in metamorphic rocks produce useful supplies of water. In Southern Maine, for example, Clapp (Un St. Geol. Surv., Water Supply Papers, No. 223, 1909, p. 61) states that 86 per cent of wells in granite and gneiss and 92 per cent of those in schists are successful. Yet under the climatic circumstances of East Africa the conditions in the bulk of the Nyika are unfavourable for wells, for the joints enable the water to sink so deeply and the rate of evaporation is so high that the water-table is too far below the surface, and the recovery of the small quantities of water these wells would yield would not be economically profitable.

These conclusions apply also to the compact sandstones forming the older westerly members of the Duruma Sandstone series.

The conditions in the Nyika most favourable for wells are where large alluvial deposits occur at the foot of the gneissic hills ; and where sheets of lava have been poured out over the plains. Heavy rain-storms wash large quantities of detritus down the hill slopes and valleys ; at the foot of the hills where the valleys widen out to the plains the material is spread out in fan-shaped sheets. The streams sink into these fans and continue as underflows beneath the dry stream beds, and may be tapped by wells. Promising places for wells are indicated by pools of water at the foot of the slopes lasting well into the dry season, or by bushes whose roots reach underground water or by patches of plants nourished by water raised to the surface by capillary action. Such alluvial fans may hold stores of water large enough to last throughout a dry season. If the fans are thin and steep and consist of coarse gravel they may soon be drained, and wells in them may yield water only for a short time after rain. If, however, the fans are large, their slopes gentle, and their materials fine sand or silt, they may hold large quantities of water and yield it so gradually that wells in them may be perennial.

Water usually flows through gently sloping sand at the rate of about a mile a year ; a delta fan a mile long, which is composed of sand and receives water at its upper end at two rainy seasons a year, would have two waves of water travelling down it ; these waves would spread out in the lower part of the fan into a constant gentle flow of water.

The slowness of the passage of water through sand explains many apparently puzzling features in the discharge of springs. For example, water poured during the rainy season, say, in April, into the upper end of a delta fan three-quarters of a mile long, through which the water passes at the rate of a mile a year, would reach the lower end in the following February, and the springs there might begin to flow, or flow most abundantly, toward the end of the dry season.

3. *Wells in the Lava Sheets of the Nyika.*—The plains of the Nyika are covered in places by sheets of lava which is not porous, but is traversed by many fissures and joints due to the shrinkage of the rock as it cooled after eruption. The lava was poured out over an old land, baked the soil, and thus rendered it impermeable. In such cases a sheet of fissured rock rests on an impermeable foundation ; the lowest layer of lava or rock below it might be expected to contain water and would be worth testing for wells. Such positions are the sheets of lava (basalt) near Kibwezi, Shimba, and Sultan Hamud,

and on a larger scale the phonolitic lava of the Kapiti and Athi plains. While this chapter was passing through the press I have heard from Mr. James Scott that two bores near Sultan Hamud, in positions which I had recommended in accordance with the principles here summarized, found water under the conditions predicted.

4. *Water Supply by Dams.*—The hilly districts of the Nyika may not be favourable for wells, but they often offer suitable sites for dams. The country is intersected by deep ravines, or valleys, which carry large streams of water during the rains ; as has been shown by Captain F. O. B. Wilson, D.S.O., of Kilima Kiu, the earth in these dongas makes strong, impermeable dams, and such reservoirs offer the most promising method of securing water for stock farms in the dry season.

5. *The Volcanic Highlands.*—In the volcanic uplands of the Kikuyu country, and of the Nandi and Lumbwa Plateaus, there has hitherto been but little trouble with water since the country has a heavy rainfall, and as it was densely forested, the soil regulated the discharge of the streams and maintained their flow throughout the year. But with the destruction of forests the rivers will doubtless have a larger discharge during the rainy season and a much smaller flow in the dry season, during which some of the rivers may cease to run.

Under these conditions wells would become important. In some of the volcanic uplands, however, there are no beds of sand which will readily yield their water to wells. Thus in parts of the Kikuyu country the ground consists of a thick sheet of rich red earth which imbibes water readily, but will not part with it. And under such conditions beds of volcanic tuff, which may have been originally open-textured and porous, or sheets of fissured lava, may be choked by fine particles of clay washed into the open spaces.

In the volcanic districts bosses of gneiss project into the volcanic rocks ; their decay gives rise to beds of sand, and a well which entered a bed of such sand would no doubt yield water.

It seems therefore clear from the freshness of its waters that Lake Naivasha has a subterranean outlet. Near the S.W. corner of the lake there is a depression over 600 ft. deep ; this is probably a volcanic hollow, as the crescentic island in the S.E. part is a fragment of a crater rim. This deep pit doubtless traverses beds of volcanic tuff through which there is probably a continuous leakage. The water probably finds its way southward as the floor of the Rift Valley falls rapidly in that direction, till at Lake Magadi, 70 miles to the S., the level is over 4000 ft. lower than at Lake Naivasha.

The fall is by a series of steps, which are diagrammatically shown in a section by Mr. McGregor Ross (Fig. 38), and deep bores in the basins between these steps may reach and utilize the subterranean overflow from Lake Naivasha.

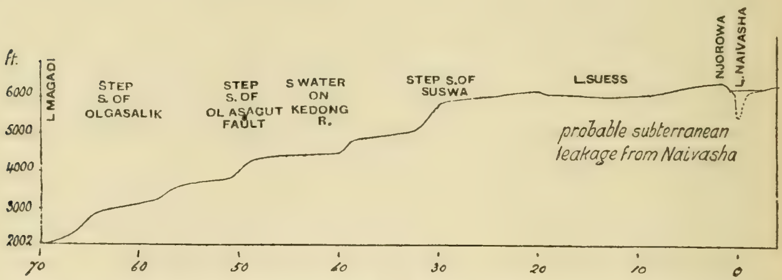


Fig. 38.—The descent along the Rift Valley from Naivasha to Magadi. (Distances marked in miles.)

V. Water Supplies where Wells are Impracticable

Wells in B.E.A. have not been adequately tried, and many of those sunk have been unsuccessful as they were put down as forlorn hopes in places where water would have been especially useful, rather than where it would be likely to occur, and many have been sunk on the recommendation of water diviners, in whom faith is widespread in East Africa.

The preliminary discussion shows that the general belief that wells will reach water anywhere if they only go deep enough is unsound, for in many parts of the country the water which sinks into the ground during the rains is sucked up again and lost by evaporation during the dry season. In such areas, except where special conditions have caused a local collection of water and protected it from evaporation, wells are hopeless; and the exceptional places can only be discovered through accident, or through the guidance of the native reports, or by careful observation of the district during a considerable number of years. The conditions in many localities are sufficiently hopeful to justify trial bores and wells. The experience of countries apparently less propitious than even the driest areas of B.E.A. is encouraging to well-selected trials. The country to the N. of the West Australian goldfields was once regarded as a waterless waste of "spinifex and sand," doomed to eternal sterility and to remain impassable, except, with difficulty, to well-appointed camel caravans. Now, however, by a chain of wells 15 to 20 miles apart, Canning's Road across these deserts affords a practicable route for mobs of cattle from the northern ranches to the goldfields. These wells, however, occur in beds of sandstone which collect and preserve the surplus rainfall, and the experience of other parts of Australia is against the expectation of establishing perennial wells in the metamorphic rocks of the Nyika.

For these areas the main reliance of East Africa for water must be placed on the conservation of the rain either by dams in river valleys or by the preparation of tanks and impermeable collecting slopes. In Dalmatia, for example, as the land is high, as the country is drained by deep valleys, and as the rocks are too porous to uphold water, wells are impracticable, and the collection of water off roofs is the simplest method of obtaining domestic supplies; larger quantities are collected from waterproof surfaces on the hill-sides. Some of the railway stations in Dalmatia are watered by an acre or two of the adjacent hill-sides having been smoothed and rendered water-tight, and the rain thereon collected in a tank. At the worst in East Africa domestic supplies can be obtained from corrugated iron roofs, for every inch of rain on a house 40 ft. by 25 ft. amounts to 516 gallons. Since 20 ins. of rain over an acre amounts to 450,000 gallons in even the driest parts of B.E.A., adequate water for domestic purposes is obtainable by the use of the water-collecting surfaces.

6. *Wells in the Rift Valley.*—The Rift Valley S. of Lake Naivasha may yield wells from seepage from the lake through beds of volcanic tuff and jointed lavas. Lake Naivasha, the highest lake in the Rift Valley, presents the anomaly of an old lake without an outlet, but consisting of fresh water. It receives two considerable rivers, and the level of the lake varies according to the drainage into the lake. The water which enters the lake must be lost either by evaporation or through a subterranean outlet. Lakes which have no outlet and lose their water by evaporation soon become saline owing to the gradual concentration of the salts carried into them by the drainage; and this process would be all the more rapid in Naivasha owing to the richness in soda of the adjacent rocks. The freshness of the water of Naivasha has been explained on the ground that it is such a young lake that the process of concentration has not gone on for a sufficient time to make the water saline; and the youth of the lake has been

supported by the claim that it has not yet been inhabited by fish. Mr. A. G. Bush, however, informs me that swarms of small fish, similar in appearance to that of Lake Magadi, live in it; and I am informed that two kinds of larger fish have been seen in the lake. The view that Lake Naivasha is of recent origin is contradicted by

Fig. 39.—The present (darker line) and former extent of Lake Naivasha.
Scale, 1 inch = about 6 miles.

the geological evidence; the lake dates from pre-glacial times, and probably from the Pliocene. The present lake is the shrunken remnant of a once much greater lake, the level of the water of which stood 150 ft. higher than the present lake, and its area (Fig. 39) was at least 2½ times as large. Hence, on the view that the lake has been reduced by evaporation, the present water has been concentrated from a volume of water many times larger, and it should have long since become saline.

[1] B.E.A., Dep. Agric. Bull., No. 3, 1914, p. 20.

[2] According to the same bulletin, there was no rain whatever at Karungu in 1913 between March and September, both inclusive; but this probably represents rather a failure in the records than in the rain.

[3] A. R. Binnie, "On Mean or Average Annual Rainfall, and the Fluctuations to which it is subject." *Proc. Inst. Civ. Eng.*, 1892, CIX, p. 107.

[4] H. F. Blanford, *Climates and Weather of India*, etc., 1889, p. 69.

[5] Report Indian Irrigation Commission, 1901–1903, 1903, p. 13. Quoted by R. B. Buckley, 1913, p. 213.

[6] Blanford, *op. cit.*, p. 278.

[7] W. B. Tripp, *Proc. Inst. Civ. Eng.*, XC, p. 299.

[8] W. L. Strange, Report on Reconnaissance of Vaal River. Pretoria, 1905. Quoted by Buckley, Irrigation Pocket Book, 1913, p. 231.

CHAPTER XXI

The Mineral Resources

THE mineral resources of a country include four classes of materials: (1) Minerals required for low-priced articles of which local manufacture is essential, such as clays for bricks and tiles, building stone, and road metal. (2) Low-priced minerals which can be used most profitably near cheap fuel or power, such as low-grade ores of iron, limestones for cement, and bauxite for the extraction of aluminium. (3) Minerals which will repay long-distance transport, such as ores of the more valuable metals, gems, and minerals of special service, such as fertilisers, mica, and graphite. (4) Fuels—coal and oil.

In a country of the size and structure of B.E.A. the useful minerals will no doubt ultimately prove extensive and varied. They have been hitherto inadequately investigated, and the information available does not encourage much hope that the country will be found rich in the more valuable and high-priced minerals.

I. Locally Required Minerals

Among the East African minerals suitable for local use are ordinary brick clays, and numerous pottery clays which will naturally be used for the manufacture of pottery and earthenware. The most interesting of these materials is diatomite, which occurs in extensive beds at many places in the Rift Valley, notably at Elmentaita, along the Nderit River, in the valley of the Sugota, N. of Baringo, and beside the Magadi Railway at miles 60–62. Mr. Hobley (1910) has directed attention to the abundance of diatomite along the Rift Valley. The microscopic character of the diatomites has been illustrated by Mr. J. K. Creighton (1911), and a list of sixty kinds of diatoms found in the clay at Elmentaita is recorded by Ferguson (1901, pp. 369–370). Though some varieties include the desired long-shelled diatoms, the clay that has been tested is of poor quality. Experiments at the Imperial Institute have, however, proved that it can be used for the manufacture of light tiles, which in a tropical climate are of great value for roofing, as they are cool, and convenient for the collection of rainwater.

Building-stones of good quality and variety are abundant.

II. Low-Grade Ores and Minerals

The second category is represented in B.E.A. by iron ores, limestones, and bauxite. Among the iron ores of the Samia Hills (recorded by Scott Elliot and Gregory, 1895, p. 678) are some of good quality (*v.* p. 44). Roccati (1909, p. 40) gives an analysis of an iron ore at Kisumu with 56·62% of sesquioxide of iron, 32·78% of silica and other insoluble matters, 10·60% of water, and a trace of alumina. Low-grade iron ores are widespread and include deposits of laterite. The limestones are likely to be the mineral of this class first extensively used, for some of them would no doubt produce good cement. The limestones are of three types : (1) ordinary limestones deposited in the sea and found in the coastal districts, such as the Kambe Limestone ; (2) efflorescent limestones deposited by the evaporation of water containing lime which has been dissolved out of lava ; (3) crystalline limestones in the Eozoic rocks which include beds of excellent marble, as in the Taita Mountains, near Machakos, and in the Maroto country (about $2\frac{1}{2}°$ N., $34\frac{3}{4}°$ E.) W. of the southern part of Lake Rudolf. The inter-volcanic beds will no doubt be found to contain seams of bauxite which may ultimately be valuable as an ore of aluminium. The development of these materials will be seriously hampered by the absence of local fuel.

III. The More Valuable Minerals

The kinds of minerals of sufficient value to pay for export which may be expected in B.E.A. may be judged by comparison with those of similarly situated and constituted countries. The foundation of B.E.A. consists of Eozoic rocks like those of India and Brazil, and its minerals are likely to be the same as are found in those countries. So far as is at present known, the minerals which are most probable in commercially important quantities are mica, manganese, and graphite ; of these the two first are the characteristic minerals of Brazil and India, and graphite is abundant in the Eozoic rocks of Ceylon and Madagascar.

(1) Mica.—Mica in minute flakes is one of the most widely distributed of mineral species, but mica is only of direct commercial

value when found as crystals large enough to produce flakes from some inches to a foot or more in diameter. The chief mica mines of the world are in the Eozoic rocks of India ; increasing quantities are coming from Brazil ; while G.E.A. yields mica of especial value for electrical purposes.

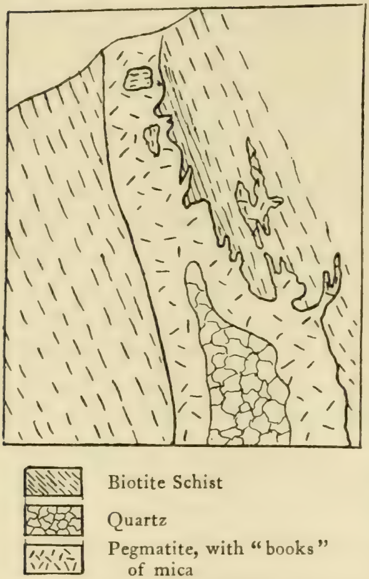


Fig. 40.—Vertical section exposed in the Kenzi Mica Mine.

The geological distribution of commercial mica is restricted to very ancient and deep-seated rocks, and it is usually associated with coarse-grained dykes of the quartz-felspar rock known as pegmatite. Mica is found in B.E.A. in the Eozoic rocks of the primeval mountain chain, in the Ulu Mountains, and to the E. of Kenya ; and it is reported from the Lol Daika Range. The mica occurrence on which most work has been done is at Kenzi, about 10 miles N. of Sultan Hamud Station. Other mica outcrops have been discovered in the same neighbourhood. The country rock is gneiss and schist ; it includes some beautiful garnet-granulite, and is intersected by veins of pegmatite and reefs of quartz. The mica lode at Kenzi has been worked in an open cut which has exposed 80 ft. of a vein of pegmatite ; the vein is 10 ft. wide above, where it is bounded by black mica-schist, and thickens below to about 25 ft. owing to the development in it of a body of quartz. The pegmatite forms a sheath on each side of the quartz (Fig. 40). The best " books " of mica are found in the pegmatite sheath.

The mica is thus found under conditions similar to that of some of the chief Indian mines, as in them the mica occurs in a sheath of pegmatite beside reefs and masses of quartz.

The profitable working of mica mines depends on four factors : the daily output per miner of rough mica ; the proportion of cut mica ready for the market to the rough mica extracted from the mine ; the value of the cut mica ; and the local rates of wages. The average proportion in India of cut to rough mica varies from between 9 and 12%, and the average value of Indian cut mica for the five years before the war was about 9/- per pound. It is difficult to forecast the average value of mica from a new mine. The mica is prepared for sale by being cut into pieces which are valued according to their size and clearness. They are graded according to size, usually into sizes Nos. 1–7, with two extra sizes, special and extra special, for the largest pieces. No. 7, the smallest size, includes at least a square inch. According to clearness, mica is usually divided into three grades—stained, partly stained, and clear.

The prices of Indian mica early in 1919 ranged from 7d. a pound for No. 7 up to 37/- a pound for " clear " specimens of extra special size. A mine in which the mica " books " are so small or irregular that the bulk of its cut mica is of the smallest size can hardly pay under existing conditions. But the Kenzi lode should yield a fair proportion of mica of medium size, and the prospects of its success depend on the quantity that can be produced per unit of wages. The Indian mines pay their miners about 6d. to 8d. a day. A mine with a daily output by each miner of 32 pounds of rough mica, which when cut yields 12½% of cut mica, would produce 4 pounds of cut mica per miner per day. If this mica were all No. 7 at 7d. a pound, after paying the miner's wages there would be a balance of only 1/8 per day for cutting, working expenses, and interest on capital. But if the 4 pounds were equal in quality to the average Indian mica for the five years before the war, it would be worth 9/- a pound; the output per miner per day would be worth 36/-, and a mine with such an output would be a very profitable undertaking.

The Ulu mica has not yet been adequately tried. Mica " books " near the surface are usually so stained and crumpled that they are of no value, but improve below the surface staining and disturbance. The value of a mica deposit cannot therefore be judged from its outcrop; but in view of the quantity and quality of mica already exposed in the Kenzi district the deposits are worthy of further testing.

(2) Graphite, the crystalline form of carbon, is formed by alteration of a mineral hydrocarbon, or of plant remains. It is generally found in black schists, and the richest deposits now being worked are of Eozoic age. The occurrence of graphite in East Africa was reported from Usambara by Farler (1879, p. 82). Its occurrence in

quantity in B.E.A. was discovered by Mr. Hobley, in the Taita Mountains. It is known also in the Ulu Mountains, and is reported from Lol Daika, the Eozoic range to the N.W. of Kenya. The commercial value of the graphite deposits of B.E.A. is still unknown. The present time is not propitious for new graphite mines, as during the war the increased demand for it for crucibles caused a graphite boom and the opening in many parts of the world of mines which have since had to close down.

The most valuable graphite is that from Ceylon, in which the cleavage, instead of dividing the mineral into thin parallel flakes, is irregular. The possibility that the Taita Hills may be really rich in graphite is encouraged by the enormous quantities under somewhat similar geological conditions in Madagascar. It is estimated that five million tons above the depth of 185 ft. are already proved in the deposits there, and that they can produce flake graphite to the amount of from 30,000 to 40,000 tons a year for 2½d. a pound. Ceylon, in 1916, produced 34,000 tons, but its production fell to less than half that amount in 1918, after the cessation of the war demand and the fall in prices.

East African graphite is not likely to pay unless it can be produced at a price to compete with Madagascan graphite at about 2½d. a pound. The average price of manufactured graphite in recent years has been generally from 3d. to 3½d. a pound.

(3) Manganese, of which the chief supplies come from India and Brazil, is also present in B.E.A., but the quality and extent of the deposits have not yet been proved. India in 1917 produced 600,000 tons, and Brazil 530,000 tons. The United States during the war increased its yield to that of the third producer in the world, with 124,000 tons ; but with the return to peace conditions its production will probably diminish. The manganese supply will be again mainly derived from the tropics, where it is concentrated on the surface owing to the solution of manganese salts, and their deposition on the surface by evaporation during the dry season.

Manganese ores, to be of commercial value, must occur in large quantities and be of standard quality. The price varies according to the richness of the ore and the proportion of silica and phosphorus. Thus, in 1917, for manganese ores with less than 8% of silica and less than ·25% of phosphorus, the American prices per ton were for ore containing from 35% to 40% of manganese from 86 cents to 1 dollar for each 1% of manganese ; with from 40 to 50%, from 1 dollar to 1·20 dollars per unit; for over 50%, from 1·20 to 1·30 dollars per unit. Good manganese ore is, therefore, a valuable mineral. B.E.A. may be expected ultimately to yield considerable quantities, but it is possible that these may not pay to work until the more accessible deposits of other countries have been exhausted.

(4) Soda is the only mineral which has been extensively mined in B.E.A. The great deposit of trona (Na_2CO_3, $HNaCO_3$, $2H_2O$; i.e. hydrous sesquicarbonate of soda) around Lake Magadi is the biggest known, and it is expected to be the chief source of supply of this material to Eastern Africa and Southern Asia. The trona lies on the floor of Lake Magadi in a deep depression; the locality is connected to the coast by railway, but the material has to be hauled 377 miles and raised from 2000 ft. at the lake to the height of 5536 ft. on the Kapiti Plains. Carbonate of soda in such a position can only be worked profitably on a large scale, and it is hampered by the high cost of transport to the coast. (For the origin of the soda, *cf.* p. 178; and analysis in Appendix X, No. 1.)

(5) Metallic Ores.—Various metallic ores have been recorded from B.E.A., but none have yet been proved of commercial value. Gold is said to occur in the Lol Daika hills and has been recorded from Jombo (Gregory, *Foundation of B.E.A.*, 1901, p. 238). A silver-bearing lead ore (galena) was worked about 1892 by the B.E.A. Company in the sandstones at Mazeras. Galena had been previously found in that area by Krapf and Hildebrandt (Beyrich, 1878, p. 768). Hildebrandt (1879, pp. 253, 258, and 260) heard of antimony ores in the Duruma Sandstone to the W. of Mombasa, but was unable to find them; these reports may have been based upon the galena.

Fuels.—B.E.A. is very poorly provided with mineral fuel. Oil and bituminous residues occur in the Uganda Protectorate beside the Albert Nyanza, but the quantity is unknown. Coal is possible in the Permian rocks behind the Coast Range of B.E.A. which is at least on a coal-bearing horizon. The block of coal referred to on p. 53 shows that coal seams once existed in the country. It is improbable that the only surviving block of coal should have been found by chance in a railway cutting, so search in its neighbourhood by boring is desirable; but as no coal seams have been observed in the adjacent stream banks it would be unwise to rest high expectations on that single boulder; yet important coalfields have elsewhere been discovered by following up such a clue. There is a chance of coal occurring in the Duruma Sandstone in the still unsearched land between the Sabaki River and the Uganda Railway. In the interior there is no special indication of coal, but the occurrence of beds of lignite (brown coal) under the lava sheets is possible. At present the indications are that wood may be the only local fuel in B.E.A. The water supply of the rivers of Kenya and Kikuyu should, however, yield cheap electric power.

CHAPTER XXII

The Soils

THE soils of B.E.A. are the main basis of its wealth and prospects. Investigations upon the soils have been initiated by the analyses prepared at the Imperial Institute and in the laboratory of the Government chemist at Nairobi. The scientific examination of the soils has only just begun. During my visit in 1893 the subject was premature, and last year I especially regretted my limited time, as it rendered impossible serious consideration of the many interesting soil problems.

The soils of B.E.A. are of four chief types—the red, dry, sandy soil of the Nyika ; the rich red-clay soils of the volcanic regions ; the black " cotton soils " which are widely distributed on the plateaus ; and the varied alluvial and sandy soils of the coastlands.

I. *The Nyika Soils.*—These are found both on the Eozoic rocks and on the Duruma Sandstone, and their constituents are derived from the waste of those rocks. These soils are usually sandy and porous, so that in the dry season they are parched and arid, and their grains are easily moved by the wind. Hence the vegetation consists chiefly of tufts of dry grass, or of trees that can resist drought. Areas covered by these soils at the end of the dry season have the characteristic features of deserts, and the aspect of the Nyika then is not encouraging to the agriculturist. The barrenness of these soils is due to their incapacity to retain moisture, and not to their poverty in plant foods. The soils resting upon the schistose quartzites and in positions whence the finer constituents are removed by the wind may consist only of particles of quartz, and be quite barren. But the soils formed by the decay of the ordinary gneiss, schist, and felspathic sandstone, which form most of the Nyika, are rich in plant foods ; and as they have been long rested, much of their food material is at once available for use by plants.

The richness of some of these desert soils is shown by the analyses by Mr. Kirkham (E.A.P., Lab. Rep., 1918, p. 36) of samples from the Mua Hills, W. of Machakos, overlooking the Athi Plains. They contain from 6 to 7% of organic matter, from ·04 to ·06% of phosphoric acid, and from ·04 to ·06% of carbonates.[1] Their potash content is not recorded; but that it is exceptionally high in some of the soils is shown by an analysis kindly made for me by Prof. Berry and Mr. N. McArthur, of the West of Scotland Agricultural College, from a specimen collected near Mount Melilli on Captain F. O. B. Wilson's station at Kilima Kiu. This soil has the exceptionally high potash content of 5½%, which is no doubt derived from the potash felspars of the gneiss.

II. *The Red Volcanic Soils.*—The second important group of soils includes those formed upon the volcanic rocks. It includes the rich, fine-grained red soils of the Kikuyu Uplands, of the Guas Ngishu Plateau, etc. The red-clay soils are especially good when formed of decomposed volcanic tuffs. These soils are so fine-grained that they are very retentive of water, and so keep moist throughout the dry season. They are therefore covered by perennial vegetation and are rich in organic matter. These soils support the coffee plantations and fields of flax of the European settlers; and as they are especially suitable for culture by hand labour, on them are situated the prolific plantations of the Kikuyu. The chemical composition of these soils is illustrated by Mr. Kirkham's analyses (E.A.P., Lab. Rep., 1918, p. 36) of soils and subsoils from Muhoroni. In these three soils the organic matter is 15%; lime soluble in hydrochloric acid from ·24 to ·75%; the phosphoric acid from ·11 to ·19%; the potash from ·10 to ·23%. The red volcanic soils of East Africa are, with suitable rainfall, of the very highest grade of fertility.

III. *The Black "Cotton" Soils.*—These early attracted attention, but are less valuable than the red forest soils. The prevalent belief appears to be that these black soils are all due to decomposed volcanic rocks and are always of high fertility. They include, however, soils of two different origins. The weathering of the phonolites produces a black soil, which is rich in alkali and has adequate supplies of other food materials. After rain it supports a rich growth of herbage; but the soil quickly loses its moisture in the dry season and is best adapted to crops that only require rain during the early stages of growth or, like sisal, will live through a long dry season. When wet, this fine clay becomes a sheet of mud, of which the tillage is impracticable; so that these soils must be worked during the dry season and may require treatment by the methods of dry farming.

Black soil is also formed upon gneiss and schist in depressions where water lodges after rain. These black soils are chemically poorer than those formed from the lavas, and during the dry season are hot and sterile. They may, however, be exceptionally rich in potash, as is shown by the analysis quoted on p. 386.

The view that the black soils are all due to decomposed volcanic rocks and are all of great fertility is untenable. I visited the station at Kilima Kiu in the expectation of finding that the black soils there lay upon the phonolite of the Kapiti Plains; but the pebbles and larger grains in them are all debris from gneiss, and the soils are unquestionably formed from the Eozoic rocks. A chemical analysis by Prof. Berry and Mr. McArthur shows that the black soil is chemically similar to the typical red sandy soils of the Nyika. The difference in aspect is due to the water-logging and different condition of the iron salts.

Mr. Hobley (1895, p. 555) has referred to the presence of "black cotton soil" S. of Kilibasi, which was also no doubt formed from gneiss. Again, between Voroni and the Tana, the soil is often in places quite black; the pebbles and grains in it are of quartz, and this black soil was clearly due to decomposition *in situ* of metamorphic rocks and not of lava.

IV. *The Coastal Soils.*—The soils along the coastland are very varied owing to the great differences in the underlying rocks and the wide extent of the transported soils deposited by rivers. There are three chief types—those of the alluvial areas, the calcareous soils on the raised limestones, and the sandy soils of the Magarini Sand. The clayey alluvial soils may be illustrated by those of the Gosha district of the lower Juba, of which an instructive series of analyses have been published by the Imperial Institute (1914, pp. 515–540). A characteristic feature of these soils is that, though they are mainly composed of clay, they are very rich in lime, probably derived from sea-shells, coral, etc.; they usually contain adequate amounts of potash and phosphoric acid, and more than the ordinary proportion of oxide of iron. In a series of twenty-four analyses the lime varies from 1·74 to 11·72%; the magnesia from ·19 to ·3%, and is usually over ·2%; it may be a drawback when, as in some of the samples, the amount is higher than that of the lime. The potash varies from ·37 to 1·4%; the phosphoric acid is usually from ·1 up to ·36%, but in one sample, a dry loam, it was only ·02%. The oxide of iron varies from 2·68 to 8·96%. These soils contain more alkaline carbonate than some plants can endure.

The soil on the Magarini Sands is illustrated by a series of analyses reported by Mr. Kirkham (E.A.P., Lab. Rep., 1918, p. 38) from the plantations at Miritini. Their composition is very variable. The carbonates are usually very low, being from ·01 to ·02%; but in one sample they are 15%. This may, however, have been derived from the underlying Jurassic beds on the margin of the Magarini Sand. The phosphoric acid varies from ·02 to ·18%; the organic matter in four of the analyses is between 1% and 2·5%; in three others it varies from 9·4 to 12%. These soils are probably chemically poorer than those of the barren slopes of the adjacent Chamgamwe Shale; nevertheless the Magarini Sand supports the main plantations of the district, as, owing to its superior texture, it is more easily tilled and retains underground moisture which can be reached by the roots of the coconut-palms and trees. The slopes of the Jurassic shales are swept bare of soil by the heavy rain, and are too dry and hot during the dry season to be of any agricultural value.

The soils of some depressions in East Africa, especially in the volcanic areas, are sterile owing to the presence of an amount of alkaline carbonate, especially bicarbonate of sodium, which is poisonous to many plants. Such ground can only be used for plants which are tolerant of this salt, or after its elimination by appropriate manures. Barley, for example, can withstand nine times as much sodium carbonate as wheat; kaffir corn, maize, and ordinary fruit trees are very sensitive to it; millet (Sorghum), on the other hand, will grow in the presence of quantities of alkali, by which other grains would be completely poisoned. These alkaline soils can be cured by the application of gypsum (sulphate of lime), and soils which are sterile for this reason may ultimately be rendered of high agricultural value.

[1] Mr. Kirkham tells me that the entry "chalk" in some of the analyses stands for the total carbonates.

PART III

The Geology of Eastern Africa in Relation to the Great Rift Valley

CHAPTER XXIII

Uganda & the Victoria Nyanza

THE Uganda Protectorate, situated to the N. and N.W. of the Victoria Nyanza, includes in addition to the Province of Uganda, the districts of Unyoro near the Albert Nyanza, Ankole between the Victoria Nyanza and the Albert Edward Nyanza, Usoga between Uganda proper and the frontier of B.E.A., Elgon and the northern Province which lie between Lake Rudolf and the Nile. Most of the Protectorate lies on the floor of a broad depression between the western and eastern branches of the Great Rift Valley. It is all part of the Nile basin, except the north-eastern part which drains to Lake Rudolf. The most important geographical unit in Uganda is the Victoria Nyanza, the largest lake in the Old World; it is due to the collection of water in a shallow basin on the floor of the depression. The water level is determined by the outlet of the Victoria Nile over the Ripon Falls.[1] The Victoria Nyanza, unlike the Rift Valley lakes, has generally sinuous and shelving shores, while its basin is remarkably shallow. The greatest depth on the British Chart is 269 ft., two miles from the eastern coast near Kitna; but slightly greater depths have been obtained by Berson (Kuntz, 1909, p. 214).

Kavirondo Gulf is so shallow that the steamers are limited to a draft of 8 ft., and even so they churn up the mud on the lake bed. In contrast with the precipitous walls beside the Albert Nyanza or Tanganyika, according to Sir Frederick Treves (1910, p. 144), his first view of the Victoria Nyanza was "woefully disappointing," as free from grandeur or romance as a mud flat on the Thames. "At the end of a shabby plain is a pond of dirty water. That is all."

That the Victoria Nyanza is due to the collection of the local drainage in a normal depression was recognized by Burton (1860, II, p. 137). The lake has extremely irregular shores, and is littered with archipelagos. That the shores are often of considerable antiquity is shown by the picturesque weathering of the granite near Mwanza, as shown by Mr. McGregor Ross's photograph (Pl. III, Fig. B, opp. p. 36) of the tors there. Speke Gulf and Kavirondo Gulf, which project eastward, and Emin Gulf and Smith Sound, which project southward, are generally recognized as valleys which have been drowned by the gradual rise of the water.

The shore has in places been determined by N.–S. faults ; thus the western shore S. of the mouth of the Kagera is straight and high, and has been universally recognized (for example Stuhlmann, 1894, p. 834, and Herrmann, 1899, p. 170) as a fault line. The N.–S. faults have controlled the topography of Karagwe and Ruanda. According to Colonel Lyons (1908, pp. 389–390), " the most important factor in determining the orography of the lake plateau has been the earth-movements which are indicated by the numerous lines of faulting ; and as a result of these movements large masses, many kilometres long, have been raised, lowered, or tilted, and in the valleys formed along the fracture lines the main drainage lines of the district run. Lake Victoria itself is outlined by such fractures."

The tectonic structure of the country S.W. of the Victoria Nyanza, according to Herrmann (1899, pp. 170–171), consists of five rift valleys separated by five tectonic blocks. The easternmost block forms the islands of Bukerebe ; the channel between them and the shore is Herrmann's first rift valley. The steep coast S. of the mouth of the Kagera is the eastern face of the second block, which rises from 300–900 ft. ; its summit slopes gradually downward inland to the second rift valley, that of the Ngono, Riviga, and Nyarumba Rivers. West of this valley is the third fault block ; it is cut off to the W. by the third rift valley, which is occupied by Lakes Kamakara and Urigi and the Muisa River. The fourth block forms the plateau of Bugara and Uyagoma, bounded by the Kagera Valley, which is the fourth of Herrmann's rift valleys. Then follows the block of Ruanda, succeeded to the W. by the Western Branch of the Great Rift Valley.

Meyer (1912, p. 108) also describes the valleys of these Ruanda and Urundi districts as rift valleys (Graben-bruch) ; for example, he describes Ihangiro, which includes Lake Burigi, of which the northern end is 43 miles S.W. of Bukoba, as probably a rift valley nearly 20 miles wide.

The view has also been expressed that the Emin Gulf and Smith Sound both lie along depressions made by faulting ; but their existing features, as far as can be judged from the maps, appear due largely to denudation on lines of weakness due to faulting.

The level of the Victoria Nyanza has varied considerably in the past. The fossil mammals found in the lake beds at Karungu show that the basin dates back to the Miocene, and the lake then stood at least 300 ft. above its present level, and if the Muhoroni bone bed was also deposited by the Nyanza, the level must have been over 500 ft. higher than at present. In comparatively recent times the level must also have been higher, as Scott Elliot (1896, pp. 39–40) has described old beach deposits formed by the lake, 100 ft. above its present level. Along the northern coast the watershed lies but a few miles N. of the lake, beyond which the streams discharge northward into the Kafu and Lake Kiogo. This part of the coast is so deeply indented by bays and girt by islands that it presents the characteristics of a typical drowned coast. The irregularity of this shore is due to earth movements which, according to Colonel Lyons (1908–1911), are shown by the Entebbe lake gauge to be still in progress.[2] The outlet north-westward by the Victoria Nile through Lake Kiogo to the Albert Nyanza must be of very recent age. For above the Murchison Falls the Nile flows through a narrow cleft which, according to Weldon (1908, p. 289, and Betton, *Nature*, 19th June, 1902, p. 188), is only 6½ yards wide.

The narrowness of this canyon and existence of the Murchison Falls (130 ft. high) are clear evidence that this part of the Nile is geologically very young. Lyons remarks (1906, p. 60) that it appears to be " a trough between two orographic blocks " ; and he suggests (Lyons, 1908, p. 390) that " The Nile leaving the lake at the Ripon Falls may mark a S.S.E. to N.N.W. fault, lying, as it does, parallel to the numerous islands, and the general shore lines of the N.E. corner of the lake."

The drainage from the high watershed S.E. of the Albert Nyanza is towards the Victoria Nyanza. Formerly that watershed probably continued across the Nile near the Murchison Falls through northern Uganda to the highlands of Marangoli W. of Lake Rudolf. The drainage of N.W. Uganda was probably then into the Victoria Nyanza, and the numerous bays on the north-western shore of the lake are the estuaries of these rivers. The breaching of this watershed by the Victoria Nile (the section between the Victoria and Albert Nyanzas) reversed its direction.[3] Before that change the discharge from the Victoria Nyanza basin (alt. 3720 ft.) was either north-eastward to the deep depression of Lake Rudolf (alt. 1250 ft.) or northward, as suggested by Mr. Hobley (in Knox, 1905, p. 103) through the Ruzi Valley to the Sobat near Nasser. With either alternative the essential fact remains that the north-westward route over the Murchison Falls is a modern development. Earth movements, possibly aided by volcanic eruptions, blocked the original outlet; the water rose in the Victoria Nyanza region until it found an outlet through a gap in the north-western watershed, and overflowed into the Albert Nyanza basin by the Murchison Falls.

The geology of the Uganda Protectorate is comparatively simple; the literature is brief, but now that a Geological Survey for the Protectorate has been established under Mr. E. J. Wayland, much fuller information will be available. The first geological section across the Uganda Protectorate (Elliot and Gregory, 1895) was based on material collected by Mr. Scott Elliot in his expedition to Ruwenzori. It showed that the foundation of the country consists of the ordinary gneiss and schists of the Eozoic Group of Eastern Africa. Ruwenzori had previously been regarded as volcanic; but Mr. Scott Elliot's collection proved that it is a block of Eozoic rocks left upstanding between the down-faulted valleys of the Semliki to the W. and of the Edward Nyanza and Toru to the E.

This interpretation of Ruwenzori as a fault block of Eozoic rocks, with some plutonic rocks, left between two zones of fractures, was fully confirmed by Prof. Roccati (1907, p. 150) and Prof. R. Almagia (1908).

Karagwe Series.—The Eozoic rocks are covered in places, especially in Karagwe and Ankole, by slates, sandstones, and quartzites, for which was proposed the name of the Karagwe Series (Scott Elliot and Gregory, 1895, p. 678). They were then regarded as possibly Lower Paleozoic; they are the typical representatives of the Archeozoic Group in Eastern Equatorial Africa.

The extension of the Eozoic and Karagwe Series through Uganda has been shown by the collections made by officials of the Protectorate Government, and sent home by Sir H. H. Johnston, and described by Dr. G. T. Prior (1902 and 1904).

Volcanic rocks have been discharged in Uganda along the line of the Rift Valley faults. The extinct craters and lava sheets around Fort Portal have been shown by Prof. Colomba (1909, p. 252) to consist of phonolitic tuffs, which were probably deposited in a lake. These rocks are part of the same volcanic series as the great volcanos of Mfumbiro, S. of the Uganda frontier. With the exception of the volcanic rocks, the only established post-Archeozoic deposits are the drifts. They appear to be thick. On the floor of the Western Rift Valley near the Albert Nyanza they contain some bituminous material, which has been considered as an indication of oil.

Of special interest are the glacial drifts and moraines on the flanks of Ruwenzori. Mr. Scott Elliot (in Elliot and Gregory, 1895, p. 676) recognized from them the former extension of glaciers in the Mobuku Valley down to only 5000 ft. above sea-level. This record is confirmed by Prof. Roccati (1907, p. 152; 1909, p. 143, in the latter Pl. 22 is a photograph of these moraines), who gives the lowest limit of the ice as having been 4600 ft., whereas the existing glaciers end at the height of 13,450 ft.

The much lower descent of glaciers on Ruwenzori than on Kenya or Kilima Njaro (*v.* pp. 150, 152) was probably due to Ruwenzori having had a heavy rainfall maintained by evaporation from the Victoria Nyanza and Congo forests. As the winds were suddenly uplifted over the steep slopes of the mountain their moisture was precipitated as snow, which, converted into ice, flowed furthest down the south-eastern slopes as they were protected from the afternoon sun. The glaciers of Ruwenzori thus reached lower levels than any tropical glaciers known in the recent geological eras.

[1] This outlet, according to Kuntz (1909, p. 214), is over a dyke of phonolite; according to Garstin (1904, p. 20) and Lyons (1906, p. 19), over a dyke of diorite; according to Hobley (1914, p. 474), over a bar of granite. The weir is probably a hard band in the Eozoic rocks.

[2] According to the French edition of Suess (*Face de la Terre*, III, p. 966), this movement is explained as due to a displacement of the scales on the instruments; but that interpretation is not accepted by Colonel Lyons.

[3] This change or a reversal further N. down the White Nile was suggested in 1896 (G.R.V., p. 259). The fuller evidence now available greatly strengthens the case for this reversal.

CHAPTER XXIV

The Western Branch of the Great Rift Valley

THE Upper Nile and its branch through the Albert Nyanza to the Semliki Valley, Lake Kivu, and Lake Tanganyika, lie in a great rift valley, the extent of which has now been proved from near Gondokoro (lat. 5° N.) to the southern end of Tanganyika. Branches from it pass south-westward into the eastern Congo and south-eastward through the Rukwa Valley to Lake Nyasa. If the Nyasa-Ruaha Rift Valley is not connected with the Eastern Rift Valley, then that of Lake Nyasa, the Shire, and Portuguese East Africa from the Zambesi to the Sabi is the continuation of the Rift Valley of Tanganyika and the Nile, and not of the main branch including Naivasha, Lake Rudolf, and the Red Sea. The continuity of the Nyasa and Tanganyika basins through the Rukwa basin (or Lake Leopold—so named after the son of Queen Victoria) is well established. Indeed, according to some recent authorities, the Nyasa-Rukwa Valley formerly continued westward beyond the site of Tanganyika as the Lukuga Valley, and this older valley was dismembered by the infall of the Tanganyika Rift Valley.[1] According to this view, Tanganyika is one of the youngest of the East African lakes, a conclusion supported by weighty evidence and the fact that the drainage of the surrounding country is still mainly away from the lake.

Tanganyika is the greatest lake in the African Rift Valleys, and being 4708 ft. deep (Marquardsen, 1916), is the second deepest lake in the world; it is exceeded only by Lake Baikal, 4990 ft. deep, which also lies in a rift valley. If the surface level of Tanganyika be taken as 2536 ft. (according to Marquardsen it is 2559 ft.), the floor of the lake is 2172 ft. below sea-level.

The lake trends N. and S., and lies in a trough which has high walls, except where they have been breached by intersecting rift valleys or by inflowing rivers.

The special character of the Tanganyika basin was recognized by

Sir Richard Burton (1860, II, pp. 43, 137–138), who with Speke was the first European to reach the Central African lakes. Burton described the eastern wall of Tanganyika as " a short foreground of rugged and precipitous hill fold, down which the footpath zigzags painfully " to the " riant shores of this vast crevasse." The western wall could be seen in the distance as a " high and broken wall of steel-coloured mountain." " The general formation suggests, as in the case of the Dead Sea, the idea of a volcano of depression—not, like the Nyanza or Ukerewe, a vast reservoir formed by the drainage of the mountains." He therefore realized the formation of this basin by the subsidence of its floor. Stanley and Joseph Thomson (1882, p. 623) also both explained the lake by direct earth-movements. The steepness of its boundary scarp is indicated in the remark by Capitaine J. Maury (1912, col. 253) that it is an immense " couloir " between high rock walls.

From the northern end of Tanganyika the valley of the Ruzizi continues northward and leads to the Nile through one of the most striking sections of the whole Rift Valley system. For example, Thurston (1900, pp. 142–143) describes the Albert Nyanza, which lies in this valley, as bounded on the E. by a precipitous bank 1000 to 1500 ft. high, while " the western shore is formed by a chain of lofty mountains, the highest peaks of which must be at least 8000 ft. above the level of the lake. The sides of these mountains are like walls, rising out of the water. . . . The whole scene . . . resembles a fjord in Norway."

The abruptness of the walls of this valley is also emphasized by many other travellers. Thus Stanley (1890, II, p. 308), who reached its edge from the forests of the Congo, described it as a " yawning abyss," made by earth-movements. Colonel Jack (1914, p. 85), who speaks of it as a " big rift," explains (p. 134) that one unexpected result of its abruptness was that instead of the watershed between the Albert Nyanza and the Congo being sufficiently far back to give us there a valuable strip of territory, it is so near the lake as to limit the British territory to " a strip not a mile wide of rough rocky ground falling sheer into the lake."

The rift valley between the Albert Nyanza and Lake Tanganyika also has steep walls, but they are in places broken and irregular. Thus at the southern end of this section the Ruzizi Valley has a rough floor and uneven walls ; spurs projecting from its sides form Mount Suria on the E. and Mount Tshamata on the W. ; and Maury (1912, col. 253) describes the western wall, which is composed of schist and gneiss, as rough and jagged. This valley has undergone great recent geographical changes. It now carries S. to Tanganyika the drainage from Lake Kivu which until about fifteen years ago discharged northward to the Nile. The southern boundary of this branch of the Nile basin was a ridge of gneiss and schist, which is called by Capitaine Maury (1912, col. 254–255) "La Digue" of the Kivu; it has been cut through by the Ruzizi River in consequence, according to Maury (1912, col. 256), of the eruptions of Lubilé in 1905, which blocked the northern outlet and diverted the drainage to Tanganyika. This change of direction has also been pointed out by Sir Alfred Sharpe (1913, *Geog. Journ.*, p. 549) and Wauters (1912). In the Lake Kivu section of the valley a peninsula projects from the western wall of the lake; but the character of the valley as a trough cut through a plateau is well shown in the map by Wichmann (1911).

The height of the present watershed between Tanganyika and the Nile is doubtful (Hinks, 1918, p. 225); but from it the rift valley declines northward to 3000 ft. at the Edward Nyanza[2] and 2037 ft. at the Albert Nyanza.

The major irregularities of the wall of the Western Rift Valley appear to be due to two main causes. In some parts the structure has been obscured by the eruptions which built up "the sky-scraping cones," as they were called by Speke, now the most vigorous of African volcanos.[3] The major cause, however, may be explained by the relations of the valley to the geological structure of the adjacent country. Although small-scaled maps demonstrate the continuity of the valley, more detailed examination shows that the long, straight, even scarps are broken by spurs and gaps, and the valley in places appears to consist of segments arranged in echelon; some of the branch valleys are wider than the section of the main valley with which they overlap.

This overlapping feature recurs at intervals from the southern end of Tanganyika to Ruwenzori. For example, the Rukwa Rift Valley overlaps the southern end of Tanganyika. The valleys of Lake Moeru and Upemba (both of which are described as rift valleys by Belgian geologists, e.g. Cornet, 1905, p. 216, and Robert, 1912, p. 8, and are accepted as such by Dr. Willy Koert, 1916, p. 19) overlap Tanganyika to the S.W. and explain the breaches in its western wall. The Upemba trough (including Lakes Kajibajiba, Kabue, Kabele, Upemba, Kisale, Niange, and Kalamba) trends from about N.E. by

N. to S.W. by S.; the section by Cornet (1905, Pl. IX, Fig. 1) shows that it lies along a series of faults between the Kundelungu plateau of conglomerate and sandstone to the E., and granites and schists to the W. This valley, however, is obviously very old, and its walls have not been renewed by fresh faulting; so that though doubtless originally a rift valley, it is now a valley with denuded banks. The Upemba fractures may explain the breach in the western rim of the Tanganyika basin at Baraka, and those of Lake Moeru may be connected with the breach further S. near Albertville.

The irregularity of the walls is due to projecting spurs as well as to branch valleys. Near Baraka the long Ubwari peninsula projects into Tanganyika, and the projection of the north-western shore of Lake Kivu is formed by a spur from the western wall. A corresponding spur S. of Lake Edward, to the W. of the Ruchuru River, forms the western boundary of the pass described by Sharpe. Another breach in the wall is due to the Lake Edward section of the Rift Valley continuing north-eastwards to Lake George, on the eastern side of the great block mountain of Ruwenzori; while the Semliki River escapes northwards from Lake Edward through a branch valley between Ruwenzori and the mountains S. of Beni. Then by a sudden bend the Semliki[4] enters the long Albert Nyanza section of the Rift Valley, while the parallel Lake Edward section ends in the highlands of Toru.

This irregularity in the course of the western branch of the Rift Valley may be explained by the structural grain of the country. The valley is crescent-shaped; it begins along Tanganyika on a course somewhat to the W. of N., and bends round till at the Albert Nyanza it runs from S.W. to N.E. In this curve it cuts across the grain of the country, for the average strike of the rocks near Lake Edward is to the N.N.W., and therefore cuts obliquely across the valley.

A fracture across a plank of grained wood generally gives off overlapping branch cracks, or itself here and there alters its course to follow the grain. The overlapping segments and projecting spurs of the Tanganyika-Kivu-Semliki Rift is a development of the same feature on a regional scale.

The main continuation of the Albert Nyanza section continues north-westward beyond the Murchison Falls, while by a rift similar in direction to that through which the Semliki discharges from Lake Edward, the White Nile passes northward down a valley, the character of which, as a rift valley, has been shown by Dr. Holmes (1916) and Captain Stigand (1916).

The north-eastward continuation of the Albert Nyanza fracture is not yet established. From the scanty information available in 1893, I thought that it probably went eastward, along the line of the Kiogo and Salisbury lake-chain, and then by a well-marked pass reached the Turkwell, and down its valley to Lake Rudolf. The courses of any connecting fractures between the Albert Nyanza and Lake Rudolf are, however, still uncertain. The continuity of the western branch of the Rift Valley with that of Lake Nyasa is now firmly established; and some connection with that of Lake Rudolf is probable, though the scarps along this northern connection may not have been renewed by later earth movements. Only worn-down faults may remain to mark the tectonic connection between the two branches of the Rift Valley N. of the Victoria Nyanza.

[1] This view has been advanced by Scholz (Pflanzer, 1914, p. 84) and O. E. Meyer (*N. Jahrb. Min.*, *Beil. Bd.*, XXXVIII, 1915, pp. 855, 862); it is consistent with a suggestion by Kohlschütter (1901, *Deut. Geographentag*, XIII, Breslau, pp. 145–146) and with the native traditions (G.R.V., 1896, p. 5) of the submergence of villages on the formation of the lake. It is inconsistent with the view of Mr. J. E. S. Moore (1903, No. 1) that Tanganyika is the remnant of a Jurassic sea. This theory was based on the resemblance of some of the shells of Tanganyika to those of the marine Jurassic deposits in North-Western Europe. It has been discussed and rejected by Hudleston (1904), Calman (*Proc. Zool. Soc.*, 1906, p. 204), Lemoine (1906, p. 403), Cunnington, and others. It is dismissed emphatically by that distinguished authority on the geology of the Eastern Congo, J. Cornet (1896, p. 3): "Le Tanganyika n'est pas un Relicten-See; il est d'origine continentale et est dû à un effondrement. Y trouvat-on une baleine, je préférerais croire qu'elle est tombée du ciel plutôt que d'admettre une théorie qui a contre elle tout ce que nous savons de la géologie de l'Afrique équatoriale."

[2] According to Wauters (1897, col. 1–6, and col. 13–18 and plate), the Albert Edward Nyanza was once a much greater lake which discharged to Tanganyika; he has discussed the changes by which it was connected with the Nile, and he predicts that by future silting the whole lake will be replaced by an alluvial plain.

[3] The activity of these volcanos was discovered by Count von Goetzen (1895, *cf.* Frontispiece and plates opp. pp. 201 and 211), who showed that the Kirunga volcano was in eruption during his visit to the district; the investigation of his collection by Tenne (1895, pp. 390–391) shows that these very recent lavas are nephelinites. An excellent account of the volcanos and their eruptions in 1900–1902 has been given by Herrmann (1904); the rocks

he collected have been identified by Finckh as nephelinites, with leucite and melilite as frequent minerals. That these rocks have been discharged by the latest phase of volcanic activity is shown by the occurrence of a melilite-leucite-nephelinite on the rim of the Kiringa crater (Herrmann, 1904, p. 60). The volcanos were also in eruption during the visit of Sir Alfred Sharpe in December, 1912 (1916, p. 21), and the new volcano then upbuilt has been described by Schumacher (1915, p. 202).

[4] Major R. G. T. Bright (1909, p. 142) describes the Semliki Valley as "generally admitted to be a trough subsidence, or rift valley, between roughly parallel faults."

CHAPTER XXV

German East Africa—Tanganyika Territory

THE territory that comprised the colony of G.E.A. is geologically the best known part of Equatorial Africa. Its caravan routes to the interior from Bagamoyo and Dar-es-Salaam were traversed by Europeans, including Burton, Speke, Livingstone, Cameron, Stanley, Keith Johnston, Thomson, Fischer, and other travellers, much earlier than geographical exploration in B.E.A. The conditions of travel and scientific work there were easier than further N., as may be judged by comparison of the geological results obtained by Joseph Thomson in G.E.A. with those of his later and more famous expedition across British Masailand. Moreover, Germany was able to devote to the country, as the most promising and favourite of its colonies, a larger share of attention than the United Kingdom could spare for B.E.A.

G.E.A. was a well-marked geographical unit. It was bounded to the N. by the British Protectorates of Uganda and B.E.A. ; to the S. by the Rovuma River and Portuguese East Africa ; to the E. by the coast ; to the W. by the Western or Central African branch of the Great Rift Valley, including Tanganyika, the Semliki Valley, and the Albert Nyanza ; and to the S.W. by Northern Rhodesia and Nyasaland. Parts of this area have been assigned to the Belgian Congo and to Portuguese East Africa ; the rest, included in the British mandate, has been officially named the Tanganyika Territory. This name is not yet widely known and may be misunderstood, for it includes only part of the Tanganyika basin, and only a small proportion of it lies in that basin ; the term in physical geography would be as apt to mislead as that of Victoria Nyanza territory for B.E.A. Hence until the rearrangement of the political spheres in Eastern Africa is finally settled and the new names generally established, it is most convenient to consider together all the area of the former German colony and refer to it by the name which is definite and well understood.

Geographically, G.E.A. consists of a vast undulating plateau, broken by residual hills and ridges left by the lowering of the surface by denudation. The northern section is a continuation of B.E.A. It includes the Usambara Mountains and the volcanic cones of the Kilima Njaro chain ; the broad steppes of Masailand ; to the W., the volcanic highlands beside the Rift Valley and near Lake Kivu, between which lies the basin of the Victoria Nyanza. The middle section is traversed E. and W. by the wide valley and steppes of the Rufiji and Malagarasi. The southern frontier lies along the valley of the Rovuma. To the E., the plateau descends steeply, except where the scarp has been broken down by the river valleys, to the coastlands which are formed of Mesozoic and Kainozoic beds. To the W. the descent is abrupt to the shores of Tanganyika and the valley of the Ruzizi and Lake Kivu ; on the S.W. the scarp of the Livingstone Mountains falls precipitously to Lake Nyasa.

Before tracing the course of the Rift Valley across this country it is advisable to summarize the geological structure of the country, though the literature is so voluminous and the information available so extensive that only a brief summary is possible.

I. The Eozoic Group

The foundation of the whole country consists of Eozoic rocks, which occupy the surface throughout most of it, as shown on the sketch map (Fig. 41).

The rocks consist mainly of gneiss, schist, and granite, which are often intimately associated. The gneisses are especially predominant in the mountain belts down the eastern and western sides of the country. The largest area of granite forms the Unyamwesi Plateau, S. of the Victoria Nyanza, and granite tors occur along the shore (Pl. III, Fig. B, opp. p. 36).

Baumann (1894, map), in a diagrammatic section across G.E.A., represented the gneisses and schists as forming the " East African Schiefergebirge " between the coast and the Pangani Valley, and the " Central African Schiefergebirge " near Tanganyika and the western branch of the Rift Valley. Between these mountainous rims lies the undulating plateau which forms the bulk of the country, and includes vast areas of granite with belts of schists and gneiss. Baumann's suggestion as to the general plan of the country has been substantially confirmed.

The predominant Eozoic rock is a quartz-biotite gneiss, similar to that of B.E.A., and, as there, muscovite-gneiss is comparatively exceptional. Hornblende-gneiss is widely distributed, and passes through hornblende-schist into schistose amphibolite. The gneiss in the eastern and northern districts is often garnetiferous, as shown, for example, by the rock descriptions by Schmidt (1886, p. 451) and Tippelskirch (1898, pp. 160–161) ; garnets are less common in the south-western districts.

Gneisses of very varied composition occur around Morogoro (about 100 miles W. of Dar-es-Salaam), whence Tippelskirch (1898, pp. 162–167) records andalusite-garnet-gneiss, pyroxene-hornblende-gneiss, and epidote-biotite-gneiss. The abundance of the last rock in that district is indicated also by specimens collected by Mr. E. J. Starey. Kyanite gneiss is recorded by Tippelskirch (1898, p. 195) from the Shipunga and Hindmara Mountains, where it is found with pyroxene-hornblende-gneiss (*ibid.*, p. 196).

The normal gneiss is associated with bands of graphitic gneiss, as in the Uluguru Mountains, with various granulites, granular and schistose quartzites, and crystalline limestone which occurs in beds up to 30 ft. in thickness and is locally interstratified with hornblende-gneiss. The limestone often contains silicates or is dolomitic. The dolomites are the southern continuation of those of the Taita and Ulu Mountains of South-Eastern B.E.A., and, as there, the accompanying schists sometimes contain graphite, as recorded originally from Usambara by Farler (1879, p. 82). Further W., dolomites and coarsely crystalline limestones occur also at Chimyo (Tippelskirch, 1898, p. 173).

The Eozoic schists are widely distributed and include mica-schist, hornblende-schist, andalusite-schist (e.g. Lenk, in Baumann, 1894, p. 276), and actinolite-schist near Gumbo (Tippelskirch, 1898, p. 167). The schists often weather more rapidly than the gneisses and therefore form belts of lower land, as in the case of the mica-schist of Irangi (Obst, 1912, p. 161). Hence where the Rift Valley traverses such rocks its walls are often in bad repair.

The schists and gneisses are often associated with plutonic masses, the largest of which consist of varieties of biotite-granite ; hornblende- and microcline-granites also occur. Some of these granites are probably older than the gneisses, but others are later as the granite is intrusive. Among the intrusive rocks are diorite, diabase, plagioclase-amphibolite, gabbro, olivine-gabbro (e.g. Lenk, in Baumann, 1894, p. 280), and peridotite (e.g., in the Masai steppes, Jaegar, 1913, p. 12). Associated with the intrusions of diorite and

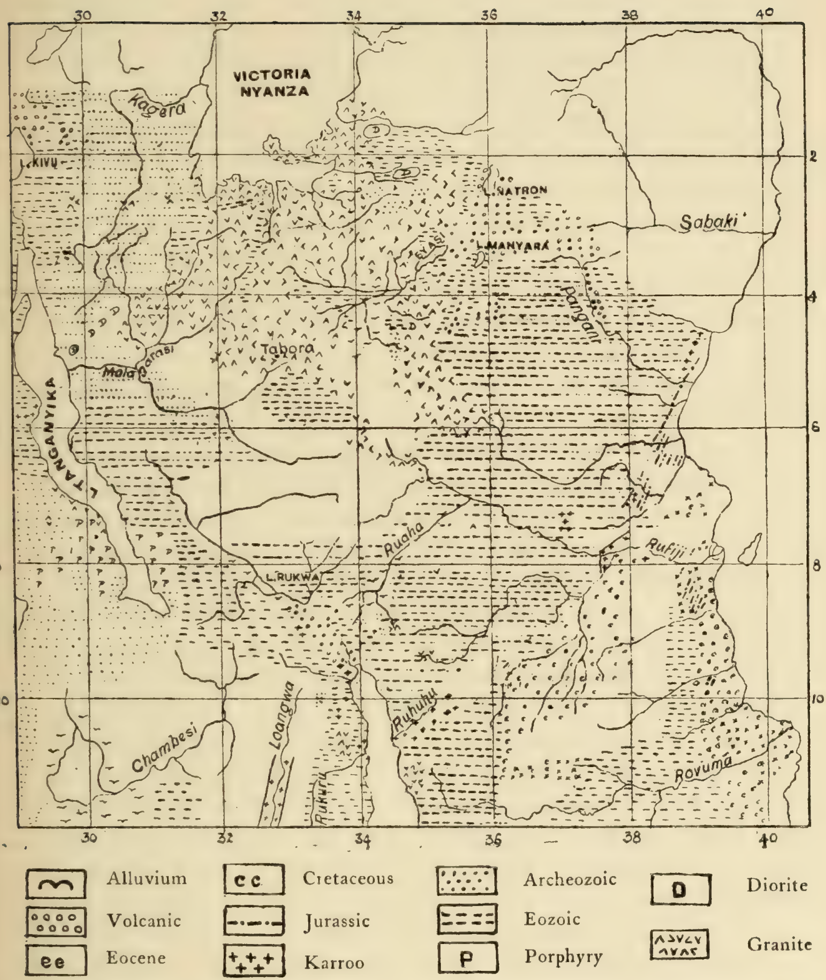


FIG. 41.—Geological Sketch Map of the Tanganyika Territory (formerly German East Africa).

Scale, 1 inch = 200 miles.

diabase are the chief gold deposits yet discovered in Eastern Equatorial Africa, including those at Sekenke in the Wembere Sunkland, Msalda (S.S.W. of Smith Sound), Samuyu (N.N.E. of Tabora), Ikoma and along the Orangi Valley (E. of the Speke Gulf), and Kasama (S.S.E. of Nasa on the same gulf).

The gneisses have been invaded by numerous dykes, including, in the Morogoro district, bodies and veins of pegmatite, with which are associated the chief mica deposits of East Africa. The walls of the Hohenlohe Rift Valley have been cut through by dykes of olivine-diabase (Jaeger, 1913, p. 70) and quartz-porphyry (Lenk, in Baumann, 1894, p. 277). The rocks in these dykes are much altered ; they are, e.g., often uralitized, and Tippelskirch (1898, p. 186) describes the Iramba diabase as dynamo-metamorphosed. The majority of the dykes are probably of Eozoic age. The existence of ancient basic lavas is indicated by the occurrence of diabase amygdaloids (Lenk, in Baumann, 1894, p. 279).

The gneisses and crystalline schists are mostly altered sedimentary rocks ; they agree in general character and in their relations with the schists of the Swaziland System of Southern Africa, which, as pointed out by Studt (1914, p. 64), also appear to be younger than the underlying gneiss and granite.

The strike of the Eozoic rocks throws light on the earliest earth movements in the country. The strike follows approximately the plan of a horseshoe, with the Victoria Nyanza between the two ends. Thus in Usambara the records by Baumann (1890, pp. 150–151) show that near the southern foot of Kilima Njaro the strike of the rocks trends from N.W. to S.E., as in the Jaschatu Mountains and Kivambugu ; to the S.E. the course changes to N.–S., as through Handei and near Magila (W. of Tanga), and it retains this direction in Southern Usambara. W. of this area the strike undergoes the same change. Thus in the Masai Steppes (S.W. of Kilima Njaro) the strike in the northern districts varies from between N.W. to S.E. and N. to S. ; whereas in the south-eastern districts it varies between N.E. to S.W. and E. to W. In the S., on the Upper Rovuma, it is in places E.–W. (e.g., Stromer, 1896, p. 87). It is generally N.E. to S.W. in the eastern parts of the north-eastern quarter of G.E.A. (Tippelskirch, 1898, p. 199).

S. of Usambara the "East African Schiefergebirge" continue through the district of Useguha, as gneiss, granite, and schist, and the predominant strike is N. to S. (Stromer von Reichenbach, 1896,

p. 33). Further S., beyond the Tanganyika Railway near Morogoro, in the Uluguru Mountains and in the Usagara Highlands, the trend of the foliation has become N.N.E. to S.S.W. Further S., in the Ruheho Mountains, the strike turns to N.W.–S.E., for that part of the country is under the influence of the movements between Southern Tanganyika and Nyasa. From the northern end of Nyasa the foliated rocks extend northward E. of Tanganyika; they pass the northern half of that lake, with a strike of N.N.E. to S.S.W., which is prevalent in N. Uha, Urundi, and S. Ruanda. The dip of the gneiss is often gentle (10° to 50°), but near Lake Nyasa it is generally very steep; it is often nearly vertical, and sometimes intensely folded.

The surface of the Archean rocks is sometimes rugged, with steep ridges abruptly rising out of sandy plains. The ridges follow a similar horseshoe to the foliation, being approximately N.–S. behind the coastlands and E. of Tanganyika, and curving round to E.–W. in Southern G.E.A. In the arid districts behind the coast are many of the isolated ridges and hills known as "inselberge," or Rumpfberge (hump-mountains), the nature of which is considered on pp. 35–36.

II. The Archeozoic Group. The Karagwe Series and Tanganyika Sandstones

The second group of rocks in G.E.A. includes slates, phyllites, and quartzites, which are much less altered than the Eozoic rocks and yet are often steeply tilted as they have been folded into the ancient foundation. They may be correlated with the Karagwe beds to the W. of the Victoria Nyanza. These rocks are widely distributed to the S.E., S., and S.W. of the Victoria Nyanza (e.g., Stromer von Reichenbach, 1896, pp. 44–48). These rocks contain the quartzites and conglomerates of Usongo, which, according to Kuntz (1909, p. 212), are indistinguishable in hand specimens from those of the Witwatersrand beds, so he correlated them with that series of gold-bearing rocks.[1] The normal members of this series in Equatorial Africa appear, however, more closely to resemble the Transvaal System of Southern Africa; both these systems may be represented in Eastern Equatorial Africa—the Transvaal System by the beds of Karagwe; the Rand System by the quartzites and conglomerates of Usongo.

The uppermost of the four divisions of the Karagwe Series consists of white granular quartzites and sandstones, which resemble the horizontally bedded, unfossiliferous sandstones and quartzites so well developed on both sides of Tanganyika, that they are known as the Tanganyika Sandstone. They rest unconformably upon the older rocks, sometimes on the schists, and sometimes on the granite, and form conspicuous, flat-topped plateaus. The rocks are sometimes still in the condition of sandstones, which are interbedded with shale and conglomerate. The existence of the same series on the plateau above Merere's, in S.W. G.E.A., was recorded by Elton (1879, p. 335) and by Thomson (1881, II, p. 228). These rocks have been referred (as doubtfully by Bornhardt, 1900, p. 461) to the Cape Formation of South Africa, in which case they would be Devonian in age. They appear, however, to correspond with the older unfossiliferous, horizontal sandstones which are so widely distributed in Southern and Central Africa. They are so little altered that there is a tendency to regard them as of Paleozoic age, but for reasons stated on p. 42 they are probably Archeozoic and the northern representatives of the Waterberg Sandstone of South Africa.

III. The Karroo System

The oldest known fossiliferous beds in G.E.A., as in B.E.A., are continental deposits that contain land plants and fresh-water fossils which lived on the ancient continent of Gondwanaland. The beds include coal seams.

In G.E.A. these rocks occur in three chief areas—around the northern end of Lake Nyasa ; near the coast in the Rufiji Valley ; and in the north-eastern districts near Tanga.

The rocks which admit of most satisfactory correlation with the Karroo beds of Southern Africa are those of the Nyasa area. The beds are of two types. In the Ruhuhu Valley they lie in a valley cut through the Eozoic rocks of the Livingstone Range ; they consist of sandstones with numerous coal seams, which are, however, mostly thin ; and the coal, as far as it is represented by the analyses published by Bornhardt (1900, p. 150), is of poor quality.

To the N.W. of Lake Nyasa the coal seams are less numerous ; but they are from 6–16 ft. thick, and appear more promising economically ; in the same region the sandstones are often calcareous, enclose layers of limestone, and are fossiliferous (*v.* p. 296).

The coastal Karroo System is best known from the Rufiji Valley, where, according to Bornhardt (1900, p. 463), the sequence is :—

5. Thick-bedded, firm, fine-grained sandstones, light grayish brown to reddish brown ; about 1000 ft. thick.

4. Sandy shales and bedded sandstones ; greenish gray to gray-brown ; 350 ft.

3. Thick-banked, coarse-grained sandstone which weathers to a dirty grayish brown colour ; about 500 ft.

2. Light to dark gray shales with plant remains in short, broken pieces (häckselartigen). These "seem to belong to *Glossopteris*" ;[2] about 160 ft.

1. Thick-banked, medium-grained to conglomeratic sandstones, which in places become coarse conglomerate ; in repeated alternation, with light to dark gray, sometimes sandy shales ; about 330 ft.

The third representative of the Karroo System in North-Eastern G.E.A. occurs between Tanga and Moa, and may represent the continuation of the Mazeras or Upper Duruma Sandstone of B.E.A. Lithologically, they resemble the Rufiji beds ; but their fossils, such as *Voltziopsis* (determined by Potonié, in Bornhardt, 1900, p. 504), are Rhætic rather than Permian or Triassic. As Bornhardt (1900, p. 463) remarks, they represent the horizon of the Stormberg beds of South Africa, and thus belong to the uppermost division of the Karroo.

IV. The Jurassic System

The Jurassic beds of G.E.A. have a fuller sequence and more abundant and better known fossils than any other part of Eastern Africa. They are mainly a marine series due to the occupation of the coastlands by a sea which covered some parts of the country from the Bathonian to the Kimmeridgian. The marine Liassic at the base of the Jurassic and the marine Portlandian (Tithonian) at its top, which are both reported from Somaliland, are not known in G.E.A., so that the sea appears to have invaded the land later and left it earlier than N. of the Equator.

The Jurassic beds have been described in many well-known memoirs, and the knowledge of them admirably summarized by Krenkel and Dacqué (1910). The distribution of the Bathonian beds shows that the sea had then reached Africa throughout the width of G.E.A.

1. *Bathonian.*—The Bathonian Series is developed in three areas—in the N. near Tanga, W. of Dar-es-Salaam, and in the S. behind Kiswere. The northernmost of the Bathonian areas is near Tanga, where the chief bed consists of hard, gray, massive and oolitic limestones, outcropping in the Mkulumusi estuary along the Usambara

Railway, about 3 miles from Tanga, and at Mtaru. It was first recorded by Farler (1879, p. 87) at five hours' march from Kwambembe. Lieder collected some fossils which were identified by Prof. O. Jaekel (1893, pp. 507–508) as Oxfordian ; they included the spines of *Cidaris glandifera* Goldf., which may be the same species as a spine which I collected from the Kambe Limestone near Mtesa ; but, according to Koert (1904, p. 153), Lieder's fossils came from beds that underlie the Callovian, and both Koert and Dacqué (1910, p. 54) regard them as Bathonian. The limestones are often unfossiliferous, but they contain some foraminifera and radiolaria, as was recorded by Baumann (1891, pp. 4, 116). These rocks resemble the unfossiliferous and oolitic bands of the Kambe Limestone (see p. 64). The best developed Bathonian beds occur on the railway from Dar-es-Salaam to Morogoro (see, e.g., Fraas, 1908), beyond the station at Pendambili. They are a thick series of micaceous calcareous sandstones, with nodules containing indeterminable *Lopha* (*Alectryonia*) and oolitic and pisolitic limestones ; further W., after km. 141, the Bathonian beds, according to Fraas (1908, p. 444), rest conformably on unfossiliferous sandstones which he refers to the Karroo System, and they, in turn, lie on the gneiss. The calcareous sandstones W. of Dar-es-Salaam have yielded *Corbula pectinata* Sow. and *Pseudomonotis echinata* Sow. (Dacqué, 1910, pp. 54, 55).

The Bathonian beds in this area are relatively unfossiliferous, but they are followed by Callovian limestones, marls, and septaria, with many fossils. The Bathonian beds are also rich in fossils (e.g. Müller, in Bornhardt, 1900, p. 520, etc.), as W. of Saadani, where the basal Jurassic rocks are calcareous micaceous sandstones with *Pecten lens* Sow., and *Trigonia costata* Park. ; at Msogo, W. of Bagamoyo, where they have yielded *Velopecten abjectus* (Phill.), *Rhynchonella aff. lacunosa* Qu., and *Pseudomonotis echinata* Sow. (Müller, in Bornhardt, 1900, p. 520). Still further S., behind Kiswere, on the lower Mbenkuru River, and on the Mandawa occur the pisolitic limestones described by Rothpletz (in Bornhardt, 1900, App. IV, pp. 273, etc.) as formed by calcareous algæ ; and in the same district occur corals, *Velopecten abjectus* (Phill.) and *Rhynchonella* cf. *lotharingica* Haas.

2. *Callovian.*—Callovian beds follow the Bathonian in each of the three Bathonian areas. In the N., near Tanga, Koert (1904) described Callovian beds in the Mkulumusi estuary, where they are shales with oolitic limestones and many ammonites ; these beds are also well exposed 3 miles from Tanga, beside the Usambara Railway,

where they yielded *Phylloceras mediterraneum* Neumayr, *Phylloceras feddeni* Waagen, *Perisphinctes funatus* (Opp.), *Macrocephalites macrocephalus* (Schl.), and *Sphæroceras bullatum* (Orb.).

In the second Jurassic area, that W. of Dar-es-Salaam, the Callovian beds are well developed and are richly fossiliferous. They consist of marl, shales with septaria, and siliceous limestones, succeeded by a hard *Gryphæa* limestone. Dantz collected many Callovian fossils from the neighbourhood of Pendambili, a railway station 127 km. from Dar-es-Salaam; amongst them Menzel (1902) identified the well-known European species, *Pecten lens* Sow., *Ceromya concentrica* Sow., *Trigonia costata* Park., and *Gresslya abducta* Phil. The sequence at this locality has been described by Fraas (1908, pp. 644–645), and the Callovian age of the chief fossiliferous beds is reaffirmed by Dacqué (*ibid.*, p. 642).

At Mameha, inland from Bagamoyo, is a coral limestone[3] containing the reef corals *Isastræa bernensis* Et., *Thamnastrea lamellosa* Sol., and *Th. mœschi* Koby. The southern area of Callovian beds is in the Mandawa Valley, where they include pisolitic limestones and *Pseudomonotis echinata* Sow., *Ostrea* cf. *marshi* Sow., etc.; also the Mahokondo limestone which Bornhardt (1900, p. 466), in consequence of the identification of the fossils by Müller, explained as Kimmeridgian beds down-faulted into older rocks, but is assigned by Dacqué (1909, p. 168) to the Callovian.

3. *Oxfordian.*—In the Tanga district Mtaru, in the Mkulumusi estuary, is well known geologically, as many of the earliest fossils from East Africa were collected by Stuhlmann from its septarian marls and described by Tornquist (1893) as *Macrocephalites olcostephanoides*, *M. horologium*, *M. panganensis*, *Perisphinctes mtaruensis*, *P. migrans*, and *Rhynchonella equatorialis.*

The sequence near Tanga (according to Lieder, in Futterer, 1894, p. 16) begins with a basal conglomerate, with gray calcareous cement and pebbles of gneiss; this bed is covered by bluish gray shale, with pyritic concretions, ammonites, and belemnites; at the top is a dense, massive, fossiliferous limestone, nearly 300 ft. thick. Futterer identified among the fossils *Aspidoceras africanum* Futt., *A. depressum* Futt., *Macrocephalites aff. stuhlmanni* Tornqu., *M. olcostephanoides* Tornqu., *Perisphinctes mtaruensis* Tornqu., *Aptychus latus* Park., *Belemnites tanganensis* Futt., *Ostrea dextrorsum* Qu., *Pecten bipartitus* Futt., *Terebratula biplicata* L. v. B., and *Rhynchonella aff. jordanica* Nötling.

W. of Dar-es-Salaam, on the railway line at km. 110, the Oxfordian is represented by the *bimammatus* zone (Fraas, 1918, pp. 644–645).

In the southern districts the Upper Oxfordian includes the lowest of the three local horizons which have yielded fossil reptile bones. Its age is fixed by its position below the *Nerinea* beds of Tendaguru.

4. *Kimmeridgian–Tithonian.*—The presence of Upper Jurassic beds in G.E.A., as in B.E.A., has been alternately asserted and denied. In some cases, as that of Mahokondo, near Kiswere, the beds are clearly earlier (e.g. Dacqué, 1909, p. 168). But the Kimmeridgian age of the Middle Reptile beds is now again accepted (e.g. Behrend, 1918, p. 115), and the overlying *Trigonia smeei* beds are regarded as Tithonian or Upper Kimmeridgian.

5. *The Gigantosaurus Beds.*—The Mesozoic shales of the Tendaguru district are now geologically world famous as the source of the bones of *Gigantosaurus*, the most colossal animal known to have lived on the earth. According to Fraas (1908, p. 144), its mean length was from 45–50 ft., but since then much larger specimens have been described. *Diplodocus*, the allied American reptile, is about 70 ft. long. A thigh bone of *Gigantosaurus* found in the Tendaguru district was 11 ft. long, so that the animal must have stood 20 ft. high ; and as the corresponding bone of *Diplodocus* is only 3¾ ft. long, *Gigantosaurus* is considered to have attained a greater length than *Diplodocus.*[4] The reptile is of Upper Jurassic or lowermost Cretaceous type. The Tendaguru reptile beds are interstratified in the Makonde beds, which were for a time regarded as Upper Cretaceous. Hence Fraas interpreted *Gigantosaurus* as a " relict-form," or as a survival in East Africa into Upper Cretaceous time of a Jurassic animal. Hennig and Janensch,[5] however, after further investigations of the bone beds, have shown that the evidence for their Upper Cretaceous age is inconclusive, and have referred the extinct reptiles of East Africa to three horizons ranging from the Oxfordian to the Wealden. This conclusion restores *Gigantosaurus* to its normal geological horizon.

The Tendaguru succession is, according to Hennig and Janensch :—

CRETACEOUS : Aptian–Makonde beds. Unfossiliferous red and brown sandstones and marls ; and Newala Sandstone.

Neocomian. Calcareous sandstones with concretions and *Trigonia schwarzi* G. Müll.

Wealden. Upper Saurian bed ; 150 ft. thick, calcareous red and gray sandy marls.

JURASSIC: Tithonian and Upper Kimmeridgian. Yellow and gray sandstones, with some conglomeratic beds with *Trigonia smeei* Sow. (=*T. beyschlagi* G. Müll.), 65 ft.

Kimmeridgian. Middle Saurian bed; red and gray sandy marls, 50 ft.

Upper Oxfordian. { Nerinea bed; gray calcareous sandstones, 80 ft.
Lower Saurian bed. Gray to reddish. sandy marls, 65 ft.

V. THE CRETACEOUS SYSTEM

The Lower Cretaceous beds are of two types—the unfossiliferous sandstones and shales, named by Bornhardt the Makonde beds; they include the Newala sandstones and form a series of plateaus lying from 10 to 100 miles back from the coast and rising to the height of over 2300 ft. above sea-level.

The second type includes marine fossiliferous beds of two ages. Aptian coral limestones occur behind Kiswere in the Kiturika district and rise to the height of 1000 ft. above sea-level. The Neocomian includes the *Trigonia schwarzi* beds, which are interstratified with the Saurian beds and determine their age; and also the limestones with *Toucasia carinata* (Math.) of the Makangaga district. After the Aptian there is a considerable unrepresented interval. Upper Cretaceous beds and marls which rise to the height of 1300 ft. occur at Kigua, 25 miles W. of Bagamoyo; for micaceous sandstones and marls yield the typical Cenomanian fossils, *Vola quinque-costata* (Sow.) and *Exogyra columba* (Lam.). Near the Ngerengere, in Usaramo (N.W. of the mouth of the Rufiji), beds containing *Radiolites* are assigned either to the Turonian (Behrend, 1918, p. 121) or possibly to Senonian (Krenkel, 1909, p. 210).

VI. THE KAINOZOIC GROUP

The tendency for the marine beds to be best developed in the southern districts, which is marked throughout the Mesozoic, is also a feature of the Lower Kainozoic, since beds of that age are found along the coast from Lindi past Kilwa to Kitulo, where they occur up to 430 ft. above sea-level (Bornhardt, 1900, p. 468).

The presence of at least two series of marine Lower Kainozoic rocks along the southern coast of G.E.A. is proved by Scholz (1911,

p. 369), who has identified from the N.W. of Lindi a Middle Eocene species of foraminifera, and from the same district the Upper Oligocene limestones (Aquitanian), including *Lepidocyclina formosa* Schl. and the two Indian sea-urchins *Echinolampas discoideus* Arch. & H. and *Clypeaster complanatus* D. & Sl. (*ibid.*, p. 371), and two new species *Plesianthus böhmi* Scholz and *Schizaster uhligi* Scholz (*ibid.*, pp. 377–378). The coral bed W. of Mtshinga with *Cyclolites* (Weissermel, in Bornhardt, 1900, p. 593) is probably also Oligocene. That age of the beds at Lindi is supported by the occurrence there of the teeth of the well-known shark *Carcharodon megalodon* Ag. (Hennig, 1893, pp. 314–315).

According to an authoritative correlation of the Kainozoic beds by Oppenheim (1916), the horizons present are the Lower Eocene at Kitulo, the Middle Eocene with *Nummulites perforatus* Lam., on the Lukuledi River; the Upper Eocene with *Nummulites* of the *striatus* group, and *Orthophragmina dispansa* Sow., etc., on the same river. Then follows the Upper Oligocene (Aquitanian) with *Lepidocyclina dilatata* Michelotti, *Echinolampas discoideus* Arch. & H., etc. The next horizon accepted by Oppenheim is that of the *Pecten vasseli* beds, which he refers to as apparently Pleistocene (*ibid.*, p. 111).

The Mikindani Beds.—The largest development of Kainozoic beds in G.E.A. is that of the Mikindani beds of Bornhardt, which consist of reddish sands, loams, and pebble beds, and are several hundreds of yards thick. They occur all along the coast, in the off-lying islands, and extend inland in places to the level of over 1600 ft. Bornhardt records them on the route to Lake Nyasa at the level of 2700 ft. He attributes them to an invasion of the sea, and explains the general absence of marine fossils by the sandy beds being unsuited to their preservation.

These beds resemble the Magarini Sand of B.E.A., which appears clearly a non-marine series and older than the earliest date which, according to Bornhardt, would be possible for his Mikindani Beds. Werth (1901, pp. 297, 298) has, however, further investigated those beds and concludes that they do not all belong to one series, and that the formation is fluviatile owing to their clayey nature and the nature of the rolled pebbles. Their fluviatile and terrestrial origin is accepted by most of the authorities (for references, see p. 78).

The Magarini Sand is probably earlier than the Upper Pliocene (*v.* p. 77), whereas, according to the position assigned by Wolff (1902) to the Mikindani Beds in a bore at Dar-es-Salaam, they would be later than that horizon. The bore gives interesting evidence of the repeated submergence and emergence of the coast. It was sunk in the boma of Dar-es-Salaam on a terrace between 30 and 60 ft. above sea-level ; it reached the depth of 530 ft., and yielded water at 92 ft. and salt water at 407 ft. The beds passed through in descending order are :—

(7) Yellow sands (surface soil).

(6) White sands and

(5) Sandy clay which Wolff regards as possibly the Mikindani beds.

(4) The upper marine beds from 18 to 92 ft., containing indeterminable corals in a reef limestone.

(3) Brackish-water marls with *Cerithium* at 144 ft.

(2) Beds containing fossil wood, 180 to 187 ft.

(1) The lower marine bed from 190–531 ft.

The *Cerithium* at 144 ft. Wolff records as allied to *C. pusillum*, and the same bed yielded *Arca granulosa*, both species still living in the Indian Ocean. He regards the lower marine bed from its fossils as probably Pliocene (*ibid.*, pp. 155, 157), since some of the mollusca (the *Cypræa* and *Tellina obliquaria*) are not quite the same as the living species. He suggests its comparison to the older coral limestone of Ortmann, of which the fauna so far is not known.

As this lower marine bed has not yielded *Pecten vasseli*, it is possibly younger than the North Mombasa Crag (*v.* Chap. VI, p. 75). If Wolff be correct in correlating the " upper white sands " with the Mikindani Beds, that formation would be considerably younger than the Magarini Sand. Nevertheless the general agreement in character and distribution between the Mikindani and Magarini beds seems to suggest that they are on the same horizon. If so, the bulk of the Mikindani beds would be earlier than the oldest beds in the Dar-es-Salaam bore.

The latest beds on the coast are estuarine silts, sand-dunes, and raised coral reefs, all of which may be safely included in the Pleistocene.

THE RIFT VALLEY IN GERMAN EAST AFRICA

1. *The Rocks Traversed.*—The Rift Valley has now been traced across G.E.A. from the British frontier to the depression of Kilimatinde, though for part of its course its eastern wall is ill defined. It

traverses the plateau of granites, gneisses, and schists which form the main mass of G.E.A. These primeval rocks are covered in places by Archeozoic quartzites, which though steeply tilted some distance away from the Rift Valley are horizontal or slightly inclined where they occur in its walls at Lakes Eyasi and Balangida. There are no rocks intermediate between these ancient quartzites and the volcanic series to define the date of the Rift Valley movements except for the Karroo beds of Lake Nyasa.

The volcanic rocks are less extensive than in B.E.A. The main volcanic area extends from Kilima Njaro westward to the Giant Caldron Mountains, and is cut through by the Rift Valley near Lake Manyara. Both N. and S. of this band occur isolated volcanic mountains, of which the chief are Gelei, Kitumbeine, and Ngai to the N., and Ufiome and Gurui to the S. To the N.W. of Gurui is the group of Bossutu crater lakes, occupying small depressions in volcanic tuffs. S. of Gurui is a long area without volcanic rocks, which occur next along the Rift Valley on its floor N.W. of Lake Nyasa.

Lake Tanganyika is devoid of volcanic rocks, but they are extensively developed N. of it in the Western Branch of the Rift Valley around Lake Kivu. Along the eastern side of Lake Tanganyika is an extensive area of the Archeozoic Tanganyika Sandstone.

The only fossiliferous rocks in the Western Branch of the Rift Valley, or which are known *in situ* beside Lake Nyasa, belong to the Karroo Series. They indicate that the Rift Valley movements are all later than the Karroo, though Studt (1914, pp. 74, 95) regards them as earlier than these rocks, which he regards as having been deposited in depressions formed by down-faulting.

The oldest volcanic rocks in G.E.A. traversed by the Rift Valley are the tuffs and lava of the plains, which extend from the south-western foot of Kilima Njaro for 150 miles westward to the Zerengeti Plains, and southward to Gurui. The rocks include basalts, trachytes, and trachytic tuffs, and probably correspond to the Laikipian Series of B.E.A. They now form treeless plains, while the volcanic centres have been worn down and left only as low, blunt hills.

2. *The adjacent Volcanos.*—The volcanic mountains around the Giant Caldron Mountains, some of which have been built up on the Zerengeti tuffs, and the majestic cones of Kilima Njaro and Meru belong to a later eruptive period and include kenytes and nephelinites. Some of these lavas are comparatively recent, and belong to the same stage as the tuffs of Doinyo Ngai, the only still active volcano in

G.E.A. (apart from those of the Kivu district) and the most active along the eastern branch of the Rift Valley. It has been well described by Reck (1914 (3)). It was emitting "a column of smoke" when Fischer (1884, pp. 85, 86; 1885, p. 208) passed it in 1883. The specimens he collected from the mountain were determined by Mügge (1885, pp. 252, 259, 262) as nephelinite, melilite-basalt, and sanidinite. Those collected by Kaiser (1898, p. 321) during the Schöller expedition were determined by Künzli (1901, pp. 148, 151) as nephelinitoid-phonolite and as a variety intermediate between nephelinite and nepheline-tephrite; and Kaiser (1898, p. 321) described tuffs rich in mica as resting at the foot of older eruptions of nepheline-basalt.

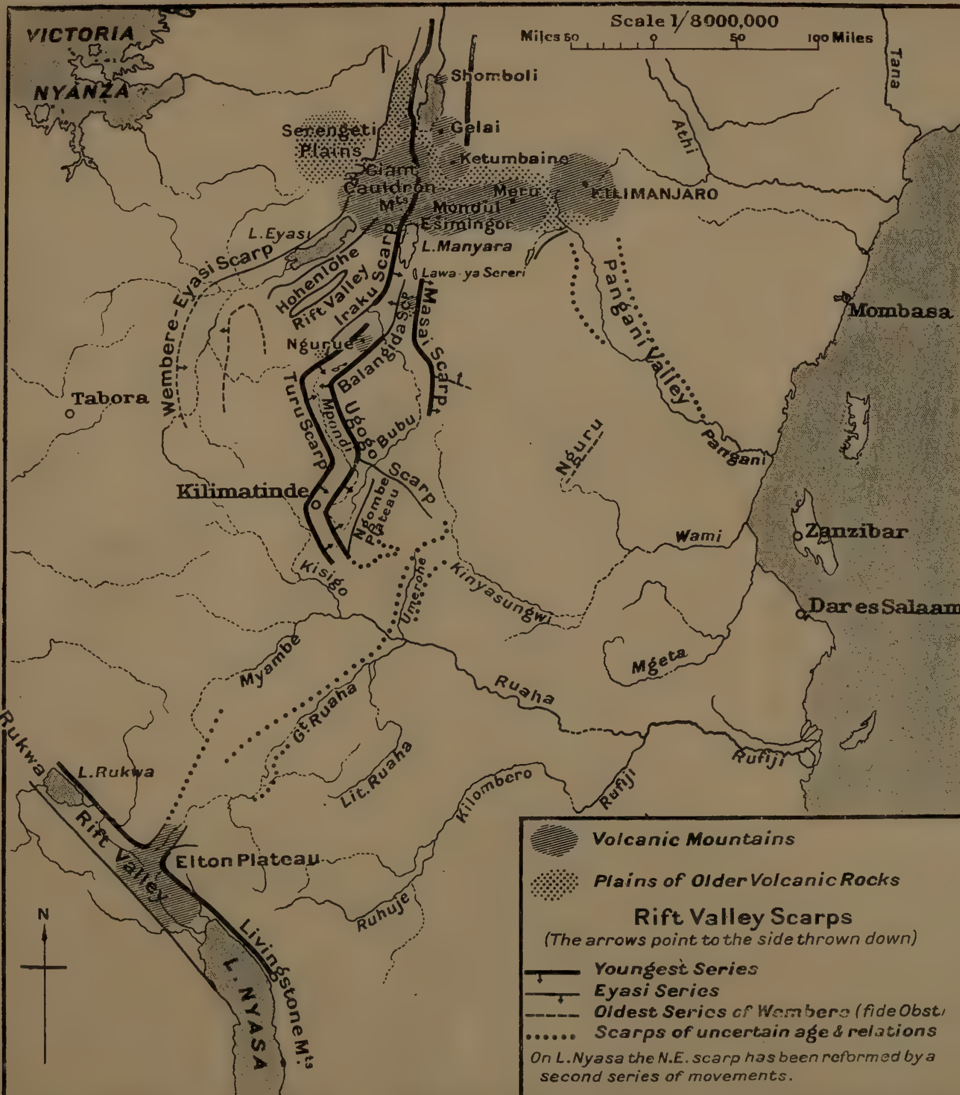
The eruption of Doinyo Ngai, of which the fullest evidence is available, was from January to June, 1917 (Hobley, 1918, pp. 339–343). It was seen from Mount Meru, 50 miles to the E. It covered the country for miles around with a pall of gray volcanic dust. The Masai were so alarmed that to appease the disturbed spirits of the volcano their women sacrificed animals and poured calabashes of milk on its slopes. According to Mr. Hobley, the ejecta from the volcano was rich in some soda salt, and some of the ash discharged in 1917, which was sent by Major E. D. Browne to Mr. Hobley, proves, on chemical examination by Miss Ethel Currie, to contain free carbonate of soda. Mr. Hobley (1918, p. 342) quotes the information given him by Kaiser, who ascended Doinyo Ngai during the Schöller Expedition, that the white deposit on the upper part is soda.

Dr. Reck describes the material at the sinter field within the crater as a soda-mud, which when hardened projects in pinnacles (Reck, 1914 (3), pp. 400–401, Pl. XV, Fig. 2). Its nature is uncertain in the absence of analyses, but its soda is probably deposited by the hot springs. This origin is only possible for the soda in the tuffs collected by Major Browne if they included old spring deposits blown to dust by volcanic explosions. The free soda in the tuffs may be due to the silicate of soda in their nepheline being weathered into bicarbonate; and though that salt is soluble and would be washed down to the plains, as the reaction would be continuous and the bicarbonate constantly renewed, the upper part of the mountain might be left painted white. Doinyo Ngai, seen from Lake Magadi, certainly presents a remarkably white glint, and a white crust of bicarbonate of soda, though unusual, would involve no chemical impossibility.

3. *Course of the Rift Valley.*—The course through G.E.A. is irregular and zigzag, in marked contrast to its straight, simple direction across B.E.A. Its line is repeatedly deflected westward. It starts on longitude 36° E. at Lake Natron; it reaches as far W. as 33½° E. at the junction of the Ruaha and Rukwa Valleys; but along Lake Nyasa it has swung back and lies between 34° and 35° E. This eastward return at Lake Nyasa is one illustration of the influence by which the valley tends to resume its meridional direction. It returns eastward by right-angled bends, as just W. of Lake Balangida and again at Kilimatinde. The same factor may explain the position of the Ruaha Valley eastward of the line of the Rift Valley at Kilimatinde.

4. *The Pangani Valley.*—This same influence has probably caused the trifurcation of the valley in G.E.A. with now isolated branches to the S.E. and S.W. To the S.W., between Kilima Njaro and the coast, lies the deep valley of the Pangani River, which was described as a rift valley by Baumann (1894, p. 134). Jaeger (1913, pp. 16–17) remarks that its structure as a rift valley is not fully proved, but he apparently regards this interpretation as probable. The north-eastern wall of the valley is long and straight, and appears to be along a fault; but the south-western wall is irregular. The Pangani Valley is not improbably a rift valley of the earliest series, of which the walls have been very denuded.

5. *The Eyasi Rift Valley and Wembere Sunkland.*—From the Great Rift Valley two important branches trend off to the S.W. The larger includes Lake Eyasi (or Njarasa) and the Wembere Sunkland. The second is the smaller and shorter Hohenlohe Rift Valley, which includes Lake Yaido. The formation of the Eyasi depression by down-faulting was recognized by Baumann (1894, p. 134). It, and the adjacent district, are especially well known owing to the descriptions and discussions by Jaegar (1913) and Obst (1911–1913). The Eyasi-Wembere branch consists of two sections—the rift valley of Lake Eyasi, which trends south-westward from the volcanic hills of the Giant Caldron Mountains past the Iramba Plateau; there it joins the second section, the basin of Wembere, which trends N.–S. The two form a closed basin which at Lake Eyasi is 3430 ft. above the sea. It may once have continued north-eastward to the site of the Rift Valley near Lake Natron (2030 ft.), from which it has been cut off by the volcanic eruptions that have filled up the north-eastern end both of this valley and of the Hohenlohe Rift Valley.



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Sketch Map of the Rift Valley across (formerly) German East Africa.

The volcanic rocks include kenyte, alkali-trachyte, nephelinite, nepheline-basanite, limburgite, etc. (Finckh, 1911, pp. 78–81). The volcanos are all extinct, but a mud volcano is reported by Obst (1911, p. 11) near Lake Eyasi.

After Lake Eyasi was thus closed to the N.E. its waters rose higher than their present level. Stuhlmann and Kunst suggested that it had an outlet north-westward to the Victoria Nyanza at Smith Sound; but neither Jaegar (1913, p. 89) nor Dantz found any lake deposits sufficiently high above these lakes to prove the former continuity of their waters. The reduction in area of Lake Eyasi is due to long-continued evaporation, and its waters are now very salt (see, for example, analysis, App. X, No. 4). Common salt (sodium chloride) constitutes 83 per cent of the salt, and is probably derived from the neighbouring volcanic materials.

The basin of Lake Eyasi is bounded by two parallel scarps composed of crystalline rocks, including granite, gneiss, and schist, with some Archeozoic sandstones at the eastern end. The north-western wall of Eyasi is a well-marked scarp 3000 ft. high; it is clearly displayed in the photogravure of the lake by Jaeger (1913, opp. p. 78). The opposite wall rises only to 1330 ft. and is intensely dissected at its south-western end. Kunst therefore regarded the two walls as of different ages, the south-eastern being the older. Jaeger, however, points out that the difference in age is not between the opposite walls, but between different parts of the same wall. The northern ends of the scarps both of Eyasi and of Wembere are higher and better preserved than the southern parts. Jaegar attributes this difference to the rejuvenation of the walls by earth movements, which have uplifted the northern parts of the country more than the southern.

Obst (1912, p. 126) also attributes the difference in the walls along the Eyasi Valley to their formation by dislocations at two long-separated dates, between which the walls were, to a large extent, planed down and denuded.

Lake Eyasi is separated from the Hohenlohe Rift Valley by the narrow Kidaro block-mountain, which is composed of gneiss and granite, with intrusive sheets of diabase. Lake Yaido has no outlet, but its waters are fresh; hence Jaeger (1913, p. 74) naturally concludes there must be a subterranean outlet. The walls are steep and well preserved, though especially the eastern wall has been much denuded; but its main faults appear to have been contemporary with those of Lake Eyasi. The Wembere Sunkland is bounded at its western end partly by granite and partly by the diorite, which includes the Sekenke gold mine. The eastern wall is formed by the plateau of Iramba, which rises from 665 ft. at the S. to 1330 ft. at the N.; an exception to the rule in this district is the lower western wall. The Iramba Scarp appears to have been renovated by a second series of earth movements, which from their trend and the freshness of the scarps were probably contemporary with those of the Great Rift Valley. The main depression of Wembere appears, however, to be much older. It is a wide, shallow basin; according to Obst (1912, p. 126), the faults that caused it were formed either at the end of the Paleozoic or at least early in the Mesozoic; but according to Kohlschütter (1901, p. 147) the western wall of Wembere, though only 100 ft. high, is "sehr deutlich ausgebildet," and the great age assigned to it seems doubtful.

6. *The Main Valley.*—Between the branch rift valleys of the Pangani and Lake Eyasi the Great Rift Valley goes S. through the basins of Lakes Natron and Manyara. The western wall remains high and sharp; but the eastern wall becomes indistinct and is replaced by gentle slopes. Prof. C. Uhlig, of Tubingen, describes the Manyara basin as not in a rift valley, but as lying at the foot of a fault-step (Bruchstufe). He regards the Manyara basin as due to subsidence along a single fault, and not between a pair of faults. This structure seems, however, to be only the extreme development of the asymmetry of the Magadi type (*v.* p. 179). The wearing down of the eastern steps at Magadi into a continuous slope would produce there the same appearance of a single scarp to the W. rising above the end of a long descent on the E. This eastern slope has been made over faulted ground; for faults, though now inconspicuous, are marked on it E. of Manyara on the map by Jaeger (1913, Map V). The Manyara basin is part of the Rift Valley where a block appears to have sunk unevenly; the western edge of the block has been downthrown 2100 ft.; while the eastern side sank along a succession of small faults, the sunken block has been tilted by the unequal subsidence. This structure[6] occurs to the W. of the great volcanic chain which includes Kilima Njaro, Meru (14950 ft.), and Essimingor (7550 ft.) (see Gregory, 1920, Fig. D, p. 24).

This Manyara structure does not continue far; the eastern boundary of the Rift Valley soon again becomes distinct. S. of Lake Lawa-ya-Sereri it is an abrupt scarp, and the Rift Valley proceeds as a normal trough past Lake Balangida to the basin of Kilimatinde.

Dr. Holmes has pointed out the same asymmetry and gradual disappearance of the eastern scarp, as at Manyara, in the rift valley of the White Nile. It is bounded at the Albert Nyanza by a pair of scarps of which the western is the higher. Dr. Holmes remarks (1916, p. 150): "The two walls of a rift valley rarely die out together." His sections (*ibid.*, pp. 152–153) show that, proceeding northward, the eastern side of the Rift Valley in the Bahr-el-Jebel (White Nile) is a long, gradual slope, and that still further N. the Nyiri and Kuku scarps on the western bank of the Nile rapids are well marked, while on the eastern side the valley is bounded by a low and gentle slope.

Between Kilimatinde and Lake Nyasa the continuity of the Rift Valley is unproved. Suess left a gap in the Rift Valley of 350 miles between Lakes Manyara and Nyasa; and O. E. Meyer (1912, p. 4) remarks that the great tectonic valley which extends from Palestine to central G.E.A. ends there in Ugogo at about 6° 35′ S. The long gap accepted by Suess has, however, already been reduced, according to O. E. Meyer (1915, Pl. XXXIV), to about 20 miles in the Kisigo Valley and about 60 miles along the lower Ruaha; and there is evidence that the Nyasa basin is the tectonic continuation of the eastern branch of the Great Rift Valley, and not of the western branch. The extension of the Rift Valley has been established S. beyond Kilimatinde, and the main gap is in the Ruaha Valley, which most of the German authorities (e.g. Dantz, 1900, No. 2, p. 126; Kohlschütter, 1901, p. 145; Koert, 1913, p. 208; Uhlig; Jaeger, 1913, p. 160; and O. E. Meyer, 1912, p. 4; 1915, p. 853) describe as a "Graben" (i.e. a rift valley).

Elton's map (1879, after p. 417) represented the Ruaha Valley as lying between a series of parallel scarps to the N.W. and what is now known as the Elton Plateau. The maps in Bornhardt (1900, Map IV) and those by Dantz (1900) show a rift valley with well-marked faults branching from the Nyasa-Rukwa Valley and going north-eastward to the Ruaha Valley. Dantz (1900–1902, p. 126) attributes the sudden projection of the southern wall at Madabira to a cross-fracture (Querbruche). It is true that the last official map of the area (G.E.A., 1 : 300,000, sheet Iringa) does not show well-marked scarps along Dantz's faults; but this sheet is sketchy and incomplete, and it may afford less insight into the structure of the country than the impressionist maps of Elton and Dantz. Scholz (1914 (1), p. 54) confirms them by representing the S.W. face of the Elton Plateau as a worn back fault-scarp.

The only remaining gap in the Rift Valley is between the Ruaha Valley and the end of the well-defined rift valley in Ugogo. The topographic maps give no indication of trough faulting along the line between them; but O. E. Meyer (1915, pp. 831–833, Pls. 34, 35) shows a fault continuing that of the left wall of the Ruaha Valley north-eastward towards Mpapwa, and also a fault along the Kisigo River running N.W. from its confluence with the Ruaha and ending about 20 miles from the Ugogo Rift Valley. This fault line is parallel to the diagonal series, by which the course of the Rift Valley between Lake Manyara and Kilimatinde is repeatedly deflected to the S.E. These diagonal faults are doubtless due to the earlier Rift Valley subsidences; and along the valley of the Kisigo River the fault scarps have been so denuded as to be no longer direct topographic features.

The zigzag and irregular development of the Rift Valley in G.E.A. may be explained by the influence of the diagonal N.E.–S.W. fractures, which ruptured the country earlier than the formation of the N.–S. faults (*cf.* Chap. XXXII, p. 375). These diagonal fractures were probably contemporary with the formation of the East African coast and separation of Madagascar during one of the chief subsidences of the western division of the Indian Ocean. The coastal front of the East African plateau has been so denuded that its faults are often obscure and no longer coincide with the slopes. Similarly the diagonal scarps in the interior, unless revived by later faulting, have been worn down into curved hill-sides, and the fault lines have been left in front of them and buried by talus and alluvium.

The continuity of the Rift Valley movements across southern G.E.A. from Kilimatinde along the Kisigo and Ruaha Valleys to Lake Nyasa seems most probable; but these movements were Oligocene in age. Their scarps have therefore been converted into denudation slopes, and were not renewed as scarps by the Pliocene and Pleistocene faulting, which passed W. of this area along the Rukwa Valley to Tanganyika.

[1] Jahnke, in 1896, found gold in the quartz veins in these rocks at Usindya, S. of the Victoria Nyanza. Dantz also found gold in them N.E. of Lake Nyasa.

[2] Fossil leaves from the Rufiji are figured by Potonié, in Bornhardt, 1900, p. 502, as "Wohl *Glossopteris*."

[3] According to Behrend, 1918, p. 110, this coral limestone is Lower Oxfordian.

[4] The comparative size of Gigantosaurus and man are shown by a figure in Gregory, *Geology of To-day*, 1915, opp. p. 258. The general distribution of these Cretaceous giant reptiles, and an account of the country in which they occur, has been given in a popular work by Hennig (1912).

[5] There has been great difficulty in obtaining a copy of this work (see Bibliography : Branca), and the only copy, so far as I know, in the country is not complete. For some time I only knew the results from the excellent summary by Dr. Schuchert in the *Bull. Geol. Soc. Amer.*, XXIX, pp. 264–280.

[6] According to Uhlig (1907, pp. 501, 503) overthrust faulting occurs in this district; but the evidence is indefinite and Jaeger (1913, p. 161) remarks that any such action can only be local. Krenkel (1910, p. 270) dismisses the overthrusts as " Kaum haltbar.")

CHAPTER XXVI

Lake Nyasa & the Southern End of the Rift Valley

LAKE NYASA is the southernmost of the great fiord-like lakes of Africa, and its relation to the main structural lines of the continent are shown by its parallelism to the eastern coast from Cape Delgado to Mozambique. The main trend of the African coast of the Indian Ocean is from about N.N.E. to S.S.W., which is followed by the eastern coast of Madagascar and the central line of the Mozambique Channel. The coast of the mainland follows a zigzag course, with three sections trending N. to S. (viz. those from Cape Guardafui to Ras Mabber, from opposite Zanzibar to Mozambique, and Sofala to Cape Corrientes), alternating with four sections trending from N.E. to S.W. (viz. Somaliland and B.E.A., Mozambique to Sofala, Cape Corrientes to Delagoa Bay, and Natal and Cape Colony). Lake Nyasa, extending N. and S., is parallel to the coast E. of it, and is in line with that from Sofala to Cape Corrientes.

The country around Lake Nyasa is divided between six politically distinct territories. The western and southern end of the lake are in Nyasaland, W. of which is North-Eastern Rhodesia; to the N. and N.E. is the "Tanganyika Territory," or G.E.A.; E. of the lake is Portuguese East Africa; S. of the Zambezi the Rift Valley crosses Portuguese East Africa to the coast near Beira, and is bounded to the W. by the plateau of Southern Rhodesia. The chief tectonic lines of this area are shown on Fig. 42, p. 301.

I. Geological Structure

The chief authorities on the geology of this area are, for Nyasaland, Andrew and Bailey (1910); for North-Eastern Rhodesia, Molyneux (1909) and Studt (1914); for Portuguese East Africa N. of the Zambezi, Holmes and Wray (1912), Holmes (1916, 1917), and Wray (1915); S. of the Zambezi to the Sabi, Teale and Wilson (1915); for the area between the Sabi and the lower Limpopo, Erskine (1875 and 1878), and A. Freire d'Andrade (1894).

1. *Eozoic Foundation.*—The foundation of the whole region consists of Eozoic rocks, some of which are igneous in origin. The Eozoic rocks are mainly gneisses and schists. The characteristic rock is a gray biotite-gneiss, like that of B.E.A. ; it is associated with graphitic-gneiss, kyanite-gneiss, garnet-amphibolite, granulites, and crystalline limestones, which resemble those of the Taita and Ulu Mountains of B.E.A. The gneisses appear to be mainly altered sediments, with intrusions of granite and syenite, many of which have been foliated. The rocks have been described by Andrew and Bailey (1910, pp. 190–195). Dr. Holmes has given a classification of those in Northern Portuguese East Africa (1917, pp. 90–91), and supported their identification as early pre-Cambrian by observations of their ratio of lead to uranium. According to Dr. Holmes' classification (1917, p. 90), the oldest series in Mozambique includes biotite-gneiss, hornblende-gneiss, garnetiferous-gneiss, amphibolite, eclogite, mica-schist, hornblende-schist, hæmatite- and quartz-magnetite-schist, limestone with forsterite (a variety of olivine), and crystalline limestones.

This series was followed by intrusive rocks, including biotite-granite, pyroxene-granite, diorite, pegmatite, aplite, etc., dating from the Middle Eozoic. This series was succeeded later, though probably still in Eozoic times, by intrusions of later biotite-granites, coarse pegmatites, and quartz veins. Some ultra-basic dykes (picrites and pyroxenites) in the Mozambique district are of unknown age.

The Archeozoic Group is represented to the N.E. of Lake Nyasa, in the lofty Kinga Mountains, by mica-schists, phyllitic-slates, and clay-slates, similar to those of the Karagwe Series W. of the Victoria Nyanza ; and also by unfossiliferous quartzites, felspathic sandstones, schistose flags, and thin, phyllitic bands which form the Mafingi Mountains, about 40 miles W. of the northern end of Lake Nyasa. This quartzitic division is about 10,000 ft. thick ; the beds dip steeply, 40° to 70° N.W., and have in places been inverted ; their general trend is N.E.–S.W. Where the Archeozoic rocks are horizontal they give rise to flat-topped hills, as described by Bornhardt (1900, p. 460) for the area N.E. of Nyasa. N. of Lake Nyasa the Archeozoic sandstones were described by Elton (1879, p. 335) and Thomson (1881, I, p. 315).

Rocks which probably belong to the Archeozoic Group are well developed in Portuguese East Africa in the Sabi district, where, 130 miles W.S.W. of Beira, their associated intrusive dolerites form the Spungabera Series of Teale and Wilson (1915, p. 24). Some unfossiliferous sandstones in southern Portuguese East Africa may also be Archeozoic.

2. *The Karroo System.*—The oldest fossiliferous rocks in the Nyasa area belong to the Karroo System; they are commercially important, as they include coal seams, which are of especially good quality at Mount Waller. Andrew and Bailey classify the Karroo rocks of Nyasaland into three divisions—a lower division, 1000 ft. thick, of sandstones and conglomerate; a middle division, 200 ft. thick, of shales and mudstones with coal; and an upper division, 3000 ft. thick, of grits with fresh-water limestones. The middle division contains the fossil plant *Glossopteris;* the limestones of the upper division (at Nkana and Mpata, in the extreme N. of Nyasaland) contain the fresh-water shell *Palæomutela oblonga* (T. R. J.) and teeth and scales of the fish *Colobodus africanus* (Traq.), *Acrolepis* (?) *drummondi* Traq., etc. Stromer von Reichenbach found fossil fish teeth (*Acrolepis* or *Gyrolepis*) and a lamellibranch in these limestones (Bornhardt, 1900, p. 462). Interstratified in the sandstones of the upper division, beginning some 20 miles W. of Port Herald in the lower Shire district, are basaltic lavas, with andesites and rhyolites, and dykes of quartz-porphyry; as the lavas are interstratified with the upper sandstones, they are assigned to the Upper Karroo.

The Nyasaland Karroo beds extend into G.E.A.; to the E. of the Nyasa they occur (Bornhardt, 1900, p. 461) in the valley of the Ruhuhu, and on the opposite side of the lake in the basin of the Songwe and Kivira rivers. On the Ruhuhu the coal series is 260 ft. thick; but the coal seams are thin and valueless. N.W. of the lake the coal is more useful, as the seams are from 6–16 ft. thick.

The preservation of the Karroo beds near Lake Nyasa is mainly due to their having been lowered by faults into the foundation of gneiss. The faults which intersect the Karroo beds trend in all directions and are quite independent of the Rift Valley faults, a fact well shown at Mount Waller (*cf.* map by Andrew and Bailey, 1910, p. 214).

The Karroo System does not appear to be represented in Portuguese East Africa N. of the Zambezi; but S. of the river it is known near Tete, where it was investigated by a French expedition in 1882, and was described by Guyot (1882), Lapierre (1883), Zeiller (1883), and Kuss (1884). The age of the beds at Tete is definitely determined as Carboniferous by Zeiller's identification of their fossil plants, which belong to the *Glossopteris* flora. The Karroo beds also form a small outlier S. of the Spungabera highlands, and they are well known in the coalfields of Rhodesia.

3. *Mesozoic*.—The marine Jurassic beds so well developed in B.E.A. and G.E.A. are not known to occur anywhere in Africa S. of the latter territory. By the Cretaceous Era the sea had reached South-Eastern Africa in Cape Colony and Natal, behind Delagoa Bay (where the Aptian was described by Kilian, 1902), and in Northern Mozambique, where the Lower Cretaceous Makonde beds of G.E.A. extend across the Rovuma into Mozambique. The most instructive marine Mesozoic rocks between the Rovuma and Natal occur near Mozambique, where they include Neocomian, Aptian, and Cenomanian. At Fernão Vellozo or Masamima Harbour are limestones and shales from which Holmes and Wray (1912, p. 415) obtained a series of Neocomian fossils with affinities to those of the Uitenhage beds of South Africa. Peters, in 1843, found at Conducia Bay an Ammonite which was described by Neumayr (1885, p. 139, Pl. I, Fig. 2) as *Phylloceras semistriatum* Orb., and therefore of Neocomian age; the specific identification was confirmed by Zwierzycki (1913, p. 325). Above these beds are some sandstones which form the flat-topped hill of Mount Meza, 1000 ft. above sea-level; these are referred by Holmes and Wray to the Aptian and Albian. Above them are the Conducia beds, that have yielded the remarkable horned ammonite, *Pachydiscus conduciensis*, described by Choffat (1903); the beds are assigned to the Lower Cenomanian. Choffat remarked the affinities of the fauna to that of Southern India, so that the Cenomanian, as well as the Neocomian seas probably advanced on to southern East Africa from the S.E. Near Lake Sofala, further S. in Portuguese East Africa, occur Cenomanian beds, underlying Turonian. At Sena, for about 80 miles upwards along the Zambezi, Teale and Wilson record the presence of Cretaceous; and still further S. in Portuguese East Africa the presence of Upper Cretaceous in the Buzi River, near Sofala, was proved in 1896 by Mr. R. B. Newton (1896 (2)), who identified the fossil oyster *Lopha ungulata* (Schlot.), collected there by Draper.

4. *The Marine Kainozoic*.—The marine Kainozoic beds in this part of Africa occur at intervals along the coast, and extend inland via the Zambezi Valley up to the Rift Valley and perhaps along it. Eocene and Lower Miocene beds are known near Mozambique. Some coral and foraminiferal limestones thence were assigned by Sadebeck (1879, p. 36) to the Oligocene or Upper Eocene. Sadebeck was not

definite in this opinion; but from his identification the later lavas have been regarded as post-Oligocene. On referring the matter to Mr. Newton, he informs me that Sadebeck's evidence is no proof of Oligocene beds in Mozambique, and he considers that the beds in question are probably Eocene.

The presence of marine Lower Miocene at Chandane, on the coast of Mozambique, is shown by Priem (1907, pp. 77–79), who identified thence fish teeth belonging to ten genera, including *Carcharodon megalodon* Ag., *Hemipristis serra* Ag., and *Sphyrna prisca* Ag., which are characteristic Miocene species.

S. of the Zambezi Mr. R. B. Newton (1896 (1)) has recorded the Eocene from 100 miles W. of the mouth of the Buzi River, from Nummulites collected by Draper; and Lower Eocene beds have been found by Teale and Wilson (1915, pp. 29, 33) to form the western scarp and foundation of the Sheringoma Plateau, which is the eastern edge of the Urema Rift Valley. Their age has been fixed by Mr. R. B. Newton's determination of one fossil as the nautiloid *Hercoglossa diderrichi* Vinc., a species from the Lower Eocene of the lower Congo.

The limestones collected by Teale and Wilson (1913, p. 43) at the top of the Sheringoma Plateau were provisionally identified as Miocene; but further investigation has led to the identification of the contained foraminifera as Eocene, and there is now no evidence of any Oligocene or Miocene marine beds in Portuguese East Africa.

Reymond (1886, p. 39), on the evidence of some fossils collected by Giraud at Iendwe, near Mpata (some miles N.W. of the northern end of Nyasa), which he identified as "Cyrènes" and teeth of the fish *Lepidosteus*, regarded the beds as Nummulitic (i.e. Eocene) or Upper Cretaceous. But they are probably estuarine deposits belonging to the Upper Karroo.

5. *A Fossil Sea-Urchin.*—No marine beds have been described from the Nyasa basin; but the Geological Department of the British Museum contains a fossil sea-urchin (E 2419; figured on Pl. IV, Fig. B, opp. p. 39), *Echinolampas discoideus* Arch. and H., which was presented to the Museum by a missionary whose name was not recorded. The locality on the label is recorded as "Lake Nyanza," and which lake was intended would be uncertain but for the date and the specimen having been brought back by a missionary. The name naturally suggests the Victoria Nyanza; but the first missionaries only arrived there in 1877, and the only member of that party who

lived to return was Wilson. He came back for a visit in 1880, but it is almost certain that he was not the donor of the specimen. It was probably presented to the Museum before 1880, as it was re-registered in 1889 as from the "Old Collection."

British missionaries had, on the other hand, reached Lake Nyasa as early as January, 1861 (D. and C. Livingstone, 1865, p. 348), and the Scottish mission has been working there since 1875 (H. H. Johnston, 1898, p. 66), so that the date is consistent with the specimen having been brought from Lake Nyasa. The spelling Nyanza on the label was probably due to the missionaries at first using that form of the name. Sir H. H. Johnston remarks (1898, p. 61) Nyasa is the Yao form, "but the most common appellation is Nyanja." Livingstone is responsible for the general adoption of Nyasa, but in his correspondence (e.g. 1861, p. 263) he spelt it Nyanja. The name Lake Nyanza has never been commonly adopted for the Victoria Nyanza, which has been either so-called to distinguish it from the Albert Nyanza or Lake Victoria.[1]

The specimen is well preserved and is either identical with or very nearly allied to the *Echinolampas discoideus* Arch. and H., from the Upper Oligocene beds of Western India. In 1896 (G.R.V., pp. 229–231) I mentioned the specimen briefly, in the hope that others would be found and give more precise evidence as to the locality. I referred to it as an Eocene fossil, as it was then impossible to separate the East African Oligocene from the Eocene. After consultation with Dr. A. S. Woodward, to whom the specimen was given and whose recollection of its presentation to the Museum was quite distinct, I felt bound to accept the conclusion that it came from Lake Nyasa, and that at least the southern end of that lake was reached in the Oligocene by an arm of the sea through the Zambezi Valley.

The possibility that the fossil might have been brought from India by some trader was duly considered; but its lithological character, colour, and structure do not agree exactly with those of the Indian specimens. This fossil has been discussed by Moore (1903 (1), p. 72, and 1903 (2), p. 683) and Blanford (1903 (1), p. 290, and 1903 (2), pp. 92, 94) in reference to the possible introduction of a marine fauna into Lake Tanganyika, a theory to which it gives no support.

So long, however, as this specimen of *Echinolampas discoideus* was the only one from Africa, its evidence was not free from doubt. But as the species has now been found on the coast of G.E.A. at Lindi (Scholz, 1911, pp. 371, 377), it is African as well as Indian. There is accordingly no reason to suspect the locality assigned to the British Museum specimen. It probably came from near Lake Nyasa: presumably from the lowlands of the Shire Valley or from the southern end of the lake.[2] It is not likely to have come from the adjacent plateaus, since no marine Oligocene or Miocene beds have been found at any considerable elevation above the sea in this part of Africa. If the identification as Miocene of the limestones which cap the Sheringoma Plateau had been maintained, the Urema Rift Valley, and probably also its northern extension along the Nyasa and Shire would have been post-Miocene. The extension of an Oligocene bay into this part of the Rift Valley would then have been improbable; but as the faults at Sheringoma may be as early as the end of the Eocene the evidence from that district is consistent with the Oligocene age of the earlier Rift Valley faults and with the occupation of the southern end of the Rift Valley by an Oligocene sea.

6. *Kainozoic Volcanic Rocks.* — Widespread volcanic rocks, including basalts, andesites, trachytes, and tuffs, occur to the N. of Lake Nyasa (*cf.* p. 275). These rocks are Kainozoic and probably belong to a late part of the Kainozoic Era. The lavas themselves do not extend into Nyasaland; but some patches of tuffs with pebbles of trachyte and phonolite in the Nkana Valley and near Chungu are the remnants of a sheet of tuff of this period (Andrew and Bailey, 1910, p. 222). On the northern coast of Portuguese East Africa, Holmes and Wray (1912, p. 416) record basaltic lavas for 20 miles to the northwards of Mokambo Bay; with the lavas are dykes of dolerite. The basalt contains no olivine, which is replaced by rhombic pyroxene. The lavas have altered the Cretaceous rocks and overlie Lower Eocene beds; so they are clearly later than the Lower Eocene. In the Zambezi Valley a band of volcanic rocks from 8 to 10 miles wide is cut through by the Zambezi at the Lupata Gorge, about 40 miles down the river from Tete (see Teale and Wilson, 1915, Fig. opp. pp. 25 and 31).

II. The Structure and Age of the Nyasa Basin and its Southern Continuation

1. *Lake Nyasa.*—Lake Nyasa being the most accessible of the long, narrow African lakes is the best known. It was the second to be reached by European explorers, the visit of Livingstone and Kirk in 1859 having been preceded only by that of Burton and Speke to

Tanganyika in 1858; but Nyasa was the first African lake to be explored. It has been the seat of mission work since 1861, and its basin includes the oldest British Protectorate in East Africa.

The lake is 360 miles long by from 15 to 20 in breadth; its normal level above the sea is taken as 1645 ft., its depth is as much as 2316 ft.; hence the floor sinks 671 ft. below sea-level. The water is fresh, an outlet being usually maintained through the Shire Valley into the Zambezi; but when the level is low the discharge ceases and the upper part of the Shire is reversed and flows northwards into the lake.

That the trough of Lake Nyasa was formed as a rift valley seems indisputable. The lake is bounded by steep, high cliffs. The lake basin is obviously due to the subsidence of the block which once occupied it. Andrew and Bailey (1910, p. 234) have referred to the possibility of its formation by erosion; but they reject this view and conclude: "Taking all the facts into consideration, there seems to be no doubt whatever

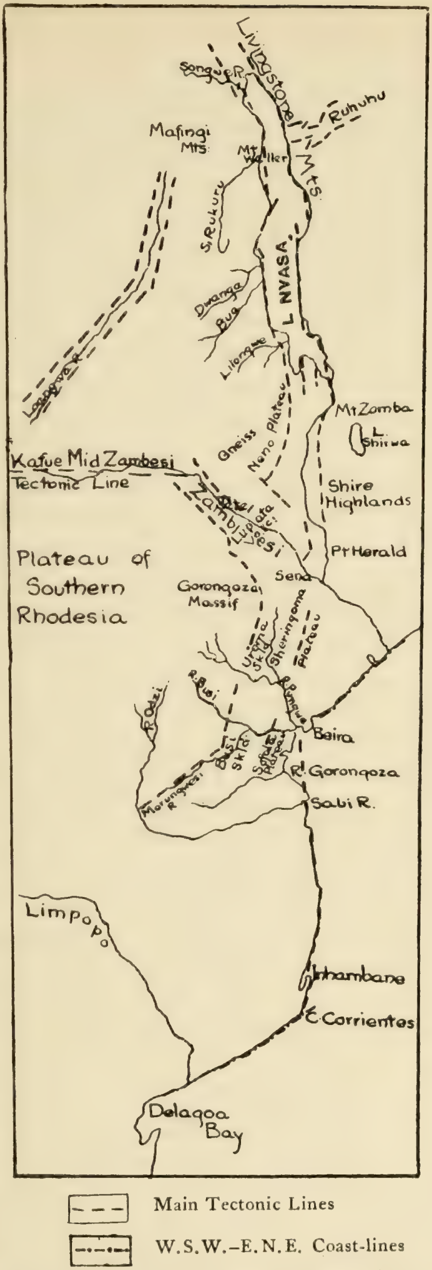


FIG. 42.—The Tectonic Lines of the south end of the Great Rift Valley. Scale, 1 inch = about 206 miles.

that the Nyasa trough originated in, and has subsequently been developed by, earth-movements."

According to these authors, the steep faces of the plateaus are fault fractures, and some of the plains beside the lake (e.g. the coast plains behind Kota-kota) are platforms due to step-faults. The front of the Livingstone Range along the eastern shore of the lake is due to the eastern boundary fault ; but along its north-western side the lake is bounded by a platform which slopes into the lake and may continue eastward under it to the sub-lacustrine foot of the Livingstone Range; so Andrew and Bailey (1910, p. 234) suggested that " the fault running along the western side of the Rift Valley is deflected westwards, while the eastern fault continues along the edge of the Livingstone Range." The faults generally trend N. and S., but they suffer local deflections or die out for a space.

S. of Lake Nyasa the southern extension of the Rift Valley is less evident. The Shire Valley, by which the overflow from Lake Nyasa is discharged to the Zambezi, is also part of the Rift Valley and due to down-faulting of its floor between the Shire Highlands to the E. and the Neno Plateau (gneiss) and lava hills of Kansembi to the W. (Andrew and Bailey, 1910, p. 216).

2. *The Age of the Shire Valley.*—In connection with the possible extension of the sea up the Shire Valley it is necessary to remember the suggestion that it was crossed by a barrier several hundred feet higher than the present floor of the valley. This hypothesis was proposed to account for the beaches, 400 ft. and even 700 ft. above the present lake level, at Masiunjuti, 15 miles from the lake, N. of Mount Waller. Conglomerates and marls at these levels contain fossil shells of *Viviparus*, a mollusc still living in the lake. Mr. R. B. Newton (1910, p. 240) has pointed out that the recent limestones at Chisali indicate that the lake extended at least 15 miles to the N.W. of its present end. The high-level beaches have been broken by faults with a displacement of as much as 100 ft. The quite recent earth movements which made these faults may explain the position of the high-level beaches, and the assumed high barrier across the Shire Valley is unnecessary (Andrew and Bailey, 1910, p. 224).

3. *The Urema Sunkland.*—The extension of the Great Rift Valley to the S. of the Zambezi has been described in two valuable papers by Teale and Wilson (1915) and Teale (1915). These authors have shown that S. of the Shire Valley the Rift Valley is continued by the Urema Valley between the Sheringoma Plateau to the E., and

the Gorongoza Massif to the W. The eastern boundary of the Urema Valley is shown by Teale (1915, Oct., p. 283) to be certainly due to a fault. The evidence regarding the western wall is inconclusive; the floor of the valley ends against the rugged and precipitous wall of the Gorongoza Massif (Teale and Wilson, 1915, p. 26), which is composed of syenitic plutonic rocks. The massif rises nearly 6000 ft. above sea-level and nearly 4000 ft. above the surrounding country. It receives a good rainfall, and so its southern and south-eastern slopes are covered by dense forest which makes exploration difficult. Teale and Wilson consider various explanations of its relations to the country at its foot; the conclusion which they adopt, and which was readvanced after further discussion by Teale, is that the boundary between the Gorongoza Massif and the Urema Valley is due to renewed faulting along an old tectonic line. This explanation certainly seems the most probable from the evidence available.

If so, the Urema Sunkland of Teale and Wilson is bounded on both sides by faults and is part of the Great Rift Valley. The later paper by Teale represents the probable extension of the Urema Valley beyond the Pungwe. Beyond that river the Sofala Plateau extends 50 miles southward; its western edge rises 500 ft. above sea-level, and it ends in a limestone cliff which overlooks the Buzi Sunkland. Mr. Teale, from the close resemblance of this cliff to that of Sheringoma and from their occurrence on the same line, concludes " the Buzi-Sofala Scarp is therefore tentatively regarded as of fault origin " (Teale, 1915, Oct., p. 258). The Sofala Plateau is about 500 ft. high, whereas that of Sheringoma is 1000 ft.; so Teale concludes that the dislocation dies out to the S., " merging into the sandy gravel-capped lowlands of the Sabi basin."

The western wall of the Buzi Sunkland bends westward along the fault which bounds the Spungabera Mass and forms the N.W. bank of the Morungwesi River; by this trend to the S.W. that wall becomes parallel to the coast from Mozambique to Beira and to Molyneux's great fault along the Loangwa.

This westward deflection of the southern end of the Rift Valley illustrates the tendency, manifested so often along its course, to bend or give off branches to the S.W. A remarkable example of this tendency is the departure from the northern end of Nyasa of the Machinga or Loangwa Fault of Molyneux; this fault has a downthrow to the S.E. of at least 5000 ft., and it forms the valley of the Loangwa and of the middle Zambezi, between about $15\frac{3}{4}°$ S. 29° E.

and the Victoria Falls. The trend and importance of this fault are probably due to the line of weakness on the north-western margin of the solid block of Southern Rhodesia.

A branch fault on the southern side of the Urema Sunkland may be indicated by the course of the southern coast of Portuguese East Africa from Beira to Cape Corrientes.

The breach of the Sheringoma-Buzi Scarp by the Pungwe Valley may be due to a branch fault that continues due southward.

4. *The Age of the Rift Valley Faults in Relation to the River System.*—The faults which dropped the Karroo beds of Nyasaland into the gneiss foundation are clearly post-Karroo ; but they are older than the Rift Valley, since at Mount Waller (Andrew and Bailey, 1910, p. 214) they are cut across abruptly and at various angles by the lake shore. According to Teale and Wilson (1915, p. 32), the faulting which formed the valley of the lower Zambezi began at the end of Karroo times and continued to Late Kainozoic. These faults probably date from the movements which in Jurassic times first admitted the Indian Ocean to the East African coast, and subsequently faulted the Jurassic and Cretaceous rocks against the Eozoic. These movements certainly began much earlier than those of the Rift Valley. The most direct evidence as to the age of the Nyasa subsidence, apart from the fossil *Echinolampas* (*v.* p. 298), is given by the rivers. The absence or smallness of their deltas, the sharp, unworn character of the cliffs along the eastern shore and especially of the Livingstone Range, and the character of the eastern rivers (except the Ruhuhu) afford clear evidence of the recent origin of the lake. These facts are conclusive as to the recent formation of the eastern wall. The western side is older as the deltas are larger ; and the rivers, such as the southern Rukuru and Bua, flow to the lake through deep gorges, and, as Andrew and Bailey remark (1910, p. 236), " they have been cut as a consequence of the formation of the Rift Valley and are clearly not the work of a day."

The striking differences between the rivers on the opposite sides are due to the eastern rivers rising near the edge of the Rift Valley and discharging eastward to the Indian Ocean. Similarly further S. on the Shire highlands the watershed is close to the Rift Valley, and the rivers flow down a long slope eastwards. The route adopted by some of the eastern rivers is shaped like a double fish-hook ; thus most of the country E. of the lake drains into the Rovuma. Some of its head-streams flow first westwards toward the lake ; they then run N. or S. parallel to it, and finally turn eastwards to the Indian Ocean. The Rufiji rises opposite the northern end of the lake, but flows away from it by a zigzag course to the Indian Ocean.

The eastern drainage from Lake Nyasa (with the exception of the Ruhuhu, which will be considered later) is, therefore, what would have been expected if the Rift Valley had originated in a low arch with the sides sloping to E. and W. The western rivers, as Andrew and Bailey have remarked, at first sight do not accord with this idea, since, instead of flowing away from the lake, they flow into it. These rivers show that the land W. of the lake has been disturbed by earth-movements later than the establishment of these rivers. Thus the Lilongwe, which crosses Nyasaland from S.W. to N.E., flows at first eastward down the general slope of the land ; but near the lake the ground rises into a ridge, through which the river has cut its way in a " shallow gorge." The river is older than this ridge. Similarly the Lilongwe, near its eastern end, has cut a " fine gorge " through the foot of the Vipya Mountains ; and the Bua flows from Fort Manning north-eastward across a plateau, from which it descends to the lake, N. of Kota-kota, through a short gorge.

The course of the western rivers may be explained by unequal subsidence of the top of the original Rift Valley arch. To the W., beyond the narrow highlands of Nyasaland, is the great depression of the Loangwa Valley in North-Eastern Rhodesia ; so that from the highest summits in Nyasaland (viz. the Nyika Plateau, N.W. of Mount Waller ; and further S., Mount Chongoni, nearly 8000 ft., in the highlands of Angoniland) and from the depression between 4000 to 5000 ft. high opposite the middle of the lake, there is a general descent to the W. The watershed, however, is much further from the lake than on the eastern side, and is separated by a belt in which the rocks dip toward the lake. The Nyasa basin is, therefore, asymmetric ; the eastern side is due to one main fault, with a throw of as much as 8000 ft. ; while the western part of the down-thrown Nyasan block was dropped in steps by parallel faults, with the steps sloping to the E. Hence some of the western rivers run easily to the lake. The upper part of the Lilongwe runs down the slope, but at its lower end it reaches a ridge left between two of the faults ; but as the river had its present course before the western ground had sunk it was able to cut through the ridge and maintain its course eastward.

The one exceptional Nyasan river is the Ruhuhu, which flows in a broad valley right through the Livingstone Range and enters the lake at Ngoma (Pangona). It rises a little W. of the meridian of 36° E., its eastern head-stream being the Mhangasi, from which a divide at the level of about 2900 ft. separates the Ruhuhu from the basin of the Luwegu, a tributary of the Rufiji. Many of the tributaries of the Ruhuhu start south-eastward from the Livingstone Mountains towards the Luwegu, but they appear to have been captured by the drainage to the Nyasa and thus reversed in direction.

The Ruhuhu, to the E. of the lake, continues the direction of the lower end of the South Rukuru, on the western side. The Rukuru no doubt once flowed at the level of 6000 ft. over a plateau which included the Nyika and the scattered summits of the Musambwe Mountains. From its source on this plateau the Southern Rukuru was able to cross the site of the lake and continue along the Karroo sandstones, which had been faulted down into the Livingstone Range, on to the plateau at the eastern part of the Ruhuhu basin and over it, at the level of 2900 ft., to the Luwegu, and thus to the Rufiji.

The Ruhuhu is one of the exceptional rivers which survive from the ancient E. and W. drainage across East Africa; it dates from before the earth-movements of the Rift Valley system.

[1] The adoption of the East African term "Nyanza" for Lakes Victoria, Albert, etc., has the advantage of distinguishing them from the numerous other synonymous lakes, such as the Lakes Victoria in Newfoundland, Quebec, Victoria, New South Wales, etc.

[2] Mr. Moore (1903 (1), p. 290; 1903 (2), pp. 92, 94) refers to the fossil as if reported from Northern Nyasaland; it probably came from the southern end of the lake.

CHAPTER XXVII

Madagascar

THE island of Madagascar is built up of a varied series of rocks which have yielded a rich fauna of fossils, and it has an extensive geological literature.[1] Its geology throws great light on the geological history of East Africa, and indirectly on the Rift Valley.

I. Parallelism of the Coast to the Mainland

The topographic outlines of Madagascar present a suggestive parallelism to the trend of the East African coast.

The long, straight, eastern coast of the island trends about 17° W. of S., roughly parallel to the general trend of the mainland from Cape Guardafui to Cape Colony. Its N.W. shore is almost parallel to the section of the coast from Mozambique to Beira ; the middle part of the western coast runs due S., parallel to the great tectonic line which passes along Lake Nyasa and is continued on the coast from Beira to Cape Corrientes. A third section of the W. coast trends S.S.W.

II. The East Coast Fault

That the eastern coast was determined by a fault is indicated by its remarkable straightness, by its independence of the grain of the land and of the transverse folds, by the frequency of earthquakes along it, and by its abrupt descent from the highlands to the ocean floor. According to Dr. Lemoine (1906, p. 235) : "La rectilinité absolue de la ligne de côte, qui paraît de plus en plus rigoureuse au fur et à mesure que les travaux géodésiques se font plus précis." The age of the fault is not earlier than Upper Cretaceous, as Middle Cretaceous beds lie along it, and it is probably still later.

III. The Geological Systems

1. *Eozoic*.—Madagascar consists of belts of rocks extending along the island from N. to S. The broadest belt, occupying about two-thirds of the total area, consists of Eozoic rocks—schists, granites,

etc.—similar to those of the mainland. Upon them rest volcanic rocks, including basalts and phonolites.

2. *Permian.*—The lower parts of the western slope include four sedimentary belts; the oldest, occurring at the N.W. end of the island, consists of Permian sandstones, which clearly belong to the terrestrial deposits of Gondwanaland, as they include such plants as *Glossopteris*, and fresh-water and estuarine shells, including *Planorbis* (R. B. Newton, 1910, pp. 6–10). The Permian age of these estuarine beds is proved by the fish (A. S. Woodward, 1910).[2]

3. *Jurassic.*—The western part of Madagascar includes a fairly full succession of beds from the Middle Lias to the Miocene. The beds are known by the work of many French geologists, including Grandidier, Lemoine, Haug, Douvillé, Boule, Lambert, and Grossouvre, and by the important collections made by the Rev. R. Baron and described by R. B. Newton.

The oldest Jurassic fossiliferous representatives belong to the Middle Lias. They include such characteristic Liassic fossils as *Harpoceras* cf. *serpentinum* (Rein), *Phylloceras heterophyllum* (Sow.), and *Rhynchonella* cf. *tetrædra* Sow.

Terrestrial Upper Liassic deposits are represented by sandstones with the stems of *Cedroxylon* and *Araucarioxylon*, which were at first assigned to the Trias, but have been shown by H. Douvillé (1904, p. 211) to be intercalated in the Upper Lias.

The Lower Oolites are represented by both the Bajocian and Bathonian Series. The Bajocian at Kahavo is characterized by *Trigonia costata* Park. and *Sonninia decora* Buckm., and other marine fossils; while at Andranosamonta the Bajocian beds are partly lagoon deposits and contain the crocodile *Steneosaurus baroni* R. B. N. The Bathonian at the northern end of the island includes a rich coral limestone, of which the corals do not appear to have been described; the main band in the western part of the island is a massive limestone with many cephalopods and other mollusca, including *Belemnopsis sulcata* (Mill.), *Nerinea bathonica* Sauv. and Rig., *Pholodomya ovulum* Ag., *P. angustatum* (Sow.), *Ceromya plicata* Ag., *Terebratula fimbria* Sow., and the undetermined corals.

The Middle and Upper Jurassic consists of a comparatively uniform series of clays and marls with some limestones, which are known at intervals along the western side of the island from Analalava (14½° S.) to Tulear (23½° S.). The chief variation consists in the development S. of the Betsiboka River (which discharges at Majunga) of yellow oolitic limestones similar to that of the Chari beds (Callovian) of Cutch in India. The Middle Jurassic is represented by these Callovian limestones along the Betsiboka River and around Lake Kinkony, which have yielded *Macrocephalites macrocephalus* (Schl.), *Cosmoceras* cf. *calloviense* (Sow.), and *Rhynchonella orbignyi* Oppel.

The Oxfordian is developed as ferruginous limestone along the Sakondry River with *Perisphinctes plicatilis* (Sow.), *Macrocephalites subcompressum* Waag., *Ostrea marshi* Sow., and *Pecten nummularis* Phil.

The Corallian and Kimmeridgian are mainly marls and clays with *Macrocephalites transiens* Waag. and *M. polyphemus* Waag., and it shows a less marked resemblance to the beds of the mainland, with which it is, however, connected by the presence of *Belemnites tanganensis* Futt.

The Kimmeridgian clays N. of the Betsiboka River have yielded various species of *Perisphinctes*, such as *P.* cf. *biplex* (Sow.), *P.* cf. *beyrichi* Futt., *Haploceras deplanatum* Waag., *Ceromya excentrica* Voltz, etc. Of these, *P. biplex* (Sow.) and *H. deplanatum* have been found in India. *C. excentrica* has been recorded elsewhere from East Africa only from Somaliland ; but *P. beyrichi* is a well-known species from Mombasa and G.E.A.

4. *Cretaceous.*—The Cretaceous System is less widely developed than the Jurassic, though almost the full succession is represented. The Cretaceous rocks occur in three chief areas—in a long belt extending southwards from Analava, on the N.W. bight nearly to the S.W. corner of the island ; at the northern end of the island around Diego Suarez ; and in some small but significant patches along the eastern coast. The horizons represented may be summarized as follows :—

Lower Cretaceous : Neocomian. The Neocomian is known at Beseva, near Majunga, from Belemnites collected by Baron and identified by R. B. Newton. Other Neocomian horizons are the beds near Analalava with *Hoplites neocomiensis* (Orb.), and those at Mævatanana with well-preserved Lower Neocomian Ammonites of species found also in South Africa, such as *Holcostephanus atherstoni* (Forbes), and *Trigoniæ*, also allied to those of South Africa.

Middle Cretaceous : Albian. The Albian occurs at Besarotra in the Sakondry basin, and in the Mavetanana district, where it has yielded large Ammonites, such as *Acanthoceras mamillatus* (Schloth.). Albian mollusca also occur at the mouth of the Manambolo.

Cenomanian. This series is widely distributed, as on the Sakondry River, where it was first found by Gautier; they are well developed at the northern end of the island near Diego Suarez, where they contain representatives of both the Lower Cenomanian ("Vraconian") and Upper Cenomanian. The fauna is varied, and includes *Anisoceras armatum* (Sow.), *Schlœnbachia propinqua* Stolicz., *S. inflata* (Sow.), *Phylloceras velledæ* (Mich.), *Desmoceras planulatum* (Sow.), *Acanthoceras rhotomagense* Defr., *Scaphites æqualis* (Sow.), *Inoceramus* cf. *concentricus* Sow., *Ostrea vesicularis* Lam., *Acteon ovum* Duj., etc.

Upper Cretaceous: Senonian. This series occurs near Diego Suarez, and has yielded such cephalopods as *Barroisia haberfellneri* (Hauer), *Holcodiscus theobaldinus* Stolicz., *Placenticeras placenta* Dekay, and *Nautilus bouchardi* Orb.; such lamellibranchs as *Ostrea deshayesi* Fisch. and *O. santonensis* Orb.; and the sea-urchins *Lampadaster grandidieri* Cott., *Micraster meunieri* Lambt., and *Infulaster boulei* Lambt.

Turonian. This series is represented near Majunga by terrestrial deposits containing bones of the Dinosaurs *Titanosaurus madagascariensis* Dep. and *Megalosaurus crenatissimus* Dep.

5. *Kainozoic.*—The existence of Eocene rocks in Madagascar has been known since 1855, owing to the discovery of limestones containing *Nummulites*, as well as other foraminifera such as *Alveolina* and *Orthophragmina*. These Eocene limestones occur at intervals along the western coast. They occur at the Cape Amber peninsula at the northern end of the island, and between Tulear and Cape Mary at the southern end. Between these two areas are outcrops at Majunga, further S.W. at Soulala (16° S.), and on the Morondava River at about 20½° S. The southern Eocene beds have not yielded *Nummulites*, so their correlation with the northern outcrops is uncertain; but the distribution of the system suggests that the whole western coast was washed by the Eocene sea. The only other Kainozoic marine series represented are the Upper Oligocene (Aquitanian) and Lower Miocene (Burdigalian), which have been identified from their foraminifera by R. Douvillé (1908, pp. 322, 323). The Aquitanian was discovered by Lemoine at the northern end of the island beside Diego Suarez Bay and in an inlet (14° S.) S.W. of the Hellville peninsula. These beds are limestones with the foraminifera *Lepidocyclina*, some corals, and calcareous seaweeds. The rocks at Bobaombi, near Diego Suarez, are interstratified with basalts and limburgites. The contemporary volcanic rocks at Ankaratra include (Lemoine,

1906, p. 277) nepheline-phonolite, showing that the discharge of the alkali-rich rocks had been begun.

IV. Geographical Relations of Madagascar

The early land connections of Madagascar have been the subject of prolonged discussions, which have revealed important evidence as to the relative movements of Africa and the Indian Ocean. Two primary facts have been established :—

(1) Throughout the Paleozoic and the Trias, Madagascar was part of a great land, for no marine deposits of those times have been found on the island. (The reported marine Trias has not been confirmed.)

(2) In the Jurassic and Cretaceous Periods Madagascar was part of a land which separated the seas to the W. from those to the E. and S.E. The Jurassic beds of Western Madagascar closely resemble those of Cutch in N.W. India, from the Putchum, through the Chari, to the Katrol and Umia beds.

Indian Series.	Madagascar Representatives.
Umia	Sandstones with large *Trigonia* of Bara country.
Katrol	Septarian clay with *Aptychus* of Bemara.
Chari	Yellow oolites with *Macrocephalites*, and beds with ironstone nodules with *Hecticoceras* of Suberbieville.
Putchum	Limestones of Bemara and Kahavo.

Hence the Jurassic deposits on the western side of the Eozoic horst of Madagascar are similar to those on the N.W. side of the Eozoic mass of the Indian Peninsula. Further, it has been shown by H. Douvillé (1904, p. 217) that the Upper Cretaceous beds of Eastern Madagascar reproduce the characters of those on the eastern coast of India ; while the Upper Cretaceous fauna of Western Madagascar is more closely related to the Mediterranean fauna than to that of Southern India. Hence from the Lias to the Eocene a land which extended from S.E. Africa through Madagascar to India must have separated the sea that lay along the coast of Africa as far S. as Mozambique from the southern ocean that deposited the beds of Uitenhage in South Africa and of Southern India.

An additional item of evidence has recently been discovered by Mr. R. B. Newton, who has recognized that some Cretaceous fresh-water fossils, including stems of the plant *Chara*, from Rhodesia, are allied to those associated with the Deccan traps of the Nagpur district in West-Central India.

At the beginning of the Kainozoic Era, the Eocene, the sea covered some western parts of the island ; but it had withdrawn in the Oligocene, when Madagascar was united to the mainland, whence the country was entered by the lemurs that are now the characteristic members of the Madagascan fauna. In the two succeeding periods, the Miocene and the Pliocene, no marine beds are known on the island (those referred to the Pliocene being probably later), so that the sea had apparently entirely lost contact with the existing land. This Miocene and Pliocene retreat of the sea either reunited Madagascar to the mainland, or left it isolated only by channels so narrow that *Hippopotamus* and the river-hog, *Potamochœrus*, were able to swim them, and thus reach the island. In the Pleistocene the sea again advanced, isolated Madagascar, and deposited coral reefs and raised beach deposits which in some places are 200 ft. above present sea-level (Lemoine, 1906, p. 319).

The oscillations of the land in the Pliocene and Pleistocene were accompanied by further outbursts of volcanic activity, and to them were due many volcanos with well-preserved craters and extensive flows of basalt and of rocks rich in alkalies, such as tinguaite and phonolite.

A still earlier alkaline, igneous series is represented by the nepheline-syenites which are intrusive into the Jurassic rocks of N.W. Madagascar and have been described by Lacroix (1902, pp. 167–171). He regards them as representatives of the alkalic igneous rocks found along the Rift Valley. The age of these nepheline-syenites is certainly post-Liassic and almost certainly post-Callovian ; and according to observations of Colcanap at Bekotapa they are post-Kimmeridgian. They may be of the same age as the nepheline-syenite of Jombo, S.W. of Mombasa, and mark in Madagascar the first outbreak of the Cretaceous-Kainozoic volcanic eruptions of East Africa.

[1] For summaries of the structure of the island, bibliographies, and lists of fossils, etc., see R. B. Newton (*Q.J.G.S.*, LI, 1895, pp. 71–91, 2 Pls.) ; M. Boule (*Congrès. Geol. Intern., Sess.*, VIII, 1900, 16 pp., Pl. XII) ; H. Dou-

villé (Sur quelques fossiles de Madagascar, *Bull. Soc. géol. Fr.* (4), IV, 1904, pp. 207–217, Pl. 8); Lemoine, (*Études géologiques dans le Nord de Madagascar*, 1906, 520 pp., 4 Pls., Map I); Grandidier (*Bibliographie de Madagascar*, 1906 (1905), VIII, 433 pp.); Lemoine (Madagascar, *Handbuch Reg. Geol.*, VII, Pt. 4, Heidelberg, 1911, 44 pp.).

[2] These fish and Naiadites beds were regarded by H. Douvillé (1910, pp. 260–261) as marine Trias; subsequently, however, in conjunction with Priem, he has accepted their Permian age.

CHAPTER XXVIII

The Geology of Somaliland & its Relations to the Rift Valley

THE geology of Somaliland supplements that of B.E.A. and Abyssinia in reference to the Rift Valley; for it furnishes important evidence both about the Mesozoic history of Equatorial Africa and about the age of the Rift Valley movements. In Southern Somaliland the extensive plains of the Juba basin include a varied series of fossiliferous Mesozoic rocks; and the fossils in the rocks beside the Sunkland of the Gulf of Aden define the age of the earth-movements in the middle part of the Great Rift Valley.

I. The Geological Succession

The most precise information as to the geology of the Juba Valley and of the country between it and Lake Rudolf, and Lakes Margherita and Ciamo, we owe to materials collected by Sacchi during Bottego's last expedition. As both those explorers were killed during the expedition, their collections were described by Prof. G. de Angelis d'Ossat and Prof. F. Millosevich (they gave a preliminary account in Vannutelli and Citerni, L'Omo, 1899, pp. 575–594 and map, followed by a separate work, 1900).

1. *Eozoic.*—Eozoic rocks (schists, gneiss, granites, etc.) occur between Lakes Rudolf and Stefanie, in the country S. of Burgi, and thence eastward to 39° 40′ E. on the upper Daua (the main eastern tributary of the Juba). They outcrop E. of the Juba, N. and S. of the limestones of Matagoi. The occurrence of the microcline-granitite from Scillei, S. of Matagoi and S.E. of Bardera (Millosevich, 1900, pp. 50–51 and *cf.* p. 3), of amphibolite-granitite at Decie (*ibid.*, p. 54), and of a quartz-schist at Monte Egherta (*ibid.*, p. 58), both localities E. of Bardera, shows that the crystalline foundation outcrops extensively. The map by Stefanini (1916) represents the Eozoic rocks as exposed in many scattered outcrops in an area of sandy drift; and it supports the information given me by Mr. S. F. Deck that gneiss ridges rise above the plain W. of the Juba at Sorori (1° 20′ N.), although Stefanini's map marks the hills there as limestone.

Eozoic rocks are known from Central Somaliland by the detailed descriptions by C. Riva (1899, pp. 328–331) of gneiss from the Ogaden country, of amphibolite and pegmatite from the Ogaden and Merehan, and of normal basalt, with olivine and labradorite, from the Ogaden, in the valley of Fanfan, and at Monte Soro. The Eozoic forms the foundation of all Northern and Eastern Somaliland (e.g. Gregory, 1897, 1900, pp. 28–29), of North-Western Somaliland (e.g. Dr. C. A. Raisin, 1888, pp. 414–418), and of its eastern outlier, the islands of Socotra and Abd-el-Kuri (e.g. Bonney, 1883, pp. 273–294, Pls. 6, 7; and Gregory, 1899, pp. 529–533).

2. *Trias.*—The Mesozoic rocks extend up the valley of the Middle Juba, first appearing from beneath the coastal alluvium to the W. of Sorori on the Juba (1° 20′ N.), where they rest on the Eozoic on both sides of the river. Further up the Juba the Jurassics widen, spreading W. up the Dara to about 4° N. and 38⅔° E. and S.W. of Gurbi, to the foot of the highlands E. of Lake Stefanie. North-eastward they extend from Bardera and Lugh to the upper valley of the Shebeyli; they continue northwards, between the Eozoic highlands of the Rift Valley and of the Somali Plateau, until they widen where the sea so long covered Northern Somaliland and plains E. of Abyssinia.

The oldest of the Mesozoic rocks are assigned to the Trias. Along the Upper Juba, around Lugh and up its northern tributary, the Doria, is a series of gypsum-bearing sandstones which have yielded a fish tooth, identified by Angelis d'Ossat (1900, p. 106, Pl. III, Fig. 1) as *Colobodus* cf. *maximus* (Qu.) and as Middle Trias in age. This fossil was found at the foot of the hill of Dodo Gadudo, near Lugh, in the oldest fossiliferous horizon yet found in Somaliland. The section there includes (Angelis and Millosevich, 1900, pp. 9–10)—

5. Pebbly bed with pebbles of quartz and olivine-diabase.

4. Pure fibrous gypsum.

3. Red clay, with thick layers of less pure compact gypsum.

2. Red clay, with interstratified beds of transparent reddish, fibrous gypsum.

1. Thin-bedded, greenish sandstone with *Colobodus*.

The gypsiferous nature of the *Colobodus* sandstones suggests the deposition of these beds in brackish lagoons under very different physical conditions from those under which were formed the older sedimentary rocks of B.E.A. That the Lugh gypsiferous sandstones were deposited along the seashore is supported by the occurrence in the upper beds of a fossil shell, collected by Sacchi and identified by Angelis d'Ossat as *Modiola minuta* (Goldf.). The fossil was collected by Sacchi (Angelis d'Ossat and Millosevich, 1900, p. 13) in the valley of the Webi on the hills of " Arabchi-Uoladdeje," the locality marked on the 1–3,000,000 map of East Africa as Waladeh (42° 3′ E., 4° 10′ N.). The position whence this specimen came is uncertain; but an identical rock occurs (Angelis and Millosevich, *ibid.*, p. 13) at the foot of the hills in the following section :—

3. Horizontal thin-bedded magnesian limestones of dull yellow colour.

2. Saccharoidal, compact, white gypsum.

1. Reddish sandstone, similar to that at Lugh, with indeterminable fossils of the same aspect as the *Modiola minuta ;* they occur on the floor of the valley, 3–6 ft. above the river. This *Modiola*, according to its identification by Angelis D'Ossat, would be Upper Trias and would be definite evidence of marine conditions. Mr. R. B. Newton has kindly examined the figures and tells me that they are too indefinite to give any clear evidence as to age; and he remarks that the fact of *Modiola minuta*, where found, generally occurring in great numbers, suggests doubt as to the identification.

Hennig (1917, p. 76) not only accepted this fossil as proof of the Triassic sea having occupied the Juba Valley, but he regards the gypsiferous beds of the plains of Afar (*v.* pp. 331, 342) as also due to marine Trias, and, following Douvillé, considers that the Triassic sea reached Madagascar. He further represented this sea as having extended across Abyssinia into the Congo basin and there spread out into a great Central African sea.

That the Triassic sea reached East or Central Africa is still unproved; for (*cf.* pp. 308, 311) the supposed marine Trias of Madagascar consists of estuarine and terrestrial Permian beds; the marine fossil identified from the Juba Trias is doubtful; and there is no evidence that the Triassic beds E. of Abyssinia are marine. The Trias of the Upper Congo is probably fresh-water or estuarine.

3. *Jurassic.*—The Jurassic fossils of Southern Somaliland are abundant and distinctive; most of those hitherto recorded have been described by Angelis d'Ossat, according to whom they represent a Jurassic succession ranging from the Lias to the Portlandian; but as the eight Jurassic horizons are based on ten species of invertebrates (viz. six species of lamellibranchs, one gastropod, two of corals, and one sponge) they require confirmation.

The most important Upper Jurassic section is at Anole, 2° N., which is E. of the Juba and S. of Bardera :—

6. Compact unfossiliferous limestone occurring in large slabs.

5. A thin bed, with 88 per cent of carbonate of lime and broken gastropods and *Belemnopsis*.

4. Compact fragile limestone : *Rhynchonella aff. moravica* Uhl., *R. subnobilis* Müll., *Terebratula*, *Cidaris*, large *Modiola*, etc.

3. Fissile-jointed marls (" galestrino "), some tens of yards thick, with 62 per cent of carbonate of lime, rare *Belemnites*, smooth *Pectens*, *Plicatula*, and traces of ammonites (*Perisphinctes*).

2. A compact bed with small gastropods, abundant *Plicatula*, *Lima harronis*, *Exogyra*, *Lopha* (*Alectryonia*), *Terebratula aff. subsella*, and *Waldheimia*.

1. Sandy argillaceous limestone ; 76 % of carbonate of lime with *Perisphinctes wischniakoffi* Tornq., *P. curvicosta* Tornq., *Macrocephalites aff. olcostephanoides* Tornq., from Mtaru, and *aff. M. rabai* Dacqué, of Mombasa ; also *Peltoceras*, *Hecticoceras*, *Nautilus*, *Pholadomya carinata* Goldf., *Pleuronectites aubryi* Douv., *Ceromya concentrica* Sow., etc.

The lowest bed (No. 1) appears to be Oxfordian ; the overlying limestones are Upper Jurassic. A coral limestone of an horizon which, according to Stefanini, probably belongs just above No. 6, occurs in the Juba Valley, near Allengo, and at Biobahal.

Mr. V. G. Glenday informs me that he has found the Lower Jurassic beds widespread in the north-western part of the Juba basin.

Belemnites and Ammonites, collected by Mr. J. Parkinson on the lower Juba at Kukatta (S. of Bardera, at 2° 8′ N.) and at Serenli (N. of Bardera, at 2° 24′ N.), have been identified by G. C. Crick (in Parkinson, 1915, p. 6) as Upper Oxfordian or Corallian (Sequanian).

Angelis d'Ossat has described a series of fossils from two localities in North-Western Somaliland near Harrar ; from Gialdessa eleven species are identified as representing horizons from the Lias to the Portlandian ; from Monte Egeo, five species are identified as representing horizons from the Lias to the Bathonian.

Whether there is a complete Jurassic succession in Somaliland is perhaps still doubtful ; but the evidence is clear that the Jurassic sea covered large areas in Somaliland through most of the Jurassic period. The following series have been identified in Southern Somaliland :—

Portlandian. S.E. of Lugh. Sponge, *Pachastrella antiqua* (Moore).
Kimmeridgian. S.E. of Lugh. *Ostrea virgula* (Defr.), *O. spiralis* Orb., N.W. of Lugh; and *Exogyra bruntrutana* (Thurm.) in the Daua Valley.
Corallian. S.E. of Lugh. *Astarte minima* Phil., *Thamnastrea arachnoides* Ed. and H.
Daua Valley; *Arca subterebrans* Lor.
Oxfordian. Kukatta, near Barderah. Belemnites, etc.
Bathonian. N.W. of Lugh. *Cerithium granulato-costatum* Münst.
Bajocian. S.W. of Lugh. *Thamnastræa* cf. *terquemi* Ed. and H.
Lias. Daua Valley. *Leda complanata* (Phil.).

The Jurassic rocks extend northward into Central Somaliland, where Dr. Donaldson Smith collected a series of Ammonites from Tug Terfa, a tributary of the Shebeyli, which were described by Crick (1897, pp. 426–428), according to whose determinations they would be Kimmeridgian or Tithonian in age. The species recorded are: *Perisphinctes* cf. *adelus* Gemmellaro, *P.* cf. *frequens* (Opp.), *P.* cf. *denseplicatus* Waag., and *P.* cf. *torquatus* Sow. A Brachiopod, *Rhynchonella subtetrædra* Dav., apparently from the same locality (Gregory, 1897, p. 424), is usually a Bajocian species.

Dr. Donaldson Smith (1897, p. 84) also discovered the "caves of Wyndlawn," so named after his home, in a bed of limestone which, according to Heilprin, contains corals; but as no fossils from this limestone have been determined, it is uncertain whether it represents the northern continuation of the coral reefs of the Kambe Limestone. Corallian-Kimmeridgian fossils (including Ammonites) from Harro Rufa, in North-Western Somaliland, were found by the Erlanger Expedition (Neumann, 1901, p. 101) and identified by Dacqué (1905, pp. 121–123; 1910, pp. 43, 45).

On the coastland of Northern Somaliland occurs the Bihindula or Bihin Limestone, which when first described (Gregory, 1896, p. 421) was referred to the Bathonian; but it may be younger, for it is clearly of the same age as the lower of two limestones in Southern Arabia which Mr. R. B. Newton (in Newton and Crick, 1908, p. 5) regards as Sequanian (Corallian), and Mr. Crick (*ibid.*, p. 24) as Kimmeridgian. These later conclusions are not accepted by Mr. G. H. Tipper (1910), who has found the mollusc relied on by Mr. Newton, *Parallelodon egertonianus* Stolicz., to be associated in India with the Bajocian Ammonite, *Stephanoceras humphriesianum* (Sow.), so it dates back to even earlier than the Bathonian.[1] The Ammonite horizon appears to be some miles distant from the Parallelodon limestone; the former is probably Kimmeridgian, and the latter Bathonian.

4. *Cretaceous.*—The Cretaceous System is represented in Northern Somaliland[2] and Socotra by three distinct series—Neocomian; an Upper Cretaceous series, either Turonian or Cenomanian; and Cenomanian and Senonian in Socotra. The Neocomian has been known in Somaliland since the well-known paper by Mayer-Eymar (1893). Rochebrune (1882) determined the Neocomian from the Singele district of North-Western Somaliland. The Erlanger expedition found Lower Cretaceous rocks in the Gillett Mountains in Central Somaliland (Neumann, 1901, p. 102).

5. *The Matagoi Limestone.*—The existence of the Cretaceous in Southern Somaliland is, however, doubtful. Prof. Angelis d'Ossat has suggested its presence there on the evidence of a new species of *Montlivaltia*, *M. doriai* (p. 127, Pl. 3, Fig. 4), from the limestones of Matagoi, S.E. of Bardera. It is natural to compare this coral with the large series belonging to the same genus from the Bathonian (Putchum) rocks from Kach. It does not agree exactly with any of the species described from there (Gregory, 1900, *Pal. India*, Ser. IX, II, Pt. 2, pp. 84–115), but it is sufficiently allied to some to render unnecessary its reference to the Cretaceous. It seems a Jurassic rather than a Cretaceous type.

Angelis d'Ossat supports the Cretaceous age of the Matagoi limestones by a problematic fossil which he compares (1900, pp. 130–131) to the Coralliopsidæ of Waagen and also to the brachiopod *Richthofenia;* the form, the banded structure, and dense tissues suggest that the fossil may be a hydroid coral, and, if so, it is as likely to be Jurassic as Cretaceous.

That the Matagoi Limestone is Jurassic, and probably Lower Jurassic, has been established by the discovery in it of the teeth of a Megalodont fish, which is regarded by Stefanini as Liassic (1916, p. 37), and of a *Gervillia aff. ombonii.*

6. *Kainozoic.*—The apparent absence of the Cretaceous from Southern Somaliland therefore renders probable the final expulsion of the sea from that region and its uplift before the plateau eruptions around the Arabian Sea. The sea appears to have been excluded from Southern Somaliland and from the Rift Valley W. of it throughout the Kainozoic Era. Eocene beds are known in Northern Somali-

land,[3] both on the plateau and at its northern foot; but they are unknown in the Juba Valley.

The Eocene beds of Northern Somaliland include the Dobar Uradu limestones, which were assigned to the Cretaceous mainly on the evidence of a mollusc identified as a *Nerinæa*. This fossil has been found to be a *Campanile*. The limestone of the Garrasgooi Mountain (5200 ft.), 3 miles S.W. of Sheikh, which was at first regarded as Cenomanian, is also Eocene, as the fossil on which the first determination was based has been redescribed by Mr. Newton (1905, p.167) as a new species, *Gryphea gregoryi*, of Eocene affinities.

The extension of the sea in Upper Kainozoic times into the Lake Rudolf basin was once suggested by the identification of fossils collected there as *Ostrea* (Angelis d'Ossat and Millosevich, 1900, p. 198; and in Vannutelli and Citerni, 1899, pp. 590, 593); this record was doubtless based, as recognized by these authors (1900, p. 198), on the thick, ostrea-like shells of the fresh-water genus *Ætheria*.

In the Lake Rudolf district there is a long gap after the Jurassic in the sedimentary series, which only begins again in the Late Pliocene with the bone beds of the lower Omo,[4] and the lake beds deposited when Lake Rudolf was much larger than it has been within recent years. The Lake Rudolf deposits include many Pleistocene fresh-water Mollusca. Angelis d'Ossat gives a list of seventeen species, which are widely distributed in the African lakes and rivers; some of them live in the Kison and Lake of Galilee, in Palestine, and in Cilicia in Asia Minor.

Angelis d'Ossat and Millosevich consider the possibility of the freshwater limestones of Lake Rudolf being Pliocene, but they regard them as certainly Pleistocene (1900, p. 201). Mr. R. B. Newton (in Parkinson, 1915, pp. 6–8), however, regards the lakes which formerly existed in North-Western B.E.A., to the E. of Lake Rudolf, as Pliocene. That age is now adopted for the bone beds of the Omo Valley, which are important, as they lie on the floor of the Rift Valley and show that it was formed before their deposition; and as they contain bones of *Dinotherium* and *Elephas*, they are regarded as of Upper Pliocene age. Lake Rudolf therefore dates back to the Pliocene.

Angelis d'Ossat and Millosevich (1900, pp. 208–209) consider various possibilities as to the geographical relations of the Lake

Rudolf basin, and conclude that it was formerly a valley connected to the Nile and isolated by a geologically recent subsidence.

II. The Volcanic Geology

1. *The Volcanic Series.* — For the later geological history of Southern and Western Somaliland we are mainly dependent on the volcanic rocks, which in this region of Africa belong to five groups.

Pleistocene—volcanos with often well-preserved craters, such as those of Aden and of the islands of the Red Sea.

Pliocene—the volcanic rocks of the Hawash Valley (=Naivashan of B.E.A.).

Miocene or perhaps Oligocene—the Magdala basalts and alkalic lavas (=Laikipian).

Eocene or Upper Cretaceous—the Ashangi traps of Blanford. Tinguaites of Allengo, E. of the Juba (=Doinyan and Kapitian).

Lower Mesozoic—Upper Trias—the basalts and tuffs of the gypsiferous sandstones of the Juba Valley near Lugh.

2. *The reported Upper Triassic Volcanic Series of Lugh.*—This volcanic horizon is provisionally accepted on the evidence reported by Prof. Stefanini (1916, pp. 37–41), but the age of the rocks is not free from doubt. The series includes basaltic lavas and acid tuffs, which belong to the upper part of the gypsiferous sandstones; large pebbles of the same basalt were also collected (Manasse, *ibid.*, p. 189) lower down the Juba at Marile and Godobei. According to Prof. Stefanini the eruptive rocks are exposed only in the banks of the Juba, near Lugh, where they occur in the upper part of the sandstones and never outcrop with the Jurassic beds; hence he regards them as older than the Jurassic limestones.

According to the description by Prof. Manasse (1916, p. 185), the rock from Cuteta, near Lugh, is a compact labradorite-augite basalt, with a little olivine, magnetite, and ilmenite; it is therefore a normal and not an alkalic basalt. It is described by Stefanini as overlying trachytic and liparitic tuffs.

These basalts, according to Stefanini (1916, p. 41), are part of a widespread sheet, which also outcrops in Mount Saro by the Fanfan River, in the Ogaden country of Northern Somaliland. Otherwise nothing is known in East Africa of any corresponding volcanic rocks. The basalts, however, resemble those of the Upper Karroo of the Zambezi Valley and may correspond with them in age. The existence on Eastern Equatorial Africa of an early Mesozoic volcanic series rests on the evidence of these outcrops near Lugh. As they are associated with tuffs, they appear to be clearly lavas and not intrusions; but the identification of the tuffs as rhyolitic (liparitic) and trachytic, and as containing anorthoclase and ægirine-augite, suggests doubt as to whether they may not be connected with the post-Jurassic alkalic volcanic series of Allengo, or with the rhyolites and trachytes of the Burgi-Lake Margherita area.

It should also be remembered that the olivine-diabase of Lafet, near Lugh, which belongs to this Upper Triassic group, is included by Millosevich (1900, pp. 49, 58) among the ancient crystalline rocks; but as his description of this rock shows that the olivine is comparatively unaltered the rock may be later than Eozoic.

3. *The Post-Jurassic Volcanic Series.*—Further down the Juba, N. of Bardera, at about 2° 50′ N., near Allengo, and at Adalile Hill (Bur Hedlilla of Stefanini's map) are outcrops of a lava sheet later than the Jurassic rocks of the neighbourhood. The rock E. of the Juba at Degderr, near Allengo, is identified by Prof. E. Manasse (1916, p. 186) as a tinguaite. It is described as an aphanitic rock containing sanidine, nepheline, sodalite, ægirine, and probably cossyrite. It is therefore clearly an alkalic lava, and, according to Stefanini (1916, p. 42), it is part of an eruptive sheet "spread over the limestones of the plateau." This rock is doubtless to be correlated with the post-Jurassic lavas.

Around Lake Margherita and S. of it, near Burgi, are extensive developments of volcanic rocks which, according to Millosevich (1900, pp. 79–86, 90–102), include rhyolites (liparites), quartz-trachytes, augite- and hypersthene-andesites, and various basalts and dolerites; but nothing in the descriptions indicates the special alkalic types of the recent igneous rocks; the felspars, e.g., are determined as labradorite (*ibid.*, pp. 81, 99) and bytownite (pp. 83, 98), with normal augite, olivine, and sometimes biotite; it is true that in one case (p. 82) he mentions with a query the possible presence of anorthoclase in a basalt.

The basalts of this group, according to Stefanini, are different from those of Lugh, and he is disposed (1916, p. 43) to refer all the eruptive rocks of Southern Somaliland to the "plateau traps" of Marinelli and Dainelli (*cf.* p. 343), which includes both the Ashangi (Cretaceous-Eocene) and the Magdala (Miocene) Series of Abyssinia.

The lavas were probably discharged earlier than the last faults of the Rift Valley Series and are doubtless older than the Pliocene bone bed of the Omo Valley, and are apparently Miocene ; they appear to represent in this part of the country the Magdala Series of Abyssinia and the Laikipian Series of B.E.A.

Dr. Donaldson Smith collected some trachytic or phonolitic tuffs from the Omo Valley and from Marsabit which show that the latter includes trachytoid phonolite (Gregory, 1897, pp. 423–424). That the alkalic igneous rocks extend to the extreme N.E. of Somaliland is obvious, as riebeckite, which is one of the mineral species most characteristic of these rocks, was first described from Socotra, where it was found by Emil Riebeck in 1880 (Sauer, 1888), and the same chemical type of igneous rocks occurs on the opposite side of the Gulf of Aden (*cf.* p. 327).

III. Tectonic Features

Somaliland is, therefore, a plateau composed of a foundation of Archean rocks capped by various Mesozoic and Eocene limestones. It agrees in its geological history with African countries bordering the Rift Valley by the absence of any marine deposits earlier than the Jurassic (with the possible exception of the doubtful Trias on the Juba) or later than the Eocene (except for the raised beaches along the coast). The subsidence of the surrounding areas has left Somaliland isolated by steep scarps to W., N., and E. Only on the S. a long slope descends gently to the lowlands and the sea.

On the western side the Somali Plateau is broken by a series of valleys which branch from the Great Rift Valley. Where that valley makes its sharp south-westward bend N.E. of Lake Stefanie, Dr. Donaldson Smith (1897, map sheet IV) discovered a valley 15 miles wide trending S.S.E. ; this valley lies between the Elwayi Scarp to the E. (on the prolongation of which occurs the volcano Sogida, at 4° 20′ N., 38° 40′ E.), and on the W. a scarp line of " jagged mountains."

Parallel to this valley, and nearer Lake Stefanie, are the hills of Gogo, near Foroli ; and the description of them by Dr. Donaldson Smith suggests that they are a fault scarp. His account is confirmed by later travellers, such as Major Maud (1904, p. 564), who describes the Goro hill line as " almost precipitous," and its straightness and abruptness are expressed by Gwynn (1911, p. 121) in his comparison of it to " a retaining wall." Along this line, further S., evidence of recent volcanic activity is reported by Maud (1904, p. 571), who describes Garo Dillo as a crater 1 mile in diameter, with volcanic hills around it and a salt lake on its floor ; and this volcanic line continues past Foroli and the basin of Lake Korole, now dry except for some brackish springs (see Wickenburg, 1903, p. 197, Pl. 19), and further to the volcanic plateau of Siria above the Guaso Nyiro (*ibid.*, p. 198).

The most important tectonic feature in Somaliland is the northern front of the plateau facing the Gulf of Aden. The geological evidence collected by Mr. and Mrs. Lort Phillip and Mr. G. P. V. Alymer indicated the existence of powerful E.–W. faults, by which

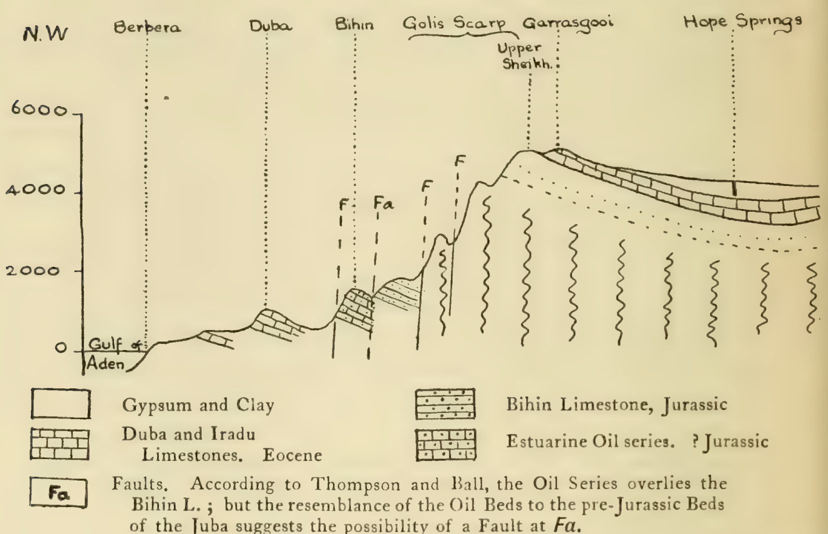
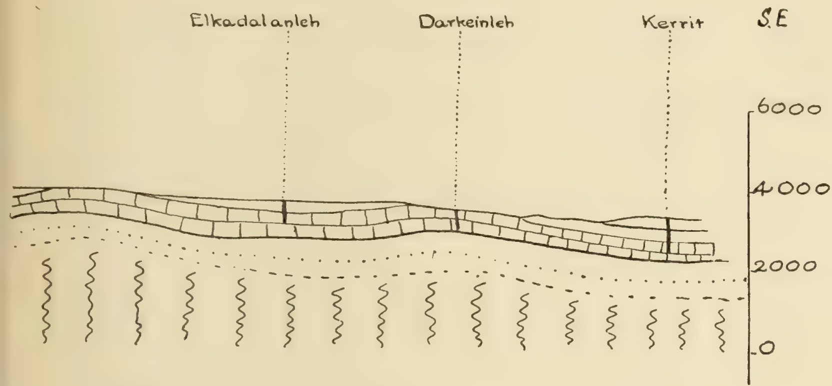


FIG. 43.—Geological Section across

Scale in length :

the country N. of the plateau had been thrown down ; for only thus did it appear possible to explain (Gregory, 1900, p. 27) the occurrence of the Jurassic and Eocene limestones at the level of a little over 1000 ft. on the lower plateau and on the higher plateau, where Eocene limestones occur at heights of over 5000 ft. This view has been confirmed by the description of Major R. G. Edwards Leckie (in Knox, 1905, p. 99) : " North of the Somaliland watershed the formation is much broken by a series of faults through which the country has subsided in successive steps to the coast, eventually forming the Gulf of Aden."

These earth-movements were proved in 1900 to be post-Eocene (Gregory, 1900 (2)), since they have cut through Eocene limestones on the edge of the plateau ; and the evidence for this date has been strengthened by Mr. Newton's determination (1905) that the limestones at Dobar at the foot of the plateau and at Bur Dab upon the plateau are both Eocene in age. The age of the limestones at Dobar was tentatively suggested as Neocomian on the evidence of a fossil coral (Gregory, 1896, p. 291), and this view was definitely readvanced (Gregory, 1900 (2), p. 43) on the identification of two molluscs from



Purple Sandstones

Gneiss and Schist, Eozoic. According to information given me in 1899, these rocks outcrop in various places between the Golis Scarp and Kerrit.

Borings

Faults

Northern Somaliland.

1 inch = about 15 miles.

it as Neocomian. Their redetermination leaves no evidence of Neocomian beds on the coastal plain S. of Berbera. The sea covered that plain at some time during the Jurassic. It had withdrawn throughout the Cretaceous, but returned in the Eocene, after which faulting formed the northern scarp of Somaliland, and separated the Eocene limestones at 1000 ft. on the coast plain from their former continuation at the level of 5000 ft. on the plateau.

Along the eastern part of the northern front of Somaliland the plateau, as it projects northward, is cut across by dry valleys which run from the Gulf of Aden to the Indian Ocean, S. of Cape Guardafui; such are the valleys that run inland eastward from Bender Khor and the valley of Daror which reaches the eastern coast at Ras Hafun. These valleys have been described by Révoil (1882, map, and Chap. XIII), and are probably due to parallel faults which branch from the southern boundary fault of the Gulf of Aden.

The earth-movements probably continued until recent times, as along the northern and western fractures there were eruptions of the alkalic lavas so widely associated with the Rift Valley faults. Those of the Gulf of Aden are best known by the extinct volcanos at Aden, which are of late Kainozoic and Pleistocene age.

Along the eastern scarp of Somaliland, S. of Cape Guardafui, no volcanic rocks are known. Manasse (1916, p. 190) has described a hypersthene pumice from the shore near Mogadoxo; but this rock probably drifted to East Africa from Krakatoa after the explosion of that mountain in 1883. Banks of the Krakatoa pumice occur along the coast of B.E.A., where, according to evidence that I collected in 1892, it began to drift ashore in 1885.

SOUTHERN ARABIA

Opposite Somaliland, on the northern side of the Gulf of Aden, is the plateau of Southern Arabia, which, according to a Somali legend, was connected to Africa when the early members of the tribe crossed from Asia. The former connection of the two countries, though at a date earlier than that of the Somali migration, is shown by their similarity in composition and structure. Like Somaliland, Southern Arabia consists of a foundation of Eozoic gneisses, upon which lie Jurassic limestones, which Newton and Crick (1908) correlate with the Bihin Limestone.

The Jurassic marine beds are covered by volcanic rocks which are probably Upper Cretaceous, as they are correlated with the Deccan Traps. They occur on the Arabian Plateau 90 miles N. of Aden, at Dala (also spelt Dihala) at the height of from 6000 to 7000 ft. Observations by Captain Lloyd show that the lavas there consist of olivine-dolerite in sheets from 1 to 20 ft. thick, which dip 20° to 30° southward; they are cut through by vertical dykes trending E.–W., and are also pierced by volcanic pipes of which the central column has been left surrounded by tuffs dipping away on all sides. These Deccan Traps in this area were therefore associated with vents of the normal type and are not due to fissure eruptions.

The rocks collected by Captain Lloyd at Dala have been described by Dr. Vredenburg (1910), who identifies them as acid rhyolites, doubtful andesites, basalts with and without olivine, and dolerites.

The Cretaceous traps were succeeded by an interval during which the Eocene limestones were deposited in Southern Arabia. Subsequently late Kainozoic earth-movements led to a renewal of volcanic activity, and the last eruptions built up the craters of Aden. The lavas were originally described by Niedzwiedzki (1871) and McMahon (1883, pp. 145–158), and are known to include alkalic rocks similar to those of the East African volcanic province; for Tenne (1893, pp. 458, 459, 461) has identified among them andesite with violet augite, and typical phonolite.

[1] I (1900, p. 45) had previously remarked that the bed might be later than the Bathonian; *cf.* also Newton (1896, pp. 294–296) and Crick (1896, pp. 296–297), who determined the Bihin Belemnite as a lower Callovian species. Dacqué (1910–1911) retains it as Bathonian.

[2] For the distribution of the limestones and their relations to the Eozoic rocks in Northern Somaliland, *cf.* F. B. Parkinson (1898, pp. 17, 19, 25, 28).

[3] Dr. C. A. Raisin (1888, pp. 417–418) has referred the limestones of Eilo, S. of Zeila, to the late Cretaceous or Kainozoic on the evidence of the foraminifera. Prof. Bonney (1883, pp. 289–290) has referred the limestones in Socotra to the Miocene.

[4] A preliminary account of these fossils has been given in Haug, *Traité Géol.*, 1911, II, pp. 17–27. The promised memoir on the geology of the late Vicomte du Bourg du Bozas' expedition has not yet been published.

CHAPTER XXIX

The Abyssinian Section of the Rift Valley between Lake Rudolf & the Red Sea

I. The Abyssinian Highlands

IF the Somali Peninsula be regarded as the eastern bastion of Africa, the Abyssinian Highlands are its impregnable keep. Abyssinia has been instructively described as the Switzerland of Eastern Africa owing to its national freedom and mountainous character ; with the exception of Liberia, it is the last part of Africa to preserve its independence, and it includes the largest area in Africa over 6000 ft. above sea-level. Its mountainous relief and the fortresses provided by its flat-topped, rocky hills, like the kopjes of South Africa, render Abyssinia easy of defence. Its widespread lavas weather to a rich soil, and as its monsoonal winds and elevation give it an average annual rainfall of about 30–50 ins. (as against 10–15 ins. in the surrounding lowlands) it is naturally one of the most fertile countries in eastern tropical Africa. Its rich soils and invigorating climate have attracted settlers from the adjacent regions—from the desert wastes and barren hills of Libya to the N., from the arid limestone moorlands of Somaliland to the E., and from the sterile steppes of Jubaland to the S. It is only on the west that the country is united by fertile and well-watered tracks to areas with a large population.

Immigration into Abyssinia has been going on from prehistoric times ; the country has long been the military camp of East Africa, with the mixture of peoples usual under such conditions. The name Abyssinia, which is based on that of its people, the Habeshi, means " mixed," and refers to the exceptionally varied elements in its population. Semites, including the " black Jews," or Falashas, have entered from South-Western Asia. Hamites have entered it from the Lower Nile and Southern Arabia. Soudanese have found its western slope an easy route on to the Abyssinian Highlands. The desert belt in the Lake Rudolf region separated it from the negro countries to the S. and S.W. ; but that barrier has proved ineffective, and the intimate intercourse between Abyssinia and Uganda may have a powerful influence on the political development of Central Africa. Abyssinia has long been the well-garrisoned camp guarding the chief portal from Asia into tropical Africa. Its strategic importance is due to its position on the western edge of the Rift Valley near its branch —the Aden Sunkland. The Abyssinian Highlands consist of a solid block or " horst," which remained upstanding while the surrounding countries foundered ; and it has been thus left as the best watered, most fertile, and most easily defended of East African lands. While enjoying the advantage of easy communication through the Gulf of Aden and the Red Sea to South-Western Asia, its steep eastern front, which is the western wall of the Rift Valley, has acted as an almost impenetrable frontier. The Rift Valley, to the S. and E., lies like a natural moat in front of Abyssinia, which it has helped to render the most independent of African countries and the natural home of the Ethiopian political movement.

II. The Rift Valley in Afar[1]

The plains at the foot of the Abyssinian Scarp are due to the contraction of the Red Sea while the Red Sea trough maintains its normal width. At its southern end the Red Sea contracts from a width of 190 miles opposite Massawa (about 17° N.) to 14 miles at the Straits of Bab-el-Mandeb. This contraction is due partly to the Arabian coast trending more southerly (S. by E.), but mainly to the eastward advance of the African coast on a trend to the S.E. The African highlands, however, instead of sharing this change of course, maintain the trend of the coast N. of Massawa and continue to S. by E., so they are parallel to the Arabian instead of to the African coast. The Red Sea trough therefore maintains its normal width, the narrowing of the sea being counterbalanced by the widening of the coastal belt from a thin strip N. of Massawa to the broad plains of Afar that separate the Abyssinian Highlands from the sea.

Near Massawa the land rises steeply from the shore to the levels of 3035 ft. (at Ghedem, S. by E. of Massawa), and the country further W. attains the height of 8760 ft. Further S., near the edge of the Abyssinian Plateau, are areas of over 10,000 ft. (e.g. 11,191 ft. at Alaji, 13° S.), while the rim is all above the level of 6000 ft. The eastern face of the plateau occurs sometimes as straight, steep scarps, as W. of Lake Assala (14° S.); but in places it has been rendered very irregular by dissection. At the foot of this scarp lie the plains of Afar and the Danakil country, which are separated from the Red Sea by a mountainous tract, the Danakil Horst, which begins as the Buri Peninsula, E. of Annesley Bay; most of it is over 2000 ft. high: it rises to 6800 ft. and 7000 ft. at 13° 25′ S., N.W. of Assab, and it is cut off abruptly to the S. by the cross-faults which formed the Gulf of Tajura. This mountainous tract forms the Italian colony of Eritrea, and it appears to consist of a horst of Eozoic rocks smothered by recent volcanic materials.

Against the Danakil Horst the Red Sea trough bifurcates; the eastern branch is the funnel-shaped basin which has its narrow outlet through the straits of Bab-el-Mandeb to the Gulf of Aden. The western branch lies between the Eritrean Horst and the Abyssinian Plateau, and is the continuation of the Rift Valley of Equatorial Africa.

The Abyssinian section of the Rift Valley begins with Annesley Bay or the Gulf of Zula, a blunt-ended gulf with approximately parallel sides. The gulf lies along a volcanic line, at the foot of the Eozoic plateau, and recent (Pleistocene) volcanos have blocked the valley at its southern end. South of these volcanic hills the valley descends through salt plains to Lake Assala, which lies 380 ft. below sea-level.

The history of volcanic activity in the Eritrean area has been worked out in a series of memoirs by Dainelli and Marinelli (1906–1908), and especially in their important monograph (1912, pp. 189–313). They show that the activity of the volcanos around the Red Sea was less recent than had been generally reported. Suess (1891, pp. 565–567, 569–570) quoted Erta-Alé as being still of Strombolian activity; but Dainelli and Marinelli (1907, p. 25) conclude that there is no certain evidence of its recent activity, and that the last eruption in the region was that of Dubbi in 1861 (1908, pp. 257–264). Afdera has also been active in modern times (Dainelli and Marinelli, 1912, pp. 238–241). Since 1861 the only volcanic activity in the district and in the islands of the Red Sea has been that of solfataras and steam vents. They have described Erta-Alé (1906, pp. 261–270) and Maraho (1907, pp. 129–141, Pl. 3, and 1912, pp. 192–196, Pl. XX), and quote the description of the lavas of that volcano by Prof. Manasse, who determined them all as olivine-basalt with labradorite as the felspar (1907, pp. 257–274). The volcano Alid, which stands S. of Annesley Bay, trends E.–W., and consists of trachyte and basalt.

S. of Lake Assala the floor of the valley rises to the height of over 1300 ft. in Southern Afar, about 13° S., 41° E.; it sinks again to about 300 ft. at the lake and depression of Golima in Movaia (12° 35′ S., 40° 40′ E.). This small lake lies in the basin of Southern Afar, which is bounded to the S. by the transverse ridge that trends from W.S.W. to E.N.E. from Assab to Magdala; this ridge varies in height from 6769 ft. in Mount Musali, W.S.W. of Assab, and 9000 ft. near Magdala, down to 1640 ft. at the pass leading to the valley of the Hawash. This transverse Musali-Magdala ridge and the hills and spurs connected with it interrupt the Rift Valley, which in this area is not easily demarcated.

The irregularities are probably due to the older meridional earth movements and have been obscured by later movements contemporary with the subsidence of the Gulf of Aden. The western wall of the Rift Valley may be traced fairly regularly along the eastern front of the Abyssinian Plateau; but the eastern wall is repeatedly broken by projections trending E.N.E. to W.S.W., parallel to the southern coast of Arabia. These transverse features include the Gulf of Tajura, the westernmost offshoot from the Gulf of Aden. It runs 60 miles W.S.W. into the land of the Aussa Somali; inland from its head is a small salt lake (Lake Assal), which lies 570 ft. below sea-level. This Tajura-Assal depression is continued on a south-westerly course as the basin of the Lower Hawash and its tributary the Haroli. The south-westerly deflection of the Rift Valley near Lake Zwai (Dembel) may be attributed to the factors that caused the tectonic lines of Southern Arabia. The Hawash–Zwai basin is the western end of the sunkland, of which the eastern end is the Gulf of Aden. A rectangular lowland (for the hills on the Lower Hawash are low) continues the depression of the Gulf of Aden westward between the Magdala-Assab ridge to the N. and the scarp of the Somaliland Plateau to the S., till it ends against the Abyssinian Plateau near Ankober.

Small scale maps represent the Abyssinian Highlands as bounded by a steep mountain wall along the meridian of 40° This representation appears to be essentially correct, though on larger maps the Rift Valley in Southern Afar appears irregular; but the country has not been mapped in detail, and preliminary sketch maps, by their exaggeration of foothills, often minimize the importance of straight scarps. When contoured maps are available, the dominance of scarp lines may be more apparent.

III. The Rift Valley between Abyssinia and Somaliland

The best available maps (e.g. the 1 : 1 m. map of Africa, sheets Asmara and Addis Abbaba) express the fundamental fact that a meridional valley separates the Abyssinian Plateau on the W. from the Danakil Horst and Somali Plateau on the E. and connects the trough of the Red Sea with Lake Rudolf. The valley consists of three chief constituents: (1) the plains of Afar from Massawa ($15\frac{3}{4}°$ N.) to the Musali-Magdala Ridge ($11\frac{1}{2}°$ N.); (2) the valley of the Hawash, which continues southward and south-westward to about 8° N.; (3) the valley of the Abyssinian lakes, extending from Lake Zwai to Lake Stefanie.

The map in Vannutelli and Citerni's work (1899) expresses the impression made on them by their own observations near Lakes Margherita and Rudolf and between Addis Abbaba and Harrar, and by their interpretation of the reports regarding the intervening country and the eastern front of Abyssinia. Their map represents the bold scarp of the Abyssinian Plateau from 14° to $9\frac{1}{2}°$ N. as in places a single scarp, as from Ankober along the Hawash Valley, and further N. as two scarps separated by a platform (e.g. the Taltal-Kello platform), which is widest on 12° N. At Ankober the western wall is marked as swinging round to the W.S.W. above Addis Abbaba, in accordance with the trend lines of the Gulf of Aden; while the wide lowlands of Southern Afar end against the northern scarp of Somaliland, which also trends W.S.W. from S. of the Gulf of Aden past Harrar to Lake Zwai.

Where the western prolongation of the northern and southern boundaries of the Gulf of Aden reach the Rift Valley its structure is irregular and obscure. The northern boundary of the Aden Sunkland is on the same line as the Musali-Magdala Ridge, and its southern boundary is the northern scarp of the Somali Plateau which continues westward past Harrar to Lake Zwai.

As the Rift Valley passes southward beyond these transverse disturbances its structure again becomes normal. It forms a well-defined trench between the scarps of Ankober and Marako (W. of Lake Zwai) on the N.W., and of the Gugu and Gudda Mountains on the S.E. The abrupt and scarp-like nature of the walls of this

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Sketch Map of the Abyssinian Section of the Great Rift Valley.

trench is shown by various descriptions. Thus, according to Prof. Stefanini (1916, p. 25), the south-eastern wall of the "tectonic depression of the valley of the Hauasc [Hawash] and of the Great Lakes, is a precipitous scarp (una ripida scarpata) which is continued eastward as the northern coast of the Somali peninsula." The ascent of the opposite wall is described by Count Wickenburg (1903, p. 193) as by a steep track, which suddenly reaches the surface of the Abyssinian Plateau, when at once occurs a great change in the character of the country. He (*ibid.*, p. 194) also reports that S. of this route on to the plateau the Gurage Mountains, which form the western wall of the Rift Valley above the Zwai lakes, rise as a massive rock wall, steep and abrupt (schroff). Major Gwynn (1911, p. 117) speaks of this part of the valley as bounded by high walls; and he describes a broad gap in the eastern wall above the head-streams of the Webi, between the Gugu and Chillalo Mountains; and this gap occurs in line with the Ankober Scarp. Further S. the descent from the Somali Plateau to Lake Margherita (Lake Abbaya) is described by Vannutelli and Citerni (1899, p. 239) as down "queste enormi pareti verticali," and Lake Chamo as bounded by rock bastions which spring from its edge. The expedition of Viscount Du Bourg du Bozas (1906) passed along the valley past Lake Zwai at the foot of the Guragu Scarp, and the map of his route (No. 2) represents the straight scarp from S. of the Upper Hawash going S.S.W. to Mounts Kassa and Lemo, W. of Lake Challa, and then, after the break, the scarp is resumed on a south-westward course to the N.W. of Lake Margherita.

Before the contraction of the Rift Valley to this steep-sided trench both walls are divided by platforms into two or more steps. At the foot of the Abyssinian Plateau, along Southern Afar, from W. of Lake Assala past Lake Ashangi and Magdala, lies a broad platform, of which the northern end, Taltal, shares the aridity of the lowlands; its southern end, Kallo, maintains the two lakes, Ardibbo and Haik, which are the sources of the Melli River. This Kallo-Taltal Platform is twice interrupted by ridges (Azaraba, about $13\frac{1}{3}°$ N., and Zabul, 12° 10′ N.) which project north-eastward from the plateau. On the opposite side of the Rift Valley is a wider platform W. of Harrar, between the Obora Scarp and the Somali Plateau and the lower, more dissected scarp of the Gebel Ahmar.

The platforms on both sides of the Rift Valley disappear as it contracts to the narrower valley which encloses the lake chain of South-

Eastern Abyssinia, including Lakes Zwai (5400 ft.), Hora (5425 ft.), Margherita (Abbaya), and Chamo (3460 ft.).

Along this part of the valley the structure is less regular than was represented on the earlier maps; but the irregularities appear to be tectonic and not due to erosion. Thus, opposite the point where the prolongation of the N. Somaliland line meets the western wall of the Rift Valley, the Magazago Scarp (which trends S.S.W., S. of Ankober) is cut off abruptly by the Kassam Valley; the main scarp runs westward as the Barren Mountains (as named on the War Office map, 1 : 1 m., sheet 67, 1917) N. of the Addis Abbaba Railway. The main direction is continued by a broken line of hills, which passes between the two lofty volcanos, Sekwala (10,030 ft.) and Mount Bas (Bosat), and is continued as the Gosehan and Kambata Scarps to the W. and S.W. of the Zwai lakes. The continuation of the higher scarps may be traced south-westward through the Guraghe Mountains, S.W. of Addis Abbaba; they have taken the N.E.–S.W. trend which is predominant between Shoa, Addis Abbaba, and Lake Rudolf, although along the Middle Omo the river valleys are irregular in course and their lines have been obviously determined by denudation.

The main break in the Abyssinian Scarp occurs, therefore, where the North Somaliland line intercepts it, and by forming the Kassam Valley has left the plateau projecting as the great bastion of South-Eastern Shoa. Similarly, the main break in the opposite wall of the Rift Valley occurs where it is intersected, E. of Lake Zwai, by the prolongation of the part of the Abyssinian Scarp which trends N. and S.; at this break the long scarp of the Gugu Mountains is separated from its prolongation, the Gudda Scarp, by the valley beside the Sahatu Range, which trends N. and S. The Gudda Scarp, after bending to form the broad embayment E. of the Gidaba River, is continued through the Gergeda Mountains, E. of Lake Margherita, to the Mount Delo range (11,480 ft.), which takes on the N. and S. course of the scarps and faults of the Rudolf basin and of B.E.A.

The irregularity of the Rift Valley in its Abyssinian portion arises, therefore, from cross-disturbances due to the intersection of the N.–S. faults of the Great Rift Valley and of those, trending W.S.W. to E.N.E., connected with the foundering of the Gulf of Aden. The structural irregularity is rendered the more apparent by burial of many of the older rocks and fault lines by volcanic eruptions.

The volcanic nature of the Kummi and Ajelu group (on 41° N., N. of Gebel Ahmar), of Fantali, and Dofane were shown by Fritzsche (1890, p. 118). Cecchi (1885, II, p. 468) reports the predominant rock from S. of the Hawash River to the Kaffa border as a nepheline-basalt; while in the volcanic country between Shoa and Kaffa, including Mount Sekwala[2] and Mount Jerer, the predominant rock is sanidine trachyte (Cecchi, *ibid.*, 1885, p. 467). S. of the Lake Zwai group (Lake Zwai, 5400 ft.; Lake Hora or Ororeccio, 5425 ft.; and Lake Lamina) the Rift Valley is bounded by lofty volcanic mountains such as Mount Dalbu, 10,400 ft., on the western bank, and Mount Delo, 11,480 ft., E. of Lake Chamo on the eastern side; and these appear to have buried the Rift Valley. A geological map (Angelis d'Ossat and Millosevich, 1900, p. 36) shows that Lake Margherita is completely surrounded by basalts, rhyolites, and trachytic tuffs, and near it are hot springs which suggest the recent date of the volcanic activity. The Margherita-Chamo Valley is blocked to the S. by the volcanic masses of the Beverley Range; and the only representative of the Rift Valley depression is the plain occupied by the cotton fields of Bugadi, which (alt. 5300 ft.) are separated by a relatively low divide from the upper Manta. This river is at the level of 4350 ft. at Godigea and joins the Galana Sagan, the main affluent to Lake Stefanie (1830 ft.).

The volcanic eruptions around Lakes Margherita and Chamo appear to have buried the lower floor of the Rift Valley and obscured its walls, though even such volcanic activity could not conceal the great Margherita trough between such mountains as Guge, 13,778 ft., and Shie, 12,460 ft., to the W., and the volcanic piles resting on the gneissic platform of Mount Delo to the E.

According to the Vannutelli-Citerni map, the bold Delo-Burgi Range is cut off abruptly by the Galana Sagan Valley, which ends westward at the foot of the mountain country that forms the western wall of the Rift Valley between Lakes Margherita and Stefanie.

It appears, then, that the Rift Valley of Southern Abyssinia was compressed by the western projection of the Somali Plateau, under the influence of the W.S.W. to E.N.E. lines of the Gulf of Aden, and reaches its narrowest width and highest level near Lake Chamo. As its floor there is at the level of from 5500 to 6000 ft., it is the second highest section of the Rift Valley. Lake Zwai is at 5400 ft., and its neighbour Lake Hora at 5425 ft. From the watershed S. of these lakes, probably at about 6000 ft., the level descends to Lakes

Margherita and Chamo. The divide between those lakes and the Manta must be well above 5300 ft. and probably approaches 6000 ft.; so there is a steep descent southward to Lake Stefanie (1830 ft.) and Lake Rudolf (1250 ft.).

IV. The Branching of the Rift Valley N. of Lake Rudolf

The Lake Rudolf basin belongs to the British East African section of the Rift Valley, where the course and structure are both simpler than in Abyssinia; but it is convenient to consider the northern ending of the Rudolf basin in connection with the Abyssinian section. The Lake Rudolf basin divides northwards into three branches; two belong to the Omo basin; the third passes north-eastward to Lake Stefanie.

The first branch is the lower valley of that much-debated river, the Omo, which continues the trough of Lake Rudolf straight northward; it was expected to prove the main northern continuation of the Rift Valley in B.E.A. Suess (1892, p. 130) speaks of the "continuation of the Omo graben in the subsidence of Afar"; but the tectonic valley of the lower Omo is only 100 miles long, and ends against the Abyssinian Plateau; and the Upper Omo has a very sinuous valley, doubtless made by river erosion.

The second branch follows the Lower Omo to its hairpin reversal at 5° 30′. It continues for another 40 miles up the valley of the Usno; it is there separated from the Omo by the Ngalibong Range (4890 ft.), which appears to be a horst projecting from the Abyssinian mountains, and it ends in the mountains W. of Mount Guge 13,778 ft.).

The third branch connects the British East African and Abyssinian sections of the Great Rift Valley. It was, however, represented by Suess (1891, p. 132) as a blind "graben," branching from Lake Rudolf at 4° N. and ending with Lake Stefanie. The G.S., G.S. 1 : 1 m. map (sheet 70, 1903) shows the valley as trending N.E. to the S.W. corner of Lake Stefanie. The eastern bank of this valley would be the continuation of the Tertali Scarp (the Trr-Mountains of von Höhnel). As this branch was formed along the line of weakness between the Abyssinian and Somali Plateaus, it carries on north-eastward past Lakes Margherita and Zwai to the valley of the Hawash and across the plains of Afar to the Red Sea. The complexity of the earth movements and intensity of volcanic activity have, however, obscured the nature and continuity of the Rift Valley in this part of its course.

V. The Geology of the Abyssinian Rift Valley

The evidence as to the age of the movements on the Abyssinian section is fragmentary. Geologically this area is unusually varied. Annesley Bay lies along a Pleistocene volcanic line (*cf.* Baldacci's map, 1891) at the foot of the gneisses and schists which form the highlands to the W. The rocks of the Buri Peninsula, to the E. of Annesley Bay, have been described by Aloisi (1904, pp. 77, 84) ; the foundation consists of gneiss, saccharoidal limestone, and pegmatite, with, at Monte Gheluale, diabase and micro-felsite (*ibid.*, pp. 81–83) ; upon it rest modern lavas, including rhyolites (1904, pp. 77–81) and basalt at Asandado (*ibid.*, p. 83).

The general character of the rocks S. of Arafali, at the head of Annesley Bay, have been described by Prof. Manasse (1904) ; the Eozoic rocks include amphibolite- and epidote-gneisses, tourmaline-gneiss (*ibid.*, pp. 145–147), syenite, and microcline-pegmatite (*ibid.*, p. 143) ; the chief volcanic rocks are a spherulitic rhyolite (*ibid.*, p. 140) and normal olivine-basalts, in which the felspar is a bytownite-labradorite (*ibid.*, p. 137). The Danakil Horst also consists of an Eozoic foundation covered by volcanic rocks.

The Abyssinian Plateau to the W. of Afar also has an Eozoic foundation ; its composition is shown by the report of Prof. Roccati (1906) on the geology of the railway line from Massawa, which after leaving the raised reefs at Massawa crosses diabase at 12 km., trachyte at 18 km., and schists, gneiss, quartzite, granite, diorite, diabase and gabbro from the 25th to the 65th km. ; on the summit of the plateau at Ghinda, 72 km., the rock is again trachyte.

Sabatini, in a series of papers between 1885 and 1899, has described in detail the rocks of Eritrea. His first paper (1895) is devoted to the Eozoic rocks, including various gneisses and schists, altered igneous rocks such as epidosite, amphibolite, and pyroxenite, and a quartz-bearing prasinite (p. 468). In his second paper (1897) he described the deeper-seated igneous rocks, including granite, pegmatite, diorite, and micro-felsites. In 1899 he described the lavas, which include widely distributed ophitic basalts, some of which include olivine, and their predominant felspar is labradorite and bytownite, as, for example, at Dogali (p. 163), the valley of Ziret (p. 165) and the plateau of Damba (p. 166); andesites occur at Sahati and Arghesana (*ibid.*, pp. 160–162).

In Southern Abyssinia the similar occurrence of volcanic rocks on an Eozoic foundation was shown by Grattarola (1887) from the collections and observations of Cecchi during his journey from Zeila to Kaffa. The Eozoic rocks described include syenite (*ibid.*, p. 511), and Cecchi recorded chlorite-schist, mica-schist, and granite (*ibid.*, pp. 516–518); the volcanic rocks are widely distributed trachytes and basalt, obsidian, and a trachyte in which Grattarola doubtfully recorded nepheline (*ibid.*, p. 509).

Some of the older crystalline rocks are regarded by Dainelli and Marinelli (1912, p. 25) as of Carboniferous age; but this view is discountenanced by the fact that they are clearly pre-Carboniferous where they are seen in association with Permo-Carboniferous rocks.

The strike of the older rocks in Eastern Abyssinia was recorded by Ferret and Galinier (1847, III, pp. 13, 18, 30, 42, 76), according to whom the gneiss W. of Massawa strikes from N.N.W. to S.S.E.; and the general strike is from N.W. to S.E. parallel to the Red Sea; the strike in rocks around Adowa, that are probably Archeozoic, is from N.E. to S.W., parallel to the Gulf of Aden.

Adigrat Sandstone.—The Eozoic rocks are overlain around Senafe by Blanford's Adigrat Sandstone, which is pre-Jurassic and to be correlated either with the Karroo Sandstone or with the older sandstones once included in the Nubian Sandstone. The deposition of the Adigrat Sandstone, according to Dainelli and Marinelli (1912, p. 65), began in the Trias and occupied part of the Jurassic. Its later limits, they state, cannot be precisely determined. None of it would appear to be later than Bajocian, for it and its southern representatives are pre-Bathonian, which in Abyssinia is represented by the Antalo Limestone.

Jurassic.—The age of the Antalo Limestone has given rise to much difference of opinion. Blanford (1870, pp. 179, 180) gave a list of fossils from it and regarded it as probably belonging to the Middle Jurassic. Rochebrune (1882, pp. 9–10), after a re-examination of the fossils collected by Ferret and Galinier, described one as a new species, *Isocardia galinieri*, and as almost identical with *I. neocomiensis* d'Orb; he therefore identified the horizon as Neocomian. This view has found no support, and the Jurassic age is unquestionable. Aubry (1886, p. 221) concluded that the Antalo Limestone includes three horizons—Bajocian (from the presence of *Rhynchonella lotharingica*), Bathonian, and Corallian. Douvillé, who described Aubry's fossils, referred the three divisions to the Lower Bathonian, Upper Bathonian or perhaps Callovian, and the Astartian (i.e. Upper Corallian).

A still higher Jurassic division of the Antalo Limestone was established by Futterer (1897, p. 621) by the identification of specimens collected by Ragazzi as Pterocerian or Kimmeridgian.

The fossil which led Aubry to identify the lowest limestone as Bajocian is regarded by Dacqué and Krenkel (1909, p. 160) as distinctively Bathonian; they regard the Antalo Limestone as including Bathonian, Corallian, and Kimmeridgian.

It is therefore convenient to subdivide the limestone, adopting for the upper beds (Kimmeridgian and Corallian) Aubry's name of the Lagagima Limestone, and to restrict the term Antalo Limestone to the lower division, which is mainly or entirely Bathonian.

The Antalo Limestone rests upon gypsiferous beds containing small bivalves, to which Douvillé (1886, p. 239) refers as indeterminable "Corbules"; he compares the horizon to the Infra-Lias. The gypsiferous beds rest on sandstone with variegated clay (Aubry, 1886, p. 219). The series agrees in general character with the beds at Lugh, on the Juba, which have been assigned to the Trias; but though they appear to be equivalent, there is no adequate evidence of their Triassic age. They may be Rhætic or perhaps Liassic.

The Abyssinian marine Jurassic beds are at the elevation of 8500 ft. at Antalo; 250 miles further S., W. of Ankober, they are only at 5900 ft., so their uplift decreases to the S. They disappear to the N., and the Kainozoic volcanic rocks rest directly on the Adigrat Sandstone. The Jurassic sea apparently did not cover Northern Abyssinia.

Volcanic Rocks.—The Jurassic limestones are succeeded by volcanic rocks, which W. T. Blanford divided into three series; the oldest, his Ashangi Traps, are zeolitic basalts and dolerites, which he described as resembling the Deccan Traps and as probably their western representatives (Blanford, 1870, pp. 183–185). If so, they are Cretaceous, and this age is accepted by Baldacci (1891, p. 28). They were followed, after a long interval, by the Magdala Traps, which are a thick series of alkaline igneous rocks widely distributed around Magdala and further N. around Senafe and Adowa: these rocks Blanford identified as basalts and trachytes. The rocks have been redescribed by Dr. Prior from the specimens collected by Blanford and by Schimper. Dr. Prior (1898, pp. 93–95, and 1900, pp. 260–270) has shown that the Magdala Series includes grorudites, paisanites, lindoïtes, and tinguaites; solvsbergites (*op. cit.*, p. 265), which in their trachytic flow-structure, surface shimmer due to the platy arrangement of the felspars, and fissility resemble some of the lavas of B.E.A.; also riebeckite-trachyte, alkaline pitchstones, an olivine-dolerite which Prior describes as of ancient aspect, and a more recent-looking glassy basalt. The lavas are interstratified with sandstones containing fossil trees.

A series of rocks from the Rift Valley in Abyssinia was collected by Oscar Neumann during v. Erlanger's expedition and described by Max Weber (1906). He shows that the foundation of the country consists of gneiss, amphibolite, epidote-schist and other schists, and of plutonic rocks, including granite, syenite, and olivine-gabbro. Along parts of the Rift Valley these rocks are only occasionally exposed on the walls, for the Eozoic foundation has there been smothered by volcanic materials, most of which belong to the alkalic group. Along the floor of the Rift Valley the volcanic rocks include alkaline trachytes and rhyolites, including the riebeckite-rhyolite known as comendite. Further N., in the Hawash Valley, Neumann collected phonolitic trachytes. Some basalts lie on the plateau E. of the Rift Valley, but the typical rocks are members of the alkalic type, including phonolites with large crystals of sanidine like the Kapitian lavas; there is also nepheline-basalt, nephelinite, nepheline-basanite, and melilite-basalt—a similar association to that of the Naivashan Series of Nandi and Elgon; the volcanic series of this region clearly belongs to the same petrographic province as B.E.A.

The affinities of the rhyolite with soda-amphiboles of North-Western Somaliland, on the railway to Harrar, to comendite has been pointed out by Prof. Lacroix (1899, pp. 1354, 1356).

The presence of alkalic igneous rocks beside the North Afar depression is indicated by the presence of riebeckite in the sands (Salmojraghi, 1909, p. 70).

Hence both volcanic and Eozoic rocks along the Rift Valley in the Abyssinian section are the same kinds as those of B.E.A. The sequence of the lavas has, however, not been determined; but their distribution and petrography suggest that it is the same as in B.E.A. An outlier of coarsely porphyritic phonolite occurs in the Gillett Mountains on the Somali Plateau; from its isolated position it was probably discharged by the earlier eruptions.

The Ashangi Traps of Blanford appear to correspond with the Kapitian, and his Magdala Traps with the Laikipian and Naivashan Series of B.E.A.

Basalts, including sub-alkalic varieties, are widely distributed and appear to have followed the phonolites. The younger volcanos discharged more acid lavas, mainly trachytes and rhyolites (e.g. comendite), which, like those from the volcanos with well-preserved craters in B.E.A., are probably Pliocene and Pleistocene.

VI. The Age of the Abyssinian Rift Valley Movements

The age of the earth-movements associated with these volcanic series is indicated, in the absence of marine Cretaceous and Kainozoic rocks in the Abyssinian Highlands, by evidence from Somaliland. There the Rift Valley movements are shown to be post-Eocene, as the faults S. of the Gulf of Aden dislocate both Cretaceous and Eocene.

That the Rift Valley E. of Abyssinia was in existence in the Miocene is the conclusion adopted by Dainelli and Marinelli (1912) in their revision of the geological and geographical evidence regarding Eastern Abyssinia and Eritrea. They maintain that the Red Sea basin is older than some authorities admit, and they are emphatic as to its tectonic origin. It is, they say (*ibid.*, p. 313), " an immediate consequence of the movements of the crust of the earth which originated its basin ; movements which probably date back to the Miocene." They show (e.g. *ibid.*, map p. 155) that the main movements were certainly completed before the Pleistocene, since they were earlier than the Aden Series which these authors declare to be " at least Pliocene " (*ibid.*, p. 312), for the beds of the Aden Series extend westward up the valleys, as if the Abyssinian Scarp had been made and dissected before their deposition. The Aden Series near Massawa includes gypsiferous marls which Baldacci (1891, pp. 28, 31, 34) attributed doubtfully to the Miocene, and some overlying fossiliferous sands which he referred to the Pliocene. Dainelli and Marinelli (1912, p. 89) correlate both these marls and sands with the beds containing *Melania tuberculata* and *Corbicula fluminalis*, which some authors included in the Pliocene ; they (*ibid.*, pp. 182–183) relegate them to the Early Pleistocene before the " pluvial period," which was approximately synchronous with the glacial period of Europe. The Aden Series is older than these beds and the last volcanic eruptions of the Red Sea (Dainelli and Marinelli, 1912, Pl. III). The Aden Series is probably Late Pliocene, and shows that the southern part of the Red Sea had been completed by at least Middle Pliocene, and perhaps by the end of the Miocene.

If the general view that the Red Sea gypsiferous series consists of altered marine beds be correct, then the sea occupied the southern part of the Red Sea, at least, as far N. as Massawa, in the Pliocene Epoch, if not in the Miocene. This conclusion gives further support to the view that the main subsidence of the Rift Valley happened between the end of the Eocene and the Miocene. That it was pre-Pliocene is proved by evidence from three different parts of the Abyssinian section of the Rift Valley. At the northern end of this section the Assala basin contains lacustrine deposits which were Pliocene or perhaps very early in the Pleistocene (Dainelli and Marinelli, 1912, pp. 90, 91) and were deposited on the floor of the trough. In the middle of the Abyssinian section the Pliocene volcanos of the Hawash Valley were piled up on its down-faulted floor ; and in the S., in the Omo Valley, the bone beds discovered by the Du Bourg de Bozas Expedition (*cf.* p. 360) are Late Pliocene and were deposited in the fault trough.

Further support to the post-Eocene and pre-Miocene age of the Rift Valley subsidence follows from the general correlation of the earth-movements and the volcanic eruptions. The volcanic and post-Paleozoic history of the area is summarized in the table on the opposite page.

Summarizing the geological history of this region : The high elevation of the Bathonian and Upper Jurassic limestones (Antalo, alt. 8500 ft.) and the absence of Neocomian beds indicate that Abyssinia underwent so great an uplift at the end of the Jurassic that the Cretaceous sea only reached the foot of the plateau, though it covered a wide area to the E. Before the end of the Cretaceous a regional uplift raised all the region around Abyssinia above sea-level. Then the rapid subsidence of the bed of the Arabian Sea was accompanied by the eruption of the high-level lava sheets (the Ashangi and Magdala Series of Blanford), the oldest of which are probably Upper Cretaceous. Subsidences in the Early Eocene admitted the sea to the site of the Gulf of Aden and adjacent parts of Arabia and Somaliland. It was soon expelled again, and shortly afterwards earth-movements made the Rift Valley and probably admitted the sea into the southern end of the Red Sea trough.

	Eruptions.	Deposits.	Earth-Movements.
Pleistocene—Upper.	Last eruptions of the Red Sea and Eritrean volcanos.	Raised beaches and coral reefs.	Uplift of the raised reefs, etc.
Lower.	Main eruptions of the above volcanos and of those of Afar.	—	Subsidiary Rift Valley faults.
Pliocene—Upper	Aden eruptions.	Lacustrine beds and Gypsiferous Marls.	Entrance of Indian Ocean to Red Sea lakes and Lake Assala area.
Lower.	Hawash eruptions, upper part of the Magdala volcanic series (=Naivashan of B.E.A.).	—	Second main series of Rift Valley faults.
Miocene.	Main eruptions of the Magdala series; alkaline lavas and basalts (=Laikipian of B.E.A.	Sandstones with fossil wood.	
Oligocene.	—	—	First Rift Valley faults, beginning of Sunkland of Gulf of Aden.
Eocene	—	—	General subsidence admitted the sea into Gulf of Aden.
Cretaceous—Upper.	Ashangi lavas (=Kapitian).	—	Formation of E. African arch.
Mid.	—	—	Cenomanian sea in Somaliland.
Lower.	—	—	Neocomian sea in Somaliland.
Jurassic—Kimmeridgian and Corallian.	—	Lagagima Limestone on Abyssinian Plateau.	Sea covered Eastern Abyssinia.
Bathonian.	—	Antalo Limestone.	—
Rhætic or Trias.	—	Gypsiferous and Corbula beds.	Terrestrial and (?) estuarine.

Further movements caused the foundering of the Gulf of Aden and renewed eruptions built up great volcanos along the Hawash Valley, and choked the Rift Valley near Lake Margherita. The sea had meanwhile receded from the southern end of the Red Sea; but further subsidences enlarged the Gulf of Aden, admitted the ocean to the Red Sea, and led to the last eruptions of the volcanos of Aden, of the Danakil Horst and of Afar, and of the islands in the southern part of the Red Sea.

[1] The scattered literature on the geological structure, volcanic history, earthquakes, and hydrography of this region is catalogued by Dainelli, Marinelli, and Mori (1907).

[2] The crater of Sekwala (Zuquala) and its crater lake have been described by De Castro (1908, p. 12), who refers to the lava as basalt (*ibid.*, pp. 14, 17). Its reputation as a holy mountain is attributed by von Erlanger (1901, p. 240) to the crater lake.

CHAPTER XXX

The Nile Valley & Red Sea

ONE of the most striking facts in the map of North-Eastern Africa is that the Nile Valley from Khartoum to Cairo is generally parallel to the Red Sea. It is natural, therefore, to consider that these two great valleys are connected in origin. Sir J. W. Dawson, the distinguished Canadian geologist, recognized in 1884 that the Lower Nile Valley is due to subsidence, and regarded the sinking as associated with parallel faults. Subsequently the explanation of the Red Sea as a rift valley led to the view that the northern part of the Nile Valley was of the same nature; this conclusion was adopted by Beadnell (1901, p. 28) and other members of the Geological Survey of Egypt, by Colonel Lyons, and by Dr. Max Blanckenhorn (1902, p. 709). Thus, according to Colonel Lyons (1906, p. 294): "This trough was determined in the first instance by fractures of the crust which caused a strip of country from about Edfu (lat. 25° N.) to Cairo to be depressed, leaving the plateau standing high above it, just as the Red Sea and the gulfs of Suez and Akaba were formed, probably about the same epoch." He (*ibid.*, p. 10) describes the fractures which "let down this strip of country" as "parallel faults."

That the Nile Valley is not a rift valley of the same character as the Red Sea is obvious from the striking differences between them. The Lower Nile flows by a zigzag course in an ancient depression which in Cretaceous and Lower Kainozoic times was a gulf of the Mediterranean. The Red Sea, on the contrary, occupies a straight trough which has cut through a plateau that remained high and unbroken long after the formation of the broad depression traversed by the Nile. The existing Nile is no doubt comparatively young, but the depression in which it lies dates from the Cretaceous; it is the diminished successor to a larger river which Blanckenhorn calls the Ur-Nil, and which drained North-Eastern Africa to the Mediterranean from the Middle Eocene to the Pliocene. The formation of the existing Nile Valley within the basin of the Ur-Nil Blanckenhorn (1902, p. 695) attributes to earth-movements during the Pliocene.

He (*ibid.*, p. 703) described its formation as a catastrophic infall, whereby the Ur-Nil was left dry. The Nile Valley up to the bend at Qena (*ibid.*, p. 709) he interprets as a rift valley due to an infall before the beginning of the Middle Pliocene.

The faulting of the Nile at Assuan was recorded by Dr. Hume (1906, p. 58), who described Egypt as having been subject in the Miocene to complex earth-movements, including folding, fracturing, and rifting (*ibid.*, p. 59). Dr. Ball holds that the supposed faults are only landslips ; accordingly he and Dr. Hume interpret the valley of the Lower Nile as a depression along a system of folds, of which one set trends N. and S., and another set trends E. and W. The latter set occasions, for example, the sharp bend of the Nile at Qena. Whatever may be the nature of the subsidences along the Lower Nile, its valley is tectonically very different from that of the Red Sea ; but the existing Nile was probably formed by the union of various rivers along a great N. and S. depression by movements associated with the formation of the Great Rift Valley.

The Red Sea

The Red Sea is, therefore, a younger formation than the Nile and, instead of lying along the floor of an older depression, breaks across a vast area of highlands regardless of its structure. The scarp-like character of its Arabian coast is described as follows in the Admiralty, " Red Sea Pilot " (1909, p. 285) : " From the Gulf of Akaba to the straits of Bab-el-Mandeb, a distance of 1000 miles, the Arabian mountains are conspicuous throughout, presenting peaked summits of naked rock from 5000 to 8000 ft. in height, and varying from 12 to 60 miles in distance inland. This range falls so abruptly on its western face that it presents, towards the sea, a series of inaccessible cliffs ; other, but lower ranges approach the seashore in some places, decreasing in height as they approach. In clear weather these mountains are visible at from 40 to 70 miles. . . ."

It is convenient to consider first the history of the Gulfs of Suez and Akabah, as the most detailed information is available regarding them.

1. *The Gulf of Suez.*—Dr. Ball (1910, 1911) extends his explanation of the valley of the Lower Nile to that of the Gulf of Suez, which he claims as due to erosion along an upfold. The admitted faults along its course he regards as older and as having had no direct

influence on its formation. The supposed later faults he dismisses as landslips. Dr. Ball remarked (1912, p. 355) that there is no geological foundation for the view that the Gulf of Suez is due to trough faulting ; but the faults that would be expected along the Egyptian coast on the Rift Valley theory of the origin of the Gulf of Suez are shown in two maps—General map of Egypt, scale of 1/2 m., and map 1/1 m., sheet 4, Arabian Desert—issued by the Geological Survey of Egypt in the same year of the publication of Dr. Ball's paper.[1]

The geological history of Egypt in the Cretaceous and Lower Kainozoic has been summarized by Dr. Hume (1911, pp. 129–136, 146), who shows that the Upper Cretaceous was characterized by a great invasion of the sea from the N.E. ; then followed a break in the deposition and the formation of the Eocene marine limestones, after which continental conditions were introduced towards the end of the Eocene. The Oligocene is represented only by fresh-water and land beds, such as gravels, and by volcanic rocks, including the dolerites of Baharia and the basalts of the Fayum and near Cairo.

The occurrence of a volcanic series at the end of the Middle Cretaceous in South-Eastern Egypt has been recently shown by Barthoux (1919, p. 699), who has described from the Wadi Natasch (at 24° 25′ N., 34° 10′ E.) a series of alkaline trachytes, phonolites, and solvsbergites ; they have been derived from a nepheline-sodalite-syenite which is exposed in Gebel Abu Kbrug. Basalts occur E. of the alkalic volcanic series, and andesites to the S. of it.

The Gulf of Suez cuts through the northern end of the belt of Eozoic rocks which form the foundation of Arabia, of the peninsula of Sinai, and of the Libyan Hills to the W. of the Red Sea. At about one-third of the length of the gulf from its northern end these old rocks disappear beneath Cretaceous beds, which extend from the Nile Valley eastward across the Gulf and lap around the northern margin of the mountains of Sinai. A band of Cretaceous rocks occurs along the eastern shore of the Gulf, where they have probably been dropped by faults. The marine Eocene limestones are not found along the shores of the Gulf, except at its northern end, though they enter the Gulf depression from the W. and extend to about 29° ; but Miocene and gypsiferous beds, which are regarded as altered marine Miocene limestones, occur beside the southern part of the Gulf.

The absence of marine Eozoic rocks along the Gulf indicates that it was formed later than the Eocene; while the presence in it of Miocene beds resting on the old floor of the valley shows that its formation had begun in pre-Miocene or Early Miocene times. It was not completed in one operation. According to Dr. Barron (1907 (2), pp. 180–182), the area of the Gulf of Suez underwent re-elevation towards the close of the Upper Pliocene, and the strain caused by this uplift snapped the beds along fractures trending from N.W.–S.E. The main fractures formed the great valley between the highlands of Egypt and Sinai, while secondary fractures in the main Rift Valley determined the existing coasts of the Gulf of Suez. The boundary faults of the Red Sea basin Barron described as earlier than those which bound the Gulf of Suez.

If Dr. Barron's explanation be not correct and the Gulf was not made by faulting, it must have been excavated by river erosion. That the Gulf of Suez could have been cut by rivers is, as Dr. Hume (1910, p. 388) points out, improbable; for a river flowing southward from the northern end of the Gulf would have been blocked by a high mass of ancient rocks, unless a way had been prepared for it by fold or fault. That the Gulf of Suez in Miocene times was an upfold was remarked by Hull (1886, p. 109) and confirmed by Dr. Hume. As the Geological Survey map of Egypt represents powerful faults of a suitable trend and date, the probabilities are with Dr. Hume that the primary cause of the Gulf of Suez is faulting through the upfold. Some folding of the beds on its floor is known, but this is probably a secondary effect due to their being compressed between the main fault walls. Dr. Hume remarks (1910, p. 388) that the northern end of the Gulf was covered by a great dome, and adds: "I can conceive of no erosive agent which would break across this great earth-feature without the intervention of fracture."

The movements along the Gulf of Suez appear to have been abnormal;[2] for, according to Dr. Hume, they produced overthrust faults (at Gebel Zeit; Hume, 1916, p. 59, and Pl. XXI, Fig. E) of the kind due to lateral pressure.

Where a block of material sinks into the wedge-shaped space between two normal boundary faults the material is compressed and tends to be folded. Hence it is not surprising to find stratified deposits, such as those on the floor of the Suez arm of the Rift Valley, corrugated into a series of gentle folds. Great attention to these folds has been called by their existence in the oil fields of Jemsa Bay, on the Egyptian coast, S. of the Gulf of Suez; but these folds would appear to be secondary, while the primary cause of the trough of the Gulf of Suez was subsidence along a parallel series of older faults.

These faults are represented in Messrs. Barron and Hume's map of the area (1902, P. II) and the Geol. Survey map of Egypt (scale 1 to 1,000,000, sheet No. 4, 1910), though they are not retained in Dr. Hume's latter map (1916, Pl. I); but it would appear difficult to explain the structure of this area, as represented on the map, without some such faults.[3]

2. *The Gulf of Akabah.*—In his argument for the formation of the Gulf of Suez by erosion Dr. Ball lays stress on the difference between it and the Gulf of Akabah, which he accepts as (1911, p. 7) "admittedly a trough subsidence." The differences to which he attaches importance are the irregularity of the Gulf of Suez and its shallowness in contrast to the straightness, narrowness, and great depth of the Gulf of Akabah. But these differences appear due to the Gulf of Suez being the direct continuation of the trough of the Red Sea, while the Gulf of Akabah is a younger branch.

According to Blanckenhorn (1893, profile I), the floor of the Gulf of Akabah consists of Nubian Sandstone, which is thrown down between a pair of faults; the valley is bounded to the W. by the horst of granite and porphyry of Sinai, and to the E. by the plateau of Edom, which consists of the same ancient rocks as those to the W. and are capped by Nubian Sandstone. The Gulf of Akabah, he said (p. 132), "must be a typical 'graben,' i.e. it must have originated by an infall of a band of the earth's crust along two parallel fractures between two upstanding horsts."

3. *The Red Sea Trough.*—The Red Sea trough trends S.S.E. for a length of 1200 miles, and varies in width from 190 miles at Massawa to 14 miles at the Straits of Bab-el-Mandeb; it is in places over 1000 fathoms deep. It forks at its northern end, where the peninsula of Sinai separates the Gulf of Akabah, which leads to the Jordan, from the Gulf of Suez. Many parts of the coast are geologically little known, but the evidence is sufficient to show that the trough of the Red Sea is of considerable antiquity and is bounded by faults due to earth-movements of various dates.

The Red Sea trough has broken through the wide plateau of Eozoic rocks which form the foundations of Nubia, Abyssinia, Arabia, and Somaliland. The south-eastern part of this plateau in Abyssinia and South Arabia was lowered in Mesozoic times, and the sea then deposited on its border a varied succession of rocks; these are represented in Eastern and South-Eastern Abyssinia by the Bathonian and Kimmeridgian; while in Somaliland the Eozoic rocks are followed by a series of Mesozoic deposits, ranging from the Lias or perhaps the Trias to the Eocene.

As these marine rocks do not extend far up the Red Sea trough, the sea which deposited them apparently reached the area from the E., as an arm of the sea that covered parts of Southern Persia and North-Western India. The sea still occupied part of this area in the Eocene, at the end of which it receded eastward, since there are no known marine Oligocene, Miocene, or Pliocene deposits along the Red Sea except at the northern end. Its site had been raised above the level of the sea, which was not readmitted until the early Pleistocene.

The geology of the western coastlands of the Red Sea from 22° to 26° N. lat., from the southern boundary of Egypt to the neighbourhood of Koseir, has been described in detail by Dr. Ball (1912); some geological information as to the coast between Koseir and Suakin was given by Schweinfurth (1865, pp. 133–136, and 371). Dr. Ball has shown that in this part of the area there is no evidence of the existence of the Red Sea basin before the end of the Cretaceous. Between that date and the end of the Oligocene earth movements raised the Egyptian mountains and a complementary subsidence to the E. formed the Red Sea.

The faults of this region, according to Barron and Hume (1902, Pls. II, III, and sect. III), include a series of block faults in the Eocene and older rocks behind the port of Koseir, and some faults at Wadi Darg, which, according to Barron and Hume, were later than the Eocene and earlier than the Miocene.[4]

The evidence from the Red Sea coastlands shows that the Red Sea occupies a tectonic depression, bounded by powerful faults, formed at intervals between the Oligocene and the present time; it broke through an area of highlands, which according to Barron had been uplifted in Middle or Late Cretaceous times, and which was first invaded by the sea in the Miocene.

Further S., in the neighbourhood of Suakin and Port Sudan, the coastal features have been studied by Mr. Cyril Crossland (1913, pp. 122, 155). He is emphatic that the main trough of the Red Sea is a rift valley due to the floor being downthrown 11,000 ft.; and he explains some of the secondary features as tectonic. He regards the narrow, cleft-like harbours known as "khors" as marginal cracks along the main fractures. The facts described in Mr. Crossland's work indicates that the Red Sea trough was formed at two main periods; the eastern front of the Nubian Hills is so deeply dissected by denudation that it is doubtless the remnant of an Oligocene scarp; but the subsidence which caused the submerged part of the Red Sea trough and the marginal "khors" was clearly much later and probably due to the Pliocene earth movements.

The course of the Red Sea faults is N.W.–S.E.; but the evidence of diagonal fractures trending N.E.–S.W. is rendered probable by some topographic features in Nubia. That some of these diagonal fractures belong to the later movements is rendered probable by Dr. Chalmers Mitchell's recent discovery of a well-preserved volcanic hill within the great bend of the Nile between Berber and Korti (Gregory, 1920 (2), p. 667).

The Nile below Khartum is re-excavating an older river valley which has been filled with sandstone, and its present course is comparatively modern. At Abu Hamed it suddenly bends back and flows S.W. for 160 miles to Korti. This change of direction has not hitherto been explained. This part of the Nile, however, is in line with an also unexplained breach of the western rim of the Red Sea basin between the Gebel Elba and Adel Qaga Mountains. That this gap and the S.W. bend of the Nile might be due to the same tectonic influence was suspected as possible. Dr. Chalmers Mitchell, in his flight from Cairo to Tabora, discovered a well-preserved volcano field at Bayuda, within the Nile bend; the existence of this extinct but apparently recent volcanic area suggests that the Nile has been deflected S.W. along a subsidence due to a fault which trends from S.W. to N.E., and which, if continued, would cross the Gebel Elba breach in the Nubian Mountains. The nature of the rocks discharged from this volcano is unknown; but Dr. Campbell Smith (1920, p. 48) has recently described a riebeckite-rhyolite from Kordofan in line, as he remarks, with the Bayuda volcanic field and the Gebel Elba breach.

The mountains W. of the Red Sea do not appear to have been submerged beneath the sea, and they are probably part of the ancient highlands that extended N. and S. along East Africa. These highlands probably extended eastward across the Red Sea, and were continuous with Arabia before the formation of the Red Sea trough.

The northern margin of these highlands during the Middle Cretaceous crossed Northern Sinai and continued westward across the Gulf of Suez at about 29° N. lat.; for a marine Cenomanian bed was deposited along this line, and extends at the western foot of the highlands southward into Southern Egypt. The sea which deposited this bed continued to occupy the Nile Valley as far S. as 24° N. through the rest of Cretaceous and Eocene times; but it was not until the Miocene that the sea began to extend southward down the Red Sea.

According to Dr. Ball (1912, p. 364), the Red Sea depression happened not later than the Oligocene, and possibly during the uplift of the surrounding country at some uncertain date between the Upper Cretaceous and Oligocene; but it was not then sufficiently deep to have been invaded by the sea; it was a great land valley, occupied by a chain of fresh-water lakes and the vanished Erythrean River which extended from Abyssinia to Palestine (as suggested in G.R.V., p. 259). Dr. Ball (1912, p. 364) tells us that the main lines of the present drainage were established in the Oligocene, during which epoch the land was being sculptured by sub-ærial agencies.

By Miocene, and even Lower Miocene, times an arm of the sea had extended southward along the line of the Red Sea, and the extensive development of the gypsiferous beds[5] indicates that by the Upper Miocene and Lower Pliocene the Red Sea extended over this area as far as South-Eastern Egypt.

This sea was an extension of the Mediterranean, for its fossils are all of Mediterranean affinities, so that the southern part of the Red Sea depression was probably still a land area; but later, probably in the Pliocene, renewed subsidence in the southern part of the Red Sea trough, and the breaching of its south-eastern wall by the subsidence of the Gulf of Aden let in the Indian Ocean. But by this time the movements which raised the hills trending E.–W. between Cairo and Suez had separated the Gulf of Suez from the Mediterranean, so there was no connection between the Mediterranean and the Indian Ocean through the Red Sea.

The subsidences which admitted the waters of the Indian Ocean into the Red Sea probably happened in Late Pliocene or Pleistocene times and caused the eruptions which built up the volcanic islands in the southern part of the Red Sea and the extinct volcanos of Aden, Eritrea, and Arabia.

The Red Sea trough was, therefore, formed by earth-movements at successive dates, beginning not later than the Oligocene and continuing till quite recent times.

[1] Since this chapter was finished two bulletins have been published by the Geological Survey of Egypt (*Petrol. Research*, Bull. Nos. 7 and 8, 1920), in which Dr. Hume and his colleagues, Messrs. Madgwick, Moon, and Sadek, who have been examining the Gulf of Suez, have shown the occurrence of numerous faults parallel to the Gulf; and they describe faulting as "the controlling factor in the formation of the shore-line of the Gulf" and as "determining the present position of the Gulf of Suez" (No. 7, pp. 15–16).

[2] Overthrust faulting has been reported near Lake Manyara, but the evidence is inadequate (*cf.* p. 293).

[3] The numerous step-faults beside the Gulf of Suez are again shown in the recent maps and sections by Dr. Hume and others on the Gebel Tanka area of Western Sinai (*Petrol. Research*, Bull. No. 4, Cairo, 1920, Pl. 7 and map).

[4] Faults later than Plio-Pleistocene beds and parallel to the coast behind Koseir are shown in the recent report by Dr. Hume and his colleagues (*Petrol. Research*, Bull. No. 5, Cairo, 1920, map and section).

[5] According to Dr. Hume (1916, p. 24), the age of the gypsiferous beds is certainly between the Helvetian, i.e. Middle Miocene, and the Middle Pliocene.

CHAPTER XXXI

The Age of the Rift Valley in Palestine

PALESTINE, in addition to its unique historic attractions, is of special interest to the physical geographer, for it includes the impressive section of the Great Rift Valley, through which the Jordan descends to the deepest land surface on the globe. This valley is inhabited by the crocodile in the Zerkha River, and by many fish and plants typical of Equatorial Africa. This Asiatic valley has an African element in its fauna and flora.

Blanckenhorn, the chief authority on the geology of the Jordan Valley, regards it as having been formed as late as the Middle Pleistocene. According to this view, the youngest part of the Great Rift Valley is the Jordan Valley. It cuts through an area composed of rocks which, excluding the volcanic, are younger than those in any other part of the Rift Valley. It traverses a plateau composed of Cretaceous limestones, and it is only at the southern end of the Dead Sea that the Eozoic rocks are exposed; there also occur some Cambrian beds, the only occurrence of marine Paleozoic rocks along the Rift Valley. In Northern Palestine the Rift Valley movements have faulted Jurassic rocks. With these exceptions the trough of the Jordan and Dead Sea intercepts only Cretaceous and Eocene rocks, mostly of marine formation.

Volcanic activity along the Rift Valley in Palestine has been of minor importance. It began, as usual along the Rift Valley, in the Upper Cretaceous, for on the moorlands S. of the Bay of Acre (S.W. of Mount Carmel and N.W. of Samaria) are basaltic tuffs which underlie Turonian limestones. Geologically recent eruptions have poured basalt flows over the eastern wall of the Rift Valley to the shore of the Dead Sea (Blanckenhorn, 1910, p. 459). The volcanic action along the Jordan Valley may have lasted sufficiently late for memory of the eruptions to have been preserved in tradition. Nevertheless the lack of conspicuous evidence of volcanic action along the Rift Valley in Palestine led Hitchcock (1843, pp. 372–379) to reject the then commonly accepted view that the cities of Sodom and Gomorrah were destroyed by volcanic action. He was correct in his argument that no volcanic eruptions along the Jordan or Dead Sea have taken place in historic times. After careful consideration of the evidence, he denied any considerable change of level in the Dead Sea in historic times. He attributed the destruction of "the Cities of the Plain" to earthquakes accompanied by emission of sulphur and petroleum through fissures, and suggested that burning sulphur might have set on fire some of the bituminous material from which the Dead Sea has been called "Lake Asphaltites." Hitchcock was fully correct in the view that the Jordan–Dead Sea–Akabah Valley is primarily seismic and not volcanic, though his contention that there has not been any volcanic action around the Dead Sea cannot now be maintained.

That the Jordan Valley was formed by subsidence between parallel faults has been fully demonstrated by Blanckenhorn; but owing to the comparative softness of the rocks on either side, and rapid denudation by the Jordan and its tributaries, the walls have been so greatly eroded that Prof. Bonney (1904, p. 577), who recognizes the tectonic origin of the depression, has demurred to the term Rift Valley being still applied to it.

In Blanckenhorn's narrative of his 1908 expedition in Palestine (1912, p. 392) he classifies the movements into three series. The oldest series, Late Miocene or Lower Pliocene in age, trends E.–W. and is well seen E. of Acre and in Upper Galilee. This series is parallel to the contemporary movements in Northern Egypt. The second series was formed in the Upper Pliocene and Pluvial, and trends from between N.E. to S.W. or from N.N.E. to S.S.W.; it occurs on both sides of the Rift Valley, crossing Samaria to Judea; one of its faults, E. of the Jordan, strikes the north-eastern corner of the Dead Sea. The last series of movements cuts abruptly across the others, and Blanckenhorn assigns it to the middle part of the Pluvial Age; it trends N.–S., and formed the Jordan Valley and Dead Sea.

The Rift Valley comes to an end in Northern Syria by the type of branching which Suess calls a "virgation" (Suess, 1891, pp. 127–130, 133, 135; Diener, 1885, p. 645; and Blanckenhorn 1912, whose map shows seventeen main faults). Many faults branch to the N.E., but the main valley continues northward till it ends in Northern Syria (36° N.) against the wide-folded area of Asia Minor. Two possibly associated tectonic valleys, E. of the main series, known as Wadi Sirhan and Wadi Udian, have been described by Blanckenhorn (1914, p. 63).

The tendency to subdivide is shown by the Rift Valley at several places in its course, as near Lake Natron and at the northern end of Lake Rudolf. The southern end of the Rift Valley also occurs where it subdivides into diverging tectonic lines. The breaking up of the Rift Valley in Syria happens where it approaches the country that has been folded transversely to its course by the mountain-forming movements that upheaved the Taurus Mountains. N. of these mountains a possible continuation of the Rift Valley fractures may be indicated by the lavas discharged from the great Armenian volcano Nimrud, which Dr. Prior informs me consists of kenytes and alkalic lavas similar to those of B.E.A. Possibly the remarkable transverse fracture across the Caucasus E. of Mount Elburz (in line with the N.–S. part of the Kuma Valley) is a still more northern rupture connected with the movements that made the Palestine branch of the Great Rift Valley.

PART IV

CHAPTER XXXII

The Relations of the Rift Valley to Contemporary Earth-Movements

I. The Structure of the Rift Valley

PART II has described the geological structure of the Great Rift Valley in B.E.A.; Part III summarizes the scattered literature dealing with the structure and geological history of the parts of Africa and South-Western Asia traversed by this valley.

Stated briefly, the primary facts established by the available evidence are these :—

(1) The Great Rift Valley was formed by the subsidence of strips of the earth's crust between parallel faults.

(2) This fault-formed valley is continuous from Palestine to S. of the Zambezi, except for about 80 miles in Southern G.E.A., and branches of it extend from the Gulf of Aden westward to the Central Congo. The break in its continuity along the Kisigo Valley in G.E.A. may yet be filled, since between the known ends of the Rift Valley on either side of it are apparently continuous fractures. A tectonic connection may also be found between the Western Branch on the Upper Nile and the main eastern line at Lake Rudolf.

(3) The faulting has broken through an especially stable part of the earth's crust, which consisted of a pre-Paleozoic mountain chain that extended from Asia Minor to Natal. This primitive mountain axis of East Africa, although over 4000 miles long, includes no marine Paleozoic rocks except for a patch of Cambrian in Southern Palestine, so that throughout the whole of the earlier part of the earth's history the area from Palestine to Natal had probably been always occupied by land. During the Mesozoic Era the sea reached the site of the Rift Valley at the northern end (Palestine, Egypt, and Sinai) and at the central part (Abyssinia and Somaliland). The Eocene sea occu-

pied the same two regions, and also reached the site of the Rift Valley S. of the Zambezi.

(4) The history of the Rift Valley begins in Upper Cretaceous times, when a belt of highlands was formed throughout Eastern Africa by either the uplift of the pre-Paleozoic foundation or the subsidence of the land on each side ; the formation of this raised tract was accompanied by the outbreak of volcanic activity in Palestine, South-Eastern Egypt, South-Western Arabia, Abyssinia, B.E.A., G.E.A., and Mozambique. These eruptions were contemporary with the vast outpouring of lava which formed the " Deccan Traps " of Western India. Eruptions were renewed at intervals throughout the Kainozoic Era and were associated with periodic earth-movements. These happened along fractures due to the rending of the crust along three main series of lines—N. to S., N.W. to S.E., and N.E. to S.W.

(5) The volcanic rocks discharged are of the kind rich in soda and poor in lime ; they are therefore of the Atlantic and not of the Pacific type, since they are richer in alkalies than in lime.

(6) The formation of the Rift Valley began by movements which left an upraised tract throughout East Africa to the E. of the sunklands which formed the western basin of the Indian Ocean (the Arabian Sea), the Persian Gulf, and the Mesopotamian Valley between Arabia and Persia.

(7) The Rift Valley is bounded by faults which have been proved to occur in so many parts of its course that they probably bound the whole length. These faults are normal except for a reverse fault described by Dr. Hume at the oil-field of the Gulf of Suez and a doubtful record near Lake Manyara (*v.* p. 293).

(8) In contrast to the powerful faulting along the Rift Valley folding has been slight and gentle. The dip of the beds and the slope of the ground away from the valley on each side indicate that a broad, flat arch once stood over it. Occasionally the beds have steeper dips, but they are exceptional and are due not to folding, but to blocks being tilted.

(9) With the exception of the one reverse fault, there is no evidence along the Rift Valley of the reverse faulting and intense folding which accompanies mountain formation by lateral pressure.

(10) The floor of the Rift Valley consists of rocks which have been lowered between the parallel faults, although they are often buried beneath deposits on its floor. This structure has been proved at intervals throughout the Rift Valley and its branches : in Palestine

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(e.g. Blanckenhorn, 1896, Pls. III and IV, showing the down-faulted Cenomian beds beside the Dead Sea), in the Red Sea, in the Gulf of Akabah, in the Gulf of Aden, where the Eocene limestones occur on the lowland and on the plateau ; E. of Abyssinia, where the Eozoic rocks exposed in the walls are buried beneath the floor ; in B.E.A., where the volcanic rocks of the adjacent plateaus are found at intervals on the floor ; in G.E.A. at Lake Nyasa ; and in the Eastern Congo, as in the Lukuga Valley, where the rocks of the Karroo Formation occur on the floor of the rift valleys down-faulted into the Eozoic foundation.

II. The Age of the Great Rift Valley

The Great Rift Valley, therefore, extends from Lebanon to the Sabi River, with branches eastward to the Gulf of Aden and possibly to the Pangani Valley, and westward to Tanganyika, the Upper Nile and the rift valleys of Lakes Moero and Upemba in the Central Congo. This widespread valley system is obviously not the result of a local fracture. As the length of the main trunk is about one-sixth of the circumference of the earth, it must have had some world-wide cause, the first promising clue to which is the date of its formation.

There are two theories as to the age of the Rift Valley. According to the first, its history is geologically short, and this view at once suggests itself on inspection of the valley, as its walls are often as fresh and steep as sea cliffs. That the valley is geologically young is also suggested by tradition and folk-lore. It is tempting to explain the graphic story of the destruction of Sodom and Gomorrah by the last earth-movements which made the Dead Sea. Similarly, according to an oral tradition of the Somali, when their ancestors crossed from Southern Arabia to Somaliland the two countries were connected by land. The people, too, of Ujiji have a legend that many villages were drowned on the formation of Tanganyika. A story reported by Dr. Oswald (1914, p. 156) represents the subsidence of the Simbi crater as the punishment of an inhospitable village, whose inhabitants all but one perished in the catastrophe. These legends, however, may not be actual reminiscences of the Rift Valley movements ; they may result, like so much folk-lore, from attempts to explain local geographic features. The main faults of the Rift Valley were certainly earlier than the oldest known remains of man found along its course. Most of the Rift Valley had been formed by the

Pliocene, though the Jordan Valley and the final movements and eruptions belong to the Pleistocene Epoch. It contains no marine Pliocene beds S. of Massawa, and Late Pliocene deposits containing fresh-water shells lie upon its floor ; hence it was a valley in the Pliocene, though it was not then occupied by the sea. In B.E.A. some of the Rift Valley faults are younger than the Miocene lavas, and are therefore not earlier than Pliocene.

That the Rift Valley was not older than Pliocene or Pleistocene was my first impression of it in 1893 ; but gradually I was forced to the view that the Pliocene movements were the later stage in the development of a much older valley and that the Rift Valley has had a long and complex history. I accordingly suggested a classification (1896, p. 235) of its rocks and earth-movements, which attributed its oldest associated lavas to the Upper Cretaceous and its earliest main faults to the Oligocene. That classification has been regarded as too elaborate and as attributing too great an age to the Rift Valley.[1]

The fuller evidence, however, now available seems fully to confirm that classification. It represented, on physiographic evidence, that some of the lake deposits and bedded volcanic tuffs in B.E.A. were probably of Miocene age, and indicated a great extension of lakes at that period. This view has now been established by Dr. Andrews from the extinct mammals obtained by Mr. Hobley and Dr. Oswald. That the Rift Valley just N. of B.E.A. had been formed before the Upper Pliocene is proved by the fossil mammals (including Dinotherium and Elephant) found on the floor of the Rift Valley in the Lower Omo by the Du Bourg de Bozas expedition (*cf.* p. 205).

That the Rift Valley is post-Eocene is shown by abundant evidence at various parts of its course, as in Palestine, Egypt, the Red Sea, Abyssinia, Somaliland, and now also S. of the Zambezi, by Mr. R. B. Newton's study of Teale and Wilson's collections from Sheringoma. In these countries the Rift Valley faults cut through Eocene and sometimes Upper Eocene beds. The formation of the Rift Valley, therefore, began later than the Upper Eocene and earlier than the Upper Pliocene. To fix a date within these limits is more difficult, owing to the scantiness of the evidence. The fossil sea-urchin from Lake Nyasa, *Echinolampas discoideus* Arch. and H. (*v.* p. 298), indicates that an arm of the Oligocene sea extended up the Zambezi valley into the southern part of the Rift Valley in some part of the Oligocene Epoch. The same date is well established for the formation of the trough now occupied by the Red Sea, which the Geological Survey of Egypt has shown was in existence by the Oligocene; the first depression formed a great land valley which was occupied by a chain of fresh-water lakes that extended from Abyssinia to Palestine (*cf.* G.R.V., p. 258). According to Dr. Ball (1912, p. 364), even the main outlines of the present drainage along the Red Sea had been established as early as Oligocene times. In the next period, the Miocene, the sea, according to Dr. Hume (1916, p. 21) and Dr. Ball (1912, p. 364), invaded this depression and deposited what are now the gypsiferous limestones along the coast of South-Eastern Egypt. Issel (1900) also claimed that the Red Sea was formed by subsidence and was in existence in the Miocene (in which he included Oligocene), when it was occupied by a series of lakes. The Red Sea trough was formed by earth-movements at successive dates, beginning not later than the Oligocene and continuing until geologically recent times.

The history of the Rift Valley in B.E.A. goes back, however, earlier than its subsidences, which resulted from conditions due to earlier processes that are revealed by the volcanic history of the country. The earth-movements and eruptions are clearly connected, as the subsidence of the earth-blocks doubtless forced up the lavas along the fractures.[2] The first stage in the development of the Rift Valley was the formation[3] of a long, low arch with the axis trending N. and S. The Rift Valley intersects this upraised band and therefore cuts across domes and highlands in preference to the lowland. The intersection of the higher ground by the Rift Valley is shown on the map illustrating the paper by General Smuts (1918, opp. p. 192), by the orographic map of B.E.A. prepared at the Public Works Department by Mr. McGregor Ross, and by the truncation of the front of the Livingstone Mountains, the loftiest in the Nyasa district. Suess remarked the up-swelling of the Rift Valley borders and called it their "Aufwulstung"; and Jaeger (1913, p. 161) refers to the general elevation along the course of the Rift Valley as the "Schwellung" which preceded the faulting. The raised edges appear to be due to their having remained upstanding during the collapse of the floor of the Rift Valley, and not to independent uplift.

The second stage in the formation of the Rift Valley was the rupture of the sides of the arch as the lateral supports gave way. The top sank as the keystone of a bridge sinks if its buttresses slip or settle. The sinking of the keystone of the East African arch into the plastic layer below forced some of it up the adjacent cracks, through which the material was discharged in volcanic eruptions. Each renewal of the subsidence was followed by fresh eruptions.

To determine the dates of these events it is necessary to consider the relations of East Africa to the Arabian Sea,[4] and refer to the time when East Afiica and India were included in a continent which extended from Brazil eastward to Australia. This continent, Gondwanaland, lasted through the Carboniferous Period and through the two succeeding Periods, the Permian and Trias, so that no marine beds belonging to them were deposited in tropical or Southern Africa or the African islands.

In the next two periods, the Jurassic and Cretaceous, Gondwanaland began to break up, and the sea invaded the coastlands of India and East Africa. The Jurassic deposits were laid down quietly, undisturbed by volcanic eruptions ; but the active earth-movements in Upper Cretaceous times, and the foundering of the Indian Ocean between Africa and India, led to volcanic outbreaks on a colossal scale.

These eruptions in Western India discharged the lavas (basalts and trachytes) known as the Deccan Traps, which cover about a quarter of a million square miles in Western India and perhaps an equal area under the Indian Ocean. The age of the eruptions is fixed as Upper Cretaceous by shells in the Pab beds of West-Central India. As the formation of the Arabian Sea led to such violent volcanic activity in India, eruptions might be expected on the other sides of the foundered land ; and the widespread plateau lavas beside the Persian Gulf, in Southern Arabia, and in Abyssinia have been generally regarded as belonging to the same series as the Deccan Traps.

Volcanic activity in B.E.A. probably began at the same date with the discharge of the soda-rich phonolitic lavas of the Kapiti Plains. Mount Jombo, S.W. of Mombasa, consists of igneous rocks which are chemically related to phonolites and are intrusive in the coastal sandstones and, judging by analogy with the similar rocks in Cutch and Madagascar, are not earlier than the Cretaceous. They are nepheline-syenites and ijolites. The phonolite of the Kapiti Plains is clearly of considerable geological antiquity, for all the craters through which it was discharged have been swept away, and the floor of the valley which confined the Yatta lava-flows has been left as a high plateau by the slow wearing down of its banks.

That the earth-movements of the Rift Valley began in the Upper Cretaceous is supported by the volcanic history of most of the countries it traversed. Its course is marked by a zone of vigorous volcanic activity, and the volcanic materials ejected along it belong to the alkalic section of igneous rocks. The volcanos were doubtless the result of the subsidences that made the Rift Valley, and their eruptions began in the Upper Cretaceous or shortly later. Thus, following the Rift Valley from N. to S., the dates are as follows :—

In Palestine, in Western Samaria, the outbreak of the volcanic eruptions is definitely fixed as just post-Turonian (Upper Cretaceous, *v.* p. 354).

In Sinai and W. of the northern part of the Red Sea it is post-Cenomanian, or again Upper Cretaceous (Barthoux, 1920).

In Abyssinia and Southern Arabia the first lavas are correlated with the Deccan Traps, and are therefore Senonian, also Upper Cretaceous (*v.* pp. 326, 339).

In B.E.A., on the coast, intrusive igneous rocks, of the kinds (nepheline-syenites and ijolites) that fed the lava streams of Kenya and Kilima Njaro, are later than the coastal sandstones and probably later than the Jurassic.

E. of the Victoria Nyanza the volcanic rocks are earlier than the Lower Miocene beds with *Dinotherium hobleyi;* but there is no known fossil evidence to fix the age of the pre-Miocene lavas.

In Mozambique the evidence is only adequate to show that the lavas are later than Eocene.

The geological history of other parts of Africa also indicates that the beginning of the later volcanic period was near the end of the Cretaceous. In Northern Madagascar there is a long series of alkalic igneous rocks from the Cretaceous to the present ; and, as shown by Prof. Lacroix (1901, p. 441), the lavas dominant in the most recent eruptions are nephelinites and olivine-tephrites, similar to those of the later eruptions along the Rift Valley (e.g. Elgon, near Lake Kivu, the Giant Caldron Mountains, and Kilima Njaro). The volcanic rocks of Nigeria were originally assigned to the Eocene (Falconer, 1911, p. 253) ; but Dr. Falconer informs me in a recent letter that he now refers these eruptions to the end of the Cretaceous.

The African alkalic eruptions are associated with great subsidences. In the mountains of Tibesti, in the Central Sahara, Tilho has recently discovered an extensive area of volcanic rocks, which have been described by Lacroix (1919, p. 405) ; some are calcalkalic, but they are associated with such alkalic varieties as comendites, phonolites, and basanitoid lavas. These volcanic rocks are associated with great subsidence caldrons, of which that of Koussi is 9 miles in diameter (Lacroix and Tilho, 1919, pp. 1237–1240). The sequence was basalt, syenite, trachyte, and finally basalt scoria. The age of the eruptions is uncertain, but the last tuffs are described as very fresh (*ibid.*, p. 1239). They were not later than Pliocene, since the caldron was occupied by a lake which has gradually dried up during the recent desiccation of the country, to which is due also the deposition of the adjacent natron fields of Era Kohor.

That some of these Rift Valley movements in B.E.A. were pre-Miocene is indicated by the evidence from Kikongo, E. of the Victoria Nyanza. Some lake-beds in that district have yielded the bones of a primitive elephant, *Dinotherium hobleyi* Andrews. Its age is Lower Miocene, and Dr. Oswald (1914, p. 140) has shown that the lake-beds containing this fossil are earlier than some of the local lavas (the nephelinites), but are younger than the augite-andesite of Kikongo and the volcanic agglomerates of Metamala (Oswald, 1914, p. 144). If this augite-andesite be of the same age as the older augitic and andesine-bearing lavas of the Rift Valley, then they are pre-Miocene, and the phonolites of the Kapiti Plains must be much older than the Miocene. It may, however, be argued that the lava of Kikongo is very ancient (Paleozoic or even older) and has nothing to do with the modern volcanic series; that the phonolites of Kisumu are of the same age as the nephelinites of Kavirondo,[5] and therefore post-Miocene; and that the Kapitian phonolites are also post-Miocene owing to their striking similarity to the phonolites of Kisumu and Lumbwa. If so, the volcanic history of B.E.A. would be confined to the post-Miocene, and the oldest of its known volcanos would be Pliocene.

This correlation, however, seems to me improbable, for I nowhere saw any interbedding of the Kisumu phonolite and nephelinites. The Kapitian phonolites W. of the Rift Valley, as around Kisumu, appear to be much earlier than the nephelinites and to have been greatly dissected by denudation before the deposition of the Miocene beds or the eruption of the nephelinites.

It seems incredible that the whole volcanic history of B.E.A. can be restricted within so short a time as the post-Miocene. Kenya illustrates the antiquity of the East African volcanos. It is a volcano in an advanced stage of decay. Its peak appears from a distance as a rock pinnacle on the summit of a vast mound. Its crater was long since swept away, and the central peak is the plug of igneous rock (nepheline-syenite and kenyte) which solidified at least 3000 ft. below the floor of the crater and choked the volcano (*v.* p. 151). The weathering of the volcanic rocks around the plug has produced two different types of scenery—rough crags and sharp pinnacles, due to ordinary subærial denudation, and smooth rock surfaces and rounded summits, due to the abrading action of ice when the glaciers of Kenya descended far below their present level. The glaciated surfaces show that the valleys of the alpine zone had been excavated to their present depth by the time of the greater extension of the glaciers. Kenya had been reduced practically to its present form at the beginning of the Great Ice Age, i.e. by the end of the Pliocene. If the first eruptions in B.E.A. were later than the Miocene, the volcanic history of the country until Kenya had not only become extinct, but had been reduced to its present condition, would be confined to one geological period—the Pliocene.

The fact, then, that the crater of Kenya had been destroyed and its plug reduced to essentially its present form and dimensions by glacial times is evidence that Kenya is a very old volcano; and as it is not the earliest in B.E.A., the volcanic history of the country must be carried back into pre-Pliocene times.

The main stages in the volcanic history of B.E.A. seem to be as follows: the oldest lavas are the phonolites of the Kapiti Plains and of the Yatta Plateau, which were probably discharged in consequence of the foundering of the Indian Ocean. They may be correlated with the Deccan Traps and assigned to Upper Cretaceous times. The eruptions of the soda-rich phonolites culminated in that of the soda-rich kenyte. Then followed the eruptions which produced the basaltic agglomerates of Northern Kikuyu, the augitites of the Ngong, and the basalts of Settima. These eruptions were followed by the first Rift Valley faults, which were succeeded by a long stage of rest and denudation, until renewed volcanic disturbances discharged the rhyolites and trachytes, which are especially well developed in the Kikuyu country. Then, after further faulting, ensued a long, quiet period, during which the level of the Victoria Nyanza was higher than it is to-day; and the date of this extension is shown by the *Dinotherium hobleyi* bones in the lake deposits to have been the Miocene. Then followed the post-Miocene eruptions, which discharged the Elgon and Kavirondo nephelinites and later basalts.

Fresh faults enlarged the Rift Valley and led to the building up of great mountains of phonolitic trachyte on its floor, including Suswa, Longonot, and Menengai. Some of these latest eruptions must have been quite modern ; the lava of the north-eastern part of the crater of Menengai can hardly be more than a few centuries old. According to Mr. Hobley, the volcano that he discovered W. of the Njorowa Gorge is so bare of vegetation that it could not have been formed more than a century ago ; and eruptions from Doinyo Ngai and the Teleki Volcano have happened during the last two decades.

The history of some East African lakes also shows that the earlier stages of the volcanic activity were passed a long time ago. Lake Naivasha once stood 150 ft. above its present level and overflowed southward down the Njorowa Gorge. The outlet has been cut through a lava-flow which is much older than the great extension of Lake Naivasha and must be at least Pliocene in date ; but that lava-flow is modern compared with the earlier lavas of B.E.A.

III. The Cause of the Great Rift Valley and its Relation to Contemporary Earth-Movements

If, then, the older plateau eruptions of the Rift Valley happened in the Upper Cretaceous or Early Kainozoic, and the main Rift Valley faults between the Oligocene and the Pliocene, there are two great regional disturbances in the eastern hemisphere with which they may be correlated—the foundering of the Indian Ocean in the Upper Cretaceous and the movements which raised the Alpine-Himalayan Mountains between the Oligocene and the Pliocene.

A. 1. *Relation to the Foundering of the Indian Ocean.*—The subsidence of the Arabian Sea and the outflow of the vast quantities of lava around it left the East African arch insufficiently supported, and its summit sank between parallel fractures. This subsidence happened along the first of the Rift Valley faults.

The view that the formation of the Rift Valley was connected with the formation of the Indian Ocean has been also advocated by Obst (1913, p. 187) ; but it has been rejected by O. E. Meyer from considerations expressed in a section which, he remarks (1917, p. 867), proclaims against that view louder than words. His section is drawn to natural scale and illustrates the shallowness of the Indian Ocean and the smallness of the Rift Valley in comparison with the distance between them. But this does not disprove their connection. The existence of waves is not disproved by showing that their height is sometimes insignificant in comparison with their length. The sinking of one end of a long lever uplifts the other end ; and the connection between the two movements is not disproved by showing that they are very slight in comparison to their distance apart.

The contrast between the western coast of India and the eastern coast of Africa is that generally presented by the eastern and western sides of basins due to the sinking of the floor in later geological times; the scarps on the eastern side of a foundered area are generally higher and more abrupt than those on the western side. The well-known rule that fiords are generally restricted to western coasts illustrates this principle. Hence on the eastern side of the Arabian Sea the land rises abruptly along the great fractures of the western Ghauts, while the East African coast rises, except where cutting across the E.–W. trending highlands of Somaliland, in comparatively gentle, well-denuded steps.

2. *The Advent of the Sea in East Africa.*—The land which once extended from Africa to India was not replaced by the Indian Ocean by one movement or in one geological period, but by a series of subsidences at intervals from the beginning of the Jurassic till the early part of the Kainozoic. The dates of these earth-movements are indicated by the age of the marine beds on the East African coast and by the distribution of the animals of the adjacent lands. The gradual oscillatory advance of the sea on East Africa is shown by the following table and by the diagrammatic summary of the Mesozoic deposits.

The absence of any marine Paleozoic and Triassic beds around the western Indian Ocean is evidence that the sea did not reach the existing coast lines until post-Triassic times. Whether the land then completely occupied that part of the Indian Ocean can only be inferred from the distribution of animals and plants. The varying resemblance and distinction between the faunas and floras of India and South Africa at different dates affords some measure of the completeness of the separation or connection of those areas.

3. *The Indo-Malagasy Land.*—The identity of the *Glossopteris* flora in India and South Africa indicates that in Carboniferous and Permian times they were then included in one continuous land. Its disruption apparently began at the end of the Trias, for the sea first reached Madagascar in the Lias. By successive enlargements this sea reached the mainland of Africa ; by Bathonian times it had

Geological Division.	Zambezi and Mozambique.	Madagascar.	German East	
			Southern.	Middle.
Pleistocene.	+	+ (up to 200′).	+	+
Pliocene.	—	+	M i	k i n d a n i B
Miocene.		+ (Lower).		
Oligocene.	+	+	+ (Upper).	
Eocene.	+	+	+ Up., Mid., and Low.	
Cretaceous—Upper.	+	+ (Dinosaurs).		Kigua Marls. Ngerenge Beds.
Cretaceous—Middle.		+		
Cretaceous—Lower.		+	Makonde Beds. *Trig. schwarzi.* Up. Reptile Bed	
Tithonian and Kimmeridgian.		+	*Trig. smeei.* Mid. Reptile Bed.	
Corallian (Sequanian).		+	Nerinea Bed.	
Oxfordian.		+ (Ferruginous Limestones.)	Low. Reptile Bed.	Bimammatus Beds.
Callovian.		+	Mandawa Beds (Pisolitic).	Gryphea Limest. *Trig. costata*, etc.
Bathonian.		+	Limestones (Corals and Pisolitic).	Pendambili Beds : Ool. Limest. Many fossils W. of Saadani.
Bajocian.		+		
Lias.		Up. Terrestrial. Mid. Marine.		

Africa.	British East Africa.		Somaliland.	Abyssinia.
Northern.	Southern.	Northern.		
+	+ (80′).	+	+	
e d s.	Mombasa Crag Magarin	i Sands.		
		W. of Fundi Isa and in Juba.		
		W. of Fundi Isa.	+	
			+	
	(?) N. of Frere- town (*Ostrea* *minos*).		Neoc.	
	(?)		+	+
	Changamwe Shale.	Juba Valley.	+	+
Mtaru Beds.	Rabai and Miritini Shale.		+	
Marls with Phylloceras.	Kibiongoni Beds.		+	
Oolite with *C. glandifera*.	Kambe Limestone.		+	+
			+	+
			+	

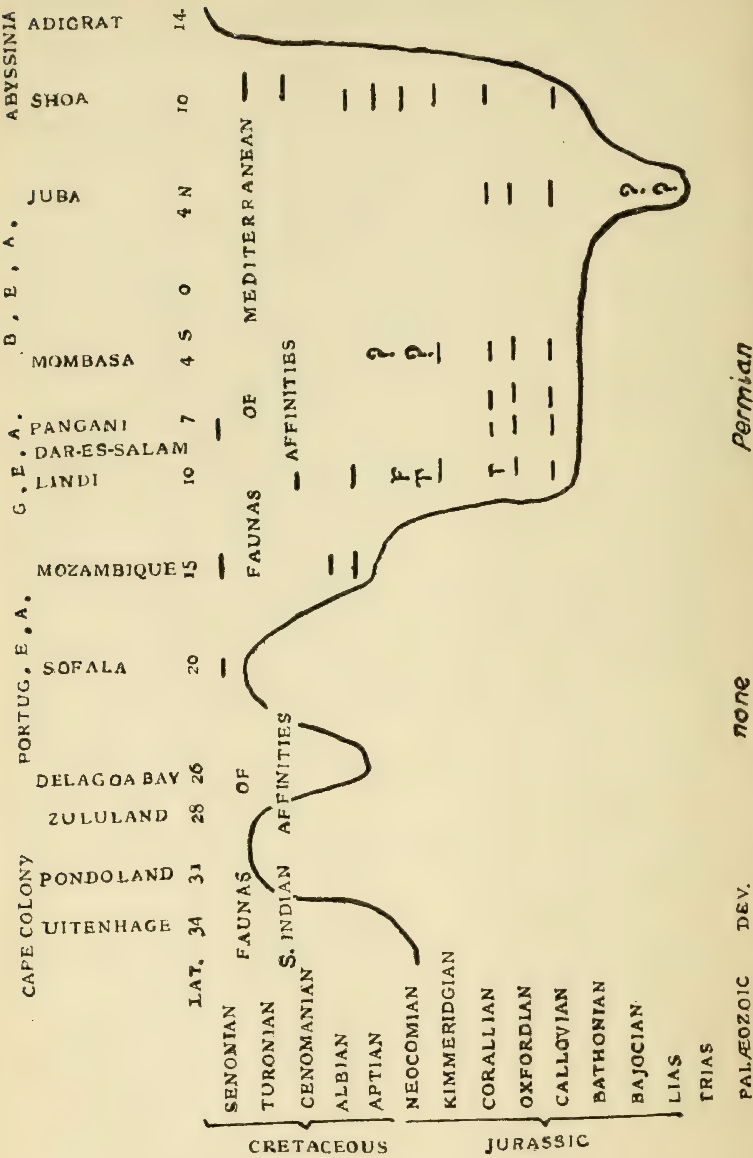


Fig. 44.—Diagram of the range of the marine Mesozoic rocks in East Africa from Cape Colony to Abyssinia; the thick line marks the base of the marine series. The three letters r under Lindi mark the intercalated reptilian horizons of Tendaguru.

reached G.E.A., Mombasa, and Abyssinia ; by the Callovian it had extended its range along the coast and up the Juba Valley, and it maintained this extension in the Oxfordian and Corallian ; during the Kimmeridgian it had receded. In the Lower Cretaceous it covered parts of G.E.A., but is only known doubtfully from one point on the coast of B.E.A. The Jurassic sea never reached South Africa, and, according to Neumayr's theory, an Indo-Malagasy continent connected India and South Africa through Madagascar. This theory was prepared by Neumayr to explain the remarkable similarity between the Lower Cretaceous faunas found in South Africa and Southern India and their striking difference from the contemporary fauna that lived further N. in East Africa, in Northern India, and in the Mediterranean. The Jurassic sea of eastern tropical Africa and Western Madagascar was clearly a branch from the sea which then extended from the Mediterranean to Western India. The Ammonites that lived in it included such typical Mediterranean genera as *Phylloceras;* the corals then living in East Africa are allied to those of Switzerland and Sicily. *Cidaris glandifera*, the sea-urchin with pegtop-shaped spines, found in G.E.A. and in the Kambe Limestone, is a characteristic Syrian fossil. There is much evidence in favour of Neumayr's view that the range of this Mediterranean fauna was limited to the S. by a land that extended from India through Madagascar to South Africa. To the S. of this land lay a Southern Ocean, which in Cretaceous times reached Cape Colony, Southern India, and Australia.

The evidence is, however, not now as simple as Neumayr thought. It has been judiciously discussed by Dr. F. L. Kitchin (1908), who insists on its speculative nature and that some of the points on which Neumayr relied have failed. There is more in common between the faunas of North-Western India (the Oomia beds of Cutch) and Cape Colony (the Uitenhage beds) than was known in Neumayr's time. But the differences are still very weighty, for the Ammonites, whose evidence is especially significant owing to their powers of free swimming and rapid migration, are strikingly dissimilar.

The separation between the seas N. and S. of the Indo-Malagasy land was not complete, as Neumayr fully recognized. The Trigonia fauna of South Africa and Southern India is represented in Patagonia and in North-Western India ; and the sea connection may have been around South America and by a strait N.E. of India, in which were deposited the Lower Cretaceous beds of Tripetty, N.E. of Cocanada, on the south-eastern coast of India.

Although the evidence is more complex than it was in Neumayr's time, the chief facts on which he relied—the still unbroken distinction between the Cretaceous sea-urchins of Northern and Southern India, Kossmat's evidence as to the distribution of the Senonian faunas of India, and further evidence of the extension of the fauna and flora of India to South Africa (such, e.g., as the discovery of Indian dinosaurs in Madagascar and the recent determination by Mr. R. B. Newton (1920) of the Indian affinities of some Cretaceous fresh-water fossils, including *Chara*, from Rhodesia) show that Neumayr's conclusion was well founded and that his barrier lasted till the end of the Cretaceous.

The land barrier had been widely breached by the Early Kainozoic owing to the striking differences between the land animals of India and Madagascar. The affinities of the Madagascar fauna are not with the Indian or African, but with the South American. This startling fact appears at first sight a *reductio ad absurdum* of the evidence of zoological distribution ; but it is explained geologically. In Cretaceous and Early Eocene times South America, Africa, and Madagascar were continuous, and one fauna, including lemurs, ranged through them. South America was first separated, and in the Oligocene Madagascar was isolated by the formation of the Mozambique Channel. A newer fauna from Europe spread S. through Africa, but this newer fauna did not reach Madagascar. The characteristic element in its fauna is the primitive lemurs, whose ancestors arrived there in the Eocene.

Since that date Madagascar has been completely separated from Africa except for a partial connection during the Pliocene by some island chain, which enabled the hippopotamus and the river-hog (*Potamochœrus*), both good swimmers, to reach the island.

Madagascar had been widely separated from India by the Oligocene and before India had been occupied by the Lorisine Lemurs, South-Eastern Asia by Tarsius, and Africa by the Galagos. None of these lemurs reached Madagascar, which is inhabited by such ancient types as the Indrisine Lemurs and the Aye-Aye (*Chiromys*), of which the nearest relatives are fossils found in the Eocene of France and North America.

The distribution of the lemurs is conclusive that Gondwanaland had been broken up by the Oligocene and that since then there has been no land connection between Southern Africa and India across the Indian Ocean.

Dr. Kitchin's discussion of the problem shows its complexity and the need for caution in dealing with the evidence of biological distribution ; but the evidence as a whole is still inexplicable except on the assumption of an Indo-Malagasy land. A continuous land connection between India and South Africa seems to be now universally accepted up to the Trias. Opinion is divided as to the extension of the land after that date. The balance of opinion is strongly in favour of the maintenance of a more or less continuous land belt throughout the Jurassic and Cretaceous. This view is supported by H. F. Blanford,[6] C. L. Griessbach,[7] W. T. Blanford,[8] R. D. Oldham,[9] F. Kossmat,[10] L. Krumbeck,[11] H. Woods,[12] E. Haug,[13] and P. Lemoine.[14]

The chief authorities, on the contrary, have been Russel Wallace,[15] de Grossouvre,[16] M. Boule,[17] and, to some extent, Dr. Kitchin,[18] though he accepts the existence of a land ridge, with possibly a strait through it, in the Jurassic and Upper Cretaceous (Kitchin, 1908, p. 54).

The main disruption of the Indo-Malagasy land was probably during the violent crustal disturbances at the end of the Cretaceous. But even in post-Oligocene times some extensive remnants of this land probably existed and served as the haunts of birds which spread from it to Somaliland and South Africa. For, according to Dr. Bowdler Sharpe (quoted in Gregory, 1896, p. 294), some of the birds of Somaliland are more nearly allied to those of the Cape than of the intervening parts of Africa, and probably entered Somaliland from a remnant of the Indo-Malagasy land. Direct evidence that the present course of the East African coast was completed by Late Kainozoic movements is shown by the faults traversing the Mikindani beds (which are Pliocene and Pleistocene).

B. *Relations to the Mountain Systems of the Eastern Hemisphere.*—The Rift Valley faults run generally N. and S., and end against the folds of the Alpine System as they approach the Taurus Mountains. There are, however, some extensions beyond this line. The Gulf of Suez is the continuation of the Red Sea trough, and this fracture line may be connected through the Ægean Sea and rift valleys of Greece with the sunkland of the Adriatic and the contemporary fractures of the Rhine Valley. The Jordan branch of the Red Sea trough may be connected with the earth-movements around the great Armenian volcano, Nimrud, and the disruption across the mountain chain of the Caucasus E. of Elburz.

Winterfeld has shown (1912) that the N. and S. fractures of Western Germany began in the Oligocene, and he regards them as belonging to the same system as those of Africa; but his view that these fractures are part of a world-wide system which radiates from the North Pole does not accord with their distribution or explain their origin.

The centre of the Rift Valley movements seems to have been tropical and not polar. Though associated movements may be traced northward into Southern and Northern Europe and southward into South Africa, they diminish in importance as they leave the tropical zone. The Great Rift Valley lies W. of the subsidences of Mesopotamia and the Indian Ocean.

The relations of the African movements to those of other continents seem rather as follows: During the Mesozoic happened a long, slow deformation of the earth's crust, including a downward sagging of the North Polar regions and the uplift of the Antarctic. The Equatorial and Temperate Zones were buckled by comparatively shallow folds, running E.–W. The sections of the African river system with that trend are probably relics of this corrugation. About the end of the Mesozoic Era the E.–W. folds were crossed by N.–S. lines of elevation. A slow uplift raised an arch along East Africa, and thus formed a range of highlands which extended from Palestine to Natal. This series of movements ended with the collapse of the floor of the Indian Ocean and the consequent regional volcanic disturbances around the Arabian Sea in the Upper Cretaceous and Eocene. The next stage was controlled by earth-movements which reached their climax in the Middle Kainozoic. Then the main earth-movements in the Western Hemisphere were a N. or S. advance, which buckled the crust into the E.–W. fold mountains of the Alpine Mountain System of Europe (including the Atlas Mountains of North Africa, the Apennines, etc.) and the Himalayan System of Asia.

One remarkable feature of this corrugation of the crust, as has been demonstrated by Suess, is that the European movements were from S. to N., and the Asiatic from N. to S. This reversal of direction is connected with the essentially different character of the segment of Europe and Africa from that of the segment including Asia and the Indian Ocean. Most of Africa in Cretaceous and Eocene times was a high plateau ; it was either stationary or was undergoing the further uplift which expelled the seas that ran up the Niger and Lower Nile, upraised the Eastern Horn of Africa, converted the Mozambique Channel into land, and forced back the seas that covered the lowlands of Natal, of Eastern Cape Colony, and of Angola. This uplift continued in the Eocene, at the end of which the African plateau was only touched by the sea at intervals along the Mediterranean, in North-Western Africa, and the south-eastern coast.

This increased uplift of Africa was coincident with a regional subsidence in the Arctic Ocean, the North Atlantic, and Northern Europe. This combined movement—subsidence to the N. and uplift to the S.—left the foundations of Europe laterally unsupported to the N., and a resulting northward movement of the northern part of the African plateau buckled the ground in front of it into the fold mountain chains of Europe and the Atlas.

In the segment of Asia and the Indian Ocean the crustal stress was in the reverse direction. The highland was to the N. in Central Asia ; the sinking area lay to the S. in the Indian Ocean and Indo-Gangetic plain. In Asia, therefore, the loss of support and lateral instability were on the southern side, and Asia was corrugated by waves advancing southward.

The separation between the European movement to the N. and the Asiatic movement to the S. was near the Sea of Azov, N. of the Black Sea. It is due N. of the Rift Valley, which is situated along the line separating the segment of the earth moving northward from the segment moving southward.

Hence (as remarked, p. 21, Pl. II) the geographical features in Eastern Africa are arranged along three main directions—E. to W., N. to S., and diagonally, N.W. to S.W. and N.E. to S.W. Of these series the earliest, the E.–W., features were caused by the buckling of the earth's crust in Mesozoic times. The diagonal series are the peripheral fractures around the sinking Indian Ocean between the end of the Cretaceous and the Oligocene.[19] The last series, the N.–S. fractures (sometimes deflected by the resistance of strong crust-blocks or by the readier yielding along the older diagonal folds), were results of the world-wide mountain-forming disturbances which culminated in the Miocene, but lasted from the Oligocene to the Pliocene.

IV. The African River System

The influence of these earth-movements on African geology is shown by the river system, which gives important help in determining their date and sequence. The Yatta Plateau (Chap. XV, p. 188) shows the pre-Kapitian age of a great N.W. to S.E. valley. The chapter on Uganda points out (p. 264) that the Nile once flowed from the Victoria Nyanza along a different route from that followed now. In the absence of fossiliferous sedimentary rocks, the study of the rivers throws much light on the dates of the earth-movements. The corrugation of Africa by Late Mesozoic folds formed broad valleys trending E.–W.; and traces of them are still apparent in B.E.A., although in the volcanic areas they have been obliterated or obscured by the eruptions. The E.–W. valleys extant in B.E.A. include: (1) the northern Guaso Narok, which is continued by the Guaso Nyiro to Lake Lorian, and by the Lak Dera to the coast near the mouth of the Juba; (2) the Upper Tana, which probably continued eastward to the sea about Port Durnford; (3) the Tiva, which doubtless once discharged through the Tana estuary; (4) the Sabaki and (5) the Voi, which both flow due E. across Southern B.E.A. These E.–W. rivers are pre-Kapitian, because the Athi, which is itself earlier than the Kapitian, had separated the Tiva from its original head-streams. The existing Guaso Narok, the westernmost source of the Guaso Nyiro, is post-Kapitian and even post-Laikipian, since it flows over a lava plateau that has probably buried the older valley of that river; but it is pre-Pliocene, as it was obviously formed before either the Elmentaita or the Laikipian Scarps, as it is the only river which rises in the Rift Valley and flows out of it across the boundary fault which is clearly younger than the river.

The second river system of B.E.A. includes those flowing from N.W. to S.E.; of these, the original Athi Valley must have been pre-Kapitian, as it was flooded by the Kapitian lavas; but the streams with this trend in Kikuyu-land must be much younger than the original Athi because they have cut their valleys through the Kikuyu volcanic rocks, and are therefore post-Laikipian. These crowded and nearly parallel Kikuyu rivers owe their direction to the slope of the land south-eastward; they are consequential on that slope; but they are now being disturbed by the development of transverse subsequent rivers (see p. 154). But this change has made such little progress that the slope which gave the drainage its set to the S.E. is of no great geological antiquity (it is probably Pliocene). It may have been caused by the subsidence of the Kapiti Plains and of the country S. of the Sub-Longonot Plateau. The modern character of the Kikuyu drainage, therefore, indicates that the southward dip of the beds in the Kikuyu Scarp is due to a geologically recent (Pliocene) movement.

The third group of British East African rivers flows N. or S. This direction was probably imposed on some of those near the coast, such as the Lower Juba and Lower Tana, by subsidences parallel to the Rift Valley faults. The most numerous of the N.–S. rivers lie in the Rift Valley and are clearly younger than the valley. Some of them, such as the southern Guaso Nyiro and the Turquell, rise outside the valley, but now flow into it. W. of the Rift Valley the main rivers to the Victoria Nyanza were probably consequential down the western slope of the Rift Valley arch ; they were considerably modified by volcanic eruptions and earth-movements.

The original course of the outflow from the Victoria Nyanza by the Nile is considered in Chapter XXIII, p. 263 ; it has obviously undergone great changes, since the gorge through which it reaches the Albert Nyanza is certainly much younger than the valleys around Lake Kiogo ; their predominant trend is E.–W., and they possibly retain the directions set by the Mesozoic folding.

This threefold classification of the East African rivers (viz. the oldest series E.–W. ; an intermediate series N.W.–S.E. ; and the youngest series N. or S.) is similar to that of Africa as a whole. The predominant African rivers, except the Nile, still lie in old valleys trending nearly E.–W., and have been disturbed by the development of the later rivers, or sections of rivers trending N. and S. The Nile is a comparatively recent composite river which has linked together many originally independent basins (*cf.*, e.g., Lyons, 1909, pp. 50–51). The section of the Lower Niger trending N.–S. has diverted the drainage of a river which extended E.–W. across the Soudan. The Nile and the Lower Niger are both younger than the transverse valleys which they cross ; and they are probably due to earth-movements on lines running N. and S. which have rearranged the older rivers due to the Mesozoic buckling of the continent into ridges and valleys trending E.–W.

V. The Contrast between the Great Rift Valley and American Structure

That the origin of the Rift Valley was not connected with the Arctic subsidences is also supported by the striking contrast between the American and African structures.

The two American formations which it is natural to compare with the African Rift Valley are the Rocky Mountain trench of Prof. Daly, which for 800 miles separates the Canadian Rocky Mountains from the rest of the Western Mountain System of Canada, and the long tectonic valley which includes the channels and fiords of West Canada, the Great Valley of California, and the Gulf of California.[20] The second of these formations corresponds approximately in length with the Great Rift Valley; but both of these American valley systems are marginal structures formed along the flanks of the fold mountain system of Western America, and are not homologous with the Great Rift Valley.

The structure impressed on the two Americas by the Kainozoic movements was fundamentally distinct from that of Africa. The American chains of fold mountains run N. and S., not E. and W. The dominant influence in America was the subsidence of the Pacific Ocean, which buckled the western edge of the continent into two great N. and S. chains of fold mountains; and a corresponding chain may be traced by its broken links along the eastern margin of Asia and Australasia from Japan to New Zealand. There are no meridional fold-mountains in Africa corresponding to those of America and to the western border of the Pacific, nor is there anything in America to correspond with the huge tension rent of the Great Rift Valley.

The essentially different character of the contemporary earth-movements of Africa and of the Pacific borders is explained by their antipodal position. Africa was antipodal to the Pacific, and it is in accordance with the well-known antipodal relation of ocean to continent that while the Pacific was sinking, and the crust beneath it undergoing compression, its antipodal land should be rising and subject to tension.

Africa, as a whole, remained throughout the Kainozoic Era as a raised and, judging from its river system, as a still rising plateau. But, since the crust on both sides sank during the formation of the Indian and South Atlantic Oceans, Africa was left unsupported laterally. Instead of its main highland axis being laterally compressed like the coastlands of the Pacific, Africa was in tension and torn by N. and S. fractures, along which the sinking of a strip of the crust formed the longest meridional land valley on earth. The Great Rift Valley is, therefore, due to a long series of earth-movements which began in the Cretaceous, and to faults formed at intervals between the Oligocene and the Pliocene. It owes its unique character to its position antipodal to the Pacific, and its course to the wrench in the crust of the Eastern Hemisphere between the segment pressing northward against Europe and that pressing southward in Asia toward the deepening basin of the Indian Ocean.

[1] Suess's view has been recently reaffirmed by Prof. Frech (1917). On the other hand, Jaeger (1913, pp. 167–168), in his detailed account of the rift valleys of Lake Eyasi district, attributes them to repeated faulting at different dates; Obst (1912, pp. 126–127; 1913, pp. 158, 188) adopts the same view; so also, amongst others, do Dantz, Kuntz, H. Meyer, Studt, and Scholz (1914, p. 84, who adopts the Nyasa-Rukwa-Lukuga Valley as Miocene and that of Tanganyika as Pliocene).

[2] The use of the boundary faults as channels for the escape of material from below may be illustrated by the basalt dykes in the faults beside Tanganyika (Reck, 1915, p. 84) and by the sinter deposits above the faults on the Dead Sea (Blanckenhorn, 1912, p. 225).

[3] Whether this arch was due to upheaval along the middle line or to the sagging down of the sides is uncertain. The term uplift is often used in geology for an area which is relatively upraised, although it may have remained stationary and the actual movement was the sinking of the adjacent areas.

[4] The part of the Indian Ocean S. of Arabia, between India and E. Africa.

[5] It might be inferred from the legend to Dr. Oswald's map (1914), which includes under one sign the phonolites and nephelinites.

[6] *Quart. Journ. Geol. Soc.*, XXXI, 1875, pp. 534–540.

[7] *Rec. Geol. Surv. India*, XIII, 1880, pp. 90, 92.

[8] *Quart. Journ. Geol. Soc.*, XLVI, 1890, Proc., pp. 88–99; and *Rec. Geol. Surv. India*, XXIX, 1896, pp. 53–54.

[9] *Geol. India*, 1893, pp. 209–211.

[10] *Rec. Geol. Surv. India*, XXVIII, 1895, p. 42; and XXX, 1897, p. 77.

[11] *Beitr. Pal. Geol. Ost. Ung.* and Orient, 1905, XVIII, p. 153.

[12] *Ann. S. Africa Mus.*, IV, 1906, p. 346.

[13] *Traité Géol.*, and *Bull. Soc. Géol. Fr.* (3), XXVII, 1899, p. 397.

[14] 1906, pp. 467–470.

[15] *Island Life*, 2nd edit., 1892, pp. 422–427.

[16] *Rech. Craie Sup.*, 1901, pp. 926–927.

[17] *Bull. Mus. Hist. Nat.*, Paris, V, 1899, pp. 130–133.

[18] 1908, pp. 51–60.

[19] The meridional fault valleys of Tonkin and Yunnan, due to earth-movements in the Oligocene and Miocene, are the geographical features in Asia most nearly related to the Great Rift Valley.

[20] *Cf.* Daly, *Geogr. Journ.*, Vol. XXVI, 1906, p. 596, and N. Amer. Cord. 49 Parallel, Canada Dep. Mines Mem. 38, 1912, p. 600; Gregory, 1913, Chap. XIV, Sect. F and G.

APPENDIX I

Physiological Value of the Cave-Earth of Lumbwa

By Prof. E. P. Cathcart, F.R.S.,

University of Glasgow Physiology Department.

Dear Professor Gregory,

I am of the opinion that, as you surmise, the value of the Lumbwa Cave material lies in its content of sodium.

The animals involved are herbivora, which normally consume a diet rich in potassium, but poor in sodium. The fact that such a potassium-rich diet gives rise to a craving for a supply of sodium is well known.

So far as I know there are two hypotheses offered in explanation of the facts—Köppe's and Bunge's. Köppe holds that it is due to the fact that in plants the inorganic salts are in organic combination (Köppe, *Physikalische Chemie in der Medizin*), only a small amount being present in soluble, dissociable form. The demand on this hypothesis is, then, for available salts. Bunge (*Textbook of Physiological and Pathological Chemistry*), supporting his contention by experimental work, maintains that the ingestion of large quantities of potassium salts, due to the resulting interaction between the inorganic salts in the organism, leads to the excretion of abnormal amounts of sodium in the urine, with the result that this loss has to be made good from outside supplies.

Bunge has drawn attention to many interesting points. Domesticated carnivora, e.g. dog and cat, prefer unsalted food to salted food ; whereas domesticated herbivora are very fond of salt. So far as observations go, the same is apparently true for wild animals : the animals which flock to " salt licks " are the herbivora. It cannot be that there is a real shortage in the intake of sodium in the food (the hypothesis of Köppe must, however, be remembered here) ; the herbivora probably consume, pound per pound weight of animal, as much sodium as the carnivora. But, as Bunge points out, the herbivora take in their food " at least three or four times as much of salts of potassium as the carnivora."

Bunge further supports his contention by reference to the human race. He collected a large amount of information from various sources, and he holds that he gets general support for his hypothesis (see, for full details, his paper, Ethnologischer Nachtrag zur Abhandlung über die Bedeutung des Kochsalzes u.s.w. Zeit. f. Biol., X, 1874. III). He reaches the general conclusion that " it appears to be a universal rule that in all times and in all lands those people who live entirely upon animal food either have never heard of salt or, if they possess it, avoid it ; whereas the people whose staple food is vegetable have the greatest desire for it and regard it as an indispensable article of diet." It is said that the Masai warriors, who are reported to live almost exclusively on a meat diet without salt, regard blood, which is rich in sodium (K_2O : Na_2O : : 2 : 19), as a great delicacy. You will be able from your own experience to confirm or refute this statement.

This appreciation of the relation of salt to the nature of the diet is of very old standing, as in ancient times it is said that sacrificial animals were offered to the gods without salt ; whereas the fruits of the field were always given accompanied by salt.

It is interesting to note in this connection that one of the few really important vegetable foods which is poor in potassium is rice (containing, as it does, about six times less K than the cereals (wheat, etc.), 10–20 times less K than peas, beans, etc., and 20–30 times less K than the potato). Hence people who live on rice as their main vegetable food should require less sodium than others who live on, say, peas, beans, lentils, maize, etc. This, I believe, is the case. The following data (content of K_2O : Na_2O) may be of interest :—

Per 1000 grm.	K_2O	Na_2O
Rice	1 grm.	0·03 grm.
Rice, Wheat, Barley, etc.	5–6 grm.	0·1–0·4 grm.
Peas	12	0·2
Hay	6–18	0·3–1·5
Clover	23	0·1
Potato	20–28	0·3–0·6

It is evident, then, that the case is pretty well made out for the herbivora demanding a larger supply of sodium salts. I gather that there are no " salt licks " in the country in which the Lumbwa Cave is situated. Hence the avidity with which the cattle consume the relatively sodium-rich material.

There is, however, one difficulty in this explanation. I understand that animals become excited and anxious to get to the cave a long way off. This is suggestive of an odour, and sodium salts are, so far as I know, devoid of smell. Hence the animal does not get excited about the sodium.

I do not think it likely that the material is consumed as an ant-acid. Nor, as the animals are herbivora and presumably consume large quantities of cellulose, do I think that the material is ingested as intestinal ballast for irritative purposes. On the other hand, the suggestion that its consumption has something to do with " discouraging intestinal parasites " is extremely interesting and may be well worth following up. We know practically nothing about the influence of the environment on the growth of intestinal parasites of any kind.

22/7/20. E. P. Cathcart.

APPENDIX II

Report on Fossils from British East Africa

By R. B. Newton, I.S.O., F.G.S.,

Senior Assistant in the Geological Department, British Museum (Retired).

I. Fossil Molluscan Remains from Consolidated Sands Forming the Northern Part of Mombasa Island

The specimens consist mainly of natural casts. Among the Gastropoda, *Bulla* cf. *ampulla* L., *Dolium*, *Conus*, *Strombus*, *Cassis*, *Cypræa*, etc., are represented ; while the Pelecypoda include *Lopha cristagalli* (L.) and a closely related form named *L. townsendi* (Melvill), besides *Plicatula* cf. *ramosa* Lam., all Indian Ocean species ; *Lucina ; Spondylus* cf. *crassicostatus* Lam. ; *Pecten vasseli* Fuchs, etc. Occasional fragments of *Operculina* also occur in the matrix of some of these specimens.

The faunistic assemblage resembles that described by Fuchs from near Suez, by myself from the Red Sea deposits of Egypt and the Mekran nodule-beds of India, and by Pilgrim from localities in the Persian Gulf.

Certain extinct forms mingled with living species characterize these deposits, thus creating difficulties in estimating their true geological age. Fuchs regarded the Suez beds as Post-Pliocene, although acknowledging that the extinct forms suggested a greater antiquity ; the Red Sea deposits were likewise considered to be of the same age ; while the Mekran nodules were determined as Mio-Pliocene, and the Persian Gulf beds as Pontian or Uppermost Miocene. It is interesting to note that *Pecten vasseli* occurs in all the deposits with the exception of the Mekran nodules, the same species being also found in the so-called " Neogene " beds of Tanga, East Africa (Koert, Zeit. Deut. Geol. Ges., 1908, LX, pp. 326–328), which is S. of Mombasa, where the present fossils were collected, thus suggesting that all these deposits would belong to a similar horizon. The fact that *Lopha virleti* occurs in the Persian and Egyptian beds, that *O. grypheoides* (Schloth.) (= *crassissima*) is found also in Persia (an unpublished record), and that *Operculina* occurs in the present Mombasa rocks, largely favours an Upper Miocene (Vindobonian) age for the whole of the beds, although provisionally it may be better to regard them as Mio-Pliocene.

II. Fossils from W. of Fundi Isa, British East Africa

(Collected by C. W. Hobley, Esq., C.M.G.)

Many of these fossils are not identifiable. Specimens numbered 531 may be regarded as of Miocene (Vindobonian) age ; while those belonging to No. 532 are Eocene. The species are comprised in the following list :—

No. 531. *Ostrea gingensis* (Schlotheim).
O. grypheoides (?) (Schlotheim) (=*crassissima* Lam.).
Lopha virleti (?) Deshayes.
Amussium cristatum Bronn.
Æquipecten cf. *malvinæ* (Dubois).
Age : Miocene (Vindobonian).

No. 532. Comprises natural casts of Gastropods :
Campanile, such as have been determined from Somaliland and elsewhere.
Volutilithes cf. *sanurensis* (Oppenheim), originally described from the Mokattam beds of Egypt. Other forms indeterminable. A section prepared from matrix of a Naticoid cast under this number exhibits *Alveolina*, *Miliolina*, and *Lithothamnium*—the two first-named genera being of the group Foraminifera, and the last of the marine Algæ.
Age: Eocene.

III. Shelly Limestone from Lake Deshek Wam, near Kismayu

Hard, compact limestone from near Lake Wam, on the western side of the Juba River, containing Molluscan remains, indeterminable Corals, and *Lithothamnium.* One of the shells represents a *Semicassis* related to *saburon* (Lamarck), which had its origin in Miocene times ; another fragmentary Gastropod represents a Muriciform shell. The assemblage is suggestive of a Miocene (Vindobonian) age.

IV. Fossil Oysters from Maunguja, near Mombasa

No. 534. *Lopha virleti* (Deshayes), Miocene—Vindobonian stage.

V. A Miocene Shell found near Nairobi

Clementia cf. *ungeri* Rolle (fam. Veneridæ).

Loc. Kabete, N.W. of Nairobi ; altitude about 6500 ft.[1]

Note.—This is a common shell frequently found in Northern Miocene areas of Africa, and regarded as of Vindobonian age (Helvetian–Tortonian). The species was originally described by Rolle : Sitz. Akad. Wiss. Wien, 1861, XLIV, Pt. I, Pl. 2, Figs. 1, 2, pp. 215, 216, from the Austrian Miocene (the "Tegel," and therefore Vindobonian).

VI. Mollusca from the Kambe Limestones

No. 15. Mombasa pipe-line at $\frac{12}{5}$ from coral limestone:
Pecten, probably similar to *P. bipartitus* Futterer, from the Jurassic of Tanga : Zeit. Deut. Geol. Ges., 1894, XLVI, p. 32, Pl. 5, Fig. 4.

No. 15. *Exogyra*, related to *E. imbricata* Krauss, from the Uitenhage beds of South Africa, which are of Neocomian age. This species is also recognized from the Choa limestones of Abyssinia, which, according to Futterer, are Bajocian (Zeit. Deut. Geol. Ges., 1897, XLIX, p. 579); it was previously described and figured by H. Douvillé from Choa: *Bull. Soc. Géol. France*, 1886, Ser. 3, XIV, Pl. 12, Figs. 8, 9, p. 230.

No. 540. Limestone E.S.E. of Jibana camping-ground:
A reddish brown, shelly limestone with obscure remains of a small Exogyriform oyster which may represent *Exogyra bruntrutana* Thurmann, as figured by Futterer from the Jurassic of Choa, in Zeit. Deut. Geol. Ges., 1897, XLIX, Pl. 19, Fig. 1, Pl. 582.

No. 549a. Mwachi River at crossing of the Mombasa pipe-line:
Rock containing Pelecypods resembling *Pseudomonotis echinata* (J. Sowerby), as figured by G. Müller in Bornhardt's *Deutsch. Ost. Afrika*, 1900, VII, p. 518. Text-figures 31–33 of "Dogger" age.

No. 21. Sandstone near the break-pressure tank on the Mombasa pipe-line:
Obscure Pelecypod remains—indeterminable.

VII. Post-Pliocene Fossils from Lake Rudolf

Collected by Capt. H. Rayne. Limestone specimens from Lat. 3° 15′, at 200 ft. above lake-level at Pelegeck:—

Pelecypoda	*Unio.*	Forms existing in Lake Rudolf at the present day.
	Leptospatha.	
	Corbicula fluminalis (Müller).	
Gastropoda	*Melania tuberculata* (Müller).	
	Viviparus cf. *unicolor* (Olivier).	

A series of more recent-looking specimens without matrix and found at Pelegeck, but at a less elevation than the limestone specimens. The species exist in Lake Rudolf at the present day:—

Pelecypoda	*Unio rothschildi* Neuv. and Anthony.
	Unio sp.
	Corbicula fluminalis (Müller).
	Ætheria sp.
Gastropoda	*Melania tuberculata* (Müller).
	Bulimus adenensis Pfeiffer var. *major* Neuv. and Anth.
	Viviparus unicolor (Olivier).

Note.—One of the latest papers on the Molluscan Fauna of Lake Rudolf is by H. Neuville and R. Anthony: Bull. Soc. Philomat. Paris, 1906, Ser. IX, VIII, pp. 275–300, Pl. XII.

[1] The specimen was picked up on the surface. It may have been carried up from the coastal limestones. It was collected by Mr. J. Leakey, Jnr.—J. W. G.

APPENDIX III

Soils from East Africa

By Prof. R. A. Berry,

Assisted in the Analyses by N. McArthur, B.Sc., and G. Hunter.

The following is the result of a mechanical and a partial chemical analysis of three soils taken by Prof. Gregory and representing three characteristic types from the plains of British East Africa :—

	Average Dry Soil per cent. Numbered		
	523	525	524
Mechanical Analysis—			
Fine gravel	12·6	14·0	3·1
Coarse sand	33·2	20·0	30·3
Fine sand	9·5	13·9	—
Silt	4·8	6·1	—
Fine silt	24·7	29·4	—
Clay	14·1	15·1	—
Chemical Analysis—			
Hygroscopic moisture	6·8	7·1	3·3
Loss on ignition, organic matter	7·8	7·1	10·38
Nitrogen	0·08	0·115	0·15
Phosphoric acid, P_2O_5, total	0·05	0·06	0·05
Potash, K_2O, total	5·17	5·55	3·01
Substances soluble in weak mineral acid	10·5	10·6	—

All three soils were distinctly acid in reaction to litmus paper.

Owing to a breakage it has not been found possible to complete the mechanical analysis of soil 524 in time.

Without knowing more of the cultural and other conditions prevailing, such as rainfall and its distribution, depth of soil and subsoil and supplies of underground water, system of cropping and manuring and the results obtained, it is difficult for me to form an opinion with the data at my disposal as to the actual agricultural value of the soils.

However, there are both in the mechanical and chemical analyses several characteristic features.

Physical Features.—Soil No. 525. Owing to the large amount of clay and silt in proportion to the rest of the mineral matter, in this country with fair rainfall, it would be too sticky and heavy a soil for arable cultivation, and would no doubt go down to permanent pasture. The clay fraction when drying shrank very perceptibly, and on moistening swelled up again rather more than is usual for clay obtained here. It would be very retentive for and impervious to water, and drainage would be difficult. In a very dry climate this would perhaps be of an advantage, provided the soil did not dry into intractable hard masses.

Soil No. 523 possesses similar features, but probably not as heavy and more amenable to cultivation.

If limestone deposits occurred within accessible reach, application of lime compounds would improve both the physical and biological character of the soils.

Chemical Character.—The outstanding feature is the very high percentage of potash in all three soils. Soils in these islands generally contain between 0·25 and 0·55 per cent ; while heavy clays run to a higher figure, 1 per cent being most exceptional. There is a marked deficiency of phosphate in each. They are poor in nitrogen, but contain quite a fair proportion of organic matter. Phosphatic manuring should greatly improve these soils.

APPENDIX IV

Igneous Rocks from British East Africa

By Agnes T. Neilson.

The British East African rocks collected by Prof. J. W. Gregory in 1919 will be considered under the following petrographic denominations :—

I. Comendites.
II. Phonolitic Rhyolites.
III. Phonolites.
IV. Phonolitic Trachytes.
V. Kenytes.
VI. Syenites and Allied Rocks.
VII. Felspathoid Basalts.
VIII. Basalts.

GROUP I. THE COMENDITES

The comendites or riebeckite-rhyolites show much structural variation, passing, from obsidian-like types with phenocrysts of graphically intergrown quartz and orthoclase and inclusions of more crystalline comendite, through dominantly spherulitic varieties, to sorts which are almost microgranular. The variation in the mineral content is also considerable. Quartz and orthoclase, or soda-orthoclase, maintain a more or less constant ratio and even distribution ; but the coloured constituents—riebeckite, ægirine, and cossyrite—may be sparsely developed in minute flakes or grains, or may attain the size of microphenocrysts, or may occur in closely aggregated patches of flakes very similar to the " pseudo-phenocryst " habit of such minerals in certain phonolites.

A. Microgranular or Paisanitic-Comendites ; 131, 132,[1] Njorowa Gorge

The quartz phenocrysts in these rocks are either large anhedral patches with long strings of minute bubbles or show a graphic intergrowth with orthoclase. The orthoclase or soda-orthoclase phenocrysts are subhedral in form when free from quartz, but when intergrown with quartz the orthoclase imposes its euhedral form on the graphic intergrowth of the two minerals. In one peculiar case ægirine occurred interlaced with graphic quartz and orthoclase.

The groundmass in these rocks is either a minutely microgranular aggregate of quartz and orthoclase or an aggregate of minute felspar fibres in a quartz base. The coloured minerals are flakes of riebeckite, more evenly distributed flakes of ægirine, and occasional flakes of cossyrite. In one slide (132) the coloured minerals are developed in abnormal excess, and the riebeckite and some of the ægirine occurs in dense patches or pseudo-phenocrysts.

B. Spherulitic Comendite; 104, Njorowa Gorge

This rock consists almost entirely of well-developed spherulites made up of long, radially disposed prisms of orthoclase, with grains or flakes of riebeckite crowded in the central area and disposed radially between the felspars in the peripheral parts of the spherulites. The centre of a spherulite is often a large flake of riebeckite showing characteristic pleochroism. Round the outer margins of the spherulites, where the felspar prism laths have radiated into separate individual terminations, there is an infilling of clear quartz which also occupies widening bands between diverging lines of spherulites. In some parts of the rock the spherulites are composed entirely of quartz and felspar without riebeckite; and in some few places there is a flow arrangement of felspar prisms in a quartz-paste, where some local movement during consolidation has prevented the spherulitic aggregation.

C. Glasses of the Comendites; 115, 134, Njorowa Gorge; 143, Ol Setian

Specimen (143) is a porphyritic and partly microgranular comendite which contains large patches of a clear isotropic glass with hair-like microlites of a very pale green colour. In some places this glass has large, dusty brown, incipient spherulitic patches, isolated examples of which also occur throughout the rock and seem to pass insensibly into the groundmass of the comendite.

Another specimen (115) is in greatest part a clear rock glass with perlitic cracking and delicate flow-line striations. In a few places it shows bands of pale brownish dusty, incipient spherulites of minute size, or shows some thin and slightly curved lenticles of isotropic material which may represent drawn-out vesicles. The rock is an obsidian, but contains an occasional phenocryst of euhedral, carlsbad twinned, graphic-quartz and orthoclase, similar to such in the comendites. In the hand specimen this rock is partly a fresh glass of a light dull yellowish-brown colour, but much of it is a banded pumice with very minute flattened and drawn-out vesicles, and with the character of pumice to the touch.

Specimen (134) shows phenocrysts of orthoclase and an occasional quartz in a decomposed micro- or cryptocrystalline groundmass, which is diversified by long, narrow lenticular patches of a pale brown colour and spherulitic structure; the narrow lenticles have a marginal or axiolitic arrangement of the microspherulitic outgrowths, which leaves a clear thin middle line along the lenticle. There are a few small inclusions of rock fragments, some of which greatly resemble the spherulitic comendite, and for this reason (134) is taken along with this group.

GROUP II. THE PHONOLITIC RHYOLITES

The phonolitic rhyolites are rock glasses characterized by the presence of phenocrysts of anorthoclase and absence of quartz, and may or may not have an occasional pale green augite of small size. The group may be classified on a structural basis into eutaxitic, axiolitic, and spherulitic types.

A. Eutaxitic Phonolitic Rhyolites; 295, Nairobi; 407, Gura; 431 and 435, N. Bank of Maragua River above Bridge

The rocks of this group have subhedral or angular fragmental phenocrysts of anorthoclase, enclosed in a welded mass of rock glass lenticles, or fragments of various sizes, varying in colour from clear isotropic yellow-brown to dark red-brown banded or microspherulitic varieties. In these rocks there are a few included rock fragments of phonolite and phonolitic trachyte.

In one specimen (435) belonging to this group a large phenocryst of anorthoclase which has been partially resorbed on one side has on another side a radial spherulitic outgrowth of felted felspar laths with dark cryptocrystalline middle lengths. This spherulitic outgrowth seems to have forced the surrounding material away from it, for the glass takes a curving flow round the secondary crystallization (see Pl. XIX, Fig. 1).

B. Axiolitic Phonolitic Rhyolites; 292, 438, Nairobi; Mukuyu (contains Fossil Wood)

The rocks in this group are all devitrified phonolitic rhyolites. In hand specimens they are a light greenish grey in colour, with a few sporadic phenocrysts of felspar small in size and of turbid, decomposed appearance. They are somewhat granular and rough in texture, like a sandy clay, and the term "claystone" has been applied to them. Under the microscope the phenocrysts in these rocks can be identified as anorthoclase; they are set in a cryptocrystalline uniformly-decomposed groundmass, which shows traces of an original axiolitic structure where spherulitic crystallization in the original glass has begun along the walls of collapsed vesicles. In one specimen definite banding can be seen, and occasional included fragments of phonolite can be identified.

C. Spherulitic Phonolitic Rhyolites; 233, Shanau; 240, Magadi; 252, Kikuyu; 479, Kedong

These rocks as seen under the microscope are dark brown undecomposed rock glasses showing either a contorted crumpling of the minute flow-line striations or a fairly developed perlitic cracking. There is a general development of dark brown spherulites of small size; partially formed star-rayed types are common in the less disturbed glass bands, while in the perlitic areas, where no movement of the glass has hindered the formation, complete radial spherulites are contained within and delimited by the perlitic curves.

In some specimens there are occasional rounded and resorbed phenocrysts of anorthoclase of macroporphyritic size, but in general the phenocrysts are microporphyritic. Slender prisms of mottled anorthoclase and a very occasional pale green rounded crystal of augite are set in the glass, but without any directional arrangement. In places, however, the small prisms of felspar stand at right angels to the general direction of the crumpled flow striations, indicating a certain amount of movement within a confined space. In one specimen (479), which is a dark brown glass showing perlitic cracking but no spherulitic structure, there are numerous long hair-lath prisms of felspar in flow alignment. Many of these show gently curved outlines in conformity with the perlitic curves or are sharply fractured with slightly curved displacement.

GROUP III. THE PHONOLITES

From a macroscopic point of view the phonolites can be separated provisionally into two groups : (A) Phonolites without phenocrysts, but minutely crystalline to the eye, generally of a slightly roughened appearance and with a slight but occasionally extreme resinous lustre. Under the microscope these are seen to be phonolites of the " kenya " type. (B) Phonolites with numerous well-developed phenocrysts of anorthoclase and some of nepheline, either or both of which occur in a very fine-grained, compact aphanitic ground of a medium gray colour. There is, however, a wide variation in the ratio of phenocrysts to fine-grained rock. In many cases minute microphenocrysts of biotite are easily distinguished by their bronze colour and high lustre, in which case the rock is certainly a phonolite of this group, the " Kapitian " phonolites.

A. Phonolites of the Kenya Type ; 321, Kisumu ; 325, 327, Nandi ; 343, Kisumu ; 346, 349, Kaimosi ; 485, Kedong (Pl. XIX, Fig. 2)

Phonolites of this well-known type contain long, prismatic microphenocrysts of orthoclase with rectangular and hexagonal idiomorphs of nepheline in a groundmass of flakes of ægirine and cossyrite, which typically form borders round the microphenocrysts of nepheline ; small laths of orthoclase ; and minute euhedral nephelines, often pseudo-ophitically enclosed in small patches of the coloured minerals or aggregated in areas poor in ægirine and cossyrite, which then play a subordinate interstitial part. Occasionally the coloured minerals are confined to definite lines, and there is a more or less well-developed flow alignment of the felspar microphenocrysts and materials of the groundmass. But typically the microphenocrysts of felspar lie scattered at widely diverging angles and roughly delimit large triangular areas, poor in coloured constituents, containing the minute felspars and nephelines of the groundmass. In some specimens there is a different structure in some parts of the groundmass, where residual spaces are occupied by ill-defined plates of felspar merging into the general groundmass ; this structure is also seen as a modification in the phonolitic trachytes. This residual platy felspar of the base, which supports extremely thin flakes of the coloured minerals on its surfaces, may from its high extinction angles (as measured from the well-developed cleavage lines), and from a patchy extinction-mottling in many cases, be referred to anorthoclase. One particular specimen (485) showed a good deal of this platy felspar in the groundmass; and from the general rotating shadow-strain-extinction of this mineral, and also from a somewhat radial arrangement of many of the small felspar prisms of the base, a pseudo-spherulitic structure seems to have developed. But other variations also make this rock a less normal kenya-phonolite. In many places the coloured mineral surrounding the euhedral nepheline (or altered or replaced nepheline, as it was in many cases) was a blue soda-amphibole, which is pleochroic in shades of dull pinkish lavender to fresh smoke-blue, and is probably arfvedsonite.

In another specimen (346), however, a definite spherulitic structure has developed. This can be seen even with the 1½-in. objective, but with the ¼-in. objective the detailed arrangement of the spherulitic aggregates can be distinguished. These spherulites of the groundmass are made up of slender radiating prisms of felspar, with their central areas densely crowded with flakes of ægirine, and in many places complete spherulites are formed. Where, however, the long microphenocrysts of orthoclase occur the spherulites, or hemi-spherulites as they become in such a case, form a fringing outgrowth along the sides of the prismatic felspars.

B. Phonolites of Kapitian Type; 267, Londiani; 324, Nandi; 358, Kaimosi; 417, 419, and 423, N. of Amboni River; 579, near Fort Ternan.

Under the microscope these phonolites are seen to contain macrophenocrysts of anorthoclase or nepheline or both together in fairly euhedral forms, with in some cases much smaller phenocrysts of olivine or, when this does not develop, augite with a little biotite. These minerals are set in a groundmass of small orthoclase or soda-orthoclase laths with a characteristic triangular distribution, small flakes of ægirine and ægirine-augite, flakes of conspicuously developed cossyrite, and, in some cases, kataphorite of the variety pleochroic in shades of dull yellow to a smoky pink. At times this latter mineral attains the dimensions of the microphenocrysts and, though never euhedral, often shows the characteristic cleavages of the amphiboles. Some small euhedrons of nepheline also occur, and small residual areas of the groundmass are occupied by this mineral or a clear isotropic material, probably sodalite.

Certain of these phonolites (358, 417, 419) may be grouped together, since they contain olivine. Of these 417, 419 are typical Kapitian types having numerous and large phenocrysts of anorthoclase with some nephelines, the latter giving fair uniaxial interference figures. The small phenocrysts of olivine of a pale yellow-green colour have dark ferriferous, anhedral margins and show an interference figure of negative sign. These phenocrysts are set in a very dense groundmass in which hair-lath felspars can just be distinguished among dusty pyroxenic flakes and fresher flakes of cossyrite. A few minute euhedrons of nepheline also occur, and kataphorite to a small extent in small ragged, crystal patches. The general structure of the groundmass is that of minute wisps and flakes of the coloured minerals gathered into small triangular areas patterned out by the small laths of felspar. The third specimen (358), containing olivine, only shows a sporadic nepheline macro-phenocryst in the hand specimen. Under the microscope numerous small anhedrons or grains of the ferriferous olivine, negative in sign, occur along with the minerals commonly developed in a phonolite of Kapitian type, but the structure is very variable; even in a single slide the common divergent triangular structure passes into a pilotaxitic intersertal type, and this into a type already referred to in another phonolite (485) with residual, platy anorthoclase. This latter structure seems a variation common to both the phonolites and phonolitic trachytes; but in the latter rocks ægirine is the common coloured mineral, and cossyrite, characteristic of the phonolites, has almost completely disappeared.

The Kapitian phonolites without olivine (267, 324) have large phenocrysts of anorthoclase and nepheline, but not in great number, with one or two small crystals of a pale green, non-pleochroic augite with extinction angles up to 42° and probably diopside. In rocks of this type a few long flakes of biotite are commonly present as microphenocrysts, sometimes fresh, but often surrounded by or entirely altered to small grains of magnetite. The groundmass is quite comparable to that described in the olivine-bearing Kapitian phonolites, an angular distribution of very small, straight, extinguishing felspars with flakes of ægirine, much decomposed material probably representing altered ægirine, flakes of cossyrite, and with nepheline filling in minute residual interspaces. One or two vesicular cavities are filled with what is most probably a soda-zeolite in long, diverging prisms with very low, double refraction, straight extinction, and a refractive index well below that of canada balsam.

Some specimens (423, 579) vary considerably from the above structural type, but from the assemblage of minerals may be considered in this group. In the rock slide of one of them (579) only one large phenocryst of nepheline occurs. This showed the rough outline of a basal section and gave a fair suggestion of an uniaxial interference figure. A flake of biotite was the only discernible microphenocryst. The groundmass supporting these minerals was extremely fine-grained cryptocrystalline and undecipherable. In the hand specimen this rock showed resinous nepheline phenocrysts and some slender glassy, well-cleaved prisms of what is probably anorthoclase, and typical minute flakes of dark bronze biotite could be distinguished by their lustre. The groundmass is a very compact homogeneous, medium dark gray rock not unlike the specimen (324), which shows phenocrysts of similar minerals.

Another rock (423) which has an excessive development of the coloured minerals ægirine and cossyrite shows a peculiar separation of these into small mossy patches, or pseudo-phenocrysts, which are evenly and thickly distributed throughout a base of almost filiform felspar prisms felted together in a trachytic pilotaxitic manner without any interstitial development of the soda-pyroxenes or amphiboles. In the hand specimen this rock is quite similar to other members of the group, having sporadic phenocrysts of resinous-looking nepheline and more glassy anorthoclase.

C. The Kijabe Phonolite

Another variety (280) (Pl. XIX, Fig. 3) of phonolite is almost completely spherulitic. This rock in the hand specimen is of a very dark gray colour, compact in texture and extremely well banded. A compact fissile banded rhyolite would be the field term most in accordance with the appearance. Under the microscope, however, the rock shows orthoclase laths, with ægirine and cossyrite in great profusion, and some residual glass. In certain areas dark and somewhat folded bands are densely crowded together; in one place a minute fragment of phonolite has formed a lenticle round which the bands had been deflected, while in other areas lines of magnificent spherulites have attained symmetrical development. Examination under the $\frac{1}{4}$-in. objective shows that the dark bands are due to the concentration of innumerable grains of a dull greenish colour, and probably referable to ægirine. Between these bands the narrow interspaces are filled with fringing felspar outgrowths from the bands, and where these spaces widen or where the surface of a band lies open to the spherulitic spaces large plumose fringes of hair-lath orthoclase, minutely intergrown with ægirine and cossyrite, form magnificent outgrowths from the denser bands. Beyond these feathery fringing areas perfect spherulites have developed in the open spaces. These spherulites are intergrowths of delicate felspar laths crowded with intercrossing wisps of ægirine and cossyrite around the central areas, with an interradial alignment of these minerals in the peripheral areas; where some free space occurs between the diverging laths of felspar and where these interradial spaces are at their widest and where the radial laths of one spherulite meet those of an adjoining one, much as septa do in confluent corals, the larger spaces have permitted the growth of microphenocryst patches of ægirine and cossyrite. In wider spaces still between diverging lines of contiguous spherulites an isotropic glass edges round and infills the outer margins of the separated spherulites.

GROUP IV. THE PHONOLITIC TRACHYTES

In hand specimens the phonolitic trachytes generally show a grayish buff colour and are rough and gritty to the touch. They may or may not have megascopic phenocrysts. From a microscopic point of view they may be separated into four groups. The members of the two groups A and B have structural differences in the arrangement of similar mineral constituents. In the third group, C, there is a difference in the mineral content as quartz, which does not occur in the previous groups, now appears in some quantity as an accessory or residual mineral. The fourth group, D, is characterized by a particularly prismoid development of the felspars and the predominance of kataphorite as the coloured constituent.

A. Phonolitic Trachytes with Microphenocrysts of Anorthoclase in a Groundmass which is not Normally Pilotaxitic

Rocks of this group (77, Mbagathi River; 304, Lumbwa; 572, Uganda Railway, 495 m.) have numerous microphenocrysts of felspar in long, euhedral prisms, often much cracked and in many cases showing the blotched extinction and infinitely fine twinning striæ of anorthoclase. These felspar prisms show a general directional alignment in which the minerals of the groundmass are likewise involved. The minerals of the groundmass, which are interlaced in a trachytic fashion, are small lath prisms of orthoclase or possible anorthoclase, flakes of more or less prismatic, anhedral ægirine, which also occurs in small ill-formed crystals of irregular distribution often almost completely altered to a fibrous decomposition product of serpentinous nature ; cossyrite is present in much less quantity than in the phonolites. Some latitude in the mineral content is possible, and in one slide kataphorite has developed in small patches of an anhedral form, pleochroic in shades of brownish pink and yellow-brown, and in some places passing insensibly into a bluish pleochroic arfvedsonite on the margins. In another specimen (572) a few small grains of olivine suggest a passage to some of the olivine-bearing Kapitian phonolites ; but cossyrite is scanty, and with the almost complete failure of this mineral in some cases there is a passage to Group B of the phonolitic trachytes.

B. Phonolitic Trachytes with or without large Phenocrysts of Anorthoclase and with Pilotaxitic Intersertal Groundmass

If macroscopic, the phenocrysts are anorthoclase with high extinction angles, mottling, and subdued striations. They are generally twinned on the carlsbad plan, and at times show the characteristic rhomb sections of anorthoclase. The phenocrysts occur in a base of closely felted felspar laths, which may be anorthoclase as well, some few of the larger ones showing the faint striæ of ultra-fine twinning ; ægirine occurs intersertal to these felspar laths in the numerous wedge-shaped interspaces, and it is in wisps or grains as the dominant coloured mineral, though very small amounts of cossyrite may be present.

In one specimen (226, Nyuki-Koora) the phenocrysts of anorthoclase were accompanied by one or two small pale green augites, non-pleochroic and with high extinction angles, and, in addition, a very occasional flake of biotite almost entirely altered to magnetite could be identified. This, from a mineral point of view, seems to link up this class of the phonolitic trachytes with the Kapitian phonolites which are without olivine.

In another specimen (167, Soit-Amut) the felspars of the base have attained a greater individuality than commonly seen in the very compacted pilotaxitic types, and in this case there was a development of ill-defined plates of anorthoclase of some considerable size, a structure similar to that seen in some variations of the Kapitian phonolites. But while there is thus some structural similarity in places between the two groups, the phonolitic trachytes of Class B are separated from the phonolites by the failure of nepheline and the almost entire absence of cossyrite. The absence of this latter mineral also characterizes the phonolitic trachytes of Class D, the anorthoclase-phonolitic trachytes.

C. Phonolitic Quartz-Trachytes

The porphyritic examples of the rocks in this class cannot be distinguished in hand specimens from the porphyritic light buff-gray trachytes of the other classes. But one non-porphyritic specimen (201, Olgasalik) presented a very individual character to the eye. It is a compact darkish gray-brown banded and seemingly spherulitic rock, the minute pinhead " spherulites " being of a pale whitish colour. The most natural field term for this rock would be spherulitic rhyolite, as it bears some resemblance to the banded spherulitic varieties of comendite. But under the microscope this rock is seen to owe its megascopic characters to a peculiar but not spherulitic aggregation of its mineral contents. In this non-porphyritic type the rock consists of small rectangular prismoids of orthoclase untwinned and without inclusions, kataphorite of the variety pleochroic in shades of dull yellow-brown to dull bottle-greenish-brown, ægirine in much smaller amount than the kataphorite, quartz as a residual mineral paste supporting the felspar prismoids. The coloured minerals occur in broken lines of discontinuous patches and almost poikilitically include small groups of felspar prismoids in echelon alignment. Between the patches of coloured minerals the felspar prismoids have a quartz paste filling the interspaces, and the beaded appearance of the rock is not due to a spherulitic structure, but to the regular interspacing of such colourless mineral aggregations.

The porphyritic phonolitic-quartz-trachytes (291, Kijabe ; 500, Kedong) contain large phenocrysts of anorthoclase in a base of orthoclase prismoids, untwinned and free from inclusions, with quartz as before filling interstitial areas round the felspars. The dominant coloured mineral is the yellow-brown kataphorite, but good ægirine is present in some small amount ; these occur in flakes between the felspar laths, but occasionally a " pseudo-spherulitic " appearance results from their aggregation in isolated patches, leaving surrounding patches in sole occupation of the quartz and felspar. This is exceptional, however, and commonly there is an irregular distribution of the kataphorite flakes among the felspars.

In another specimen (173, Tiridik) there is a modification towards a more phonolitic type of trachyte. Porphyritic anorthoclase occurs in a groundmass containing very evenly distributed flakes of an altered greenish coloured mineral, probably ægirine, and occasional flakes of cossyrite. Very small felspar laths can be distinguished, and in numerous but minute areas, where the coloured minerals fail they can be seen terminating in a residual clear mineral of higher refractive index and presumably quartz. The scale on which this occurs is so small that an almost microgranular appearance is given to the rock.

D. Anorthoclase-Phonolitic-Trachytes

This class of the phonolitic trachytes is numerically much better represented than any of the other classes. The porphyritic types show much the same gray-buff colour as porphyritic members of the other trachytes, but the fine-grained, non-porphyritic types are of a medium gray colour and either compact or very vesicular.

The typical minerals are anorthoclase and kataphorite of the yellow-brown to dull greenish brown pleochroic variety; at times a little pale green diopside is present as small phenocrysts or minute grains, and in one or two slides a small amount of quartz is seen, residual to the felspar prismoids. Cossyrite is not developed, and this, with the occasional presence of a little quartz, brings this rock type into relation with the phonolitic-quartz-trachytes. The general structure in these rocks as seen under the microscope is a trachytic intersertal relation between very individual euhedral prismoids of anorthoclase almost always crowded with inclusions and the kataphorite, which, in flakes or angular plates, fills in the interspaces of the felspar mesh. In some varieties, however, the prismoids do not show this trachytic orientation, but lie compactly disposed in all directions; and this is more particularly so in certain coarse varieties in which the anorthoclase of the base has not developed the euhedral prismoid habit, but occurs in small, roughly quadrilateral plates.

The anorthoclase phenocrysts of these phonolitic trachytes show, as anorthoclase commonly does, inclusion rims just within the borders of the crystals, the actual margins being inclusion-free. The small prismoids of the groundmass show a repetition of this, but in their case the marginal inclusion material, which is at times distinguishable as minute hair-like prisms of a pale green colour, much as diopside shows, has coalesced to occupy the middle areas of the prismoids, leaving them with a clear outer zone or shell. Where, however, the prismoids are rather larger than the average, the included material is arranged as in the larger phenocrysts, just within the outer border of the prismoid and leaving the middle area clear. From this similarity of structure, and from the presence of infinitely fine twinning striæ in many of the clearer examples, the whole of the prismoid felspars of this class may be referred to anorthoclase, and the name anorthoclase-phonolitic-trachyte given to the class.

In the non-porphyritic examples of these phonolitic trachytes the structure is usually quite uniform, but several variations may be noted. Some specimens (91, Naivasha; 231, Shanau) have dark bands or patches, of much finer grain with an excess of kataphorite in minute flakes. In such cases the trachytic arrangement of the prismoids gives place to a radial or pseudo-spherulitic disposition, with an almost graphic interposition of the brownish kataphorite. In other specimens a small amount of isotropic brownish glass occurs; while another variety (483, Kedong) shows a fibrous pyroxenic material interstitial to the prismoids, but spreading into them to form some of the inclusions. A passage from these non-porphyritic types to the porphyritic is seen in certain examples where long prismatic microphenocrysts of anorthoclase have developed along with some more platy forms.

The porphyritic anorthoclase-phonolitic-trachytes show other structural variations besides the porphyritic which mark them off from the non-porphyritic types. In some specimens as (179, Nderiki) (Pl. XIX, Fig. 4), there is little difference beyond the presence of almost euhedral but at times partly resorbed phenocrysts of anorthoclase, with one or two anhedral pale green diopsides and a patch or two of magnetite. The felspars of the groundmass are prismoids as before, but with much less of the inclusion material.

Kataphorite shows the customary interlacing with the prismoids of anorthoclase.

In other types (193, Olgasalik; 412, 442, Kikuyu; 485, Kedong) large resorbed phenocrysts of anorthoclase with inclusion borders become more numerous, with an increase of diopside and magnetite in a groundmass of prismatic rather than prismoidal felspar, fairly free from inclusions and showing no trachytic structure, while along with these occur some ill-defined plates of the same anorthoclase showing shadow-strain extinction. A curious type of alteration sometimes affects the anorthoclase phenocrysts; ferriferous decomposition products creep along the cleavage planes and stain the felspars, so that in hand specimens they appear a dark brown colour against a light gray groundmass. Beyond these structural variations there are in some specimens (195, Olgasalik) mineralogic variations towards a more basic type. The anorthoclase phenocrysts are very large anhedral plates with broad inclusion rims; diopside, with associated patches of magnetite, occurs in more numerous and larger crystals, and along with these an occasional plagioclase phenocryst has developed showing multiple twinning and extinction values indicating andesine. The groundmass of this rock has the same prismatic felspars as in others of the porphyritic class, showing at times the infinitely fine striæ of anorthoclase; but along with these a few rough prisms show multiple twinning and have probably the same constitution as the phenocrysts. Kataphorite, but much decomposed, is, as before, the dominant coloured mineral; but granular diopside is much more plentiful.

GROUP V. THE KENYTES

In hand specimens the kenytes most nearly resemble the Kapitian phonolites, but the anorthoclase phenocrysts are generally angular fragments of the mineral, and subtranslucent rather than transparent and glassy as in the phonolites. In colour they are a medium dark gray, but the very fine-grained compact types, as well as the more granular types, are of a distinctly lighter colour. One peculiar type (286, Kijabe) shows an excessive development of anorthoclase phenocrysts in a black and somewhat resinous base, which is so scanty as to seem merely a cement for the phenocrysts. This rock might almost be termed in the field a pitchstone-porphyry.

The mineralogic constituents of the kenytes as seen under the microscope are anorthoclase, in corroded or fragmentary phenocrysts with inclusion borders or centres, minute twinning striations, and blotched extinction; microcline occasionally present in equally large crystals; smaller phenocrysts of subhedral pale green diopside; colourless or brownish augite; pleochroic ægirine-augite; hornblende, sometimes secondary after augite, sometimes poikilitically enclosing small crystals of apatite; biotite often altering to aggregates of magnetite grains; olivine of a pale yellow-green colour and with dark, ferriferous margins. These minerals occur as large or small phenocrysts in a groundmass of small felspar laths distributed in angular fashion, with prisms or grains of pale green augite in the interspaces, with grains or small patches of magnetite, and generally with residual decomposition material, possibly representing nepheline. This structure of the groundmass is not unlike that seen in the Kapitian phonolites, but no soda amphiboles are present. There is a variation in some kenytes, however, towards a vitrophyric groundmass. But in general the modifications in the group are textural, the proportion of phenocrysts to groundmass is very variable, and the groundmass itself varies from coarse-grained to very fine-grained types.

Two specimens (203, 204, Olgasalik) are kenytes with large, even-grained phenocrysts of anorthoclase and smaller phenocrysts of ægirine-augite and a ferriferous olivine, or an almost colourless augite with a few resorbed hornblende crystals. In these rocks the phenocrysts show no serial gradation in size and attain only a sporadic development in a medium-grained groundmass of anorthoclase laths, pale green pyroxene prisms or grains, and magnetite dust. In another type (222, Olgasalik) the anorthoclase anhedral phenocrysts, with a good proportion of microcline showing very definite cross-hatched twinning, become extremely numerous and show a serial diminution in size down to microphenocrysts, all with inclusion rims or margins showing absorption into the general groundmass. The coloured phenocrysts in this rock are a few euhedral pale brown augites and one or two rounded, reddish brown hornblendes with poikilitic apatite. A little biotite is present in the groundmass, but also poikilitically enclosed in one large segregation patch of felspars which show a type of decomposition unusual in anorthoclase, but suggestive of a microperthite. In this case the numerous flakes of biotite are almost entirely altered to a solid magnetite, retaining cleavage traces of the original mineral. The hand specimen of this rock shows serial phenocrysts sharply cut off from the fine-grained groundmass; but in another serial type (224, Olgasalik) (Pl. XX, Fig. 1), where the serial felspars grade down into a coarse-grained groundmass, the rock presents a granular appearance entirely. Under the microscope this rock is seen to be an aggregate of subhedral or rounded and resorbed, serially graded anorthoclase and microcline plates crowded with inclusion dust, a few pale green or colourless pyroxenes with associated patches of magnetite, and an occasional flake of altered biotite. These make up the greater part of the rock, but residual areas show the normal radial and intersertal kenyte groundmass on a coarse-grained scale.

Some of the kenytes, however, are very fine-grained rocks with few phenocrysts. In such types (228, 330, Shanau, Messeno) an occasional rounded phenocryst of anorthoclase and a small hornblende or a flake or two of biotite occur in a very fine-textured groundmass of minute anorthoclase felspar laths, with grains of pale green pyroxene and magnetite in the angular interspaces. In one specimen the phenocrysts of anorthoclase have been almost completely absorbed into the groundmass, only their shadow outlines remaining. The variety of kenyte (286, Kijabe) already referred to as having in the hand specimen the appearance of a very porphyritic pitchstone-porphyry shows under the microscope large phenocrysts of rounded and much-corroded anorthoclase, with smaller rounded but also sometimes almost euhedral forms. One or two minute areas of a dark orange-coloured ferrite probably represent a fibrous alteration of some original pyroxene. These phenocrysts are set in a very dense but not glassy groundmass, which seems to be made up of a felted mass of imperfectly formed felspar prisms, either with dark, medial lines or dark, frayed terminations, indicating incomplete crystallization in a viscous magma. The half-formed laths all show a directional alignment round the phenocrysts, and are crossed or aligned with innumerable long, dark wisps or streaks similar to their own dark centres, and probably the cryptocrystalline beginnings of other laths which never reached a crystalline condition. In some cases these incipient laths have grown like bristles from the smaller phenocrysts. Infinitely minute pale green pyroxenes are distributed in this groundmass.

From a mineral point of view the kenytes already described may be termed the acid kenytes, in distinction to a more basic type.

In two specimens (569, 576, Uganda Rly.) rounded or angular and much resorbed phenocrysts of anorthoclase are sparsely developed along with a few plagioclase crystals showing more or less multiple twinning and probably oligoclase. Besides these phenocrysts a pale green euhedral pyroxene, sometimes sufficiently pleochroic to be termed ægirine-augite, and often twinned or with zoning or hour-glass structures, have attained a very liberal development. The groundmass in both specimens is extremely fine-grained, but quite similar to the microcrystalline groundmass of the acid kenytes of fine-grained type.

Three rocks (399, 404, 406) of a peculiar habit may perhaps be described along with the kenyte group. They are all characterized by an abundance of small anhedral or grain-like olivines in a trachytic mesh of felspar laths, with interstitial strings and shreds of pale green pyroxene. In hand specimens they are non-porphyritic, compact dark gray rocks, similar to the very fine-grained compact kenytes.

The specimen (399) (Pl. XX, Fig. 2) is a coarser rock than the others. In a trachytic mesh of more or less even-sized prism felspars, simply twinned at times and often showing mottling, strain extinction, and fine striation twinning of anorthoclase, small crystals of olivine are strung out in lines and enclosed as "eyes" among the felspars. The rock as seen under the microscope has almost a foliated aspect where the small olivines and also some slightly larger felspars cause a regular deflection of the smaller felspar laths with drawn-out, interstitial, pale green pyroxene.

The other two specimens are much finer-textured rocks of almost pilotaxitic structure, but in places this gives way to a more radial or angular arrangement of the felspar laths with interspersed grains of olivine, pyroxene, and dust of magnetite, an approximation to the structure of the fine-grained kenytes. One of the specimens (406) showed in place of the pale green pyroxene a liberal dust of magnetite and a few infinitely small flakes of pale blue pleochroic riebeckite. This rock had, in addition, one or two microphenocrystic prisms of simply twinned orthoclase. The occurrence of so much olivine with anorthoclase brings these rocks into association with the kenytes, and Prof. Gregory has suggested the name "phonolitoid-kenyte" for the type.

GROUP VI. SYENITES AND ALLIED ROCKS

In this 1919 collection of British East African rocks there is a set of specimens taken from the base to the summit of Jombo Hill. In the hand specimens they show considerable variation. Specimen (599), from the base of the hill, is a granular medium-grained, plutonic rock seemingly composed of dark brown augite and reddish, resinous nepheline. Under the microscope this rock is seen to be an aggregate of allotriomorphic to subhedral plates of nepheline with only one or two plates, which from cleavages and mottling may be referred to anorthoclase. Between these allotriomorphic plates subhedral prisms of strongly coloured pleochroic ægirine-augite and smaller grains of dusty nepheline take up the remaining spaces. A small amount of biotite, sphene, and magnetite, in about equal proportion, occurs along with the ægirine-augite, while some of the large nephelines are crowded with euhedral prisms of this latter mineral. The rock is not far from a true ijolite.

From the lower slopes of the hill comes a specimen (598) (Pl. XX, Fig. 3) of a much coarser texture ; great prismatic fragments of ægirine-augite with the reddish, resinous nepheline are all the eye can see. Under the microscope this rock shows a dominant development of large, rough prismatic and granular ægirine-augite and a faintly pleochroic, greenish purple-brown titanium augite. Where these subhedral prisms of augite are not too closely packed the more or less triangular interspaces are occupied by nepheline, generally dusty and decomposed, but sometimes fresh. Large plates of yellow-brown biotite occur in places along with the augite ; and large subhedral patches of dark purple perovskite and patches of magnetite take up position with the nepheline, and long, slender prisms of apatite may be included in all the minerals except perovskite. Sphene is absent. The rock may be taken as a jacupirangite facies of the ijolite. Specimen (597), collected from half-way up Jombo Hill, is, again, a coarse-grained granular rock of the dark ægirine-augite and dull red nepheline. It consists, as seen under the microscope, entirely of large plates of nepheline and ægirine-augite, with large, fairly euhedral crystals of sphene in liberal amount and some magnetite. These latter minerals, with dusty residual nepheline, are all packed round the larger plates of nepheline. There is neither biotite nor perovskite. The rock is an ijolite.

In the hand specimen the rock (595) from the summit of Jombo Hill presents quite a different appearance. It is a light-coloured granular hypidiomorphic aggregate of gray felspars and dull red nepheline and subordinate grains of dark ægirine-augite. Under the microscope the large, simply-twinned felspars are somewhat decomposed, but from their blotched appearance and from minutely structural intergrowth, revealed by slight differences in the double refraction, they may be referred to anorthoclase or microperthite. The subhedral nephelines are quite fresh except for slight development of cancrinite. Ægirine-augite, with good pleochroism and extinction up to 33° and a few fair-sized crystals of sphene, occupy the spaces between the other minerals. This rock is the nepheline-syenite of Jombo Hill, already described by Prof. Gregory (1900, No. 4).

Along with these syenites and ijolites may be taken two nepheline-ægirine phonolites from the Olgasalik district which show a curious mineralogic resemblance to the ijolites, though structurally quite different. In the hand specimen one of these rocks (207) (Pl. XX, Fig. 4) is a compact medium dark, greenish gray rock with a few small rectangular, light-coloured phenocrysts of nepheline. Under the microscope the nepheline phenocrysts are seen to be crowded with well-developed prisms of ægirine-augite, and bear an extreme resemblance to the nephelines with poikilitic ægirine-augite in the ijolite (599) rock of Jombo. These nephelines are quite fresh, giving in hexagonal sections a fair uniaxial figure, and in many places are almost completely resorbed into the groundmass with the liberation of their enclosed ægirine-augites. Along with these nephelines are large phenocrysts of deep green pleochroic ægirine-augite and good crystals of sphene, which continue the ijolite affinity. These phenocrysts occur in a very dense groundmass of small straight, extinguishing felspar laths and innumerable prismatic wisps of high-coloured ægirine-augite ; while some residual material of low, double refraction is probably nepheline. No soda-amphiboles are developed.

The hand specimen (183) shows numerous small decomposed-looking, rectangular phenocrysts in a corroded, minutely-vesicular groundmass. It is probably a much more rapidly cooled vesicular variety of (207). Similar large phenocrysts of nepheline with poikilitic ægirine-augite occur, and ægirine-augite, with a few crystals of euhedral sphene, are seen in a groundmass which in ordinary light is seen to have small clear spaces suggestive of minute nepheline. But under cross-nicols the base is either cryptocrystalline or too decomposed to give any reaction. The numerous vesicles of the rock are lined with radial outgrowths of a mineral with very low double refraction and refractive index below canada balsam. This probably zeolitic material has also replaced some of the small hexagons of the groundmass.

From Messeno Hill, in the Kisumu district, come three rocks which show an interesting passage from a medium-grained anorthoclase syenite through a partially granulated but still coarse-grained type to an extremely fine-grained biotite granulite.

In specimen (338), as seen under the microscope, the greater part of the rock is made up of even-grained subhedral or somewhat rounded felspars, all very much decomposed to a micaceous-looking aggregate of minute flakes ; and only in one or two cases, from faint twinning striations, can anorthoclase be inferred. Between the felspars occur rough plates and flakes of an amphibole showing typical cleavage angles and a pleochroism in shades of straw-yellow to a faint bluish green in prismatic sections, and shading from straw-yellow to a dull green in basal sections. Along with this amphibole numerous small grains of quartz string out among the felspars.

Specimen (336) is a modification of the previous rock. The large subhedral felspars are not so badly decomposed, and many show the minute striæ of anorthoclase or microcline. Now, however, these felspars are widely separated by a minutely granulitic aggregate of quartz and the granulated micaceous remains of other felspars which have succumbed to the mechanical eroding action of the quartz during some dynamic alteration of the rock.

The granular rounded fragments of the felspars are of much the same size as the grains of quartz, and some of the larger felspars have irregular margins with embedded grains of quartz. The amphibole is of the same variety as in (338), while in a few places a small quantity of biotite has come into existence.

The rock (333), an excessively fine-grained, dark gray-brown rock to the eye, shows under the microscope almost the appearance of a hornfelsed sandstone, minute rounded grains of quartz with flakes of red-brown secondary biotite. Under the $\frac{1}{6}$-in. objective, however, the quartz grains are seen in places to be widely separated in a dusty micaceous material exactly similar to the broken-down felspathic derivatives in the two preceding rocks. In other areas the quartz grains are associated with felspathic remnants which still retain some individual form. The hornblende has completely disappeared, but is replaced by a very liberal development of the red-brown biotite in minute flakes.

GROUP VII. THE FELSPATHOID BASALTS

A. The Augitites

In hand specimens the rocks of this class can be separated into three types: a compact fine-grained rock with no macrophenocrysts; a very coarse-grained type with numerous macrophenocrysts of augite; and a variety with macrophenocrysts of melilite in a compact groundmass.

The aphanitic rocks of the first type (502, 503, 505), all from the Ngong district, show under the microscope some medium-sized macrophenocrysts of a pale brown augite with grass-green pleochroic centres of ægirine-augite. These are often almost entirely replaced by grains of magnetite, or there has been an alteration to hornblende first and subsequent formation of nearly solid magnetite. These microphenocrysts are set in a groundmass of small prismatic augites of brown or pale green colour, with a liberal dust of magnetite. Nepheline occurs as a residual paste whenever there is room among the densely crowded augites. In the opinion of Mr. G. W. Tyrrell, there is not enough nepheline in these rocks to justify their inclusion with the nephelinites.

The augitites of the Lake Magadi district (643, 646, 647) are all coarse-textured rocks with numerous macrophenocrysts of augite. Under the microscope the augites are seen to have a light brown colour and feeble pleochroism, but they do not show the ægirine-augite centres of the phenocrysts of the Ngong specimens. Patches of magnetite are fairly numerous, and nepheline is, as before, of somewhat limited development in the residual interspaces of a groundmass of small prismatic grains of augite.

A third type of augitite is illustrated by one specimen (307). In the hand specimen this rock shows numerous macrophenocrysts of a very glassy-looking yellow-green melilite in a dark gray, compact groundmass. Under the microscope, however, subhedral or fragmentary augites, of a very pale green colour and extinction up to 42°, occur as phenocrysts along with melilite. This latter mineral is colourless in ordinary light, and the polarization colours are the peculiar deep bluish grays characteristic of the mineral. In form it occurs both in euhedral prisms and irregular patches, with a serial variation in size. The groundmass consists of small prismatic augites of a pale greenish colour, magnetite grains, and residual nepheline. As this latter mineral occurs in not much greater proportion than in the other rocks of the class, the term melilite-augite may perhaps be suggested in preference to melilite-nephelinite.

B. The Tephrites

Basaltic-looking rocks belonging to this class are represented by two fairly similar specimens (437, 506) and another (637) from the Lake Magadi district which shows considerable difference. Under the microscope the rock (437) shows a few small patches of microphenocrysts of a medium acid labradorite with a few individually larger euhedral light brown augites. These are set in a very fine-grained mesh of minute plagioclase laths of same character as the phenocrysts, very small pale green prisms or grains of augite, and a liberal dust of magnetite. Nepheline occupies certain residual interspaces. Specimen (506) may be taken as an extremely fine-grained non-porphyritic rock of the same type.

The rock (637) from the Magadi district is a non-porphyritic rock of much coarser texture than the above. It is an aggregate of acid labradorite prism laths with prisms and grains of pale green augite and intersertal grains of magnetite. Residual to these minerals a somewhat decomposed but at times quite fresh material of low, double refraction is indistinguishable from nepheline. So far the rock agrees with the already mentioned nepheline-tephrites, but in one part of the slide a small microphenocryst occurs showing the icositetrahedral outline and internal anomalous double-refraction of leucite.

C. The Basanites

These rocks are of much the same habit as the tephrites, but contain olivine. They are all macroporphyritic rocks with phenocrysts of light brown, non-pleochroic augite and olivine in a groundmass of acid labradorite laths, small prisms or grains of brown or greenish augite, magnetite grains, and some residual nepheline.

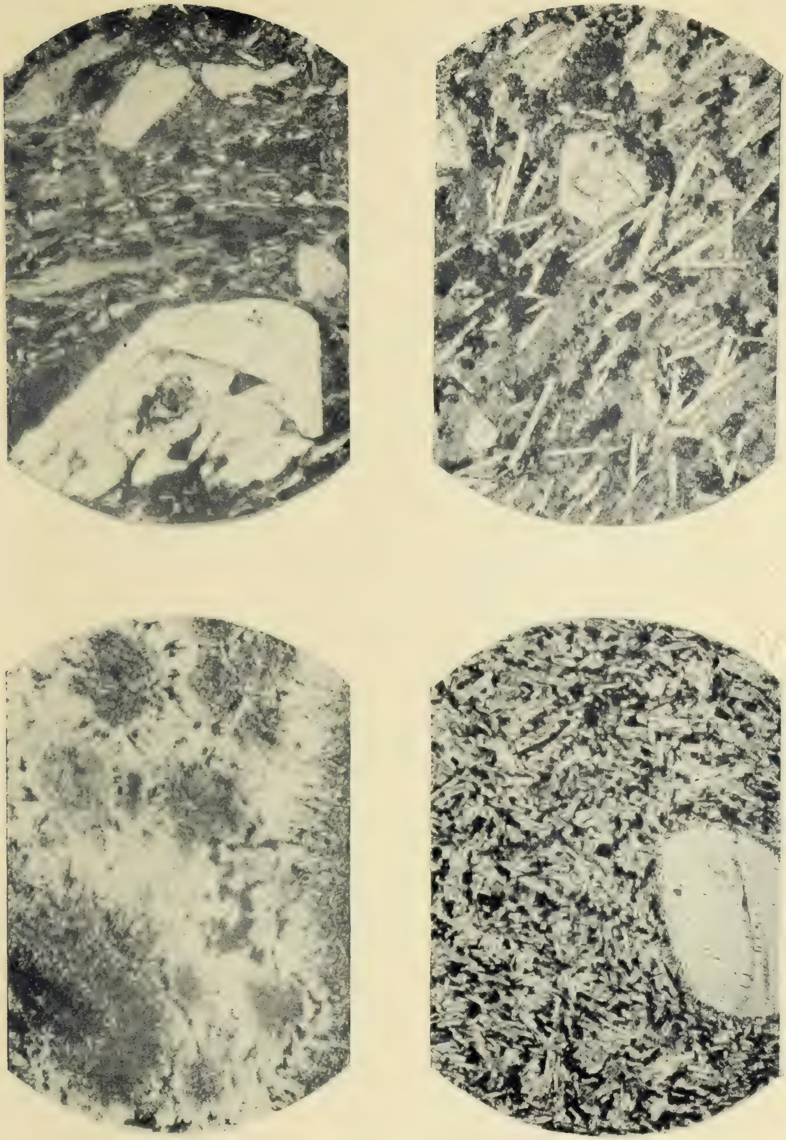
In one specimen (205) the augite phenocrysts, showing zoning and often twinning, are in excess of much smaller and slightly serpentinized olivines.

Another type (414, Muiga River) shows only large fresh olivines, with smaller altered individuals, as phenocrysts. The structure of these rocks is of the usual basaltic intersertal type. But in another specimen (392), containing some very large olivine phenocrysts and many small euhedral forms, with a microphenocryst or two of labradorite in the normal groundmass of felspar laths, pale green prisms and grains of augite, magnetite and nepheline, there is a pronounced trachytic alignment of all the smaller constituents.

GROUP VIII. THE BASALTS

The normal basalts of this collection are for the most part basalts with olivine, either occurring as phenocrysts alone or accompanied by augite

Plate XIX. (opposite p. 404).



ROCKS OF B.E.A.

Microscopic Structure of the Rocks.

phenocrysts, or as subhedral grains. The augite of these basalts, porphyritic or granular, is generally a very pale brown non-pleochroic variety, though the granular type has often a greenish tinge. The plagioclase felspar is all an acid to acid-medium labradorite. Magnetite, usually in grains or patches, sometimes shows secondary skeleton growths near decomposing pyroxenes. The general structure of the groundmass of these rocks is of the ordinary prismatic granular intersertal type commonly shown in basalts.

From the Lake Magadi district come two types. Specimens (215, 640, 641) are even-grained, non-porphyritic basalts of fine texture with granular olivine in the groundmass. Specimens of Markle type with small macrophenocrysts of labradorite are illustrated by (651, 652). These also contain granular olivine.

A Craiglockhart basalt type with large phenocrysts of olivine and augite has two representatives (385, 387) from the Aberdare district.

In another specimen (219, Nyuki) the rock is to the eye of a lighter gray colour than the normal basalts and minutely speckled in appearance. Under the microscope microphenocrysts of plagioclase and olivine are seen set in a normal intersertal groundmass of acid labradorite laths with grains of olivine and augite and some magnetite. But in a few triangular areas between the larger felspar laths there is a rather dusty-looking material, readily distinguished if the light is partly cut off, with a refractive index below both the felspar and canada balsam, and, if not absolutely isotropic, showing only occasional double-refraction anomalies. It is in all probability analcite.

EXPLANATION OF PLATES

Plate XIX

Fig. 1. Eutaxitic rhyolite, showing a large, partly resorbed crystal of anorthoclase with dark spherulitic growth on left side. Maragua River. Slide 435 × 24.

Fig. 2. Phonolite of kenya type, showing hexagons of nepheline and prisms of felspar with dark cossyrite and lighter ægirine in a fine-grained groundmass of small nephelines and felspars. Kisumu Hill. Slide 321 × 24.

Fig. 3. Spherulitic phonolite from Kijabe, showing light-coloured felspar prisms with dark ægirine and cossyrite. W. of Kijabe Station. Slide 280 × 24.

Fig. 4. Anorthoclase-phonolitic-trachyte, showing a phenocryst of anorthoclase with inclusion rim in a mesh of anorthoclase prismoids with interstitial kataphorite. Nderiki, Lower Kedong. Slide 179 × 24.

Plate XX

Fig. 1. Kenyte of the coarse-grained serial type, showing anhedral anorthoclase, striated microcline, and augite in a coarse groundmass. S.W. base of Olgasalik. Slide 224 × 24, seen under crossed nicols.

Fig. 2. Phonolitoid kenyte, showing dark "eyes" of olivine in a trachyte mesh of anorthoclase with interstitial pyroxene. Guru River, S. of Settima. Slide 399 × 24.

Fig. 3. Jacupirangite facies of ijolite, showing large augites, dusty, decomposed light-coloured nepheline, dark perovskite, and black magnetite with white hexagons of apatite. Jombo Hill. Slide 598 × 24.

Fig. 4. Nepheline-ægirine-phonolite, showing a large nepheline crystal with included prisms of ægirine-augite. At upper left-hand corner there is a small ægirine-augite with a crystal of sphene to right. Olgasalik. Slide 207 × 24.

DISTRIBUTION OF ROCKS

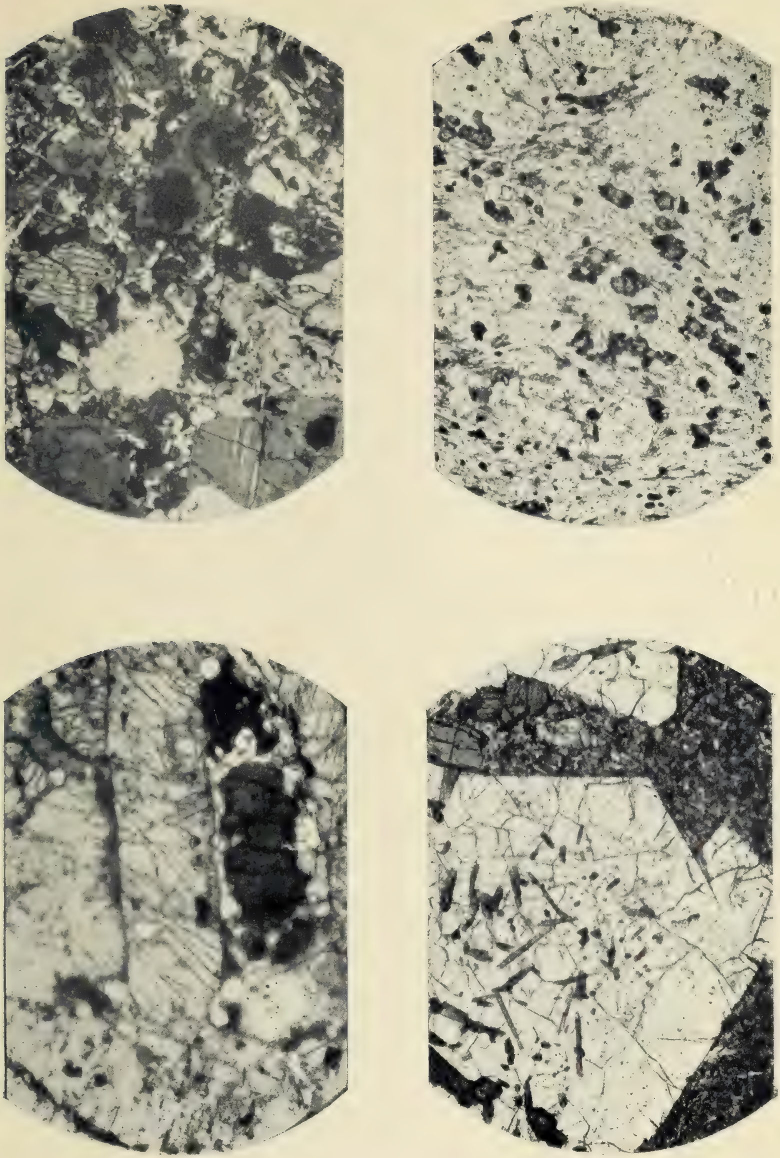
The bracketed numbers refer to rocks which are described in the text. The numbers without brackets refer to other specimens in the collection which have not received individual mention.

Lake Magadi District—

Shanau and Mt. Shelford	Rhyolite, (233). Phonolitic-trachyte D, 230, 231, 232. Kenyte, (228).
Olgasalik . . .	Phonolitic-trachytes C and D (201), (193), 195, 221. Kenytes (203, 204, 222, 224). Nepheline-ægirine-phonolite (183, 207).
Neuki and Koora .	Phonolitic-trachyte D, 212, 214, (226). Basalts, 215, (219).
Magadi . . .	Rhyolite, (240). Basalts, (651, 652).
Undingerio . . .	Phonolitic-trachyte D, 630, 631.
Sambu . . .	Tephrite, (637).
Nguruman and Kirikiti .	Basalts, (640, 641). Augitites, (646, 647).

Naivasha, Nyeri, Ngong District—

Naivasha . . .	Phonolitic-trachyte D, 90, (91).
Gura, Tumu-tumu .	Rhyolite, (407). Phonolite-trachyte D, (412). Phonolitoid Kenyte, (399, 404, 406).
Nyeri and Muiga .	Basanite, (392, 414). Olivine-augite basalt, (385, 387).
Amboni R. and Naromoru	Phonolites, (417, 419, 423).
Tana	Rhyolites, (431, 435, 438). Tephrite, (437). Basalt, 428.
Kikuyu . . .	Rhyolite, 252. Phonolitic-trachyte D, (442).
Ngong . . .	Augitites, (502, 503, 505). Tephrite, (506).
Kedong . . .	Rhyolite, (479), Phonolite, (485A). Phonolitic-trachyte C and D, (500), 483, (485D).



ROCKS OF B.E.A.

Microscopic Structure of the Rocks.

Naivasha and Njorowa District—

Njorowa Gorge . . .	Comendite group, (104, 115, 131, 132, 134).
Ol Setian . . .	Comendite, (143).
Soit Amut . . .	Phonolitic-trachytes: B, 163, (167), 168; C, (173); D, (179).

Railway from Nairobi to Kisumu—

Nairobi . . .	Rhyolite, (292, 295).
Kijabe . . .	Phonolite, (280). Phonolitic-quartz-trachyte, 291. Kenyte, (286).
Mau	Phonolitic-trachyte A, (572). Kenyte, (569).
Londiani and Lumbwa .	Phonolite, (267). Phonolitic-trachyte A, (304)
Ft. Ternan . . .	Melilite-augitite, (307). Phonolite, (579).
Kedowa . . .	Kenyte, (576).

Kisumu District—

Kisumu . . .	Phonolites, (321, 343).
Nandi . . .	Phonolite, (324, 325, 327). Kenyte, (330).
Messeno . . .	Syenites, (333, 336, 338).
Kaimosi . . .	Phonolites, (346, 349, 358).

Jombo District—

Jombo Hill . . .	Syenites and ijolites, (595, 597, 598, 599).

[1] The numbers in brackets refer to Prof. J. W. Gregory's British East African Rocks, 1919 collection, in Hunterian Museum, Glasgow University

APPENDIX V

Localities in Petrological Appendix

77. Phonolitic-trachyte. Mbagathi River, by bridge on Nairobi-Ngong road.
91. Freestone. In bluff below Commissioner's House, Nairobi.
104. Comendite. Fischer's Tower, E. entrance to Njorowa Gorge.
115. Comendite (glassy). S. end of ridge at S.W. arm of Lake Naivasha.
131. Banded comendite. At steam vent in Njorowa Gorge.
132. Comendite. Cliff near the steam vent on E. wall of Njorowa Gorge.
134. Comendite with lenticles of pitchstone. Njorowa Gorge, S. of steam vent.
143. Comendite lava. At S. foot of Ol Setian.
167. Banded phonolitic-trachyte. S. of Soit Amut.
173. Phonolitic-quartz-trachyte. Floor of valley at Tiridik, S. of pass.
179. Phonolitic-trachyte. Camp at Nderiki, S. end of Tiridik Valley.
183. Nepheline-ægirine-phonolite. Olgasalik, 2000 ft. above the pass on western side. Collected by Mr. W. McGregor Ross.
193. Phonolitic-trachyte. "Castellated Ridge," above E. side of lowest part of Kedong River.
195. Porphyritic phonolitic-trachyte. Floor of Rift Valley near the Asagut fault; 2 hrs. S. of 193.
201. Banded spherulitic phonolitic-quartz-trachyte. N.W. foot of Olgasalik. (8.30 a.m. 7.5.19.)
203., 204. Kenyte. N.W. foot of Olgasalik. (8.16 a.m. 7.5.19.)
205. Basanite. N.W. slopes of Olgasalik. (9.38 a.m. 7.5.19.)
207. Nepheline-ægirine-phonolite. S. of large swamp; N.W. of Olgasalik. (11 a.m. 7.5.19.)
215. Basalt. Magadi Railway, beside the diatomite deposits, at $\frac{62}{6}$ miles.
219. Analcite-basalt. Magadi Railway; the Nyuki Scarp, at $\frac{55}{7}$ miles, above the station.
222., 224. Kenyte. Foundation of Olgasalik; at main S.W. spur.
226. Phonolitic-trachyte. Lowest outcrop of Shanau Ridge; W. of alluvium on Koora Plain.
228. Kenyte. First plateau, 15 minutes above 226. Shanau Ridge.
231. Columnar phonolitic-trachyte. Near top of ascent to upper plateau. (9.40 a.m.). Shanau Ridge.
233. Spherulitic phonolitic-trachyte. Descent opposite Mount Shelford. (11.22 a.m.) Shanau Ridge.
240. Spherulitic phonolitic-rhyolite (Clinkstone). Top of plateau; E. of Lake Magadi, at N. end.

252. Spherulitic phonolitic-rhyolite. Ruiru. (Collected by Mrs. Roberts.)
267. Kapitian phonolite. Lumbwa phosphate caves. (Collected by Messrs. Hobley and Kirkham.)
280. Banded Kapitian phonolite. Road near edge of platform W. of Kijabe Station.
286. Porphyritic Kenyte. Road to Kedong, 10 minutes from Kijabe Station.
292. Nairobi Freestone. Ainsworth's Bridge, Nairobi.
295. Nairobi Freestone. Upper bed, quarry on road to Government Farm, S. of Mathari River.
304. Phonolitic-trachyte. Railway ballast at Londiani; quarried E. of the railway station.
307. Augitite. Fort Ternan Station.
321. Phonolite: Kenya type. S. slope of Kisumu Hill.
324. Kapitian phonolite. Foot of Nandi Scarp on Messeno road, 4¼ miles from Kisumu.
325. Phonolite: Kenya type. On the plateau, Messeno road, 5½ miles from Kisumu.
327. Phonolite: Kenya type. Overlying hornblendic granite. Messeno road, 7½ miles from Kisumu.
330. Kenyte. Wash-out on stream crossed by Messeno road, 14 miles from Kisumu.
333. Granulite dyke. Messeno Hill.
335. Intrusive rock in granulite. Messeno Hill.
336. Granulitic-syenite. Messeno Hill.
338. Granulitic-syenite. Messeno Hill.
343. Phonolite: Kenya type. P.W.D. workshops, Kisumu.
346. Phonolite: Kenya type. On Kisumu–Kaimosi road, just S.W. of brickyard at Kibos River.
349. Compact variety of the same. Above granite. Ditto.
385. Porphyritic olivine-basalt. 9480 ft. Ascent of Settima Scarp on Nyeri road.
387. Ditto. 200 ft. higher up the same scarp.
392. Fissile basanite. Summit of the pass, on Nyeri road.
399. Phonolitoid-kenyte. By Guru Bridge, E. of the pass.
404. Kenyte. Lava of Nyeri Hill. (Collected by L. A. Field-Jones, Esq.)
406. Kenyte. Summit of Tumu-Tumu Hill. (Collected by H. L. Sikes, Esq.)
407. Phonolitic-rhyolite. P.W.D. quarry, Nyeri.
412. Phonolitic-trachyte. Boulders in agglomerate, S. branch of Muiga River, Meru road.
414. Columnar basanite. N. of main Muiga River, Meru road.
417. Kapitian phonolite. N.E. of Amboni River, Meru road.
419. Kapitian phonolite. N.N.E. of Amboni River, farther along the Meru road.
423. Kapitian phonolite. Descent to Naromoru River, Meru road.
431. Phonolitic-rhyolite. N. side of bridge over Maragua River, Fort Hall road.

435. Phonolitic-rhyolite. At top of cliff above the tuffs, N. side of bridge over Maragua River, Fort Hall road.

437. Tephritic agglomerate. S. of Thaba-thaba, Fort Hall road.

438. Devitrified phonolitic-rhyolite with fossil wood. Near Mukuyu, Fort Hall road.

442. Phonolitic-trachyte. Kikuyu Mission quarry.

479. Faulted spherulitic phonolitic-rhyolite. W. of Nartje's, Kedong River.

485. Phonolites and kenyte from tuffs. Floor of Kedong basin, S.E. of Nartje's.

502. Augitite. W. of Ngong Bazar.

503. Augitite valley floor. S. of Ngong Bazar.

505. Platy augitite. W.S.W. of Ngong Bazar.

506. Tephrite. Below the quarry, E. of Ngong Boma.

569. Turi River, below bridge, Uganda Railway. Mau Scarp, $\frac{480}{1}$.

572. Phonolitic-trachyte. Deep cutting on Uganda Railway at $\frac{495}{1}$, near Londiani.

576. Dyke, columnar kenyte. On Uganda Railway at $\frac{512}{8}$, E. of Kedowa.

579. Kapitian phonolite. Near Fort Ternan on Uganda Railway at $\frac{532}{15}$.

595. Nepheline-syenite. S. of Jombo Hill. (Collected by C. B. Thompson, Esq.)

597. Ijolite. Half-way up Jombo Hill. (Collected by C. B. Thompson, Esq.)

598. Jacupirangite-ijolite. Lower slopes of Jombo Hill. (Collected by C. B. Thompson, Esq.)

599. Ijolite. Base of Jombo Hill. (Collected by C. B. Thompson, Esq.)

637. Tephrite. Foot of Nguruman Scarp. (Collected by G. St. Clair, Esq.)

640. Basalt. Upper Nguruman Scarp. (Collected by G. St. Clair, Esq.)

641. Basalt. Top of lower Nguruman Scarp. (Collected by G. St. Clair, Esq.)

643, 646, 647. Augitite. Foot of upper Nguruman Scarp. (Collected by G. St. Clair, Esq.)

651. Basalt at 48½ miles on Magadi Railway. (Collected by A. L. Lawley, Esq.)

652. Basalt at 47 miles on Magadi Railway. (Collected by A. L. Lawley, Esq.)

APPENDIX VI

Comparative Table of the Geological Succession in Southern Rhodesia (after Maufe, 1919)

Equivalents.	Formation.	Igneous Intrusions.	Earth-Movements.
	Kalahari System—		
Perhaps Kainozoic.	Kalahari Sand. ,, Ironstone. Somabula Gravels.		Uplift along N.E. and S.W. axis.
Perhaps Late Cretaceous.		Kimberlite pipes and Sills (Bembesi).	Trough-faulting in N.W., block-faulting in E.
	Karroo System—		
Karroo System. Permian, Trias, and perhaps Rhætic.	Batoka Basalts. Forest Sandstone. Escarpment Grit. Madumabisa Shales. Wankie Sandstones, fireclay, and coal.	Basalt dykes in Sabi and Tuli coalfields.	
Bushveld plutonic complex.		Great Dyke of Norite.	
Age unknown.	Sandstones and shales of Gungwe River, and eastern border.		
	Umkondo System—		
Perhaps Waterberg System.	Umkondo Beds; andesitic lavas, quartzites, shales, and limestone.	Diorite.	
	Lomagundi System—		
Probably Transvaal System.	Sandstones, green and graphitic slates, and andesites. Conglomerate, limestone. Dolomite, quartzite, and conglomerate.	Granite, granophyre. Pegmatite and aplite dykes. Felsite, Serpentine, etc.	
	Basement Schists—		
	Conglomerate, banded ironstone and greenstone schists.		

APPENDIX VII

General Glossary

(*For Rock Names, see Separate List*, pp. 415–417)

Acid (in petrology). Rocks rich in silica and poor in iron, lime, or magnesia.

Ægirine. See Pyroxene.

Æolian (Gr. *Aiolos*, god of the winds). Deposits formed on land by the action of the wind.

Amphibole (Gr. *amphibolus*, ambiguous, from the variable nature of the mineral). A group of minerals important as constituents of many rocks. Hornblende is the typical species. Riebeckite is a species rich in soda.

Analcite. See Felspathoids.

Anorthoclase. See Felspar.

Anticline (Gr. *anti*, apart, and *klino*, I bend). An archlike upfold of stratified rock.

Apatite (Gr. *apate*, deceit, and *lithos*, stone). A mineral species composed mainly of phosphate of lime.

Augite (Gr. *auge*, lustre). The typical mineral species belonging to the group of the pyroxenes.

Basic (in petrology). Rocks rich in iron, lime, or magnesia, and poor in silica.

Clastic (Gr. *klastos*, broken to pieces). Sedimentary rocks composed of fragments.

Diatoms (Gr. *dia*, through, and *tome*, a cut). A group of minute aquatic plants with siliceous shells, each of two valves.

Doinyo (Masai). A mountain.

Domo (Suahili). A door ; used also by Zanzibari for a mountain pass.

Eocene (Gr. *eos*, the dawn). The dawn of recent life, the first System of the Kainozoic.

Fault. A break in the continuity of a bed of rock by movement along a fracture.

Felspar (from German *fels*, a rock, and *spath*, a spar or mineral). A group of mineral species most important as rock-forming constituents. The species are orthoclase—a potash felspar which crystallizes in the monoclinic system ; anorthoclase, a soda-felspar, the characteristic species in the kenytes ; plagioclase, a group of species which crystallize in the triclinic system and range from the alkalic species, soda-plagioclase, albite, through the soda-lime plagioclase, oligoclase, the lime-soda plagioclase andesine, to the basic species labradorite and anorthite (lime-plagioclase).

Felspathoids (from felspar and Gr. *eidos*, a likeness). A group of mineral species which occur instead of felspars, wholly or in part. The chief species found in East Africa are nepheline, leucite, and sodalite.

Femic (Fe, the symbol for iron (L. *ferrum*), and M stands for magnesium). A term applied to substances containing much iron and magnesium.

Foliation (L. *folium*, a leaf). The arrangement of the minerals in a crystalline rock in parallel layers.

Foraminifera (L. *foramen*, an opening, and *fero*, I bear). Microscopic unicellular animals that live in the sea; their shells are important constituents of many limestones.

Guaso (Masai). A river.

Holocrystalline (Gr. *holos*, whole). A term applied to rocks wholly composed of crystalline constituents.

Hornblende (German, *horn*, metal, and *blenden*, to deceive, because containing no metal, although of a metallic lustre). The chief mineral species of the group of the Amphiboles.

Intermediate Rocks. The rocks intermediate in composition between the acid and basic.

Kilima (Suahili). A mountain or hill.

Leucite (Gr. *leukos*, white). A white-coloured mineral especially abundant in some Italian lavas.

Lithophysæ. Hollow spherulites.

Mesozoic (Gr. *mesos*, middle, and *zoe*, life). The middle Era of life; the fourth of the five Eras into which geological time is divided.

Metamorphism (Gr. *meta*, after, as in physics and metaphysics; and *morphe*, form). A change in a rock which alters the arrangement of its materials, but not its composition.

Metazoa (Gr. *meta*, after, and *zoe*, life). The sub-kingdom of animals in which each animal is composed of many cells.

Mica (L., *mico*, I glitter). A group of mineral species characterized by breaking into thin, glistening flakes.

Miocene (Gr. *meion*, less, and *kainos*, recent). The middle Period of recent life; the middle Period of the Kainozoic Era.

Mollusca (L., meaning a soft nut with a thin shell, from *mollis*, soft). The group of animals including the "shell-fish."

Monocline (Gr. *monos*, single, and *klino*, I bend). A fold with only one side.

Nepheline (Gr. *nephile*, a cloud). See Felspathoids.

Oligocene (Gr. *oligos*, little, and *kainos*, recent). The second in time of the five systems of the Kainozoic Group.

Paleozoic (Gr. *palaios*, ancient, and *zoe*, life). The Era of ancient life. The third of the five geological Groups and Eras.

Plagioclase. See Felspar.

Pleistocene (Gr. *pleistos*, most, and *kainos*, recent). The last of the five Systems of the Kainozoic Group.

Pliocene (Gr. *pleion*, more, and *kainos*, recent). The fourth in time of the five Systems of the Kainozoic Group.

Plutonic (named after Pluto, the god of the infernal regions). The igneous rocks that have solidified deep below the surface of the earth.

Porphyritic. A term applied to those igneous rocks in which one of the constituents occurs in much larger crystals than the rest.

PYROXENES (Gr. *pur*, fire, and *zenos*, a stranger). A group of mineral species found mostly in basic and intermediate igneous rocks. Augite is the most abundant species. The soda pyroxenes include ægirine and acmite.

QUARTZ. Rock crystal, the crystalline form of silica, and one of the commonest rock-forming minerals.

RIEBECKITE. See Amphibole.

ROCHES MOUTONÉES. Rock surfaces which have been rounded by the flow of a glacier across them.

SPHERULITE. Small spherical bodies found in igneous rocks and formed by radial groups of fibrous minerals.

STRATUM (L., a layer). A layer or bed of rock.

SYNCLINE (Gr. *syn.*, together, and *klino*, I bend). A trough-like fold of stratified rock.

TECTONIC (structural). A term used for features on the earth's crust due to earth-movements and upbuilding, as apart from features due to denudation.

URALITIZATION. The alteration of pyroxene to hornblende.

APPENDIX VIII

Definition of Rock Names

Amphibolite. A metamorphic rock consisting of amphibole with a plagioclase felspar and usually quartz ; it often contains garnet. Hornblende-schist is one variety.

Amygdaloid. A volcanic rock containing many spaces, usually steam cavities, which have been filled with secondary minerals.

Analcite-Basalt. A basalt containing analcite.

Andesite. An igneous rock, usually a lava, containing a lime-soda plagioclase (usually andesine), with a dark mineral, pyroxene, hornblende, or dark mica. It is the volcanic equivalent of the deep-seated rock, diorite.

Augitite. Volcanic rock containing abundant augite in a soda-rich base. The characteristic representative in B.E.A. is a nepheline-augitite.

Basalt. A fine-grained igneous rock composed of a lime-felspar and pyroxene, with or without olivine. It is the chief lava equivalent of gabbro.

Basanite. A rock resembling basalt, containing a lime-felspar, augite, olivine, and a felspathoid. In nepheline-basanite the felspathoid is nepheline ; in leucite-basanite it is leucite.

Borolanite. An intrusive rock of which the chief constituents are orthoclase and melanite, and usually nepheline.

Breccia. A rock composed of coarse, angular fragments.

Camptonite. A dyke rock composed of lime-felspar and hornblende.

Charnockite. A hypersthene granite. The charnockite series is a varied series of rocks all containing hypersthene.

Comendite. A rock originally described from Sardinia—a rhyolite with riebeckite or ægirine.

Conglomerate. A rock composed of coarse, rounded fragments.

Cortlandtite. A hornblende-peridotite. Found in East Africa on Kilima Njaro.

Dacite. Quartz andesite.

Diabase. An altered dolerite which is greenish owing to the alteration of the pyroxenes to chlorite.

Diorite. A plutonic rock, composed of lime-plagioclase and hornblende, biotite, or augite ; quartz occurs in quartz-diorite.

Dolerite. An intrusive basic rock with a granular texture. It is composed of the same minerals as basalt, but has a rougher, granular texture.

Dolomite. A rock composed of the mineral dolomite. When mixed with calcite it forms dolomitic limestone.

Epidiorite. A basic intrusive rock composed of basic plagioclase and hornblende, which is due to the alteration of the augite (uralitization).

Felsite. An acid igneous rock composed essentially of imperfectly crystalline fine-grained quartz and orthoclase.

Gabbro. A coarse-grained, deep-seated basic igneous rock composed of lime-felspar and the altered form of augite known as diallage.

Gneiss. A rock composed of the same three mineral species as granite, but arranged in parallel layers.

Granite. An acid plutonic rock composed of quartz and alkali-felspar, with a mica typically muscovite.

Granitite. Granite in which the mica is biotite.

Granulite. A granular metamorphic rock, usually composed of quartz, pyroxene, garnet, or mixtures.

Ijolite. A plutonic rock composed of nepheline and ægirine.

Jacupirangite. A plutonic rock composed of nepheline, augite, and magnetite. Found in Brazil and Elgon.

Kenyte. An alkaline igneous rock, usually a lava, containing anorthoclase, ægirine, and sometimes olivine.

Kinzigite. A granular basic metamorphic rock consisting mainly of garnet and olivine. Found in the Eozoic rocks of B.E.A.

Limburgite. An ultra-basic alkalic igneous rock composed of olivine, pyroxene, and a base rich in alkali.

Liparite. Used as synonymous with rhyolite. Rhyolite has been used for the altered representatives, and liparite for those which still contain glass.

Melilite-Basalt. A lava composed of melilite and olivine, with little or no felspar.

Nepheline-Syenite. A plutonic coarse-grained rock composed of alkali-felspar, nepheline, and usually a soda-amphibole or soda-pyroxene. It is the deep-seated equivalent of phonolite and kenyte. The more basic variety with olivine is the equivalent of olivine-kenyte.

Nephelinite. A lava composed of nepheline and augite ; neither felspar nor olivine is present.

Obsidian. Acid volcanic glass.

Orthophyre. An intrusive rock with a micro-granitic base and large crystals of orthoclase. The texture differs from that of trachyte by the absence of the parallel lath-shaped felspar.

Paisanite. An intrusive alkalic rock containing quartz, orthoclase-felspar, and riebeckite.

Pantellerite. An alkali-rhyolite containing quartz, anorthoclase, ægirine, and cossyrite.

Peridotite. Ultra-basic plutonic rocks composed of olivine with some other basic mineral, such as pyroxene, hornblende, or garnet.

Phonolite. A fine-grained alkalic igneous rock—usually a lava consisting of alkali-felspar, nepheline (or perhaps sodalite), with soda-pyroxene or soda-amphibole.

Pitchstone. A volcanic glass of trachytes, andesites, and other sub-basic volcanic rocks.

Porphyrite. A term formerly used for altered andesites, but now more generally adopted for intrusive occurrences of andesite.

Porphyry. An acid igneous rock composed essentially of fine-grained but distinctly crystalline quartz and orthoclase.

Quartzite. A cemented, very compact, altered sandstone.

Rhyolite. An acid lava, usually consisting largely of glass or altered glass.

Schist. A metamorphic rock which breaks into thin leaves or folia owing to the abundance of flat minerals, such as mica or long, fibrous minerals such as hornblende.

Shale. Clay which splits readily into flakes.

Solvsbergite. A fine-grained intrusive rock consisting of alkali-felspar with ægirine or a soda amphibole.

Tephrite. An alkalic rock consisting of nepheline, leucite or sodalite, and an alkali-plagioclase (no olivine ; *cf.* Basanite).

Tinguaite. An alkalic rock intermediate in structure between nepheline-syenite and phonolite.

Trachy-Dolerite (Abich. 1841). A term proposed for rocks intermediate between trachyte and dolerite, but now used for alkalic rocks synonymous with kenyte.

Tuff. A rock formed of small fragments of volcanic ashes and lava.

Vogesite. A dyke rock composed of a lime-soda plagioclase (e.g. andesine) and hornblende.

APPENDIX IX

Masai Place-Names, as used in the Text and on Current Maps, and the correct Forms supplied by A. C. Holles, Esq., C.M.G., etc.

	Masai
Alngaria . . .	Ol-karia *or* ol-ngariat.
Arabel, Guaso (R.) . .	E-uaso e-rabal.
Chebchuk . . .	Chep-chuk = Nandi.
Doinyo Lersubugo . .	Ol-doinyo lo-'supuko.
Doinyo Nyuki . .	Ol doinyo onyokie.
Domo Larabwal . .	Cf. Arabel.
El Barta . . .	? Em-bart = a horse.
El Narua, Guaso . .	E-uaso e-'ngarua.
Elburgon Sta. . . .	Purko = a Masai sub-district.
Engare Berisha . .	Eng-are ?
Erri Mts. . . .	Ol-doinyo lo-'iri (the mountain of the Grewia trees).
Eyasi, L. . . .	I-asi.
Gilgil	The Masai name is 'N-aitolia (the place of crested cranes).
Gopo lal Mwari . .	En-gop oo-'l-mwari.
Kajiado	Ol-keju oado (the long river).
Kamasia . . .	En-gop oo-'l-Kamasia (the country of the Kamasia).
Kamnye . . .	Kamunyei.
Kapiti Plains . . .	Kaputiei.
Karamojo . . .	Koromoj.
Keite-Thwaki . . .	? "Why do you bother me?" in Masai.
Kenya	Ol-doinyo keri.
Kibibi L. . . .	'N-dapipi (=clover).
Kinangop . . .	Kinokop.
Kipipiri	Kipeperi.
Koora	Kaora.
Kulal	Kulal.
Laikipia	'L-aikipiak.
Lanjoro	Le-'n-joro.
Larabwal, Guaso . .	E-uaso e-rabal.
Lashau, Guaso . .	E-uaso oo-'l-asho.
Lemosilla . . .	Le-mosila.
Lingithia . . .	Le-ngisia.
Logurdogi . . .	Loo-'l-kurdoki ?

	Masai
Loita Plains	'L-oita.
Lokenya	Le-'nkenya.
Lolaita Plat.	'L-oita.
Lolbogo	Ol-doinyo loo-'l-bughs (the mountain of the Terminalia trees).
Lol Daika hills	Loo-'e-taika.
Lol Marak	Loo-'e-marak.
Longonot	Loo-'n-noñgot.
Lorgasailik	Loo-'l-kisali.
(Loroidok)	Loo-'l-oitok.
Loroki	'L-oroki.
Loronyo	Ol-doinyo oronyo (the bald mountain).
Losagut	Loo-'sakut.
Losuguta, L.	Loo-'sukutan (one = le-'sukuta).
Magadi, L.	E-m'akat.
Makalia R.	Makalia.
Manyara, L.	Manyara.
Marmanet	Marmanet.
Marop	? (" I shall not do wrong again " in Masai).
Marsabit	Marsabit.
Marti	E-marti.
Menengai	E-menangai.
Mogotiu R.	Mogotiu.
Molo R.	Molo.
Mukutan R.	En-geju-E-mukutan. The river of the Albizzia anthelminthica.
Mungan, Doinyo	Ol-doinyo le-'mungan.
Muruaki R.	Eng-are e-'murua.
Naivasha	En-aiposha.
Nakuru L.	En-aikuro.
Nalesha, Doinyo	Ol-doinyo lo-'l-leleshwas (the mountain of the Tarchonanthus camphoratus plants).
Nandarua	Ol-tarakwai or en-darakwai (=Juniperus procera).
Narok, Guaso	E-uaso narok.
Naromoru R.	Narok moru.
Nderiki	'N-deriti ol-keju le-'n-derit (the dusty river); or 'n-daritik (the river of birds).
Ngobit R.	'Ng-obit.
Ngomeni	Ngomeni. Kiswahili.
Nguruman Scarp	'N-gurman.
Ngurunga Nyoka	Ngurunga nyoka = Kiswahili.
Njemps	En-gop oo-'l-jamus (the country of the Jamus).
Nkobiri	'Ng-opiri.
Nunjoro	'N-oo-'n-joro.
Nyiro, Guaso	E-uaso ñgiro.
Ol Barte	? Em barta = horse.

	Masai
Ol Bolossat . . .	Il-polosat.
Ol Burru, Doinyo . .	Ol-doinyo opuru.
Ol Doinyo Nyegi . .	Ol-doinyo onoykie.
Ol Esayet . . .	Loo-'sayet.
Ol Gumi . . .	Ol-kume.
Ol Keju Nerro . .	Ol-keju ñgiro.
Ol Orugo . . .	Ol-oruko.
Ol Setian . . .	O-setian.
Ongoswaishwi, Doinyo .	Ol-doinyo le-'n-gushwai.
Orengingnai . . .	Ol-le-'n-ginyei.
Pesi Swamp . . .	Pesi.
Rangata Ndari . .	Angata oo-'n-dare.
Rongai R. . . .	Eng-are rongai (the thin river).
Sambu R. . . .	Ol-doinyo sambu (can only be used for mountain).
Settima	O-satima.
Siria	I-siria.
Solai L.	Solai.
Songari	Shongoli ?
Subugo lal Mwari, Doinyo	Ol-doinyo loo-'l-mwari *or* O-supuko loo-'l-mwari.
Subugo Loita Endasegera .	O-supuko loo-'l-oitai en-dasegera.
Subukia	I-supukia.
Sugota Valley . . .	E-sukuta.
Suguroi R. . . .	O-suguroi.
Suswa Plain . . .	Susua, Masai name (Suswa = grass in Nandi and Dorobo).
Taveta	En-gop oo-'l-Tupeita (Country of the Taveta)
Tiridik : cf Nderiki . .	N-daritik (Ol-keju loo-'n-daritik = the river of birds).
Tsavo	Sapo. Kamba word ; the Wakamba call it Tsapo.
Turoka R. . . .	Turoko.
Weikei R. . . .	O-ikei.

APPENDIX X

List of Analyses of East African Rocks, Salts and Waters

I. Waters.

I. Spring at foot of Hospital Scarp; Lake Magadi. NaCl, ·675%; Na_2SO_4, ·013%; Na_2CO_3, ·915%; $HNaCO_3$, ·672%. By G. St. Claire. Collected 4th May, 1919.
II. Hot spring (80° C.) at Lake Manyara. Lenk, 1894, p. 293.
III. Lake Manyara. Lenk, *ibid.*, p. 293.
IV. Lake Eyasi. Lenk, *ibid.*, p. 293.
V. Hot spring, Njorowa Gorge. Fischer, 1885, p. 206. Also Mügge, 1886, p. 608.
VI. Lake Balangda. A. Bohm, in Jaeger, 1911, pp. 85–86.
VII. Lake Njara (Eyasi). A. Bohm, in Jaeger, 1911, p. 87.
VIII. Lake Ngorongoro. A. Bohm, in Jaeger, 1911, p. 97.
IX. Cauldron No. 6 in the Tungobesch plateau, W. of Lake Balangda. (For map of position see Jaeger, 1913, p. 57.) A. Bohm in Jaeger, 1911, p. 86.

II. Salts.

X. Efflorescence, L. Eyasi. Lenk, 1894, p. 292.
XI. Mangati, Lake Balangda. Lenk, 1894, p. 292.
XII. Shore. N. end of Lake Manyara. Lenk, 1894, p. 292.
XIII. Shore. S. end of Lake Manyara. Lenk, 1894, p. 292.

III. Igneous Rocks.

XIV. Kenyte from the Core of Mt. Kenya (Teleki Valley). Prior, 1903, p. 247.
XV. Kenyte from the lava-flow at the foot of Mt. Hohnel, Mt. Kenya. Prior, 1903, p. 247.
XVI. Phonolite from the base of Mt. Hohnel, Mt. Kenya. Prior, 1903, p. 247.
XVII. Phonolitic-obsidian. L. Nakuru. Prior, 1903, p. 247.
XVIII. Obsidian (glassy soda-rhyolite). L. Naivasha. Prior, 1903, p. 247.
XIX. Pantellerite. Lumbwa. Goldschlag, 1912, p. 588.
XX. Nepheline-tephrite. Lumbwa. Goldschlag, 1912, p. 592.
XXI. Nephelinite. Karungu. Goldschlag, 1912, p. 595.

XXII. Intermediate between nephelinite and nepheline-basalt. Ft Ternan. Goldschlag, 1912, p. 596.
XXIII. Phonolite. Andrakaka, Madagascar. Lemoine, 1906, p. 310.
XXIV. Phonolite. Nossykombe, Madagascar. Lacroix quoted Lemoine, 1906, p. 310.
XXV. Nepheline-syenite. Madagascar. Lacroix, 1903, p. 194.
XXVI. Trachyte. Lusambo. Finckh, 1912, p. 4.
XXVII. Trachy-dolerite. Karisimbi. Finckh, 1912, p. 11.
XXVIII. Leucite-basanite. Kisi. Finckh, 1912, p. 18.
XXIX. Leucite-basanite. Muhawara. Finckh, 1912, p. 18.
XXX. Leucite-basanite. Mukira. Finckh, 1912, p. 18.
XXXI. Leucite-basanite. Namlagira. Finckh, 1912, p. 18.
XXXII. Trachy-doleritic leucite-basanite. Nawigaavo Mt., near Kissenji. Finckh, 1912, p. 18.
XXXIII. Leucite-theralite. Namlagira. Finckh, 1912, p. 19.
XXXIV. Limburgite. Adolf Friedrich Cone. Finckh, 1912, p. 22.
XXXV. Limburgite. Adolf Friedrich Cone. Finckh, 1912, p. 22.
XXXVI. Leucite-nephelinite. Niragongo. Finckh, 1912, p. 25.
XXXVII. Melilite-nephelinite. Ngoma. Finckh, 1912, p. 26.
XXXVIII. Leucite-ijolite. Niragongo. Finckh, 1912, p. 28.
XXXIX. Ijolite. Kelimassi (Colld. by Uhlig). Finckh, 1912, p. 28.
XL. Leucitite. Wissoke. Finckh, 1912, p. 30.
XLI. Leucite-basalt. Kissenji. Finckh, 1912, p. 34.

The average composition of the above 28 igneous rocks shows their high percentage of alkalies; it is as calculated by Mr. John Weir—SiO_2, 49·56; TiO_2, 1·60; Al_2O_3, 15·43; Fe_2O_3, 5·20; FeO, 5·48; CaO, 7·23; MgO, 3·36; MnO, 0·21; K_2O, 3·84; Na_2O, 5·31; H_2O, 1·94; SO_3, 0·04; P_2O_5, 0·51; CO_2, 0·05. Total, 99·79.

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