THE GEOLOGICAL HISTORY OF THE LAKE RUDOLF BASIN, KENYA COLONY

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(*Communicated by O. T. Jones, F.R.S.—Received* 25 *October* 1937)

[Plates 26–32]

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I. INTRODUCTION

The Lake Rudolf Rift Valley Expedition was designed to carry out many different lines of investigation in the Lake Rudolf Basin. One of the chief of these was a study of the geological history of that part of the East African Rift Valley.

The expedition was assisted financially by The Royal Society, The Geological Society of London, The Royal Geographical Society, The Percy Sladen Trustees and the Geographical and Geological Sections of the British Association.

A general description of the activities of the Expedition was given in a paper read before the Royal Geographical Society (Fuchs 1935).

VOL. CCXXIX. B 560 (Price 15*s*.) 28 [Published 26 January 1939

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Owing to the tragic loss of two members of the expedition, Dr W. S. Dyson and Mr W. R. H. Martin, two fruitless months were spent searching for them. Consequently a great amount of the work planned for the east side of the lake had to be abandoned. Nevertheless, the considerable distance travelled within the 50,000 sq. miles of the Rudolf Basin has enabled me to make out the chief events of its geological history.

I am very much indebted to all those who assisted us in the field and at home, in particular to the Kenya Government, the Officers of the King's African Rifles, and Mr H. L. Sikes of the Public Works Department; I would also like to thank Mr A. M. Champion, Provincial Commissioner of Turkana, who wholeheartedly assisted us in every way possible both in the field and at home, for he has placed at my disposal his own excellent topographical maps and his extensive observations on the geology of the area. I am also deeply indebted to Professor O. T. Jones, Mr Henry Woods and Mr W. Campbell Smith for their criticisms. Mr Campbell Smith has also given me provisional identifications of the rocks.

As this paper deals with a large and little-known area I believe that it will be a useful general basis for future workers. It has therefore been thought advisable to include a certain amount of local detail which, it is hoped, will answer this purpose, and also allow the observations in the paper to be readily checked if desired.

It seems fitting that a study of the Rudolf Basin should reveal further evidence concerning the formation of the Rift Valley, since it was the discovery of the lake in 1888 that led E. Suess to conclude that the southern continuation of the Red Sea fractures lay along the African chain of lakes rather than along the coast (v. Höhnel and others 1891). That this study should supply some evidence of compressive forces is a justification of Ball's view expressed in a letter to the *Geographical Journal* (Ball 1920). He said: "I think the structures observed by Professor Gregory are far more likely to be the relics of faulting due to compression and compressional shearing, such as we are familiar with elsewhere on the earth, than to the very peculiar conditions which the trough-fault theory demands." And again: "I believe...that the faulting was chiefly brought about by compressional folding of the crust, and that the present surface configuration has resulted mainly from denudation and erosion acting subsequently on the folded and faulted areas."

II. PREVIOUS GEOLOGICAL WORK IN THE AREA

The lake was discovered in 1888 by Count Teleki and Lieut. von Höhnel (now Admiral von Höhnel), the two Austro-Hungarian explorers. It was von Höhnel who accomplished all the scientific work of the expedition, and besides his most excellent map he brought back specimens and notes on the geology of the area. These were later published by Professor E. Suess and Ludwig von Höhnel and others (von Höhnel, Rosiwal, Toula, Suess 1891).

Since that time there have been several expeditions to the lake, but until 1930 few of them did any geological work. An exception was Count Bottego's second expedition in 1895–7. The geological field work was done by Dr Sacchi, but on account of his death during the expedition, it was ultimately published by G. Angelis d' Ossat and F. Millosevich (1900).

In 1930 the Cambridge Expedition was mainly concerned with the biology of the lake, but a certain amount of geological work was accomplished in the Turkana Province (Fuchs 1934). This was unfortunately cut short by the author's illness, and the present expedition was planned to carry out a more ambitious programme in the geological field.

Meanwhile M. C. Arambourg of Paris had in 1932 led an expedition to the Omo river at the north end of the lake (Arambourg 1935) in order to investigate the fossiliferous deposits found there by the Bourg du Bozas Expedition in 1902 (Haug 1908, p. 1727).

In 1921 Professor J. W. Gregory in his book *The Rift Valleys and Geology of East Africa*, devoted a chapter to the Abyssinian and Lake Rudolf section of the Rift Valley, but he himself never visited that area.

Other work concerned with the surrounding country has been published by Dr J. Parkinson in a Colonial Office Report (Parkinson 1920) and in two papers written by him in collaboration with Mr V. G. Glenday (1926, 1927).

During the last few years Mr A. M. Champion, C.M.G., the Provincial Commissioner of the Turkana Province, has taken a great interest in the geology of the area and has made a collection of specimens, some of which have been described by Mr Campbell Smith (Smith and Champion 1937).

III. PHYSIOGRAPHY OF THE LAKE RUDOLF BASIN*

The area in which the expedition worked lies between latitudes 2° and 5° N. and longitudes 34° and 38° E. This region forms a part, though not a very clearly defined part, of the Rift Valley of East Africa. In the centre lies Lake Rudolf which is at present some 160 miles long and about 35 miles wide. The surface of the lake is now about 1250 ft. above sea-level, and the maximum known depth is 240 ft.

On the west the lake basin is bounded by the great fracture known as the Uganda escarpment. It seems that this is the true northward continuation of the rift wall from the Elgeyo escarpment in the south, for it can be traced without a break through Sekerr, Chemorongi and Moroto, to Mt Zulia and the Dodinga Hills in the north-west. Though this is the most continuous fracture, there are numerous other important tectonic features that form prominent scarps and mountain ranges. Thus the series of branches that starts with the Kamasia heights and the Alongol ridge, indicates a north to north-easterly trend for these fractures which is definitely established by the

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* Since this was written Mr Champion has published a paper entitled "The physiography of the region to the west and south-west of Lake Rudolf" (Champion 1937).

Muruanisigar-Pelekech-Kaitherin Range. Parallel to the latter run the smaller and less continuous ranges of hills and mountains called Losidok, Murueris, Lorienatom, and Labur. Between these mountains lie flat sandy expanses of desert that hide the intervening solid geology.

South of the Turkwel river mouth there is a wide sandy desert only relieved by occasional ranges of mountains and isolated hills of gneiss or schist. The plains themselves are an old peneplain surface now covered by lake deposits and wind-blown sand (see fig. 15, Plate 26). South-east of the Kerio river lies the high, lava-capped Loriyu Plateau. On the east it is truncated by a 1500 ft. scarp which forms the precipitous south-west shore of Lake Rudolf. This rocky coast continues north to Na'Arangan, where the cliffs turn away inland and shingle or sand forms the immediate shoreline. Farther to the north, and east of the Kerio river mouth, there is a prominent sandspit jutting out into the lake. This, together with the Turkwel delta and the Ferguson Gulf sandspit, form the only striking features of Lake Rudolf's western shore.

At the south end of the lake a volcanic barrier has been built up across the rift. The age of this 3000 ft. barrier will be shown later to be Middle Pleistocene, but on either side of it volcanic rocks have been extruded up to the present time. As recently as 1895 Teleki's Volcano was in active eruption (Donaldson Smith 1897). South of the Barrier* lies the Suguta Valley which once received the drainage waters of Lake Baringo a hundred miles to the south. The east end of the Barrier abuts against the base of Mount Nyiro, a mass of gneisses and schists rising to over 10,000 ft. North of Nyiro the east side of the lake is dominated by Mt Kulal, a great volcanic pile whose summit is some 7500 ft. above sea-level. Between its base and the lake shore there are numerous fault-steps in the Pleistocene lavas of the district. North of Elmolo Bay a small area of schists appears through the carpet of lavas, but beyond Bor Hill they are again covered by basalts. North of Bor the volcanic slopes of Moite (Moitat) Hill fall precipitously into the lake. Beyond Moite the lengthy Longendoti Range forms such a rocky coast that Teleki and others found it impassable. North of Longendoti, Alia Bay is a prominent feature of the coast, but the retreat of the lake has very considerably reduced its size in recent years. From Alia Bay northward to the end of the lake, the shore is gently shelving until in the region of the Omo river the edge of the lake is difficult to define on account of the periodical flooding of the marshy areas. The Omo river draws its water from the Abyssinian highlands and is the only permanent river flowing into the lake. Even the Omo has been known to dry up during certain years, as for instance in 1900 when Harrison and his companions ate their lunch in the middle of the dry river bed (Harrison 1901, p. 272).

East of the northern end of Lake Rudolf lies Lake Stefanie, which is the most southern of the lakes lying in the north-east to south-west Abyssinian rift. It seems probable that the junction of the Lake Rudolf rift fractures and those of the Abyssinian

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* The name Barrier supplies a want; I therefore follow Champion (1935) in the use of this name for the range running transverse to the rift immediately south of Lake Rudolf.

highlands is to be found in the gently folded (?) and fractured area east of Lake Rudolf (see Tectonic summary). To the east of Rudolf near the northern end of the Koroli desert lie the Huri Hills and to the south-east Mt Marsabit, both of which masses are of volcanic origin. Between them the plains are covered by a desert of lava boulders called the Dida Gulgulla. The boulders of which this desert is formed originate from the weathered surface layers of lavas that are still *in situ*. Neither these lavas nor the later ones of Pleistocene age stretched west of the Maikona-Koroli region. Over this area of Basement Complex rocks has been formed the sandy Koroli desert, which now extends westward to the foothills of Kulal and Esi. Count Wickenburg (1903 *a*, *b*) has suggested that the Koroli desert was formerly part of Lake Rudolf. On account of its altitude I believe that it more probably formed a separate lake which may or may not have had an overflow connexion with Lake Rudolf.

Finally, mention must be made of the three important islands known as North, Central and Höhnel (South) Islands. All these have been found to be entirely of volcanic origin (Fuchs, 1934), and they seem to represent a line of weakness extending along the axis of the lake. The recently active volcanoes Teleki and Andrew (Likaiyu) (Champion 1935) on the northern and southern flanks of the Barrier Range appear to be a continuation of that line.

Drainage

Lake Rudolf has occupied a closed basin since the beginning of the Upper Pleistocene, and the only permanent affluent is the Omo river which derives its waters from the Abyssinian highlands. All the other rivers flow only during the rainy season, which lasts for about 1–3 weeks during March and April.

The direction of the major watercourses seems to have been governed by the earth movements that have affected the area. Thus their tendency is to flow in a north-south line turning towards the lake when the local topography offers the opportunity. East of the lake there are no large rivers but only small stream beds draining a belt of country about 15 or 20 miles wide. To the south the course of the now dry Suguta river has been fixed by the rift fractures which stretch from Baringo to southern Rudolf. During the late Middle and Upper Pleistocene the formation of the Barrier south of Rudolf cut off the drainage of the Suguta Valley from the Lake Rudolf Basin. This gave rise to a small lake south of the Barrier which has now been reduced to a swamp on account of the decreasing precipitation over the area.

West of the lake the drainage is more complex, for there are two major rivers and a number of more or less important ones. The most southern of these, the Kerio, follows a course very nearly parallel to that of the Suguta, for it originates in the Elgeyo Valley, a parallel branch of the Kenya rift. Though the Kerio was probably initiated during the Miocene its course seems to have been modified by the Pliocene movements that upwarped the Loriyu Plateau and gave rise to its eastern escarpment. At the present time the river is cutting down through basalts which may at one time have ponded back its waters. Evidence that this has happened, in the form of a sedimentary series, has not yet been found in the Kerio Valley itself, but in the valley of a parallel strike stream, the Lokichar river, Mr Champion has found a series of sandstones and limestones interbedded with the local nephelinites. These sediments occur some 1000–1500 ft. above the present level of Lake Rudolf, and in the opinion of Mr Champion cannot be deposits formed during an earlier extension of that lake. He has expressed the opinion that they might be the local development of the Turkana Grits. It is possible too that it was the overflow from such a back ponded lake that gave rise to the Lomenyangaparat river which, having cut its way down through the Kamutili Hills, now forms the lower reaches of the Lokichar.

The other large river course on the west of the lake is the Turkwel, which originates as a strike stream flowing in a northerly direction from the foothills of Marakwet. North of Sekerr it is joined by the permanent waters of the Suam which rises on Mt Elgon at about 14,000 ft. The Suam is the only river which crosses the true watershed of the district, that is, the Uganda-Sekerr escarpment. This transgression may have been due to capture by a tributary of the Turkwel or to overspill from a lake formed on the west of the upwarped escarpment. The course of the Turkwel runs northward to a point a little south of Lodwar, where it turns abruptly east and continues directly to the lake shore. In the Lodwar region it is joined by the Kagwallas and the Lorogumu rivers which drain the Moroto embayment and the eastern slopes of the Muruanisigar-Pelekech Range.

At the time of the Acheulian precipitation maximum (see fig. 9) the waters of Lake Rudolf washed the foot of the Lodwar Hills. The mouth of the Turkwel river was therefore, at that time, in the immediate vicinity of Lodwar. With the retreat of the lake the mouth of the river followed it eastward for 40 miles to its present position. The coarse gravels and grits exposed in the banks of the Turkwel river about a mile east of Lodwar Post are probably delta deposits dating from the time of the lake's extension to that point.

North of the Turkwel the Lopi and Kabua (Kalilokwel) rivers have been formed since the retreat of the lake after the Acheulian maximum. Farther north the lake receives only storm waters from purely local streams because the greater part of the area is drained by the streams of the Gatome Valley which ultimately flow into the Lotogipi swamp on the west. On the east the watershed between the Gatome system and the Dangari-Lomogol river draining into Lake Rudolf, is formed by the southern continuation of the Lorienatom fault scarps.

At its northern end Lake Rudolf receives the Omo which has also been directed, at least in the lower part of its course, by the tectonics of the area. At the time when Lake Rudolf extended as far north as the Ngalibong Hills (Angelis d' Ossat and Millosevich 1900), the Omo and the Mago must have been distinct rivers flowing in different (tectonic?) valleys. With the filling of the Omo Valley with detrital material and the formation of a large delta, the river seems to have been diverted into the still unfilled valley of the

Mago, probably by rejuvenation consequent upon the falling lake level. It may also be that the last tectonic movements of the Pleistocene assisted in this remarkable northern diversion of the Omo. To-day the country around the mouth of the Omo river is a swampy area often flooded by a temporary rise of the lake. The shallowness of the lake itself at its northern end promises a rapid retreat of the shoreline to the south of the accepted boundary between Abyssinia and Kenya. Taken as a whole the rivers of the Lake Rudolf basin, like the lake itself, are consequent upon the earth movements which have depressed the area. That the lake has fallen below its former outlet seems to be due to a reduction of the precipitation over the area rather than to any other cause.

IV. THE GEOLOGICAL SUCCESSION

A. The Basement Complex

Within the Rudolf area the gneisses and schists of the Basement Complex appear to lie everywhere fairly near to the surface. They appear in the north-west from beneath the rhyolites and basalts of Zingout and Mogilla Mountain, and from there can be traced southward on the west of the Tarash river drainage area, to the vicinity of Puch Prasir, where they disappear again beneath the rhyolites and basalts of Muruanisigar. Eastward from the foot of Moroto Mountain to Lorogumu, the Tia river and beyond, they again appear at the surface, but to the north-east grits and lavas cover the old peneplain surface.

In southern Turkana the most prominent hills and ranges are formed of Basement Complex rocks. Ngamatak, Loichamakat and the Loriyu Plateau, together with much of the plains country between them, as at Kaputir, and west of the Kailongol-Masol Range, are, for the greater part, formed of gneisses and schists. In some places the tops of the hills are capped by lavas so that the Basement Complex is exposed only in their flanks. Examples of this are Loichamakat, which is capped with nephelinite, the Loriyu Plateau, which is covered with basalts, and the Kolossia region where lavas and tuffs form the tops of the hills. To the north and north-east of Kolossia is a large area of basalts which appear to have flowed out over the surface and now lie against the eastern foot of the Laiteruk-Kailongol scarp of gneisses and schists.

In the Kerio Valley, Basement Complex rocks are again exposed, while south of the lake the walls of the rift on either side of the Suguta swamp are composed of these rocks. The horst-like Mount Nyiro and its fellow Ol Doinyo Mara belong to the Basement Complex, and the exposure of which they are the northern part broadens as it extends to the south, where it ultimately disappears under the volcanics of Kenya Mountain and the Laikipia Plateau. East of Lake Rudolf the areas of Basement Complex are more restricted. The south-west corner of the Koroli desert* is one

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* It is probable that the sands of this desert lie directly on Basement Complex which has never been covered by lavas.

exposure and the small area of gneisses and schists in the Bor Hill region the only other. The remainder of the country is occupied by the lava fields of the Dida Gulgulla and those upon which Kulal, Marsabit and Huri Mountains have been built up.

North-west of the lake the Basement Complex rocks appear in the face of the Labur escarpment at more than 1000 ft. above the level at which the surface of the old peneplain lies in the surrounding districts.

In the Komogin Gorge south of Labur North Peak the quartz-biotite schists are strongly contorted, but farther north in a stream bed almost due west of Todenyang an interesting section was seen. There the normal dip of the schists seemed to be about 45° to the east. Such a dip was observed at the mouth of the gully where the lake beds are banked against the foot of the Basement Complex escarpment, and again about 200 ft. higher up the stream bed from about 1500 ft. to the highest point that we were able to reach. The intervening region, however, showed more complicated structure. A small but very sharp synclinal fold was found to strike N. 15° E. and to plunge north at about 3°. The rocks adjacent to and partly incorporated in this fold are remarkable for the size of the augen structure which they present. Large fragments of gneisses and schists have been caught up and included in the later-formed rock which exhibits a strong flow structure around these inclusions. The single augens are as much as 3 ft. in diameter (fig. 18, Plate 26), and the original banding in certain fragments of hornblende gneiss is still preserved.

From the position of this structure near to the foot of the Labur escarpment in the strike of the scarp itself, and from folding which will be described further south, I have been tempted to suggest that it was formed in association with the movements that elevated the Basement Complex rocks of Labur over 1000 ft. above the general level at which the surrounding peneplain surface must lie. Unfortunately, the specimens from this particular region have not reached England, and it is therefore impossible to support this suggestion. When new specimens are obtained it may be that the rock which encloses the augens will be found to be of igneous origin similar to the "eruptive breccias" of the Bågaskar Islands (Sederholm 1926).

Lower down the same river bed at the very foot of the escarpment there occurs a small recumbent fold in the schists which can be seen thrusting its way under an east-dipping series of similar rocks. The plane of movement is marked by a soft crush rock which weathers more quickly than the surrounding material and has therefore partially obscured the section with the scree that it forms. East of this disturbance the schists preserve a nearly constant dip of about 45° to the east until they disappear beneath the blanket of Pleistocene lake beds.

On the whole the metamorphic rocks of Turkana are of fairly high grade and appear to have been formed from sediments and igneous rocks. Evidence of this is found not only in the quartz-biotite-hornblende schists exposed at the foot of the Labur Range, but more especially in the Kaputir and Lokwamur regions of southern Turkana.

On a trip from Lodwar almost due south, past the east flank of the Ngamatak Hills, to Kaputir, specimens collected vary from massive hornblende schist to hornblende-garnet schist, a pure marble at Kaputir Hill itself, and farther south a rock almost entirely composed of hornblende with a few plagioclase crystals. Two or three miles south of Kaputir is a hill chiefly made up garnetiferous schists containing much staurolite. In these the garnet and staurolite crystals have been fractured and torn, the spaces being filled with quartz and biotite. In another specimen, a fine-grained hornblende-garnet schist, a pale pink garnet forms borders round a bright green hornblende. The mass of the rock is made up of quartz and felspar with some epidote and zircon.

Travelling north from Kaputir to Lokwamur along the west side of the Turkwel river, but keeping above the alluvial deposits, one passes over a continuous series of schists frequently cut by pegmatite dykes. To the west towers up the great Uganda escarpment, here known as the Suk Hills. It appears to be formed of rocks corresponding to those of the plains at its foot. Glenday and Parkinson in their paper on the Suk Hills (1926) conclude that the area is formed of (1) metamorphosed sediments and contemporaneous ashes into which had been intruded a syenitic magma, the latter now being represented by the quartz-hornblende schists, and (2) massive granitoid gneisses that build up the principal hills.

The rocks obtained in 1934 from the plains in the Kaputir-Lokwamur region compare well with those described by Glenday and Parkinson. Thus Kaputir Hill is composed of an almost pure white marble associated with coarse micaceous gneiss and a series of hornblende schists that pass southward into garnetiferous schists.

To the north in a gully on the west side of the Kakep Pass a succession of schists dipping at about 30° E.N.E. was observed. Six specimens were taken from successive horizons, and they have since been found to vary from a quartz-biotite schist to a series in which staurolite and kyanite become prominent, finally ending in a quartz-muscovite schist.

Glenday and Parkinson state (1926, p. 589) that crystalline limestones are associated with hornblende schists in the Marich Pass, and again in a later paper on the northern Suk Hills (1927) they show that their Kateruk Series also contains crystalline limestones associated with hornblende schists and acid gneisses. In the earlier paper the authors remarked (1926, p. 602) that the rocks of the Karipu Series recall those of the Kateruk Series, which they had not then described. In the later paper the conclusion that the Kateruk Series was formed of metamorphosed sandstones, argillaceous silts, limestones, and probably ashes and lavas as well, agreed with their earlier conclusions.

The present rocks from Kaputir bear out the relationship between the Kateruk and Karipu Series, thereby enabling them to be placed together in the more embracing term Turoka Series. The name Turoka Series has been used by Parkinson (1913, 1920) for the British East African crystalline schists chiefly formed from rocks which were originally of sedimentary origin.

B. The Miocene

Arambourg has described the grits which lie directly on the Basement Complex rocks of this region as the "Lubur Series", but these rocks have previously been referred to as the "Turkana Grit" (Murray-Hughes 1933), a more descriptive name both in respect of their composition and their occurrence. It is therefore proposed to continue the use of the earlier term.

Arambourg (1935) correctly describes the series as composed of conglomerates, arkoses and grits, the material having been exclusively derived from the crystalline complex. On the other hand, his correlation with the Adigrat Sandstone (Blanford 1870) of Abyssinia, said to be of Triassic age (Aubry 1886), cannot stand, for the exposure of the Turkana Grits in the Lokitaung Gorge has, since his visit, yielded massive fossil trees that have proved to be dicotyledonous types.* It would therefore appear that the grits are not earlier than Cretaceous. A further argument against the suggestion that these grits are of Triassic, or even Cretaceous, age is found in the fact that they are composed entirely of material derived from the Basement Complex. If the grits were formed before the fracture that gave rise to the Uganda escarpment, where are the deposits which must have accumulated as the result of erosion of that escarpment? There is in fact only one sedimentary series, the Turkana Grits, and I am therefore forced to the conclusion that they are the product of erosion acting on the Uganda escarpment. Further, it is unlikely that the escarpment itself is of such an early age, for it would hardly have remained so clear cut for such a great length of time. It has usually been thought that the Central African Peneplain was first disturbed in late Cretaceous times, but that rifting proper did not begin until the late Oligocene (Gregory 1921, p. 204; Wayland 1929). It is probable, therefore, that the Uganda escarpment was not formed during the Cretaceous but during the second and true rifting period of the late Oligocene. In that case the Turkana Grits would be of Oligo-Miocene age and contemporary with the Koru Limestones of Kavirondo (Wayland 1927). Recent work by Dr L. S. B. Leakey and Dr D. G. MacInnes (yet to be published) has shown that there are Lower Miocene deposits on Rusinga Island, Kiboko Island, Mfwanganu Island in Lake Victoria and in surrounding districts at Uyoma, Ombo and Songhor. All these deposits should, I think, be considered to be contemporaneous with the upper part of the Turkana Grits and the earliest Miocene volcanics in the Lake Rudolf region.

Returning to the question of the prominence of the Uganda escarpment west of Rudolf, it might be suggested that the escarpment was rejuvenated by successive movements, but if this had been the case a series of sediments corresponding to each rejuvenation would be expected. As it is the Turkana Grits appear to be the only

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* Dr H. Bancroft, of the Imperial Forestry Institute, Oxford, has kindly identified these trees as belonging to the genus *Dryoxylon*. She believes on palaeobotanical grounds that their age cannot be earlier than Cretaceous and is in fact more probably Oligo-Miocene.

sedimentary series, and they seem to be entirely conformable throughout. That the Turkana Grits are not found in the immediate vicinity of the escarpment may be accounted for by the fact that either the Miocene lavas or Quaternary deposits extend almost to its foot and may therefore hide the local development that would be expected there.

Dixey (1929) has suggested that those barren sandstones, the Adigrat Grits and the Lugh Sandstones of eastern Abyssinia, may perhaps be regarded as of Karroo age. The lithological likeness of these series to the Turkana Grits, as already pointed out by Arambourg, together with the similarity of the overlying volcanic succession of basalts and rhyolites, might well suggest that the Turkana Grits are also of Karroo age. However, for the palaeontological and other reasons already stated, it seems that they must be regarded as a purely local series of terrestrial sediments consequent upon the formation of the Uganda escarpment.

In Uganda on the west side of the escarpment the Turkana Grit Series may be represented by the Bugishu Sandstones (Wayland 1929, p. 14) in which Wayland has found dicotyledonous plant remains. These lie directly upon the Basement Complex near to the foot of Mount Elgon, and I believe that they are the product of erosion consequent upon the marginal elevation of the upthrow side of the Uganda fracture.

I also believe that a further correlation may be made between the Turkana Grits and Gregory's Kamasian Lake Beds at Lake Baringo* (Gregory 1921, p. 114), for the latter are overlain by the lavas of the Laikipian Plateau eruptions. The "Laikipian" was Gregory's Miocene; that this was a true estimate of age is now borne out by Arambourg's discovery in the Lake Rudolf area (Arambourg 1933 *a*, *b*), of a Burdigalian fauna associated with lavas which are claimed to be of similar type and occurrence to those of Gregory's "Laikipian".

The following unfortunate position has resulted from this verification of Gregory's original dating. At first Gregory looked upon the Nyasan lake deposits of the Baringo area as having been laid down in what he called Lake Kamasia. With those deposits of Lake Kamasia he tentatively correlated other lake beds in the Elementeita region. Then in 1927 Dr Leakey's East African Archaeological Expedition discovered Acheulian implements in the Elementeitan deposits and therefore quite rightly supposed that they were not Oligo-Miocene but Pleistocene in age. Unfortunately this led to the whole of Gregory's Kamasian being placed in the Pleistocene (Gregory 1931, p. 509), and the term "Kamasian" has since become widely used as a name for the lower and middle Pleistocene deposits of Kenya in which occur cultures of Chellean to late Acheulian age. To alter the meaning of the term "Kamasian" at the present time would therefore only cause additional confusion, and it is thought better to abandon the name for deposits of Miocene age and to make use of Gregory's earlier and wider

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* Since this was written Dr MacInnes and I have visited the Baringo Basin and have found fossils in the Kamasia deposits which show them to be not earlier than Pleistocene age and most probably Middle Pleistocene. The evidence will be published at a later date.

term "Nyasan" (Gregory 1921, pp. 105, 130), which included all lake beds and terrestrial deposits of Oligo-Miocene age.

Exposures of Turkana Grits are not very widespread and occur chiefly in the northern part of the Turkana Province. In the Lokitaung Gorge and in the Labur Range several hundreds of feet of grits are exposed from beneath an overlying series of basalts. At one point the grits are cut by a curious dyke-like body formed of angular quartz grains set in a glassy matrix (see p. 236). Farther south a large outcrop of Turkana Grits is found on the east of the Muruanachok Hills, while nearby in the region of the Lopi river other exposures occur. Outcrops are also found in the banks of the Turkwel river and farther south on the south-western flanks of the Loichamakat Hills. Usually the exposures appear from beneath basalts, and were it possible to trace the true extent of the grits it is probable that they would be found to stretch over a large part of Turkana Province. The known extent of these deposits can be seen from the accompanying geological map. It will be noticed that nowhere have they been found on the east side of the lake. I therefore believe that the depression in which the Turkana Grits and the succeeding Lower Miocene subaqueous tuffs were deposited existed somewhat to the west of the present lake. That this Oligo-Miocene lake was at least to some degree permanent is shown by the discovery of specimens of *Pila ovata*, the fresh-water snail, in certain members of the tuff series.

Turning now to the overlying volcanics, one finds that Arambourg (1935) has made out the following succession for the eruptive rocks in Turkana:

(4) Rhyolites.

(3) Phonolites, not very widespread.

(2) Basalts, with interbedded tuffs.

(1) Nepheline-syenites, shonkinites, that occur as rolled blocks in the Lower Miocene tuffs.

He points out that the succession (2) to (4) corresponds to Gregory's succession in the Laikipian Series. I have made no attempt to work out the relationships of the trachytes, basanites, nephelinites and basalts. All these are therefore included together under one heading in the provisional geological map accompanying this paper. They extend from west to east in Turkana, and it is thought that the lavas of the Dida Gulgulla which underlie the newer rocks on the east side of the lake may belong to this period, for as Parkinson (1920, p. 5) points out they are certainly older than any other local volcanic rocks. Besides this their mode of occurrence as wide lava fields, without visible centres of eruption, suggests some relationship to Gregory's "plateau eruptions" such as the Laikipian.

On the west of the lake the basalts lie directly on the Turkana Grits but include a series of tuffs and ashes which were evidently laid down in rather shallow water under arid conditions. From these subaqueous tuffs Arambourg obtained a lower Miocene fauna (Arambourg 1933*a*). In 1934 we found two fossiliferous horizons, one a red sedimentary tuff (probably that from which Arambourg obtained his material) yielded fragmentary but beautifully preserved material. The other a coarse tuff was highly impregnated with calcite, and the numerous remains of bones and woody material had been entirely replaced by coarse calcite crystals. It is most unfortunate that none of the material from the latter horizon was of any value since it was very rich in quantity.

The rhyolites which overlie the more basic volcanic series are very distinctive in the field, and it is possible to indicate with reasonable accuracy their occurrence in the area. They appear to be localized on the west and north-west side of the lake, for so far no record of them has come from the south or east of the basin. It is probable that the rhyolites recorded by Sacchi (Angelis d' Ossat and Millosevich 1900) from the Abyssinian highlands north-east of the lake should be correlated with these.

If we follow Gregory's dating, these rhyolites should be placed in the Upper Miocene. This is supported by the local evidence supplied by the tree trunks and wood found in the rhyolitic tuffs at Lokitoi and Naramum, for these trees have proved to be extinct in Africa to-day, but are similar to those from the Turkana Grits (Oligo-Miocene) of the Lokitaung Gorge.

Throughout Central Africa the end of the Miocene was marked by the renewal of earth movement accompanied by rifting. In the Rudolf area in particular it was the cause of the folding and faulting of the Miocene sediments and lavas, thereby giving rise to the Lake Rudolf Basin on its present site. That such movements took place at, or just after, the end of the Miocene in the Rudolf region is known from the fact that the whole succession of Miocene volcanics was heavily fractured after the extrusion of the rhyolites and before the deposition of the early Pleistocene beaches, which are locally found banked against certain of these fractures. I have therefore come to regard the Pliocene in the Rudolf Basin as a time of earth movement and not one of deposition, or of very marked volcanic activity.

Beginning with the Losidok Range where the date of the deposits is known to be lower Miocene from the mammalian fauna, it is proposed to give brief descriptions of those areas, visited by the expedition, which are of particular interest.

(1) *The Losidok Hills*

Fig. 1 shows the relation of the fossiliferous tuffs to the overlying lavas and underlying grits. It represents an east-west section through the Losidok Range at Muruaret (Amuret) Hill, that is on the north side of the track through the Lopi River Pass. The hills appear as a series of parallel ridges running north and south. At first sight they seem to be entirely composed of basalts, but in reality the greater part of the thickness is made up of the underlying series of tuffs and ashes which are generally hidden by the thick scree slopes of basalt blocks. The ridges appear to be successive outcrops of different beds all dipping west at approximately 15°. To some extent this is a false impression, for at a number of points the rocks can be seen to be folded, while in one

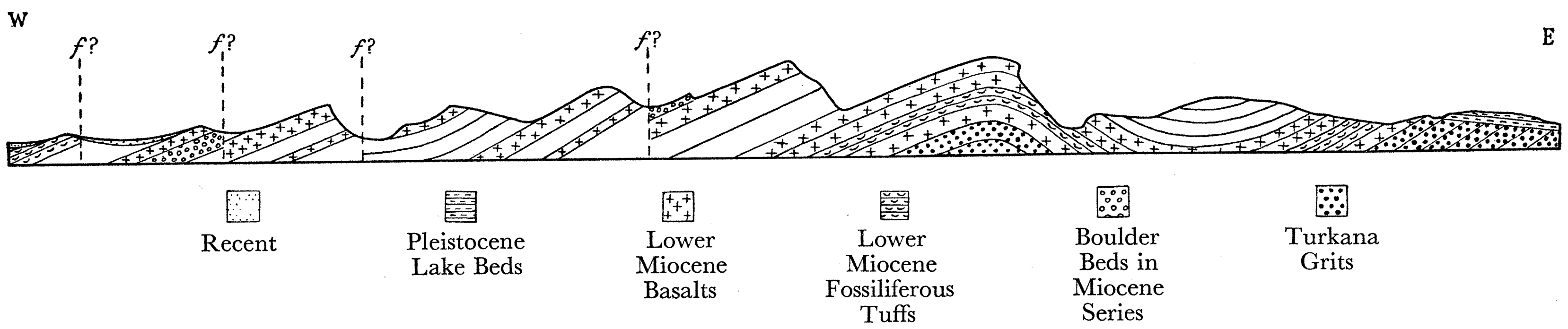

FIG. 1. Section through the east flank of the Losidok Range just north of Muruaret Hill, Lopi River Pass. *f*? = faults inferred from scarps and remains of oxidation from fumarolic action.

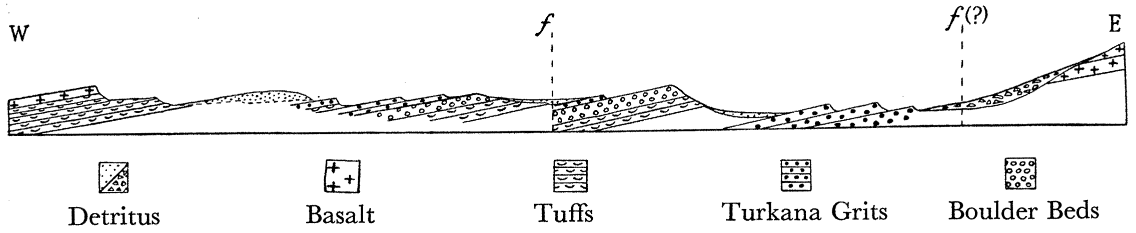

FIG. 2. Section seen on the west flank of the Losidok Hills, 3½ miles south of the Lopi Pass track. Illustrating the interbedded nature of the Turkana Grits and early Miocene volcanics.

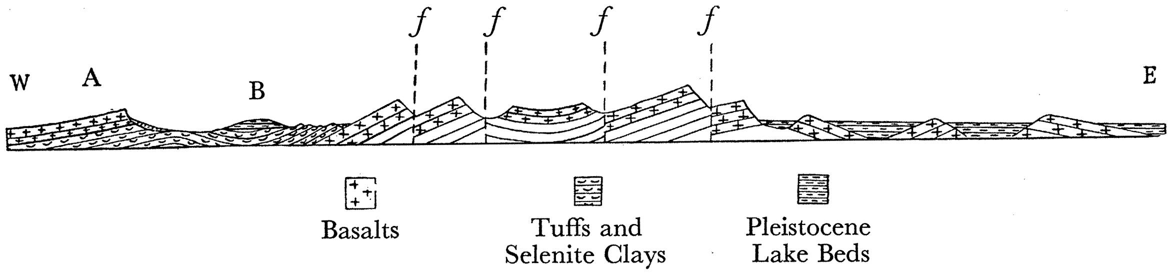

FIG. 3. Composite section across the Losidok Range at Kabua Gorge. Length of section about 7 miles.

case, at least, a highly asymmetrical anticline forms the crest of one of the ridges. This particular structure is to be seen a few yards to the north of Muruaret Hill where, fortunately, the apex of the anticline has not been masked by scree material. By continuing the strike of the tuffs involved in this fold to the south it is clearly to be seen that the exposure of west-dipping tuffs to the south of Muruaret Hill are really the eroded remnants of the western limb of the same anticlinal structure. Although this folding is not everywhere seen so clearly there are a number of other sections which show that this structure continues throughout the range. For instance, on the south side of the Lopi River Pass, but some little way to the west of the strike of Muruaret anticline, a well-marked fold is visible in the lavas.

Some 3½ miles to the south of the point where the track enters the hills from the west, the section shown in fig. 2 is seen. On the west a low lava ridge dips westward, beneath it a series of tuffs are interbedded with red sandstones which are almost certainly representatives of the Turkana Grits. Approaching the upstanding lava ridges on the east of the section one finds that a steep faulted (?) face here forms the west slope of the hills, and the red sandstones which are gently domed apparently disappear under the lavas of the Losidok Range. Unfortunately, I was unable to determine the true relationship between the lava on the east of the section and the grits. The slight doming of the grits was, however, clearly distinguishable, the dips being approximately 5° to the north and south and 10° to the west. The dip to the east could not be determined owing to the presence of the Losidok basalts.

Following the Losidok Hills northward one finds further evidence of folding in the Kabua Gorge which cuts through the range from west to east. The section shown in fig. 3 represents semi-diagrammatically the structure of the range in this region. The two synclinal zones on the west of the section were seen in the field, as was also the eastward dip of the lava on the east of the section. On the other hand, the west-dipping lavas in the middle of the section appeared to be tilted normal fault blocks. Although the Kabua Gorge is more than 12 miles along the strike from Muruaret, what appeared to be the same red fossiliferous subaqueous ash as was found at that point, was discovered in the tuffs of syncline "B". On the west of syncline "B" the tuffs are intercalated with muds which contain quantities of selenite crystals that bear witness to the arid conditions under which the series was formed.

When standing on the anticlinal ridge between synclines "A" and "B" the sedimentary series could be seen to occupy the valley to the west which was again bounded in the distance by a lava ridge. Beyond that it was impossible to see, but Mr Champion tells me that in that direction there lies a large tract of Turkana Grits; these are also shown by Arambourg (1935) in his geological map. As it was unfortunately impossible for us to reach those grits we do not know if they have been folded in the same way as where they are associated with the Losidok lavas. The occurrence of folds to the west of this area (p. 238) suggests that they probably have, but that the more readily eroded material has allowed a comparatively even surface to be formed.

On account of the foregoing I do not believe that the range is composed of a thick series of normally faulted lavas as depicted by Arambourg (1933*a*, fig. 2), but of a series of folds in a few rather thin lavas overlying or interbedded with a thicker series of volcanic agglomerates, tuffs and ashes. Undoubtedly the series has also been affected by a considerable number of fractures, for in many of the valleys between the ridges there is evidence of fumerolic action in the form of oxidized muds. Whether or not these fractures are normal faults it is impossible to say, but I suspect that many of them may ultimately be found to be reversed faults like those yet to be described from Kakalai. Such fractures would seem to be more in keeping with the folded structures to be seen elsewhere in the range.

(2) *The Lodwar Hills*

The westward extension of the folding seen in the Kabua Gorge is in line with the strike of the Lodwar Hills, which runs approximately 15° E. of N. This suggests that folded structures might be found in the Lodwar Hills.

At first sight Lodwar Hill (fig. 17, Plate 26) appears to be a denuded plug of nephelinite surrounded by a number of smaller pipes. Indeed, this would normally be the orthodox explanation of the local structure. Observed from the air the southern part of the Lodwar Hills can be seen to consist of at least three parallel rows of rocky hills standing up from the sandy plain. Since these hills are all clothed with heavy screes to within a few feet of their summits, they appear remarkably cone-like either from the air, or from casual observation on the ground. On closer inspection of a number of these hills I found that they were composed of west-dipping lava sheets which pass through them from side to side. It therefore seems that they are not plugs.

The alternative explanation seems to be that these isolated hills are remnants of eroded lava ridges comparable to those of the Losidok Range. The location of such *remanié* masses might have been determined by pipes through which the lavas were extruded, but no trace of this was actually found.

About three-quarters of a mile south of Lodwar Hill itself and between the two most easterly rows of hills I found a series of east-dipping lavas and tuffs which with the lavas of a similar dip in the east side of the base of Lodwar Hill may represent the eastern limb of an eroded anticline.

The plains between the Lodwar and Losidok Hills were covered by the waters of Lake Rudolf during mid-Pleistocene times, and the resultant gravels together with later wind-blown material obscure the underlying rocks. At one or two points, however, undulating outcrops of sandstone appear at the surface. I have little doubt that these are exposures of Turkana Grits, as are probably the lime-cemented coarse gravels that occur in the banks of the Turkwel east of Lodwar and in the strike of the Losidok Range. In none of these sediments was I able to find any fragments of volcanic rocks such as could be referred to the olivine- and augite-basalts or the nephelinites of the Lodwar and Losidok types.

(3) *Lokitaung-Labur*

The series of Miocene volcanics seen at Lodwar and Losidok is widespread in the northern part of Turkana; thus similar basic rocks are found in the Lokitaung region and as far north as Kakalai and Kangmanang.

At Lokitaung a deep gorge has been cut through the basalts and underlying grits, thereby exposing a fine section in which the dip is from 10° to 15° to the west. At two points thick dykes were seen cutting the series. The first occurs close to the point where the grits come to the surface from beneath the lavas. This dyke is a rapidly weathering analcimic olivine-dolerite rock slightly inclined to the vertical and striking due north and south. A few yards away to the west the lowest of the volcanics overlies the grits, but the rock was so badly weathered that it was impossible to take a hand specimen. Superficially it appeared to have been similar to the dyke rock and may therefore have been derived from that source. Above this come the normal series of fine-grained basalts, the lowest of which Mr Campbell Smith has identified as a porphyritic basalt with chlorophæite.

Half a mile farther down the gorge to the east, thin shale bands occur in the grits on the south side. One of these contains a number of large silicified tree trunks which have since proved to belong to the genus *Dryoxylon.** In the shales associated with these fossil trees, carbonaceous remains of leaves were found, but they are so fragmentary that they cannot be identified. Perhaps further search will yield better specimens of leaves and even seeds and spores. The horizon at which these trees occur is low down in the grit series immediately below a bright yellow band, and below all the red bands seen in the section. These fossil trees are of great importance, for it is to a large extent upon the evidence which they supply that the grits can be approximately dated as Oligo-Miocene instead of being correlated with the widespread Karroo deposits of similar character.

Near to the mouth of the gorge and about 1½ miles east of the fossil tree locality a dyke 7 ft. thick and striking E.N.E.–W.S.W. cuts through the grits which there dip west at 10°. This dyke rock contains much augite, hornblende and plagioclase, but the latter has been altered to calcite, apparently by hydrothermal action. Since these dykes have only been found cutting the grits I believe that they were formed at the time when the overlying volcanics were extruded and therefore pre-date the movements that tilted both the volcanics and the grits.

From the mouth of the Lokitaung Gorge the outcrop of the Turkana Grits runs north and south for some distance (fig. 16, Plate 26). About 4 miles to the north the schists of the Basement Complex appear at the surface from beneath the grits, and their outcrop widens in the same direction. Viewed from some distance the boundary between the grits and the schists is seen to be a gently undulating one. Though it is clear that the land surface at the time of the deposition of the grits was locally devoid of

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* A genus of fossil woods found in the Tertiary of India and Africa.

prominent physical features, it is not certain whether the undulation was present at that time or was produced by warping at a later date.

About 1 mile south of the point where the Basement Complex appears from beneath the grits one finds a number of sections that appear to show that the latter have been folded. The structure was found to be essentially the same at a number of points, and the section shown (fig. 4) therefore serves to illustrate any section drawn from east to west over a distance of several miles of the escarpment. It can be seen that whereas the westward-dipping beds appear from a distance to be members of a tilted block, they could in fact be the limb of a fold of which the axis lies almost over the foot of the present escarpment. Near the crest of the fold a disturbance of the deposits, together with evidence of past fumarolic action, seemed to indicate the existence of a fracture. At one point there was also a thin upstanding ridge of rock which was, in the field, thought to be a dyke (fig. 19, Plate 27). Microscopical examination reveals that it is composed of angular quartz grains set in an isotropic ground mass which has the appearance of a glass. This led me to believe that the "dyke" resulted from thrusting movements which fused the surfaces and that it was in fact a pseudo-tachylyte. On the other hand, several authorities to whom the specimens have been submitted are of the opinion that it cannot be pseudo-tachylyte. In particular, they insist upon the absence of crushing of the included fragments. The only alternative suggestion which I can put forward for the formation of this peculiar rock is that if a plane of weakness existed in the crest of the anticline, as is suggested by the small fracture observed at more than one point, then an injection of magma may have taken place along that plane. This would have afforded a lubricant to the surfaces of the fracture, and by reason of the friable nature of the grits a certain amount of angular material may have been incorporated in the molten rock. That some of the sedimentary material should be fused and mixed with the invading magma is easy to imagine and might well account for the unusually high refractive index of the existing glassy matrix.

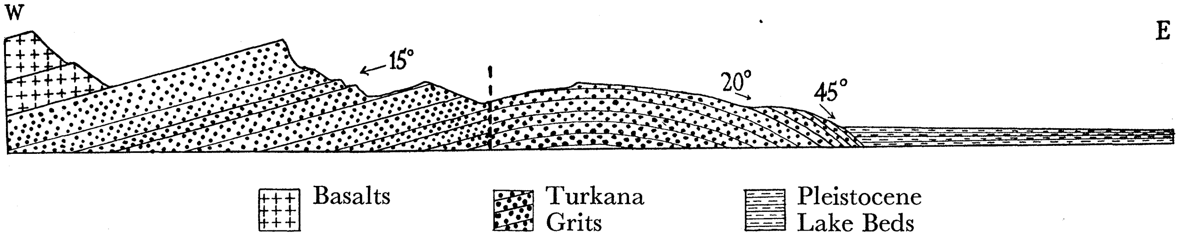

FIG. 4. Section through the foot of the Labur escarpment east of Signal Hill.

Dr K. S. Sandford (1935, p. 361) has found a rock which has a similar appearance under the microscope, but its occurrence as a thin selvedge on the edge of a crater blown through the Nubian sandstone seems to preclude any possibility of the two rocks having a similar origin. Whatever the interpretation of this curious rock,* the

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* I understand that Mr Champion has found a similar rock in the same line of strike but farther south near to the Lokitaung Gorge.

fact remains that it occurs at the foot of the Lorumel-Signal Hill escarpment at the crest of a fold which causes the grits to dip eastward beneath the Pleistocene lake deposits.

North of this point the fold is not apparent, for the foot of the escarpment is formed of rocks of the Basement Complex. That this should be the case is not surprising, since the foliation of the metamorphic rocks throughout this region gives axes running nearly north to south. Therefore any later folding having similarly directed axes would result only in accentuation of the pre-existing structure without being individually recognizable.

In view of the evidence of folding in the Signal Hill region and in the Lodwar(?) and Losidok Hills, and other areas yet to be described, I find it difficult to account for the Labur escarpment by invoking a normal fault block. More especially as the Basement Complex rocks appear over a thousand feet above the level at which they would be expected if the peneplain of which they once formed a part had not been disturbed by the fracture that gave rise to the Labur escarpment.

(4) *Murueris*

At its southern end the Labur escarpment loses altitude and at the same time its strike turns toward the south-west till it finally runs into the Murueris Range. Unfortunately the expedition was unable to visit those mountains, but from afar it appears that the scarp on their eastern face is a direct continuation of the rather minor fractures of the Kangmanang region. In the Murueris, however, their scale increases enormously, thereby taking up the movement which is farther north accommodated by the Labur escarpment. At its southern end the Murueris Range is prolonged by the northern end of the Losidok Hills which are directly continuous with it, but in comparison very small in amplitude. It is interesting to note that directly west of the high Murueris itself the otherwise continuous Kaitherin-Muruanisigar fracture is so reduced that it disappears beneath the alluvium of the Gatome river which flows westward to the Lotogipi at this point.

In the course of two very rapid journeys by lorry along the Lodwar-Lokitaung road west of Murueris local disturbances were noticed at the following points:

(1) At 34½ miles from Lokitaung folding of small amplitude appeared to have taken place in two directions, for some sections showed axes running nearly north-south, while others were directed nearly east-west. Local faulting was also inferred from a number of small hills which show bedding planes dipping steeply westward, so that they appear like "nunataks" from beneath the alluvium.

(2) At 36 miles from Lokitaung there is a hill which shows marked folding in the local lavas (rhyolites?).

(3) At 77 miles from Lokitaung the road passes over country where the dip is to the east instead of to the west as is the case in the area just to the north. Nevertheless, the roughly north-east strike of the fold axes persists, and since the road is hereabouts

running in a south-west direction the change of dip is probably due to it having crossed over the axis of a syncline.

(4) At this point, 107 miles from Lokitaung, one finds the hill called Akim. It is composed of folded Turkana Grits in which some unidentifiable carbonaceous plant remains (reeds?) were found about 40 ft. from its base. The photograph (fig. 20, Plate 27) was taken looking in a direction 15° S. of E., and from it the axis of the fold appears to run in the same direction. Seen from the south-west the fold appears to have an axis running N. 40° E. Hence the structure is either a dome or the true axis of the fold lies in a roughly N.E.–S.W. direction.

From the top of Akim the grits can be seen to underlie the whole of the country to the east, thereby linking with the area west of Kabua. Locally the grits dip eastward at approximately 10–20°, and the watercourses are deflected to the south by the strike ridges. To the west the base of the Muruanachok Hills, which Arambourg describes as of phonolites, appears to be formed of these grits.

(5) *The Kaitherin and Lorienatom Ranges*

So far as is known the Kaitherin and Lorienatom Ranges are formed entirely of rhyolitic rocks and associated tuffs. Both ranges are bounded on the east by high escarpments, whereas to the west their dip slopes give a more gentle declination. The valley between them is carpeted with alluvial deposits through which stand up minor hills formed of tuffs and rhyolites. The majority of these hills strike approximately north-south with a dip slope to the west and a steep fault scarp on the east.

In late Pleistocene and possibly Neolithic times a lake occupied the valley of the Gatome river where it lies between Kaitherin and Lorienatom, for the river now cuts through deposits which yield fresh-water Mollusca similar to those now living in Lake Rudolf. Since human implements of Levalloisian type are found on the floor of the present valley where it is not overlain by these lake beds, the valley itself must have been formed by Upper Middle Pleistocene times at the latest.

Travelling by road from Lokitaung to Naramum in the north-west, it is at Kalin Hill that one first sees low but prominent scarps stretching away to the north. These are apparently the southern continuation of the major fault that forms the east face of Lorienatom. What is probably another branch of the Lorienatom fracture is found a few miles farther to the west. There from a point just north of the road a fault scarp extends about 7 miles in a N. 15° E. direction, after which it becomes discontinuous, the single fracture being taken up by a series of smaller overlapping faults. The latter are continued northward to merge with the southern end of the Lorienatom Range.

A very wide area south of Lorienatom and west of Kangmanang (Conical Hill) is apparently composed entirely of basalts with the exception of that area immediately south of the fault which truncates the southern end of Lorienatom. There one finds a porphyritic-felspar basalt overlying rhyolites, the whole series dipping W. 20° N. at 10–20°. This rhyolite had not the appearance of a dyke, but its field relationships were somewhat obscured and it is probable that this is what it was, for otherwise one has the locally anomalous position of the basalts being younger than the rhyolites.

At the old administrative post of Kakalai just west of Kangmanang the river has cut into porphyritic-felspar basalts revealing the fact that they and the interbedded tuffs are cut by numerous small reversed faults. The photograph (fig. 21, Plate 27) was taken looking south-east. It therefore seems that if the flexions and faults have the normal strike found in the area, i.e. about 15° E. of N., then they are really even more pronounced than is shown in the observed section where the hade of the faults appears to be 30°. The nature of these faults and the associated flexures seems to indicate that the region has been subjected to pressure acting in an east-west direction.

Just to the east of Kakalai lies Kangmanang (Conical Hill), which is shown by Arambourg as having a capping of rhyolites. It is abruptly truncated on its eastern side by a fault scarp, and from a distance it seems that the main mass of the hill, like the surrounding country, is made up of basalts.

Standing on the top of Kaitherin Peak at 5100 ft. one looks westward down the eroded dip slope of the range. In the distance where the deposits disappear under the alluvium of the Lotogipi Swamp the same westward inclination of the beds is seen to be maintained (fig. 22, Plate 27). The peak itself is a plug of riebeckite-rhyolite surrounded on all sides by west-dipping yellow tuffs. This dip is constant on the west of the axis of the range, but on descending to the east marked disturbance of the beds was noticeable. At one point on the way down to Naramum at about 3500 ft. large-scale folds in the tuffs were seen to give the beds dips up to 90°. Several hundreds of feet lower on the same side of the mountain the ground surface truncates another series of small north-pitching folds in the tuffs. In the first case the amplitude of the folds was of the order of several hundred feet, in the second approximately 15–30 ft.

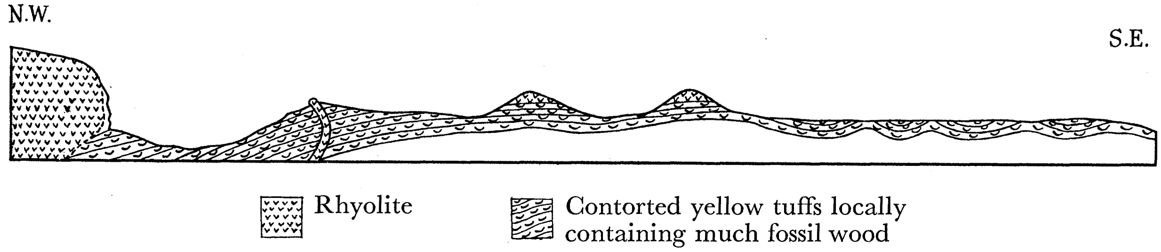


FIG. 5. Section seen about one mile south-west of Naramum Waterhole, Northern Turkana. (Length of section about $\frac{3}{4}$ mile)

South-west of our Naramum camp the section illustrated in fig. 5 was seen. The folded yellow tuffs contained large quantities of fossil wood which belongs to the same genus, *Dryoxylon*, as that recovered from the Turkana Grits in the Lokitaung Gorge and from another site near Lokitoi to the north of the present section. The rhyolite capping the two hills may or may not be part of the flow that overlies the west-dipping tuffs on the other side of the valley. The dyke conforms with the general trend of the country in striking N. 10° E., and it lies between the main fault scarp on the east and a subsidiary that joins that scarp somewhere farther to the north.

At Naramum waterhole the rhyolites dip eastward at a fairly low angle, but this dip is not constant, as can be seen in the hill just north of the point where the river bed leaves the gorge. There the main mass of the hill is formed of rhyolitic tuffs in which there is a prominent band which shows a synclinal fold. This is a crush rock apparently formed by the shattering of a more rigid horizon in the tuffs.

About half a mile north of Naramum Gorge along the foot of the escarpment the rhyolites outcrop with a nearly vertical dip, while at a distance of one mile an almost vertical rock face shows rhyolites dipping 55° to the E.S.E. but having well-developed shear planes inclined at 80° to the N.W. As the cliff face is here running nearly N.E.–S.W. these shear planes are at right angles to the line of fracture. They therefore seem to suggest that there is a reversed fault in close proximity to the foot of the cliff at this point. Such a conception is indicated in the section fig. 6, which also shows two normal faults and their associated breccias (as much as 20 ft. thick) which were found to the west of the escarpment face. Whatever is the true explanation of the shear planes it is certain that this northern part of the Gatome river valley has been much modified by normal fractures. This is particularly well seen when standing on the top of the hill just north of Naramum Gorge, from which point the photograph (fig. 23, Plate 28) was taken. On the right lie the west-dipping lavas of Lorienatom, on the left the escarpment of Kaitherin Range. From the latter the rhyolites can be seen to curve down towards the floor of the valley where at least two north-south faults must occur, as can be seen from the tilted fault blocks which stand up through the alluvium. When actually looking at the country it seemed to me that this was a fractured synclinal valley of which the northern nose had been truncated by the transverse east-west fault that forms the Lokitoi escarpment. In the case of the north-south faults on the west side of the valley fault-breccias up to 20 ft. thick were found, and though the throw of the faults could not be determined it was estimated that in a number of cases it was as much or more than 200 ft.

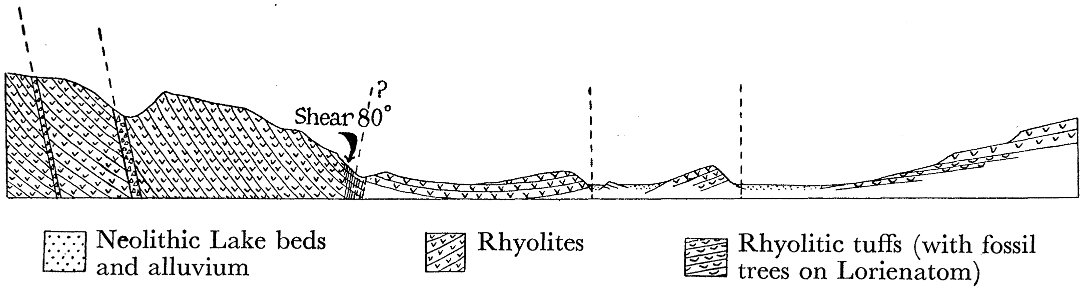


FIG. 6. Section across Lokitoi (Gatome) Valley about 1½ miles north of Naramum. (Length of section about 4 miles.)

The western slopes of Lorienatom appear to be an eroded dip surface. At its foot about half a mile from Lokitoi the track passes over an outcrop containing large quantities of silicified tree trunks and wood. There the succession was as follows, the series dipping west at about 5°:

Grey rhyolite.
Red rhyolitic tuff.
Tree trunks (*Dryoxylon*).
Yellow tuffs.

It seems that the trees were growing on a land surface formed of the yellow tuff and that they were overwhelmed by the outburst of vulcanicity that accompanied a later extrusion of rhyolitic lavas. The actual rock in which the trees are enclosed is a light-coloured banded rock of rhyolitic appearance and containing a few phenocrysts of orthoclase. Under the microscope this has been found to be a cryptocrystalline mass with a tendency to flow structure around the phenocrysts. The trees again prove to be *Dryoxylon* sp., and it is partly on their evidence that it seems more suitable to include the rhyolites in the Miocene than in the Pliocene.

At Lokitoi the fault already mentioned cuts across the plain in a W.N.W.–E.S.E. direction, thereby cutting off the end of the Gatome Valley. The throw of this fault appears to be about 400 ft. with the downthrow to the north. At the foot of the escarpment formed by the fault a gently inclined plain stretches away to the north, and it seems probable that at the time of the maximum extension of Lake Rudolf this formed a gulf of the lake. Looking south from this plain the military post of Lokitoi can be seen to be standing on a small anticlinal hill which forms a subsidiary fold within the general synclinal structure. It is bounded on the west by a north-south fault which has given rise to the steep-sided gully which debouches onto the northern flats.

Though Kaitherin and Lorienatom must in the first place have originated as volcanic piles, they appear to have been greatly modified by earth movement. This is borne out by a section seen in a gorge on Lorienatom to the north of the Kalamakat ridge. In that section the relationship of the various lavas and dykes was not very clear; nevertheless, it could be seen that the rocks had been greatly crushed with the resultant deformation of the associated yellow tuffs, and to a lesser extent of the lavas. In its upper part (at about 3000 ft.) the gorge has cut through a west-dipping series of massive red rhyolites which show comparatively little sign of fracture or folding. It may be that this is due to the fact that they lie at too great an altitude above the main zone of disturbance.

South-west of Lorienatom at the Nakinomet road turn-off, a low scarp stands up from the plains. It faces east and the dip slope is inclined to the west at 20°. This scarp is clearly a fault and can be traced in a wide curve to the north-east, where it apparently runs into the Lorienatom massif south of the Virgin's Breast. At its southern end it loses altitude and finally dies out under the alluvium south of the Sudan-Kenya boundary.

The eastern face of Lorienatom could not be visited since it was beyond the "red-line" which marks the zone of British Military influence, but from the little that was seen, from the map, and from information received from Mr Champion, it appears that on that side the range is cut off by an escarpment in much the same way as that of the Kaitherin-Lokwanamur Range. It seems, however, that this scarp is probably not a continuous fracture but the result of a series of N.E.–S.W. faults *en échelon.*

On his geological map Arambourg marks the Miocene basalts as extending beyond Lokolio and very nearly to Lorusia. Though they may skirt the foot of the escarpment on the east they do not extend over the backbone of the range from Lorum to the Loitanet river in the north-west, for I found that area to be formed of rhyolites.

Before leaving this northern area it will be well to turn to the region west of the Gatome river, where it is noticeable that the southern end of the Kaitherin Range becomes so reduced as to disappear entirely beneath the alluvium. That the southern escarpment from Pelekech to Muruanisigar is part of the same line of fracture can scarcely be doubted, and it seems to me probable that the local reduction in amplitude of the escarpment might perhaps be accounted for by the existence of the Murueris Range to the east. The formation of that massif may well have accommodated the forces which have otherwise found expression in the formation of the Muruanisigar-Pelekech-Lokwanamur-Kaitherin escarpment.

(6) *The Muruanisigar Range*

The Muruanisigar Range is a massif composed of rhyolites overlying a series of basalts and pantelleritic trachytes which rest upon a base of schists. The axis of the range is directed some 10° or 15° E. of N., and the altitude declines gradually in the same direction. It is almost as evident from the map as from the country, that the northern continuation of this range is to be found in the Lokwanamur escarpment.

Arambourg's map shows the southern and eastern foot of Muruanisigar as bounded by Basement Complex rocks, but he does not show the occurrence of any lavas except the rhyolites. Actually the rhyolites form only the capping of the range, since they lie on a thick series of basic types. The latter are well seen at the southern end of the range in the region of Capel Dome (Dome Rock). The Dome itself (fig. 25, Plate 28) is a curious mass, evidently a plug extruded through the basaltic series. The rock seems to be chiefly composed of orthoclase and may be connected with the sölvsbergites found elsewhere in the province by Champion. There seems to have been little alteration on either side of the contact which is very sharply defined. The photograph (fig. 26, Plate 28) looking north-east from the top of Dome Rock shows the southern end of the Muruanisigar escarpment here formed entirely of basalts. From specimens brought back by Champion, Campbell Smith has identified the rocks seen in the picture as basalts which farther west are associated with trachytes and trachybasalts. West of the main range, rhyolites and trachytes form the country rock right up to the Uganda escarpment, but to the north alluvium obscures the solid geology.

Seen from the south Muruanisigar appears to be a range of conformable rhyolites and basalts with a dip of approximately 5° to the west. Specimens brought in by other members of the expedition show that the rhyolites continue throughout its length, and that the whole mass of Pelekech is composed of them. At a number of points trachytic intrusions are to be found, as for instance at Kalimachuch, a small hill about 200 ft. high and $1\frac{1}{2}$ miles west of Kakuma.

For Muruanisigar to have attained its present form it is evident that it must be bounded on east and west by normal faults, or have been arched or thrust up by forces acting in an east-west direction. As we did no more than touch upon the Dome Rock area it is impossible to discuss the structure of this complicated massif. Nevertheless, Mr Champion's record of Basement Complex at an altitude of 5500 ft. (Champion 1937, p. 115) or nearly 3000 ft. above the general level of the surrounding peneplain is suggestive of uplift.

The peneplain surface of the Basement Complex rocks on the east or downthrow side of the Uganda escarpment preserves a remarkably constant plane which is gently inclined to the east throughout the province. It was upon this surface that the volcanics of Turkana were poured out. Since these volcanic rocks are not cut through by the fault that gave rise to the Uganda escarpment, they must have been erupted after the peneplain was disturbed by that fracture. Besides this, evidence from the Losidok, Labur and Kaitherin regions shows that the movements which fractured the volcanics occurred in late Miocene or Pliocene times. For this reason, and because Muruanisigar is patently the southern end of the Kaitherin-Lokwanamur-Pelekech feature, it is reasonable to suppose that they are of similar age and origin. It therefore appears that the elevation of the Basement Complex rocks to nearly 3000 ft. above the peneplain was accomplished during the Pliocene by movements which may have been of a compressive nature.

(7) *Southern Turkana*

Southern Turkana is here taken to include all that part of the country south of a line drawn from the north end of the Chemorongi Hills to the Turkwel river delta.

The greater part of the district is occupied by rocks of the Basement Complex, but large areas of basalts (and phonolites) do occur, notably in the Lothogam and Kamutili Hills, the Loriyu Plateau, and the southern part of the Kerio river valley. Nowhere are they found west of the Masol-Kailongol range and its northern extension, that range being itself entirely composed of rocks of the Basement Complex. According to Champion the basalts skirt its eastern foot very closely as far as the region of the Lokichar Valley where they are obscured by sand and alluvium. It is possible that these basalts and nephelinites are part of the same series of extrusions which farther north compose the Losidok and Lodwar Hills. This would mean that they are of Miocene age, an inference which is supported by Mr Champion's report that they have a general westward dip, for that probably means that they have been affected by the Pliocene movements which disturbed the whole of Turkana.

The northern extension of the Kailongol-Khordi-Khordi ridge seems to be found in the Ngamatak Hills. As the latter show signs of prolonged erosion it is possible that the range as a whole existed before the first rift movements formed the West Suk-Uganda escarpment, in other words as an inselberg on the Oligocene peneplain. On the other hand, the similarity of trend between the Masol-Ngamatak Range and the West Suk escarpment, together with the former's apparent origin from the latter in the south, suggests that it is of the same age, i.e. Oligocene. Such a date would afford a reasonable time for denudation acting on both flanks of the Ngamatak Hills to have sculptured such a small range into its present state, while yet the major escarpment to the west has not lost its prominence. It is likely, too, that the preservation of the main escarpment has been assisted by the Turkwel river, which, running parallel to its foot, must have removed the greater part of the debris which would otherwise have accumulated there.

Turning now to the lava-capped hills of the district one finds that they follow the general trend of the country by dipping west at varying angles. Thus, from the lake, the basalts of Lothogam appeared to dip south-west at about 10°. It was not, however, till we landed at Na'Arangan, and I had climbed up into the basaltic hills which there form the lake shore, that Lothogam could be related to the rest of the structure of the country. From that vantage point it was possible to see the strike of the lavas on which one was standing (those forming the northern nose of the Loriyu Plateau) continued northward by the seemingly parallel range of the Lothogam Hills and thence curving into the strike of the Losidok Range. Indeed, it seemed to me that the tilted lavas of Lothogam and the Kamutili Hills were the southern expression of the Losidok folds and fractures.

The evidence of earth movement seen in the Loriyu basalts bears out the structural relationship between that range and the Losidok group. A series of basalts and nephelinites is seen to overlie red and purple tuffs, the whole series having been folded and faulted to a considerable extent. The fractures which occur in the lavas have given rise to a series of scarps, but in the underlying tuffs the movement has been taken up by a series of larger or smaller flexures locally accompanied by minor faults which were observed where thin lavas were interbedded with the tuffs. Now because these faulted lavas form the escarpment on the west of the lake at this point, and because they are transgressed by lake beds up to 330 ft. above the present water-level, it is evident that the fracturing took place at or before the beginning of the middle Pleistocene. That being the case I believe that this faulting took place during the Pliocene period of movement, for as I have already said the strike of these hills appears to be a direct continuation of the structural lines in the central part of the territory.

From a point several miles out on the lake the basalts that form the northern end of the Loriyu could be seen to die out to the south, where they are banked against the

Basement Complex rocks which thereafter form the whole of the 1500 ft. escarpment. From Mr Champion I learn that the lavas form a cap to the range and that their dip slope ends in a small scarp flanking the Kerio river valley. As this seems to show that they once extended over the site of the present Kerio it may be that the lower reaches of the river are consequent upon the movements which caused the tilting of the basalts. In that case it is the erosion of the river which is responsible for the present position of the basalts as a capping to an elevated plateau. The similarity of this formation to that of the Yatta Plateau described by Gregory (1921, p. 184) has been pointed out by Champion (1937, p. 111).

So far in this discussion of southern Turkana no mention has been made of the Turkana Grits which might be expected to occur in the area. Mr Champion has recorded them from the east of Loperot, where a small exposure occurs between the western basalts and the Basement Complex on the east. It is not clear whether they were covered by the basalts and were later exposed by the Kalabata river or whether the basalts never stretched so far. The local topography suggests that the latter was the case.

Almost due north of the Loperot outcrop of Turkana Grits and very near their junction with the nephelinites of the Katigithigir Hills, Champion has found a series of magnesian limestones (see Appendix B) and coarse sandstones interbedded with the lavas. He tentatively suggests that these should be included with the Turkana Grit series. If, as I have suggested (p. 224), these sedimentary rocks were deposited in a lake formed by the ponding back of the Lokichar river, then they should certainly be regarded as belonging to the Turkana Grit series, though, on account of their being interbedded with the local nephelinites, they may be considered as a somewhat later development than the type series from the north of the Province.

There is one other exposure of sandstone resting on the Basement Complex which may possibly be assigned to the Turkana Grits. In 1934 we found that a small hill to the east of the north end of Ngamatak was formed of schists capped by ferruginous sandstones dipping steeply east (approx. 45°). This *remanié* patch of sandstone seems to suggest that there may have been a much wider area of these rocks at one time, but that subsequent to a period of movement they have been completely denuded down to the schists of the underlying Basement Complex.

So far as is at present known the above are the only exposures of the Turkana Grit Series in southern Turkana. They might be expected to occur in that part of the Turkwel Valley which runs parallel to the West Suk escarpment, but as already suggested that river will have effectively scoured its valley and will therefore have prevented the formation of a sedimentary series.

(8) *East of Lake Rudolf*

On the east side of the lake one would expect to find lavas complementary to those of Turkana. A succession of older and younger volcanics does exist, but unfortunately it is more difficult to demonstrate the boundary between the Miocene and later lavas.

Entering the area from the district south of Marsabit one passes across a great plain of Basement Complex, until about 100 miles east of the south end of Lake Rudolf the basal flows underlying Marsabit Mountain are encountered. Eastward they stretch away to the Abyssinian border, the boulder desert of the Dida Gulgulla being entirely formed of them. As Parkinson (1920, p. 5) remarks, "the rocks have the appearance of being older than the lavas of Marsabit", and indeed looking at the area as a whole it would seem that they are the local representatives of the "Plateau type" of volcanic eruption (Gregory 1921). That means that they may be contemporaneous with Gregory's first or second plateau eruptions, that is his Kapitian or Laikipian. Later the great volcanic masses of Marsabit, Kulal and Huri were built up on this pre-existing base of plateau lavas.

Travelling westward from Marsabit one descends over the Pleistocene (?) lavas that compose the mountain, finally reaching the Koroli desert which is bounded on the south and east by thin flows of olivine-basalt. From their fresh appearance these seem to belong to the late Pleistocene, but to the west rises the mass of Kulal Mountain whose deeply eroded slopes and heavily weathered rocks indicate a far greater age. Where the crater of the mountain would be expected one finds only a mighty cleft some thousand or more feet deep. This crack appears to have been formed as a result of earth movement, possibly that which gave rise to the fault-scarps along the south-eastern margin of the lake.

The western foot of Kulal is surrounded by middle and late Pleistocene basalts which have been fractured by the faulting that gave the southern end of the lake its present form. The age of these lavas has been fixed by interbedded lake deposits which can be related by their altitude and contained fossils to beaches of known age within the lake basin.

North-west of Kulal Peak and north of Elmolo Bay is Borr Hill, a prominent cone of aegirine-phonolite. It is in fact an outlier of the older rocks (Miocene?) which stretch away to the north, where they form the rocky coastline of Longendoti as far as Alia Bay. In a journey from northern Horr to Alia Bay the east extension of the same lava fields was encountered. It then became apparent that although overlain by younger lavas in places, as at Galass Waterhole and again at Gaza, the main series of lavas was older and had been faulted (and folded?) by forces acting in an east-west direction. Since it was found that the lavas were overlain by Pleistocene lake beaches corresponding in altitude to the highest on the Losidok Range, it is probable that the movements which disturbed these eastern lavas were the same as those which affected the Miocene volcanics on the west side of the lake. Seen from the west these lava scarps, like mirror images of their counterparts in Turkana, form scarps increasing in magnitude towards the lake where they culminate in the cliffs of Longendoti.

Further work in this area was prevented by the tragedy which overtook two members of the expedition. Indeed, it was only during one of the journeys undertaken in search of them that the above observations on the east side of the lake were made. Much remains to be done in the deciphering of the geology of this area, in particular in respect of the tectonic structure. Nevertheless, in the short time available I became convinced that from the region of Bor Hill northward Lake Rudolf lies not so much in a rift valley as in a downwarped basin.

C. The Pleistocene

During the Pleistocene the outlines of the lake basin as a whole were but little modified, though the extent of the lake itself varied very considerably in sympathy with the changing climatic conditions. In general it appears possible to correlate the major fluctuations of Lake Rudolf with those observed in other Central African Lakes.

The old shores of Lake Rudolf are everywhere marked by lake beaches which occur from 330 ft. above the present lake down to its present shoreline. The highest beaches have in particular been found on the east flank of the Losidok Range and on the steep scarps of the rocky shore near Na'Arangan in the south. Similar beaches are also found banked against the fractured lavas east of the lake in the Alia Bay region.

At the time of the 330 ft. level the lake extended far beyond its present boundaries, as is shown by the beaches which it has left at the foot of the Lodwar Hills (fig. 24, Plate 28), over 40 miles from its present shores. These distant shorelines can be traced south past the Ngamatak Hills, a testimony to the great size of the lake at that time.

With the fluctuating retreat of the lake, younger deposits have been laid down upon the eroded surface of the older ones. To-day these are exposed in deep gorges cut into the muds, sands, and gravels which were formed during Chellean to Makalian times. In order to differentiate between the periods of deposition it has been found necessary to rely to a large extent upon the cultural stages of the implements of prehistoric man.

Throughout the greater part of the Pleistocene there appears to have been some active vulcanicity within the area, in particular near the southern end of the lake, and indeed it has continued to the present day, for Teleki and Andrew Volcanoes are still subactive in that region. They may perhaps be better described as dormant, for though Teleki Volcano no longer smokes as it did at the time of its discovery, Champion (1935, p. 323) records hot fumes issuing from a number of pipes, an observation which I can heartily endorse as a result of my visit in 1934.

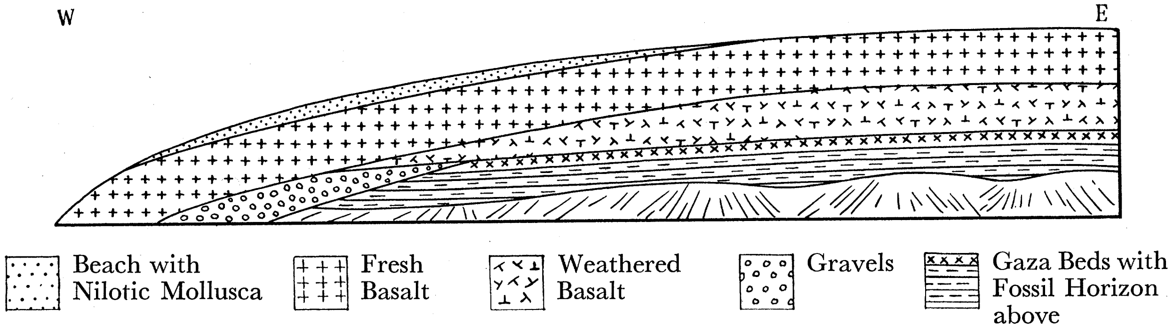
(a) *Fluctuations of the Lake*

As Arambourg (1935, pp. 12–14) points out, the Pleistocene deposits can be divided into two main series, the earlier containing *Deinotherium* and *Elephas*, which he correlates with Leakey's Kamasian, and a later series which he believes to correspond with the Gamblian (Leakey 1931 *a*). The former is well developed in the Omo Valley and also to some extent at Todenyang, where our 1934 expedition came across beds of this age.

But already in 1900 they had been recognized, both at Todenyang and in the Omo Valley, by Sacchi (Angelis d'Ossat and Millosevich 1900, pp. 40, 210) of the Second Bòttego Expedition, who gave them a similar date, namely, post-Pliocene.

In order to come to some conclusion about the age of these deposits it becomes necessary to decide arbitrarily upon a criterion by which the Pleistocene can be separated from the Pliocene. For this purpose it will be useful to follow E. Haug (1908, p. 1761), who suggested that a deposit shall be considered Pleistocene in age if it contains one or more of the three genera *Equus*, *Bos*, or *Elephas*. Since the Omo beds contain *Elephas* and *Equus*, there can, according to that definition, be no doubt of their Pleistocene age. Arambourg has also recovered *Deinotherium* and *Hippopotamus imaguncula* from the same deposits and it is therefore possible to equate them with Lower Pleistocene beds of other sites in Central Africa. This Arambourg does not do, contenting himself with correlating the Omo beds with Leakey's Kamasian of Kenya. But more recently Leakey's original conception of the Kamasian has been demonstrated to be largely Middle Pleistocene (Wayland 1934, p. 343 and Table). The beds of this age in the Naivasha-Nakuru section of the Rift Valley contain very late Acheulian and early Mousterian implements in their uppermost horizon. Their base, however, has not been recognized because the lower horizons have proved quite unfossiliferous.

Lately the discovery of the early elephants *Archidiskodon planifrons** and *A.* cf. *meridionalis* at Kanam on Lake Victoria, has provided some knowledge of the early Pleistocene fauna in Kenya. The occurrence of *A.* cf. *meridionalis* suggests some relationship of these beds with the Kaiso beds of Lake Albert. More recently a link between the Omo deposits and the Kaiso beds has been supplied not only by the elephants but also by *Hippopotamus imaguncula* which Arambourg has found in quantity in the Omo beds. On the above evidence there seems to be little doubt that the Omo beds are of Lower Pleistocene age.



Scale: 1 in. = 25 ft.

Fig. 7. Section seen at Gaza Waterhole, Northern Frontier District.

In 1934 another series of lake beds of similar or slightly earlier age was found at Gaza Waterhole on the east side of the lake. The section exposed is shown in fig. 7,

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* I learn from Dr D. G. MacInnes that this is a variety rather than typical *A. planifrons*.

from which it can be seen that the fossiliferous horizon is immediately overlain by a lava, but in spite of this the contained Mollusca are very well preserved. This lava which immediately caps the lake bed is itself overlain by a second lava, an olivine-free basalt. On the latter a mass of rubble containing numerous representatives of the modern molluscan fauna has been deposited. These include *Melanoides tuberculata*, *Corbicula africana*, *Cleopatra pirothi*, etc., all nilotic species which serve to show that the lake has been above this point since the last lava was extruded, and since the introduction of the nilotic molluscan fauna to the lake basin, that is, after the early Middle Pleistocene. On the other hand, these shells could not have reached a position about 140 ft. above the present lake at a later date than the Gamblian rise of the lake (see Table, fig. 8). Therefore they are not younger than the beginning of the Upper Pleistocene. But before that time two lavas had already been extruded, the earlier

	Sequence in the Rudolf Basin	Uganda after Wayland	Kenya after Gregory	Kenya after Leakey	Other Central African sites	Human cultures
RECENT	Retreating lake and active volcanoes			Nakuran		Gumban and Njorowan
UPPER PLEISTOCENE	90 ft. beaches Sirima, Pullo, and island volcanics 220 ft. beaches		Upper Pleistocene Phonolitic Trachytes and Basalts Last Rift Valley Faults	Makalian Gamblian	Oldoway Beds I–IV	Wilton and Elementeitan Magosian, Mousterian and –Aurignacian–
MIDDLE PLEISTOCENE	Faulting Barrier formed 300 ft. beaches 330 ft. beaches	Victoria Nile formed M-Horizon Pluvial II, part 1	Lower Pleistocene	Naivasha Rift Fractures Kamasian		Acheulian 6
LOWER PLEISTOCENE	Inferred deepening of lake by earth movement Omo Beds Gaza Beds	Movement intensifies Rifts and L. Victoria Kaiso (Pluvial I, part 2)			Kanam	Chellean I
PLIOCENE	Earth movement (formation of present basin)	Kisegi (Pluvial I, part 1) Reversal of Kafu and formation of Kioga	Naivashan			Kafuan in Uganda, Oldowan in Kenya and Tanganyika
MIOCENE	Rhyolites (Phonolites?) Nephelinites Basalts and Tuffs		Laikipian: Rhyolites Augitites Basalts		Rusinga Is., Kiboko Is. and Karungu	
OLIGOCENE	–Turkana Grits– Faulting (Uganda scarp formed) Peneplain	–Bugishu– Sandstones Rifting Peneplain	–Nyasan Lake– Beds 1st Rift Valley faults Peneplain		–Lake Beds–	

FIG. 8. Correlation Table.

having been heavily eroded before the extrusion of the latter. This fact seems to indicate a considerable lapse of time during which subaerial weathering was taking place, and this may well have been during the Chelleo-Acheulian retreat of the lake. The Mollusca recovered from the underlying deposits include only three species, but none of these is known from other fossiliferous horizons of early Middle Pleistocene or later age in the lake Rudolf Basin, and it suggests that the Gaza Beds are of still earlier age. Finally, two of the three species of Mollusca from Gaza are identical with Kaiso forms from Lake Albert and Lake Edward. The third species is also known from the Kaiso, but is given a varietal name for local palaeontological purposes (see Appendix A). On the above evidence the Gaza Beds are taken to be of Lower Pleistocene age.

Unfortunately, there is no record of Mollusca having been found in those of the Omo Beds which have yielded the mammalian fauna. Nevertheless, the occurrence of derived blocks in the later deposits on the west side of the lake, as, for instance, at Site F of the Cambridge Expedition 1931 (Fuchs 1934, fig. 3), which contain the same species as the Gaza Beds, shows that the series is more widespread in the basin than is at present known. What may be another exposure of the same age as the Gaza Beds is that reported by Champion (1937, p. 114) from the Lomogol Valley, for a specimen received from him contains all three species of Mollusca found at Gaza.

From the foregoing we find that the Omo Beds are to be assigned to the Lower Pleistocene on account of the contained mammalian fauna, and that the Gaza are of approximately the same age on the evidence of the molluscan fauna. Of the two it may be that the Gaza Beds are the earlier on account of the fact that at some localities at least the Omo Beds occur at a much lower altitude. That the part of the lake basin in which both these series of deposits have been formed has undergone considerable modification through earth movement is undoubted, for the Omo Beds themselves are extensively faulted (see p. 255). The relationship of the Omo and Gaza Beds to some others in Central Africa is shown in the Table (fig. 8).

Arambourg has correlated his second series of lake beaches with Leakey's Gamblian, but owing to the considerable amount of new evidence gathered during 1934, I believe that modification of this conception is now necessary.

My own interpretation of the evidence supplied by the lake beaches is shown in the Lake Fluctuation Curve (fig. 9). In the first place the fluctuation of the lake is limited by the depth of the basin, that is, between its lowest point and the overflow level. These limits are shown by the dotted lines. The altitude of the Gaza Beds, the oldest known within the basin, is approximately 100 ft. above the present lake. Since these are considered to have a fauna related to the Kaiso molluscan fauna of Uganda, and because the extermination of the fauna was almost certainly due to the complete desiccation of the area, the curve must fall to the lowest point of the lake basin.

It is unfortunate that so little is known of the early Lake Rudolf, but until some evidence of its maximum altitude is available one can only suppose that the great wet period, which is known to have occurred over Central Africa at that time (Wayland

1934, pp. 343–7), filled the lake basin and thereby established a connexion with the waterways associated with the Kaiso-Lake Albert.

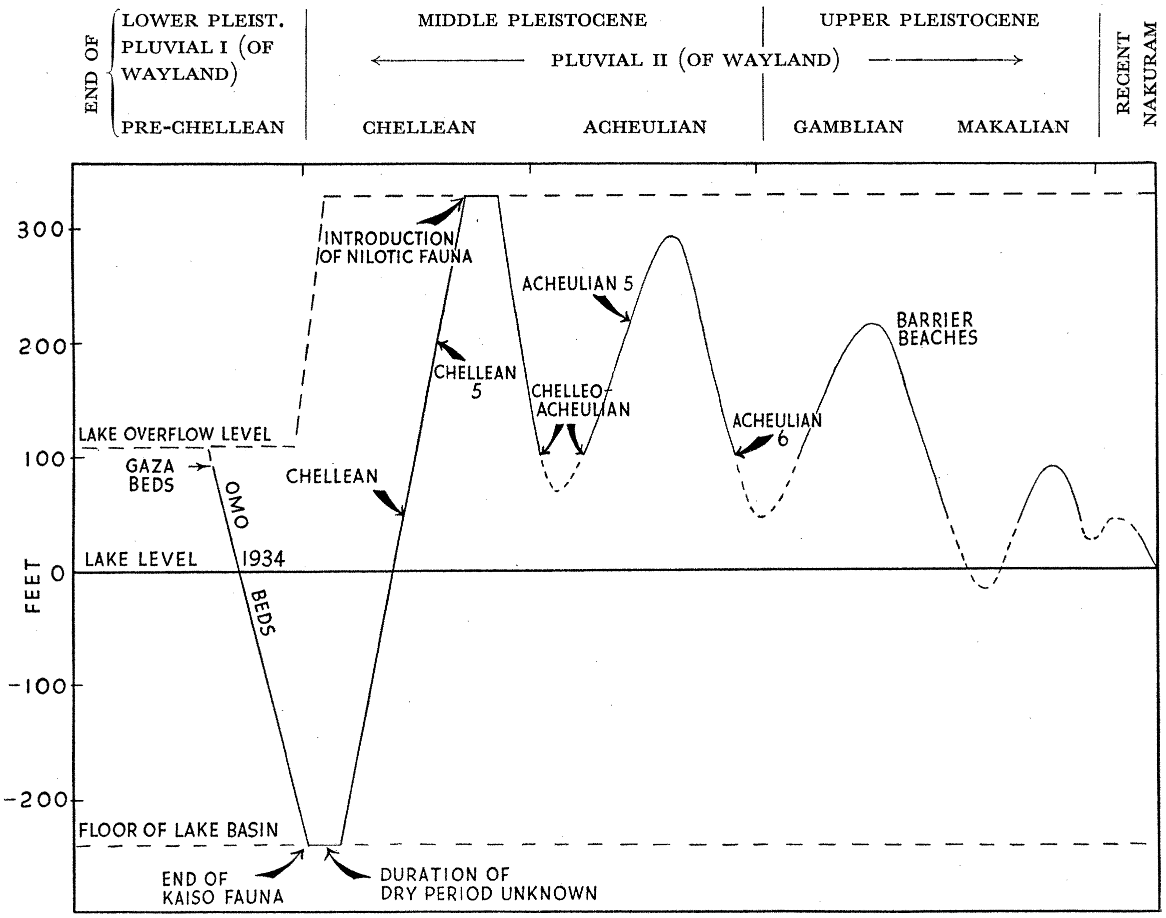

Fig. 9. Pleistocene fluctuations in Lake Rudolf.

If this early pluvial filled the Rudolf Basin, where are the corresponding lake beaches? With the exception of the Gaza Beds and perhaps those at Lomogol, only the few instances of derived boulders already remarked on show that they ever existed. It therefore seems necessary to presume that these early beaches are buried beneath others of Middle Pleistocene age. The inference is that the overflow level of the lake basin was raised some time during the early part of the Middle Pleistocene which involves the assumption of earth movement at that time. This presumed deepening of the lake basin is shown in the Fluctuation Diagram by the change in level of the dotted line marking the overflow level of the lake.

According to Wayland and others the last Kaiso bone-bed of Uganda is of very early Middle Pleistocene age. As there is no reason to suppose that the desiccation of the Rudolf area was accomplished either earlier or later than in Uganda, it is taken that it occurred at the same time. The arid conditions, however, cannot be supposed to have ended directly the lake disappeared, so the base of the curve is truncated where the aridity persisted into the Middle Pleistocene.

With renewed precipitation the water-level again rose, and at the same time new lake deposits were formed in which were incorporated the implements of early man. It has naturally been impossible to find any remains in the deposits which still lie beneath the lake, but in sections exposed not far from its present shores and about 50 ft. above the lake one or two Chellean implements have been found. These are an indication that it was during Chellean times that the lake was again rising. That this rise was continued to at least 200 ft. above its present level is shown by the discovery of two unrolled Chellean implements in some gravels exposed at Kabua waterhole.

As Dr Leakey has pointed out, similar types of primitive hand axe have been known to occur even with Acheulean cultures, and they are therefore not absolute evidence of the Chellean age of these deposits. Nevertheless, the fact that such primitive types were found, while more advanced ones were completely absent, is in itself some evidence that they are of early age, for wherever Acheulian implements occurred they did so in considerable quantity. It should also be remarked that deposits about 130 ft. above the Kabua waterhole gravels bore implements of Acheulian stage 3 upon their surface. Furthermore, no fauna of any kind was discovered in any of the deposits which yielded Chellean implements, while, on the other hand, those which contained Acheulian artifacts were usually highly fossiliferous. The appearance of this fauna, which is of nilotic type, in beds with Acheulian implements dates the connexion of the lake basin with the Nile fairly accurately. The importance of those deposits which are unfossiliferous except for a few Chellean implements, lies in the fact that it is just such an absence of fossils that would be expected in deposits laid down between the time of the extinction of the Kaiso fauna and the arrival of the Nile fauna at the height of the following lake maximum.

Towards the end of the Chellean the lake level again began to fall, though to what extent is uncertain. The discovery of very late Chellean or very early Acheulian implements in beds about 100 ft. above the present shoreline shows that the lake must have dropped to approximately that level.

That it again rose to another maximum in Acheulian times is shown by the large number of Acheulian implements which are found washing out from deposits overlying those of the Chellean. The exact altitude to which this Acheulian lake attained is somewhat uncertain, but it is probable that it was only a few feet short of the Chellean maximum. It is probable, too, that it was by the shores of this lake that the people of Acheulian 3 times lived, for their implements are now found lying upon the surface of the highest deposits of the Chellean lake in a situation only about 30 ft. above the fossiliferous beaches of the Acheulian maximum.

The occurrence of Acheulian stage 6 *in situ* some 5 miles east of the high Losidok beaches and only about 100 ft. above the present lake indicates a somewhat rapid fall of the lake during late Acheulian times. Here again we do not know to what level the water fell, and this part of the curve is therefore shown as a dotted line as in other places where its course is uncertain.

The following lake rise attained to approximately 220 ft. above the present level, and is most clearly seen on the Barrier Range at the south end of the lake. Fortunately there is no confusion with other beaches, since this is the highest that occurs on the Barrier. Evidently that range had not been formed until just before the rise of the lake to the 220 ft. level. Nevertheless, it is certain that the general contour of this southern part of the lake basin was the same as it is now, for the 330 ft. beaches occur along the steep rocky coast in the region of Na'Arangan. These beaches are doubtless continued to the south on the other side of the Barrier Range, and I have no doubt that somewhere between Lake Baringo and the Barrier Range will be found not only deposits of Middle Pleistocene age but also the Lower Pleistocene beds equivalent to those of the Omo Valley in the north.

Unfortunately, no artifacts were found in the lake deposits on the Barrier, and it is therefore difficult to date them. But since they transgress the faults which cut the lower slopes of the Barrier, and these faults are presumably to be correlated with the movements at the end of the Middle Pleistocene (the evidence for this statement is given later), it seems that the beaches must represent either a Gamblian or a Makalian rise of the lake. For the following reasons I am inclined to regard them as Gamblian.

It would be unreasonable to suppose that a fluctuation of climate in East Africa as a whole would not be reflected in the lake basins by an alteration of the water-levels. Nevertheless, a considerable change of precipitation would be necessary to effect any alteration in so large a lake and lake basin as that of Lake Rudolf. Now, Moreau (1933, p. 429) has concluded that the most recent of the pluvial periods recognized in East Africa, Leakey's Nakuran west phase, was of very small significance, the precipitation being only about 5 in. p.a. more than at the present time. That this increase of precipitation could raise Lake Rudolf to 70 or 90 ft. above its present level seems improbable. Yet between such altitudes occurs the only well-defined beach below the 220 ft. level found on the Barrier. We are therefore left with two lake beaches, the 220 ft. and the 90 ft. levels, and two periods of increased precipitation, the Gamblian and the Makalian, that are known to be widespread in Central Africa. It therefore becomes necessary to correlate the higher beach with the period of greater precipitation, which has, outside the Rudolf area, been shown to be the Gamblian (Leakey 1931 *b*, Appendix A; Wayland 1934, p. 346).

With the decline of the Gamblian the lake seems to have fallen to very nearly its present level, for beach deposits which according to the above argument belong to the Makalian rise, occur in the lower part of Sirima Gorge on the east shore, up to a height of about 90 ft. The gorge was therefore cut to its present depth by the end of Gamblian times, which means that the level of the lake must have been at least as low if not lower than it is at present.

The Neolithic rise of the lakes known as the Nakuran wet phase is thought to be not more than 3000 years old (Solomon 1931, p. 247). Since that time the decline to the present lake level has taken place. In latter years the fall has been extremely rapid, for in 1888 Höhnel recorded that Nabuyatom Cone was cut off by water from a certain point upon which he stood. To-day it is joined to that same point by a beach 40–45 ft. above the lake. That this is not a ridge due to long-shore drift is shown by the occurrence of that same beach cut into the slopes of Nabuyatom Cone itself.

This rapid fall of the lake continues, and though in the rainy period the flooded rivers may raise its level by as much as 12 in., the average net loss for the last 30 years, appears to be 9–12 in. each year. As a result the salinity of the lake water is increasing very rapidly; for instance, from April 1931 to May 1934 the alkalinity of the open water 4 miles from the west shore increased by 14·5%.*

While there can be no doubt that in the future the level of Lake Rudolf may rise again, it seems equally certain that such a rise or rises will only serve as temporary checks to the oncoming desiccation.

(*b*) *Pleistocene localities and their bearing on the tectonic and volcanic history of the Rudolf Basin*

(1) *Sanderson Gulf*

Arambourg (1935, p. 13) has recorded that the early Pleistocene deposits are tilted to the west where they disappear beneath the alluvium of the Sanderson Gulf. Elsewhere (Arambourg 1933*b*, p. 856) in a note on Sanderson Gulf he says that the two spits marking the old connexion between the Gulf and the main lake are still visible and, "Ce sont, d'une part, la plate-forme rocheuse surélevée de quelques mètres au-dessus du niveau du lac, sur laquelle est installé le poste de Nanoropus; d'autre part, à 4 km. au Nord-Nord-Ouest de ce point, l'extrémité sud d'une ligne de collines courant parallèlement au cours de l'Omo dans une direction N.N.E.–S.S.W." Yet he does not suggest a reason for the formation of these spits at this particular point. Many who have seen Sanderson Gulf have thought that the origin of the spits is to be found in the conflicting forces of the prevailing south-west wind and the local lake currents that originate near the mouth of the Omo river. Though such an explanation may perhaps seem adequate, I believe that another factor has also contributed to the formation of the Gulf, namely, the outcrop of the early Pleistocene deposits in the line of the present north and south spits. This outcropping is due to the gentle folding of the beds which strike in the same direction as the spits. The trend of the strike is apparently continued northward by the line of low hills mentioned by Arambourg.

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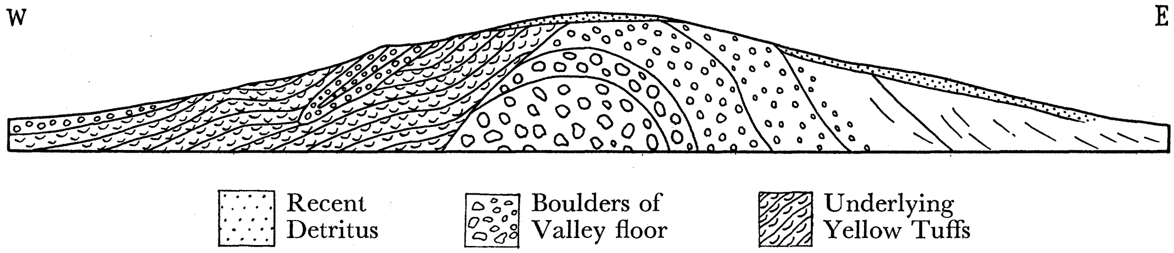
* This result was kindly worked by Mr L. C. Beadle. His figures are as follows:

	Conductivity at 18° C. × 10^6	Alkalinity (normal)
Lake Rudolf (2. iv. 31)	2860	0·0200
Open Water (4. v. 34)	3220	0·0229
	(12·6% increase)	(14·5% increase)

That Sanderson Gulf should be the surface expression of an underlying syncline is not very surprising, since we know the deposits to have been disturbed by earth movement, not only locally, but in the Omo Valley and also to the north-west at Lokitoi. In the latter case the plain north of Lokitoi Military Post is carpeted by a deposit of rounded boulders and alluvium. Across it a number of small streams make their way northwards to join the Nalingkwa river, but they are not the only agency by which the plain has been disturbed. A number of low mounds are seen to rise a few feet above its general level, and it is probable that they all owe their origin to late Middle Pleistocene movements, for about a mile and a half north of the east–west Lokitoi scarp, one of these mounds has been partially eroded revealing the section shown in fig. 10 and fig. 27, Plate 29. It could be clearly seen that pressure had caused the boulders of the Valley floor to be caught up with the underlying yellow tuffs in a series of small folds accompanied by minor thrust faults. The axes of both folds and faults run in a general north-south direction. The yellow tuffs may perhaps be the down-faulted continuation of the tuffs on which the fossil trees were growing south of Lokitoi, but no remains were found in them at this point. I believe the age of these movements to be late Middle Pleistocene on account of the fact that Levallois artifacts having a similar patination to the boulders of the Valley floor were found lying upon the surface. Though this is admittedly weak evidence, it is supported by the very existence of these mounds, which being formed of such easily eroded material as they are, would surely have been completely removed by erosion were they of much earlier origin.



(Scale: 1 in. = 17 ft.)

FIG. 10. Folded structure seen on Valley floor north of Lokitoi.

Another area where more definite Pleistocene fractures are found, and one which is more adjacent to the Sanderson Gulf region is the Omo Valley. Speaking of the deposits in this valley Arambourg (1935, p. 16) reports that they are disturbed thus: "des cassures locales orientées Nord-Sud ont haché ces dépôts en une série de petits compartiments, généralement basculés vers l'Ouest, mais parfois en sens inverse et dans l'ensemble est, en certain points, assez chaotique." Unfortunately, because of his correlation with Leakey's Kamasian (Middle Pleistocene) it is not clear to me whether these fractures only affect those of the Omo Beds which are truely Lower Pleistocene, or also deposits which may be of Middle Pleistocene age. In the latter case they may be correlated with the faults that affect the Barrier Range and the Sirima region at the south end of the lake.

In this connexion it is also interesting to note the Nakua Hills which were reported to be of volcanic origin by Athill (1920, p. 363), who speaks of his exploration of a crater. Since no pre-Pleistocene craters seem to have been preserved elsewhere in this area, it is reasonable to suppose that this one is not older than Pleistocene in age, and may in fact be the volcanic expression of the movements that fractured the deposits of the Omo Valley. If that is true I would suggest that these hills are the most northern representative of the volcanic centres which occur along the axis of Lake Rudolf. These are North, Central and Höhnel (South) Islands, besides the eruptions of Pullo, north of Sirima, and Nabuyatom Cone on the southern shore of the lake.

Reference to Table, fig. 8, will show how this period of faulting and vulcanicity in the Rudolf region is thought to correspond with the earth movements of Uganda and the major rift faulting of the Naivasha region.

(2) *Sirima Gorge*

At Sirima near the southern end of the lake a sheer gorge has been cut through the local lavas for a distance of about 8 miles. In its lower reaches the depth was estimated to be about 300 ft.

Near the mouth of the gorge is a series of permanent waterholes, and immediately below them, some 40 ft. from the floor, a lake deposit is exposed in the walls, which are otherwise entirely formed of olivine-basalt. The thickness of the lake bed varies from 3 to 6 ft., and it consists chiefly of a fine to coarse gravelly deposit containing much kunkar and fragments of lava, many of which are completely encased in a coating of calcareous material. The lower part of the band also contains numerous hard calcareous nodules in which no fossils other than ostracods were found. Near both the top and the base of the bed fossils do occur, but they are few in number and very badly preserved. They include the remains of fish vertebrae and other bones (*Lates* sp. and *Clarias* sp.) together with a number of Mollusca which include *M. tuberculata*, *Viviparus* sp., *Unio* sp., *Aetheria elliptica* and others. This fauna is sufficient to show that the deposit is later than that from Gaza, but on the other hand the position of the bed beneath some 250 ft. of lavas, which were themselves faulted before the Gamblian rise of the lake, indicates that it belongs to either Pluvial II, part 1, or part 2, and is therefore not later than early Upper Pleistocene in age. Judging from the altitude of the lake bed above the present lake, I believe that it is probably the equivalent of the 300 ft. beaches on the Losidok Range, and is therefore Middle Pleistocene (Acheulian) in age.

A section along the length of Sirima Gorge (fig. 11, p. 258) shows the relationship of the Upper Pleistocene lavas and ashes to those that form the walls in the lower part of the gorge. The latter are most probably of Lower or Middle Pleistocene age. Whether or not the dyke and fault (f_4 in the section) cut through the whole series is uncertain, but I suspect that one or more of the late Upper Pleistocene lavas overlie them both. The interpretation of the Sirima Gorge section seems to supply the following sequence of events for this region.

At the time of the formation of the Rudolf Basin (Pliocene) the 1500 ft. scarp bounding the south-west shore of the lake was formed and at the same time faults (5 and 6 in section) probably occurred along the south-eastern shores in the Sirima region. To-day these are not visible, but are inferred from the fact that the Basement Complex east and south of Kulal disappears beneath a thin covering of lavas some 3 or 4 miles east of Sirima, and does not reappear anywhere between that point and the lake. This is so in spite of the ground-level falling a thousand feet or more within a distance of less than 12 miles. In any case unless it had been let down by fractures one must surely have found the Basement Complex in the deep cut of the Sirima Gorge, yet there is no sign of it throughout its whole course.

There is at present no evidence to show the age of the basalts that lie directly upon the Basement schists in this area; it is possible that they are Miocene and pre-date the first faulting, or that they are of early Pleistocene age. Whatever their age, by Middle Pleistocene times lavas covered the Basement Complex, and it was upon them that the Sirima lake bed was deposited. That it was a shoreline deposit is shown by the great quantity of calcareous material and the tendency to oolitic structure. We know, too, that at this time considerable vulcanicity was in progress and it is therefore not surprising that the greater part of the deposit is made up of volcanic material.

After the deposition of the lake bed the water seems to have retreated, thereby allowing the deposit to dry out (post-Gamblian interpluvial) before the first of the overlying basalts was extruded. This is concluded from the smooth under surface of the lava flow which would have been corrugated had it been deposited upon soft wet material. The first lava was followed by others which built up the great pile of basalts (fig. 28, Plate 29) which now form the walls of Sirima Gorge.

The earth movements just after the end of the Middle Pleistocene fractured the Barrier Range, and gave rise in the Sirima region to the scarps that fall away westward to the lake. In the section faults 1 and 2 are inferred from the corresponding scarps. Unfortunately they were not actually visible in the walls of the gorge because small streams have cut along their strike. On the other hand, faults 3 and 4, though relatively small with a throw of only about 10 ft., are clearly visible. That the small block between these faults has been dropped down is shown by the position of the prominent band of red tuff which occurs a few feet above the lake bed. The latter ends against the western fault with a slight downward curve showing that here at least the movement of the block between faults 3 and 4 was in a normal direction. Nevertheless, the curious fact appears that the red bed is higher on the western side of the two faults than it is on the east. This means that the east end of the fault block between faults 2 and 3 has been elevated relative to the lavas east of fault 4. It follows that unless there is another fault cutting the lavas east of fault 4 (and none was observed), the block between faults 2

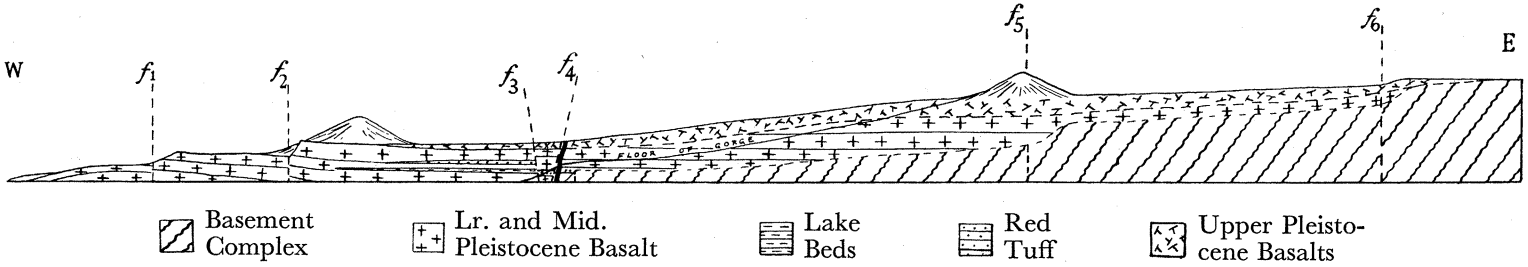
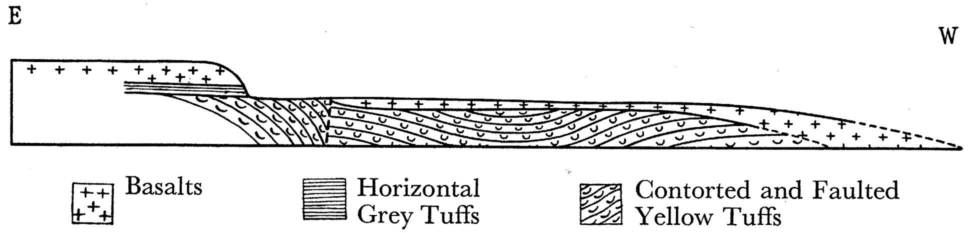
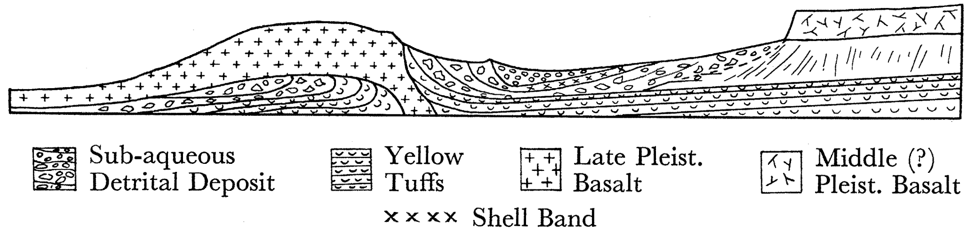


FIG. 11. Sirimi Gorge section.



(Horiz. Scale 1 in. = 300 ft.; Vert. Scale slightly exaggerated)

FIG. 12. Section about 8 miles north of Sirima Gorge.



(Horiz. Scale 1 in. = 50 ft.; Vert. Scale 1 in. = 25 ft.)

FIG. 13. Section seen about 10½ mile north of Sirima Gorge, Northern Frontier District.

and 3 must have been raised, for it is scarcely credible that so large a mass as that which must lie between fault 4 and some unknown fracture east of fault 6, could have been down-faulted while leaving such a comparatively small mass at a higher level. This point is stressed since this is not the only place where there is some suspicion that compressive forces have been at work during the Pleistocene.

Associated with fault 4 is a thin dyke of glassy olivine-basalt which Mr Campbell Smith informs me is similar to the trachybasalts of recent flows from Teleki Volcano at the south end of the lake. This dyke appears to join the fault 4 line of fracture high up in the section. It is uncertain whether the dyke reaches the surface; possibly it contributes to the lava which has transgressed the surface expression of the fault. If this is so it must be of the same age as the lavas and ashes of Sirima Hill and the surrounding cones, all of which represent the final volcanic phase of the Sirima district; that is very late Pleistocene.

Since the close of the vulcanicity the gorge has cut back its head into these late Pleistocene lavas as far as Sirima Hill itself. Before that happened it must already have been a prominent feature of the Rudolf coastline; indeed, there is evidence that at one time it formed a narrow inlet of the Gamblian Lake Rudolf. At a point not far from its mouth a deep crack cuts downward across many of the flows that make up the southern wall. This has been filled with a limestone formed almost entirely of the small mollusc *Bulimus humerosus*. I believe that the level from which this deposit filled the crack corresponds with the 220 ft. beach level on the Barrier Range and is therefore of Gamblian age.

(3) *North of Sirima Gorge*

On leaving Sirima Gorge and walking north along the lake shore it soon becomes apparent that the structure of the coast is nearly constant for a distance of about 10 miles north of the gorge. The sections shown in figs. 12 and 13 are typical of this shore, the former showing the folding which has affected the yellow tuffs underlying the lavas. Unfortunately, it was impossible in that case to make out the relationship of the overlying lava to the faulting. These yellow tuffs become a very familiar sight, for they appear from beneath the basalts at innumerable points north of Sirima Gorge and also on Höhnel Island. Sometimes they are fossiliferous, sometimes quite barren, apparently according to whether they were subaqueously or subaerially deposited. In general appearance and from the fossils that they contain, they are similar to the great pile of yellow tuffs that form the base of Pullo, itself a nest of late Pleistocene ash cones contemporary with those of Sirima, Höhnel Island, and Nabuyatom. Indeed, it is likely that the early explosive phase of Pullo was responsible for scattering these tuffs over the surrounding country. The fact that they have been faulted and folded suggests that they were formed before the movements at the close of the Middle Pleistocene, though those occurring on Höhnel Island appear to be post-faulting.

About 10 miles north of Sirima Gorge the section shown in fig. 13 was seen. There the normal lake shore section has been altered by the intrusion of a much later basalt through yellow tuffs and the debris derived from lavas that overlie them to the east. The existence of a shell band with nilotic species in the talus deposit that underlies the most recent lava shows that its extrusion took place either under water or after the retreat of the lake from this point. Since there is no sign of such subaqueous extrusion, and because the altitude of the fossiliferous horizon is only about 100 ft. above the present lake, the age of the lava is almost certainly post-Gamblian or late Upper Pleistocene.

North of this point the lavas and tuffs continue along the shore, but a coarse volcanic agglomerate appears in the series and gradually increases in thickness till it entirely replaces the tuffs and lavas. It can also be seen forming reefs beneath the water for some distance out into the lake. Though Pullo is not far distant, a nearer origin for this material is found in three small craters now breached by the lake, one of which forms a very excellent harbour.

From Loiyangallani northward much of the shoreline is marshy, but as far as Elmolo Bay there are numerous prominent ridges of agglomerate and basalt, while the Elmolo Islands themselves are formed of basalts and tuffs.

On the mainland the Laradabush soda springs may represent the last signs of the local vulcanicity, but north of Laradabush the volcanics turn inland to the east, and sandy shores indicate that one is approaching an area occupied by Basement Complex rocks. To the north the prominent cone of Bor Hill is composed of aegirine-phonolite, while a mile or two away to the east the lavas again cap the Basement Complex. From the top of Bor Hill these nearby lavas are seen to be part of the southern extension of the great Miocene (?) lava field that extends southwards from the Longendoti-Horr region.

(4) *South of Sirima Gorge*

South of Sirima Gorge the fault scarps at first run almost due south then gradually curve towards the south-west and so into the directional trend of the numerous parallel faults which cut the lower slopes of the Barrier Range. Along the top of the uppermost scarp a series of ash cones can be seen stretching away to the south, while the fault blocks themselves dip westwards with apparent arching of their constituent lavas.

At the southern end of the lake the Barrier faults are numerous and have a directional trend of N. 15° E. (fig. 29, Plate 29). The maximum apparent throw of any one fault is about 100 ft. In general the eastern faults have their downthrow sides on the west and the western faults on the east. A few exceptions to this rule give rise to small upraised or sunken blocks. The upper limit of the age of the faults is determined by the series of Gamblian lake beaches (diatomite deposits) that transgress them at an altitude of approximately 220 ft. above the present lake. Since the 330 ft. beaches of the Middle Pleistocene times do not appear on the Barrier Range, it seems that it cannot have existed, at least in its present form, until post-Middle Pleistocene times. It therefore appears that the faulting occurred at the end of the Middle Pleistocene.

On the southern shore of the lake are two prominent ash cones, Nabuyatom and Abili Agituk. The former is the younger for there is no sign of any lake levels higher than 45 ft., having been cut upon its flanks. Abili Agituk, on the other hand, has a well marked level cut at just over 200 ft. above the present lake. This fact together with its generally denuded condition shows it to be of considerably greater age than Nabuyatom. I conclude that it was formed at the time of the faulting at the end of the Middle Pleistocene, but that Nabuyatom was not erupted till much more recently, perhaps at the time of the last Pullo-Sirima eruptions.

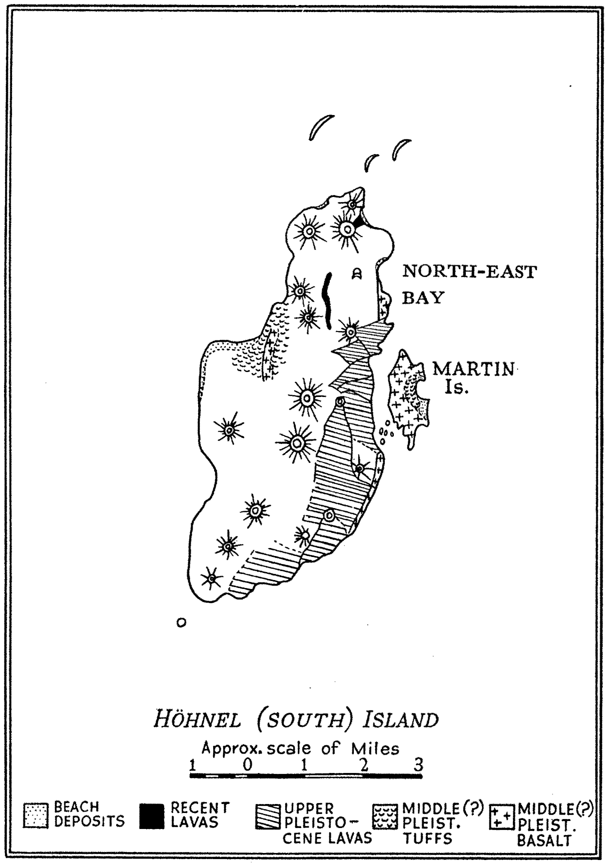


Fig. 14.

(5) *Höhnel Island* (*South Island*)

Owing to the tragic loss of two members of the expedition who were working on this island we have no topographical map, and numerous specimens are also wanting. The island is some 30 sq. miles in extent and is at first sight entirely of volcanic origin. The sketch map (fig. 14) has been compiled from von Höhnel's original map (1891, Taf. III), drawn entirely from the mainland, and from my own observations on the island itself.

Höhnel Island is surrounded by a number of smaller ones which with a single exception appear to be the fragments of submerged craters. This exception is the low-lying island on the east which can only have appeared from beneath the waters of the lake during the last 40 or 50 years, for its maximum altitude is little more than 30 ft. For the purpose of distinction from Höhnel Island I propose to call it Martin Island after W. R. H. Martin, one of the two men who lost their lives. It was on that island (fig. 30, Plate 30) that Martin found the only possible place to measure his base for the start of the survey which he was making.

Though largely covered by shingle, Martin Island is flanked on the west by vertical cliffs of basalt, while from the centre of the island almost to the eastern shore exposures of yellow tuffs occur.

Höhnel Island itself consists of a central ridge of ash cones running in a north and south direction. On the east flank from an altitude of 800 or 900 ft. a series of comparatively recent (late Upper Pleistocene?) olivine-basalt flows have clothed the slopes right down to the water's edge. The western slopes, on the other hand, are covered almost entirely by soft ashes. This is probably due to the prevalence of the wind from the south-east. The most recent signs of activity were seen in the northern part of the island, where narrow streams of fresh lava have flowed down over the ashes like black glaciers.

Though at first sight the island appears to be entirely composed of a number of small cones and their associated tuffs and lavas, there are indications that these stand upon a base of different origin. Thus the cliffs which form the south-western shore of North-East Bay (fig. 31, Plate 30) are a series of horizontally bedded lavas which have the appearance of a fault scarp. Again, on the west side of the island there is also a prominent lava scarp outcropping from beneath yellow tuffs. Below the scarp these tuffs are highly fossiliferous, containing fish and molluscan remains in considerable quantity, but those above it are completely barren. I therefore conclude that the scarp was in existence before the deposition of the tuffs. The greatest altitude of the fossiliferous beds above the present lake is about 160 ft., which suggests that they may be of Gamblian (Late Pleistocene) age.

Unfortunately, I was not on the island long enough to search for further evidence of the faulting mentioned, but the scarps occurring as they do on either side of the island and again to a lesser extent on Martin Island, leads me to believe that Höhnel Island is built up by late Pleistocene volcanics resting upon a series of pre-existing lavas which were fractured by the movements at the end of the Middle Pleistocene. Such a conception of its structure might be explained by supposing the faulting visible in the Barrier, only twelve miles to the south, to be produced in a northerly direction.

D. Recent volcanic activity

Apart from the continued progress of desiccation the most striking feature of recent times is perhaps the existence of subactive volcanoes within the lake basin. I have already described (Fuchs 1934, p. 110) the remaining activity of Central Island. More striking activity was observed in 1888 at the time of the discovery of the lake, for then Teleki Volcano on the north flank of the Barrier Range was very active. Von Höhnel (1889, p. 219) gives evidence to show how recent were some of the lavas emanating from it, while in 1895 Donaldson Smith (1897, p. 333) saw the volcano in activity in the distance. He writes: "Teleki Volcano...sent up clouds of smoke and at night a great stream of glowing lava could be seen pouring from one of the craters." In 1897 Cavendish (1898, p. 392) reported that the volcano had disappeared, and at the same time discovered another active crater on the south side of the Barrier which he called Andrew Volcano. More recently Champion (1935, p. 323) rediscovered and mapped the Teleki Volcano besides visiting the Andrew Volcano. These and many other reports of travellers to this region have recently been reviewed by Admiral Höhnel (1938, Part II) in the light of his early knowledge of the area.

In 1934 when I visited Teleki Crater from the east side of the lake it no longer smoked, but from various vents sulphurous fumes could be detected. The volcano itself is little more than a rounded black hill which from even a short distance merges with the background. The majority of maps show Nabuyatom Cone as Teleki Volcano, a mistake made by nearly every traveller until its rediscovery by Champion in 1933.

Whether or not its activity has ceased, only the future will show. Its position along the axis of this part of the rift valley certainly ensures that it will stand every chance of rejuvenation by any movements that disturb the area in the future.

E. A comparison of Pleistocene events in the Rudolf Basin with those of some other Central African areas

The Table (fig. 8) shows my correlation of the chief events of the Rudolf Basin with those in adjacent areas.

So far as the Rudolf Basin is concerned, the earliest recognizable Pleistocene deposits are the Gaza and Omo Beds. On the evidence of the Mollusca from the former, *Hippopotamus imaguncula* and possibly *Elephas* sp. from the latter, it is considered possible to equate these deposits with Wayland's Kaiso of Uganda. In that case they must be considered as deposits of what Wayland (1934, Table) calls Pluvial I, part 2.

During or after the arid period which brought the first Pluvial to an end, earth movement in Uganda intensified the rift valley and the Victoria Basin (Wayland, 1929, p. 43). In the Rudolf area such movement may be inferred from the raising of the lake overflow level after the Gaza fauna had been destroyed. In Kenya these movements should probably be correlated with the beginning of the fractures that later formed the Naivasha-Nakuru section of the rift valley.

The subsequent Middle Pleistocene rise of the lake continued till its overflow established a connexion with the Nile system. The result of this connexion was to introduce to the lake the present nilotic fauna. This period of lake maximum corresponds to the period noted by Wayland when Lake Victoria was also filled to overflowing.

The subsequent recession of Rudolf is comparable to the intra-pluvial oscillation which gave rise to Wayland's M-Horizon (Wayland 1935), for it was quickly followed by a second rise to almost the same altitude.

All the foregoing fluctuations recognized in Uganda and the Lake Rudolf Basin have, up to the present, been included in the Kamasian Pluvial in Kenya, for in the Naivasha section of the rift it has not yet been possible to trace any subdivisions.

With the end of the Middle Pleistocene the history of all three areas falls into line, for everywhere one finds a similar sequence of events. First of all widespread earth movement which in Uganda caused reversal of the rivers and the establishment of the Victoria Nile; in Kenya it completed the major faulting of the Nakuru-Naivasha section of the rift valley; while in the Rudolf area it is represented by the faulting of the Barrier Range and the Sirima Scarps, together with the Lokitoi folds and the fracturing of the Omo Beds. There seems no doubt that this faulting occurred at a time when conditions were again becoming drier with a consequent retreat of the lakes.

The Gamblian and Makalian were first recognized and named by Leakey and Solomon in Kenya, subsequently by Wayland in Uganda, and now there is evidence of their occurrence in the northern part of the East African area.

That there was a minor retreat of the Makalian lakes and a subsequent rise known as the Nakuran wet phase now seems generally accepted, for Wayland (1934) shows it in his precipitation curve, and it has long been recognized in Kenya. In the Rudolf Basin I have been unable to differentiate one of the almost innumerable strand lines as representing the Nakuran increase of precipitation.

The retreat of the Nakuran brings us to the present day when the retreat of the lake is proceeding at a very rapid rate. Looking at the Lake Rudolf fluctuation curve as a whole, it seems almost unreasonable not to continue its undulating course into the future. If ever a geologist can hope to foretell future events it is in such a case as this, where past history and present events all point to progressive desiccation, and in consequence to an accentuation of the difficulties which already beset the Water Boards of East African Territories.

V. TECTONIC SUMMARY

Before the great Central African peneplain was disturbed by the first rifting movements it extended over the site of the present Lake Rudolf Basin. The first fractures gave rise to the Uganda escarpment which extends from the Dodinga Hills in the

Sudan through Chemorongi and Sekerr to Marakwet in the south. Throughout its length the face of this scarp is formed entirely of Basement Complex rocks (except of course where it has been transgressed by late Miocene rhyolites west of Muruanisigar), a sign that it pre-dates the first of the volcanic eruptions which were associated with the rifting of this area. For this reason, and because they overlie the Turkana Grits, the lavas of the Muruanisigar-Pelekech-Kaitherin Range and the faulting which has disturbed them are considered younger than the fracture of the Uganda escarpment. The second period of movement occurred during the Pliocene and was responsible for the greater part of the tectonic features now found within the area.

In the far north-west the Zingout-Mogilla Range is composed of rhyolites dipping eastward and having a steep fault scarp on the west, a unique feature within this area, where all other major scarps west of the lake face to the east. East of Mogilla the Lotogipi Swamp occupies a low-lying area which may be called the "Lotogipi Syncline", for it is probable that even if the Kaitherin lavas seen dipping west beneath the swamp are not those which rise again in the Mogilla Range, yet the movement which fractured and uplifted (?) the respective ranges must have imparted a synclinal structure to the intervening rocks.

The altitude of the Kaitherin-Pelekech-Muruanisigar ridge may always have been higher than the surrounding country as there is evidence that eruptive centres were situated along that line. The same applies to Lorienatom, but in both cases the original altitude seems to have been accentuated by folding which culminated in fractures cutting off the eastern flanks of both these ranges. That the valley of the Gatome river between Kaitherin and Lorienatom is synclinal in origin has been shown by the evidence from the district south of Lokitoi. It is possible that this Gatome syncline extends as far south as the Lodwar-Lorogumu road, for evidence of such a structure was found for a considerable distance south along the Lokitaung-Lodwar road.

To the east of the northern end of the Gatome syncline are the massifs of Labur and Murueris whose fractures, at any rate in the case of Labur, appear to have been associated with flexures of varying amplitude and probably considerable local uplift. To the south the Lodwar and the Losidok Ranges represent similar zones of disturbance but their extent is not so great as that of their northern counterparts. That this is so is not surprising when one considers the magnitude of the Muruanisigar fractures which lie to the west of them. The much greater size of the latter may well have taken up the major part of the movement which in the north is more evenly distributed between the several different ranges.

Whether or not the truncation of the southern end of Muruanisigar is due to a fault transverse to the general trend of the country is as yet uncertain. If a fault be held responsible, it is then difficult to account for the absence of lavas over the greater part of the Moroto embayment.

Regarded as a whole the chief tectonic features of the area are seen to belong to three different periods. Firstly those of the late Oligocene period of movement which have in general a N.W.–S.E. trend; secondly, those of the Pliocene and later times which appear as branches from the pre-existing fractures; thirdly, a series of comparatively minor faults that occurred at the end of the Middle Pleistocene. The Pliocene fractures run in a general north-south direction and curve slightly eastward at their northern ends. It is noticeable that nowhere do they cross the Uganda escarpment, which suggests that the southern massif bounded by that great scarp moved as a whole when disturbance of the area took place. This is borne out to some extent by fractures of the same age which occur in the rifts encompassing the Victoria Basin. Within the area so enclosed by the rifts only relatively minor fractures occur, and these may be related to the subsidence of the Victoria Basin, and not directly connected with the movements of the rift areas.

Looking at the region in a wide sense one sees that the early fractures north of Lake Baringo divide and turn away to the north-west and the north-east. The latter trend is lost in Nyiro Mountain (10,000 ft.) which is probably an upthrust mass comparable in origin to Ruwenzori, though on a much smaller scale. North of Nyiro these early fractures disappear beneath the Miocene (?) and later lavas which have themselves been disturbed by Pleistocene fractures. It is possible that the N.E.–S.W. axes of such volcanic centres as Esi, Huri and Marsabit represent the last signs of crustal weakness induced by the earlier movements.

Turning now to the Pliocene and later movements, the north-south trend of the folds and fractures with the tendency to swing to the east in their northern extremities, clearly distinguishes them from the older faults. In the north-east of the area Lake Stefanie lies in the southern end of the N.E.–S.W. Abyssinian Rift, and from maps and von Höhnel's drawings (Höhnel 1890), it is apparent that the directional trend of that rift has turned almost due south before it ends in Mt Hummur on the west and Mt Jibbissa (Djiwiss) on the east. If the lines of these fractures be produced they are found to pass into the same strike as the faults that I have recorded from the east side of Lake Rudolf. These fractures appear to be carried on in a southern direction by the Sirima and Barrier faults, but since the latter are certainly late Middle Pleistocene, it is more probable that the true continuation of the Pliocene tectonic features of that area are now hidden by the Pleistocene lavas. Such fractures have been inferred from the local disappearance of the Basement Complex at Sirima. The Middle Pleistocene faulting which there forms the existing scarps can probably be regarded as consequent upon rejuvenation of the older scarps now hidden by volcanics.

From the foregoing it seems that the small but clearly rifted area in which the southern end of Lake Rudolf lies, is linked by the fractured and folded regions on the east and west of the lake with the Stefanie and Omo Valleys respectively. In my opinion the greater part of Lake Rudolf cannot be said to lie within a rift but to occupy a faulted synclinal area consequent upon adjacent rifting movements. This synclinal zone ends somewhere to the north of the lake in the Abyssinian highlands. In form and size it is matched by the adjacent synclinal depressions of Gatome and Lotogipi, and therefore appears to be one of a series. Whether the fractures which form the Lake Stefanie Valley are to be regarded as a continuation of the true rift, or as accompanying another syncline of this nature, must be left until a study of that area becomes possible.

From the above we now find the three northern branches of the Rudolf Basin which were recorded by Gregory (1921, p. 336) can be explained as members of a series of tectonic features consequent upon rifting movements, but none of which can be individually pointed to as the link between the Kenya and Abyssinian rifts.

In conclusion, it may be of interest to point out the difference of the "rift zone" in areas where it lies in highland country, as in Kenya and Abyssinia, and in those others where it crosses intervening low-lying country. In the former case it is narrow with steep opposing walls with little or no evidence of pressure movements in the form of folds or flexures; in the latter case, as at Rudolf, the area affected by the movements is very wide with numerous escarpments and much local evidence of folding.

Bullard (1936, p. 510) has recently concluded on account of his gravity measurements in East Africa, that the rift valleys were formed by compressional and not tensional movements. In the foregoing work on the Lake Rudolf Basin there is considerable evidence of folding associated with the fracturing of an area which is certainly the northern expression of movements which farther south gave rise to the Kenya Rift Valley. If at some time gravity observations should be made in the Lake Rudolf Basin, they should prove of considerable interest in so far as it is an area where the fractures of a true rift valley are gradually replaced by smaller and more widespread faults. In such circumstances it might be expected that negative gravity anomalies would be found in the Suguta Valley and the southern end of Lake Rudolf, besides perhaps the immediate vicinity of the foot of the Uganda escarpment. Over the rest of the area, where innumerable larger or smaller fractures have taken up the movement elsewhere expressed in the great rift fractures, gravity observations of a nearly normal nature are to be expected.

VI. GENERAL SUMMARY

Lake Rudolf has usually been considered to lie in the northern continuation of the Kenya Rift Valley. It is now found that this belief is only partially true, for though the lake occurs in an area affected by rifting movements, it does not in a proper sense lie within a rift valley.

The history of the area is traced from the time when it formed a part of the great Central African peneplain. In late Oligocene times this peneplain was fractured to form the Uganda escarpment, erosion of the scarp gave rise to the Turkana Grits which were in turn covered by the early Miocene volcanics. The latter are dated by the Burdigalian mammalian fauna found in a horizon of tuffs in the Losidok Hills.

The similarity of the volcanic succession in the Rudolf area to that found by Gregory in the more southern parts of the Kenya rift, supports Arambourg's correlation of the Rudolf Miocene with Gregory's Laikipian. In consequence the age of Gregory's Kamasian is once more called into question, and it is inferred that his original diagnosis was correct. Unfortunately owing to general modern usage of the term Kamasian for deposits of Lower and Middle Pleistocene age it is not considered advisable to revert to the old meaning, and it is proposed that Gregory's wider term Nyasan be used for deposits of Oligo-Miocene age.

Examination of numerous sites within the area shows that in the Pliocene renewed earth movement took place. This resulted in the formation of a series of prominent scarps which, it is suggested, may be due to compressional rather than tensional forces. Evidence for this view is found in numerous sections from widespread points within the area. Later movements that occurred during the Pleistocene are found to be similar in type.

The rise and fall of the lake during Pleistocene times is discussed in conjunction with the human cultures found associated with the lake beaches. An attempt is made to correlate the events within the Lake Rudolf Basin with those already known to have occurred elsewhere within the East African Province.

In the course of the descriptions of the various areas and the discussion of their interpretation, the volcanic history of the area is brought out. Thus it is found that after the extensive "Plateau Eruptions" of the early Miocene, the activity became more restricted, and that by the beginning of the Pleistocene it had almost ceased. Later, accompanying the Pleistocene movements a renewed outbreak of volcanic activity took place. This was mainly centred around the area south and east of the lake, but the three main islands and probably Nakua Hill in the north, must also have been active at that time. Within recent times Teleki and Andrew (Likaiyu) volcanoes have been active and there are also signs that Central and Höhnel (South) Islands are not yet quiescent.

Finally it is concluded from the past climatic history, that if present conditions persist the lake will continue to shrink and the area will return to the more or less completely arid conditions that prevailed in time past. How far such conditions will encroach on the southern highland areas can only be left to unhappy conjecture.

APPENDIX A

Mollusca of the Gaza Beds, Lake Rudolf

The recent molluscan fauna of Lake Rudolf is essentially of nilotic type, and there can be no doubt that in time past the lake was connected with the Nile system. From the geological evidence of the lake beaches and their associated human cultures it is known that the present fauna has occupied the lake basin since early Middle Pleistocene times, but that prior to its appearance there was an earlier molluscan fauna more nearly related to species known only from the Central African Province. In fact I believe that they represent a northern extension of the extinct Kaiso fauna of Uganda.

Elsewhere (Fuchs 1936) I have suggested that the molluscan fauna of the Kaiso beds may be ancestrally related to the peculiar modern fauna of Lake Tanganyika. The three species of mollusca known from the Gaza waterhole deposit are all known from the Kaiso Beds of the Lake Edward-Lake Albert region, but have not been found *in situ* in any of the later Lake Rudolf beaches. I would therefore suggest that the Gaza specimens are representatives of a fauna once widespread in Africa, which locally produced exotic types, but which in Lake Rudolf may have been too soon exterminated for that to have occurred.

Species recovered from the Lower Pleistocene deposits of Lake Rudolf

VIVIPARUS UNICOLOR var. RUDOLFIANUS nov.var. (fig. 32*a–d*, Plate 30)

Description. Shell medium size, thick, somewhat mammillate, perforate. Whorls 5, pronounced shoulders and flattened sides; sutures rather deep, ornamented by strongly marked straight growth lines retrocurrent at about 30° to the suture on the last whorl, but at only about 20° on the preceding whorls. An angulation on the last whorl continues the final suture. Aperture slightly oblique, ovate or pear-shaped, inner lip reflected over the umbilicus so that the latter is almost completely obscured.

Locality. Gaza waterhole deposit east of Lake Rudolf, Kenya Colony. Also from derived boulders in the Middle Pleistocene beaches east of the Losidok Hills, and from the beaches of the Lomogol Valley north-west of Labur.

Material. A very large number of specimens but many distorted by pressure.

Remarks. These shells are undoubtedly a form of *V. unicolor* and seem to approximate most nearly to the specimen figured by Pilsbry and Bequaert from Lake Kabamba, Belgian Congo. Some of the specimens also resemble in the form of the last whorl a variety described by Sturany from Lake Manyara (Baumann 1894) which has a tendency to form two carinae. In none of the Rudolf specimens does this apply to the earlier whorls, though it is well marked on those of the Manyara specimens.

These shells are important because they have not been found in any of the later Pleistocene or recent deposits of the Rudolf Basin, which are extremely rich in other molluscan species. For this reason *V. unicolor* var. *rudolfianus* is likely to prove a useful zonal fossil within the lake basin, and on that account is considered worthy of a separate varietal name for palaeontological purposes.

CLEOPATRA FERRUGINEA (Lea).

1850, *Melania ferruginea* Lea, *Proc. Zool. Soc. Lond.* p. 182 (no figure).
1897, *Cleopatra ferruginea* Martens, *Deutsche Ost-Afrika*, Band 4, Taf. vi, fig. 30.
1936, *Cleopatra ferruginea* (Lea), Fuchs, *J. Linn. Soc.* (*Zool.*), p. 99, Pl. I, figs. 13, 14.

Locality. Gaza waterhole deposit east of Lake Rudolf, Kenya Colony. Also from derived boulders in the Middle Pleistocene beaches east of the Losidok Hills, and from the beaches of the Lomogol Valley north-west of Labur.

Remarks. The majority of the Gaza waterhole specimens were well preserved. There appears to be no reason to separate these from the specimens obtained from the Kaiso deposits of Uganda. A few are larger and many have a slightly less pronounced shoulder than the Lake Edward or Lake Albert specimens. On the other hand, the aperture and the ornamentation appear to be identical. As with *V. unicolor rudolfianus* no specimens of this Cleopatra have been found in any of the later beaches whereas other Cleopatrae are common. It therefore seems that this species may also prove to be a useful zone fossil within the lake basin.

UNIO (GRANDIDIERIA) ABRUPTUS Fuchs (fig. 33, Plate 30)

1936, *Unio (Grandidieria) abruptus* Fuchs, *J. Linn. Soc.* (*Zool.*), **40** (No. 269), Pl. III, figs. 6–8, p. 101.

Locality. Gaza waterhole deposit east of Lake Rudolf, Kenya Colony. Also from derived boulders in the Middle Pleistocene beaches east of the Losidok Hills, and from the beaches of the Lomogol Valley north-west of Labur.

Remarks. The collection includes several left and right valves, mostly rather fragmentary, but showing all the characteristic features of the species. The only difference from the Lake Edward specimens appears to be the somewhat smaller size of the shell. The largest valve, a right one, is only 16 mm. long and 12 mm. high at the umbo.

Were it not for the crushing to which the deposit has been subjected by the weight of the overlying lavas, it is probable that larger specimens would have been discovered. As it is their absence may perhaps be accounted for by their greater liability to damage.

This is a very distinctive species which is so far only known from the Kaiso deposits of Lake Edward and Lake Albert. It is therefore most suggestive of some relationship between the early molluscan faunas of Lake Rudolf and that of the western rift valley.

In conclusion I would remark that nowhere have any of the foregoing three species been found singly, but always in association with each other. What is even more important is the fact that where they are found in a deposit, there is so far no record of their occurring with any species of the later nilotic fauna which now occupies the lake basin.

APPENDIX B

A NOTE ON THE MAGNESIAN LIMESTONES OF SOUTHERN TURKANA

Mr Champion's record of the sedimentary series 2 miles west of Kaureta Authrui is as follows:

> This sandstone (120) definitely lies between almost horizontal sheets of nephelinite. There is a slight tilt to the west and the beds are some fifty to eighty feet deep and would seem to be associated with numbers (118) and (119) now determined as magnesian limestones. The bedding

seems to be in conformity with the overlying volcanic rock. The beds are very strikingly exhibited outcropping along both sides, and right up to the head of a small valley which drained westward from the point where I made my camp. No fossils of any sort were found, though circumstances did not permit of a long search. The rock is much more friable than any Turkana Grit yet met with. I am convinced that these beds cannot be the remains of an old terrace or beach, but were definitely deposited between periods of vulcanicity....

Mr Campbell Smith has kindly supplied the following note concerning the specimens deposited in the British Museum:

(118) from the same locality associated with coarse grits is a magnesian limestone (Lab. No. 2110) with $MgCO_3$ 39·27, $CaCO_3$ 49·87. The rock is pale pinkish buff in colour, and has layered and perhaps concretionary structure. It is very compact and extremely fine-grained. Another magnesian limestone absolutely aphanitic and extremely compact (119) comes from between Najanaiadapai and Nathajait. This has been analysed (Lab. No. 2111) and proves to be very similar in composition to the above. SiO_2 is present in fair quantity in both rocks.

The results of the partial analysis made by Mr S. E. Ellis of the Mineral Department, British Museum (Natural History) are as follows:

	Lab. No. 2110	Lab. No. 2111
MgO	18·70	19·04
CaO	27·92	31·71
P_2O_5	·02	0·0025
Fe_2O_3 TiO_2	1·95	2·74
Al_2O_3	0·82	2·02
Calc. as $MgCO_3$	39·27	39·98
Calc. as $CaCO_3$	49·87	56·63

SiO_2, CO_2, TiO_2, and FeO were not separately determined.

I have tested the specimens (118) and (119) for dolomite by staining with aluminium chloride and hæmatoxylin. In the case of the extremely compact yellow rock (119) only minute crystals of calcite appear to be present, the remainder of the rock taking the stain to only a very slight degree. The more cavernous specimen (118) is also considerably dolomitized since staining occurs only in the linings of the cracks and cavities. As these limestones are apparently dolomites they are of considerable interest since their place and mode of occurrence suggest primary deposition.

Briefly reviewing the theories for the formation of dolomites; all those demanding a marine origin may be dismissed on account of the absence of any marine deposits within many hundreds of miles of the area. Similarly there can be no question of a clastic origin since there are no other dolomites within the area from which they might have been derived. Again the absence of any signs of organic remains seems to preclude the possibility of an organic origin, unless perhaps the original precipitation of the magnesium and calcium salts was brought about by algae.

It might be suggested that they are the alteration products of pre-existing limestones of lacustrine origin, but the extremely massive character of some specimens, and the dyke-like occurrence of others is often unfavourable to this view, for the former characteristic shows that little or no alteration in volume has taken place.

There remains the possibility of primary deposition, the magnesia having been derived from thermal springs as described by Bischof (1859, **3**, 166), or as the result of volcanic acids (Favre, 1849, p. 364) attacking the ferro-magnesian minerals of the nearby nephelinites and basalts.

Throughout Turkana there are numerous signs that the primary waters are very rich in calcium; the thick series of tuffs exposed in the Losidok Range is almost everywhere cemented and veined with calcite, as indeed are many of the lavas both there and elsewhere in the province. West of Losidok Hills in 1930 I found a line of hills (Fuchs 1934, p. 106) some forty feet high, formed entirely of a calc-tufa, while east of Losidok, where the lake beds are banked against the lavas, there is a lengthy limestone dyke.

Though analyses have not been made, I have now tested specimens of both these rocks and have obtained a considerable precipitate of the characteristic magnesium oxalate crystals. Besides this both the foregoing limestones when tested with aluminium chloride and hæmatoxylin show a few calcite crystals set in a non-staining matrix which I therefore regard as dolomite.

These occurrences of dyke-like and tufa deposits of magnesian limestone which seem to correspond to dolomite in chemical composition and their reaction to staining, suggests that they are probably chemical precipitates from thermal waters associated with the earth movement and vulcanicity of the area. A certain amount of dolomite may have been directly precipitated from the primary waters, particularly in the case of the more compact forms like (119) which is also a characteristic yellow colour. The more cavernous varieties like (118) and perhaps the tufa from west of the Losidok Hills, suggest alteration subsequent to the precipitation of the limestone. In the case of (118), which occurs beneath flows of nephelinite, it seems plausible to suggest that alteration of the original magnesian limestones was effected by the high temperature attained when the superimposed lavas were extruded.

I therefore regard the Turkana magnesian limestones as precipitates from thermal waters which in certain cases have subsequently been altered to true dolomites.

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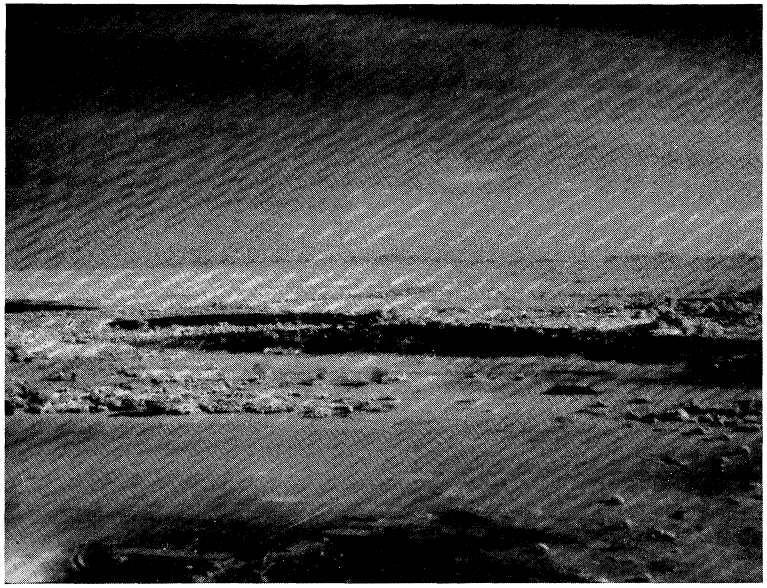


Fig. 15. The Turkana peneplain with the Ngamatak Hills 40 miles distant (infra red).

Fig. 16. The Lubar scarp looking south (photo by W. R. H. Martin).

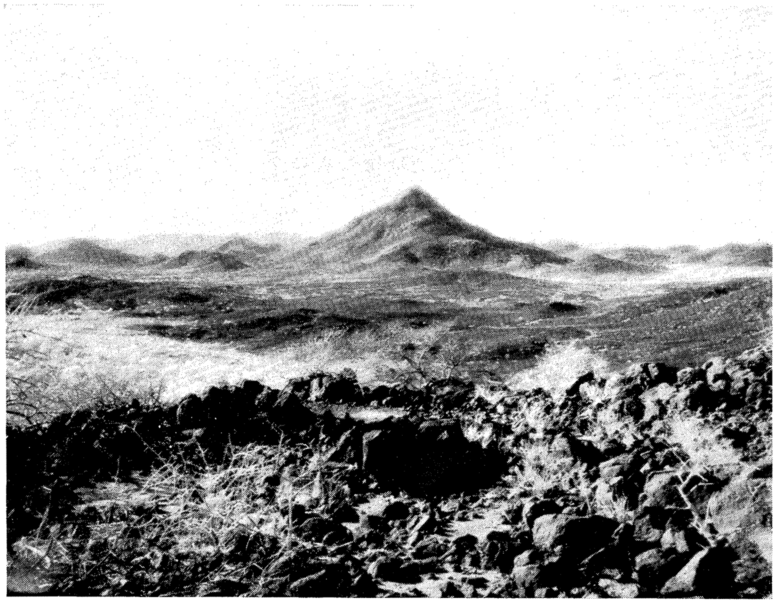


Fig. 17. Lodwar Hill from the south (infra red).

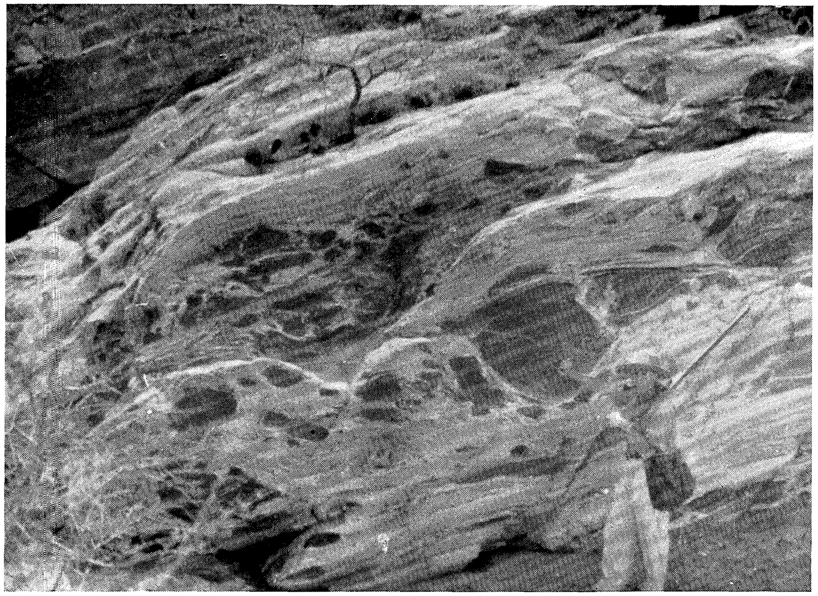


Fig. 18. Huge augen structure at the north end of Lubar escarpment.

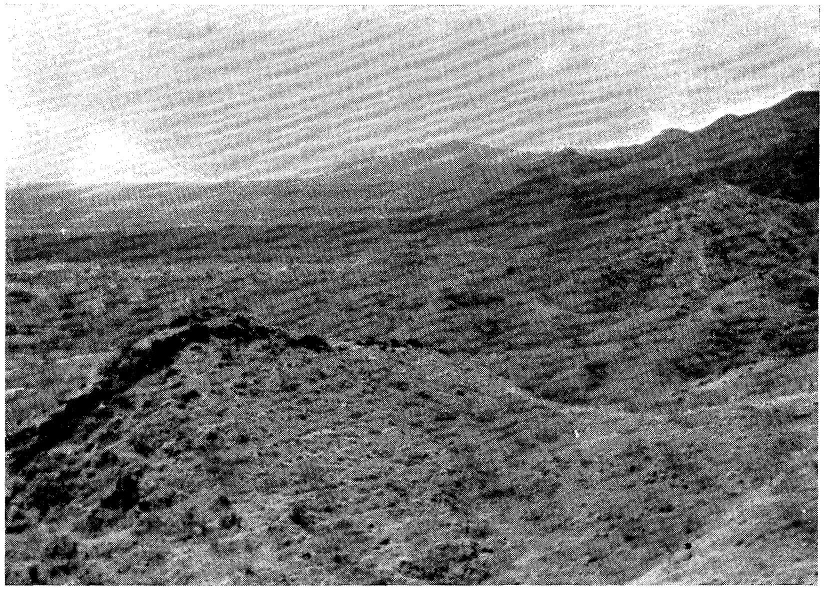


Fig. 19. The "dyke" in Turkana Grits near the foot of the Lubar scarp east of Signal Hill.

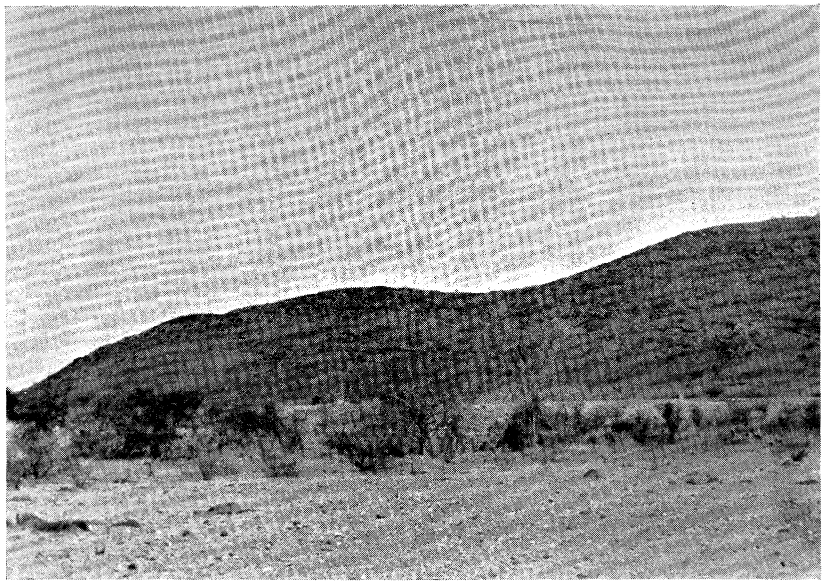


Fig. 20. Folded Turkana Grits, Akim Hill.

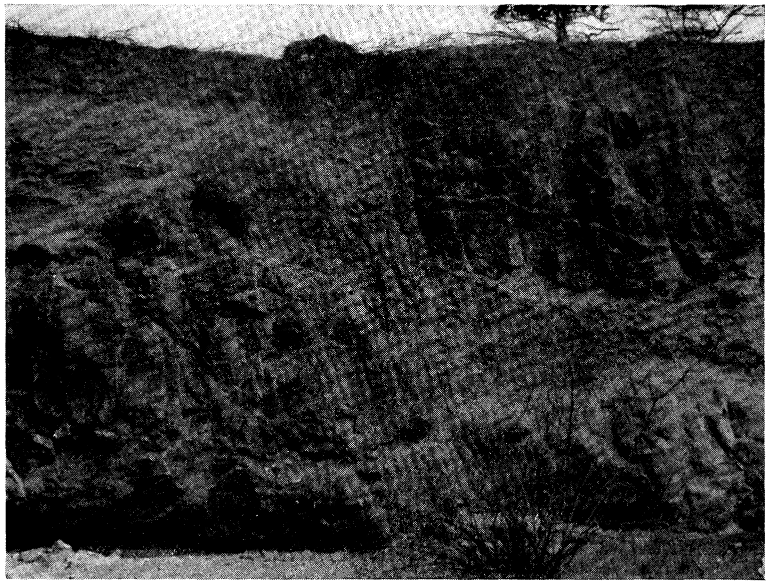


Fig. 21. Reversed fault in basalts at Kakalai.

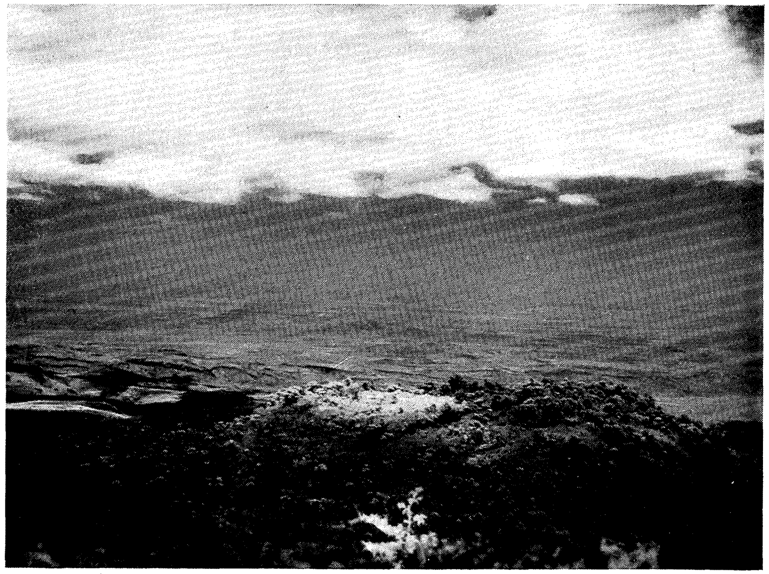


Fig. 22. Looking west down the dip slope from Kaitherin Peak to Lotogipi (infra red).

Fig. 23. Looking towards Lokitoi from above Naramum Post (photo by D. R. Buxton).

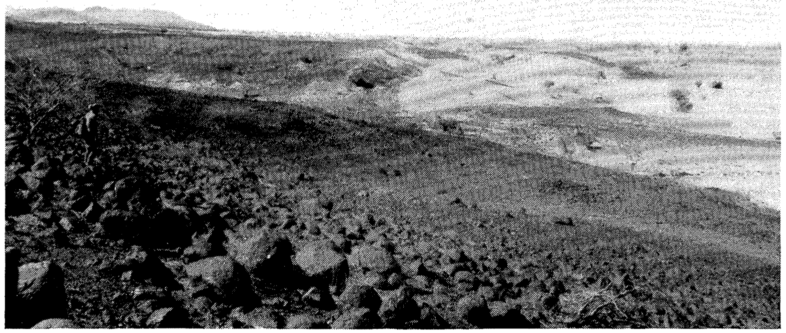


Fig. 24. Lake beaches on the east flank of the Lodwar Hills, 30 miles from the lake.

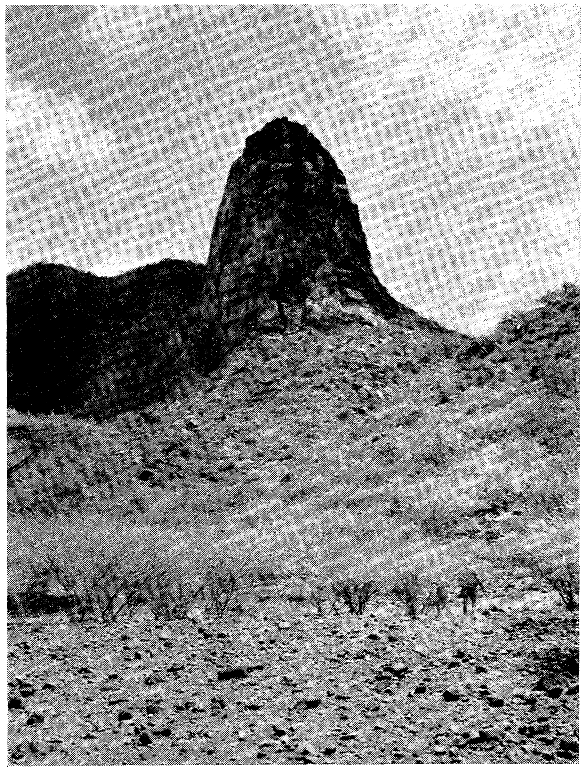


Fig. 25. Dome Rock (Capel Dome) (photo by W. R. H. Martin).

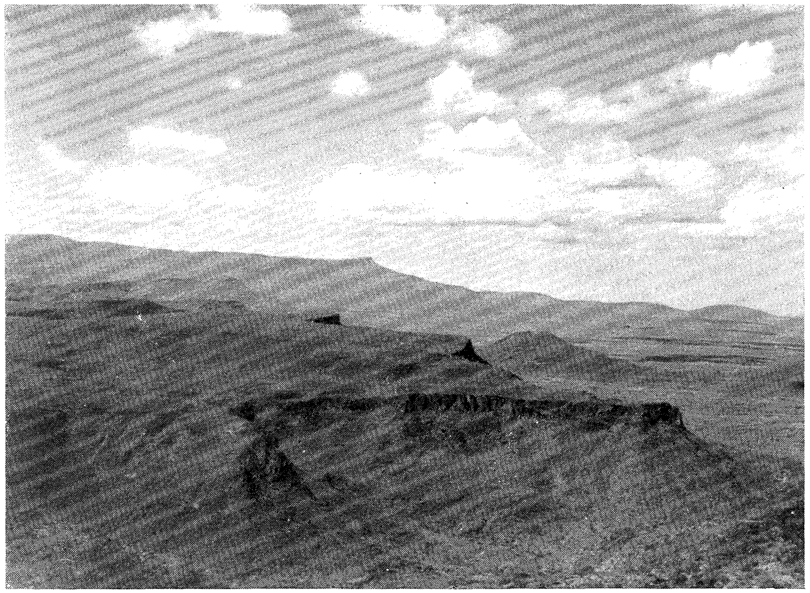


Fig. 26. The southern end of the Muruanisigar Range from the top of Dome Rock (photo by W. R. H. Martin).

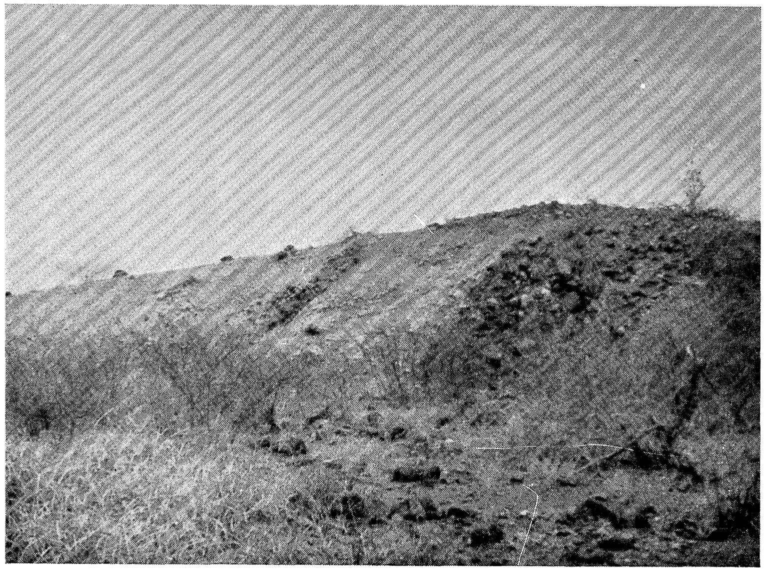


FIG. 27. Boulders of the Valley floor caught up in folds in the tuffs, north of Lokitoi Post.

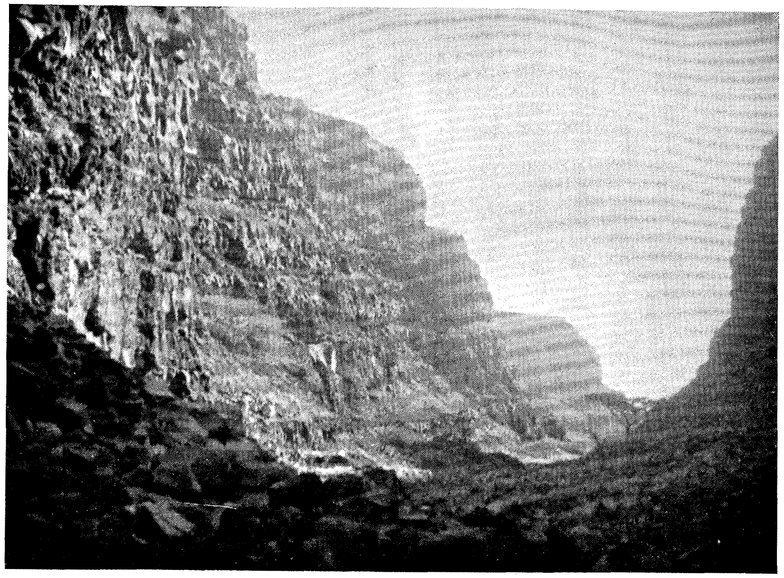


FIG. 28. The basalts of Sirima Gorge.

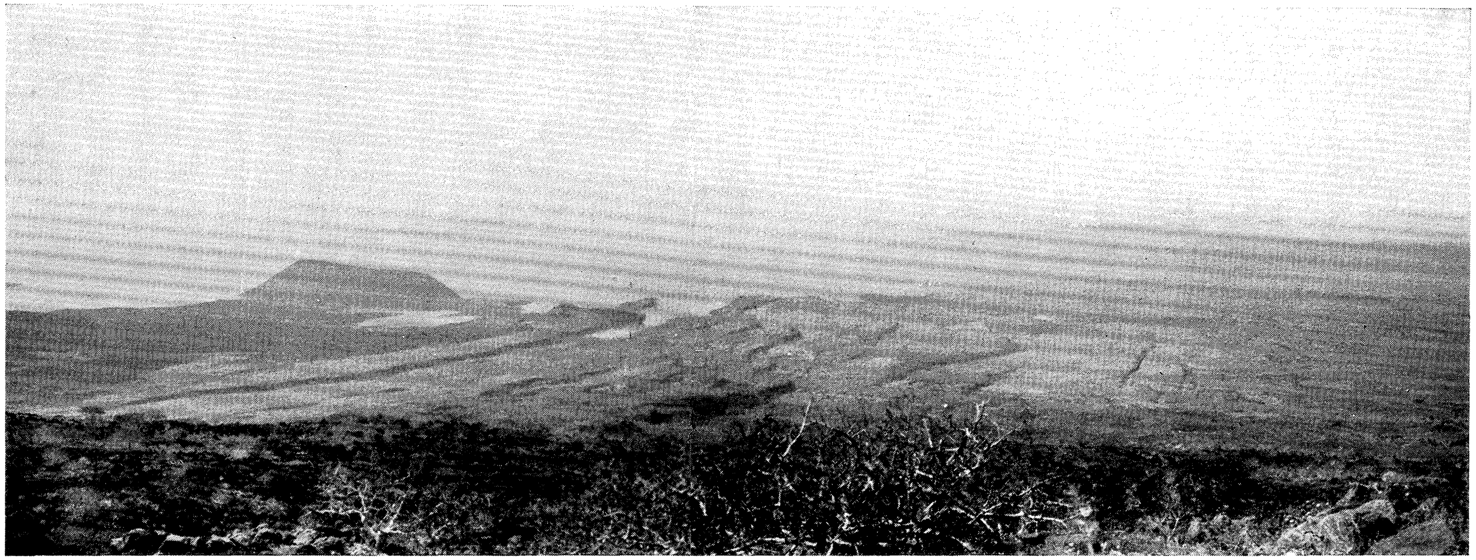


FIG. 29. The southern shore of Lake Rudolf from the Barrier Range, showing Nabuyatom Cone and the faults cutting the lower lavas: on the west can be seen the black lavas from Teleki's volcano.

FIG. 30. Martin Island from the top of Höhnel Island whose lava slopes are seen in the foreground. Mt. Kulal (7500 ft.) in the distance.

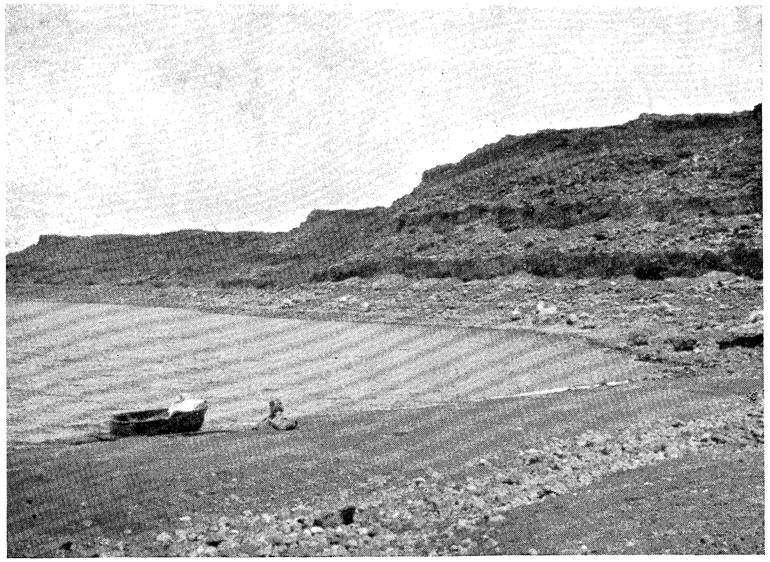


FIG. 31. The lava escarpment in North-East Bay, Höhnel Island.

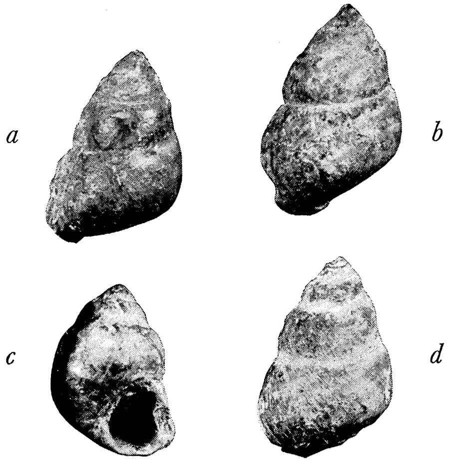


FIG. 32*a–d*. *Viviparus unicolor*, var. *rudolfianus*. (Nat. size.)

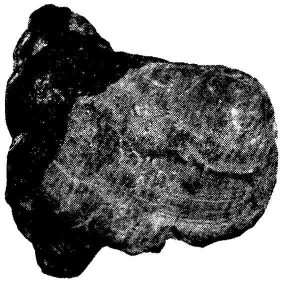


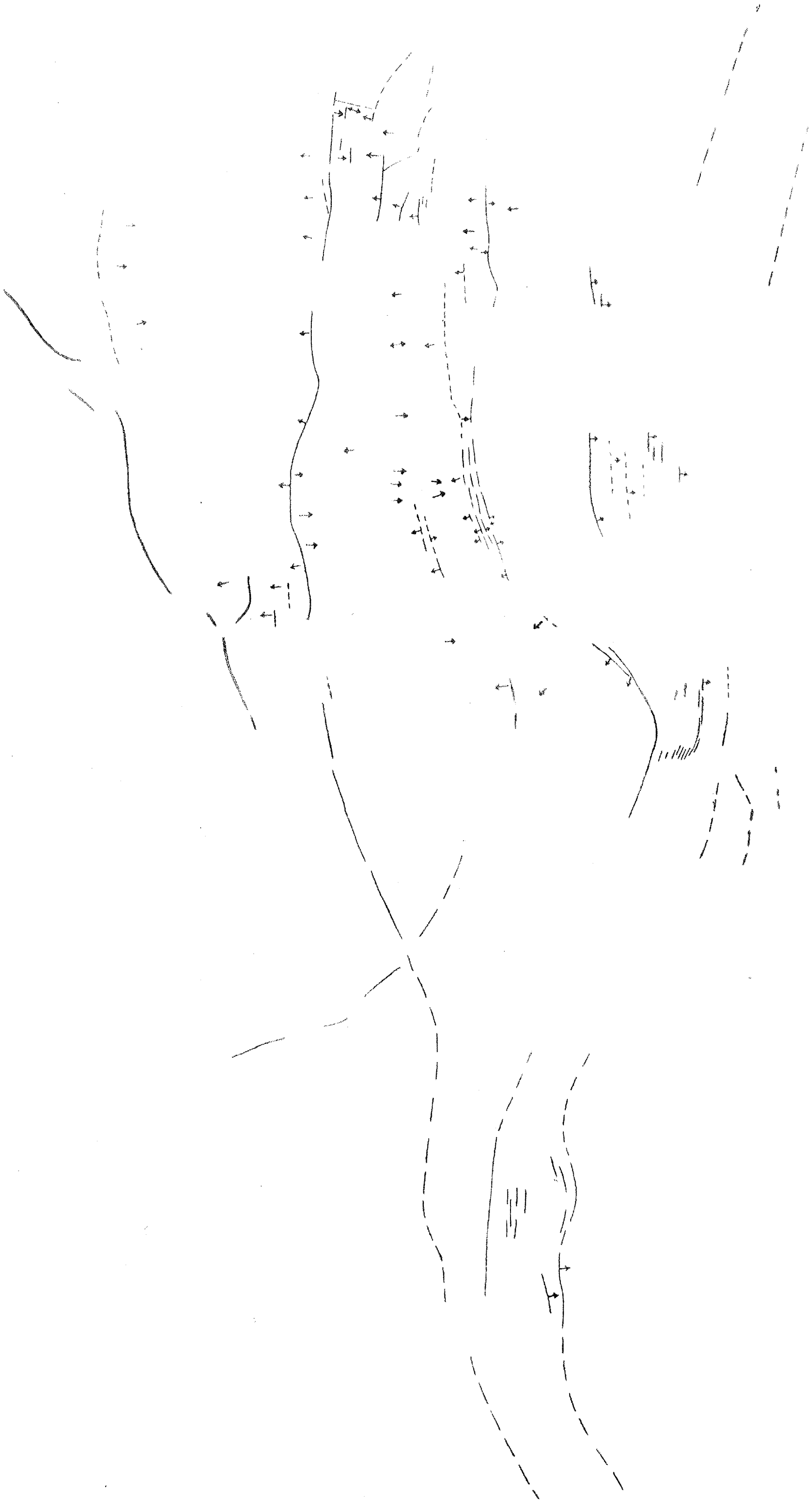
FIG. 33. *Unio* (*Grandidieria*) *abruptus*. × 2.

PROVISIONAL GEOLOGICAL MAP OF THE LAKE RUDOLF BASIN

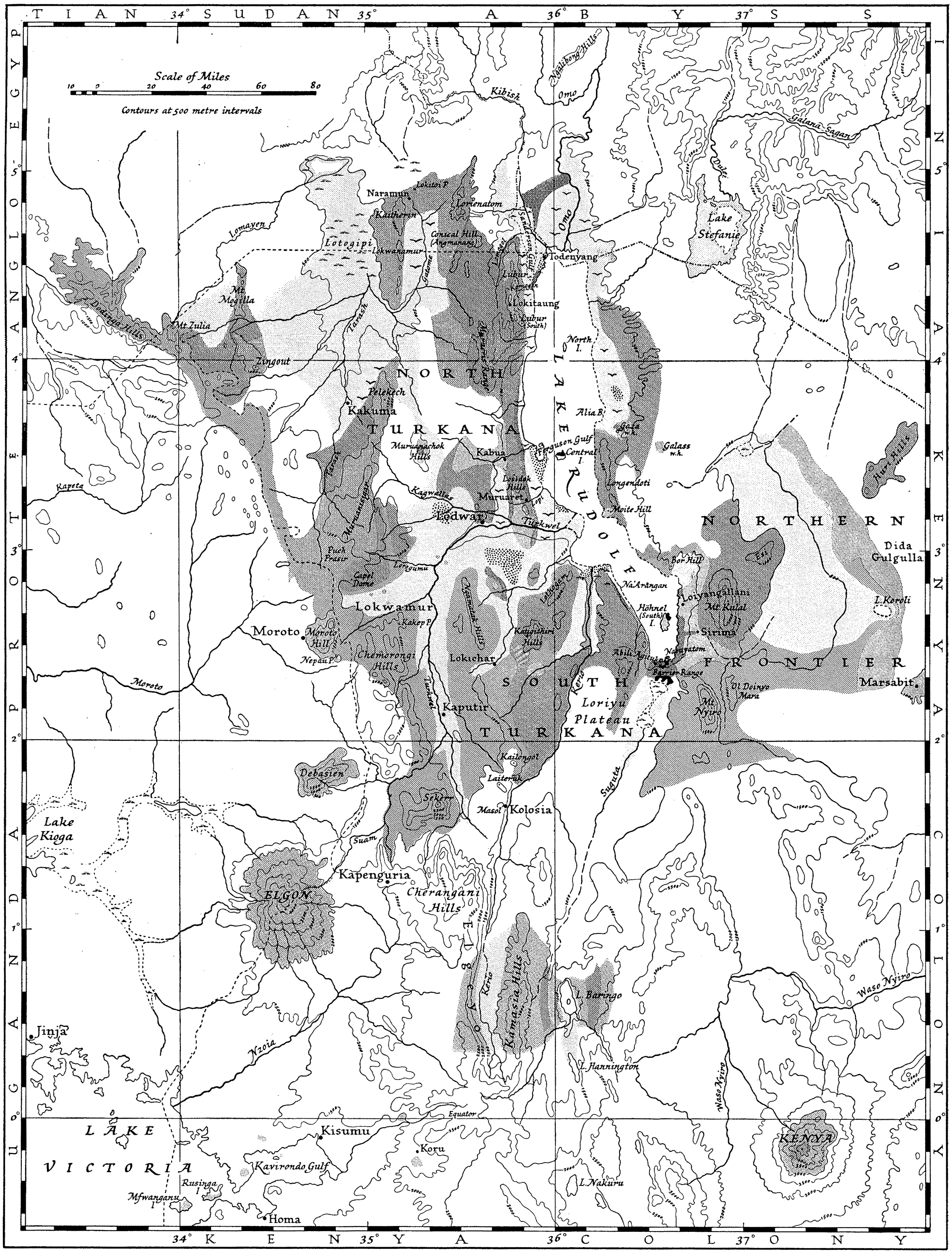
Recent	■	Recent basalts and ashes
	▒	Undifferentiated alluvial deposits
	░	Wind blown sand (dunes)
Pleistocene	░	Late Middle and Upper Pleistocene lake beds
	▒	Upper Pleistocene basalts
	▓	Lower and early Middle Pleistocene lake beds
	▓	Lower and Middle Pleistocene lavas (Trachytes and basalts)
Miocene	▓	Rhyolites
	▓	Basalts, nephelinites, phonolites
	▨	Interbedded Grits, Magnesian Limestones and nephelinites
Oligo-Miocene	▒	Turkana grits, Nyasan lake beds (Baringo) Lower Miocene Limestones, etc., of Kavirondo
Oligocene	▒	Doinyan of Gregory (Bavingo) (Elgon, Debasien, Moroto volcanics ?)
Archaean	▤	Basement complex series (schists, gneisses)
	———	Faults
	←	Dips

Compiled from observations made during the Cambridge Expedition 1931, the Lake Rudolf Rift Valley Expedition, 1934, and from information supplied by Mr A. M. Champion.

ERRATUM. The small patch in the Muruanachok Hills should have been coloured to represent Miocene basalts, etc.



PROVISIONAL GEOLOGICAL MAP OF THE LAKE RUDOLF BASIN



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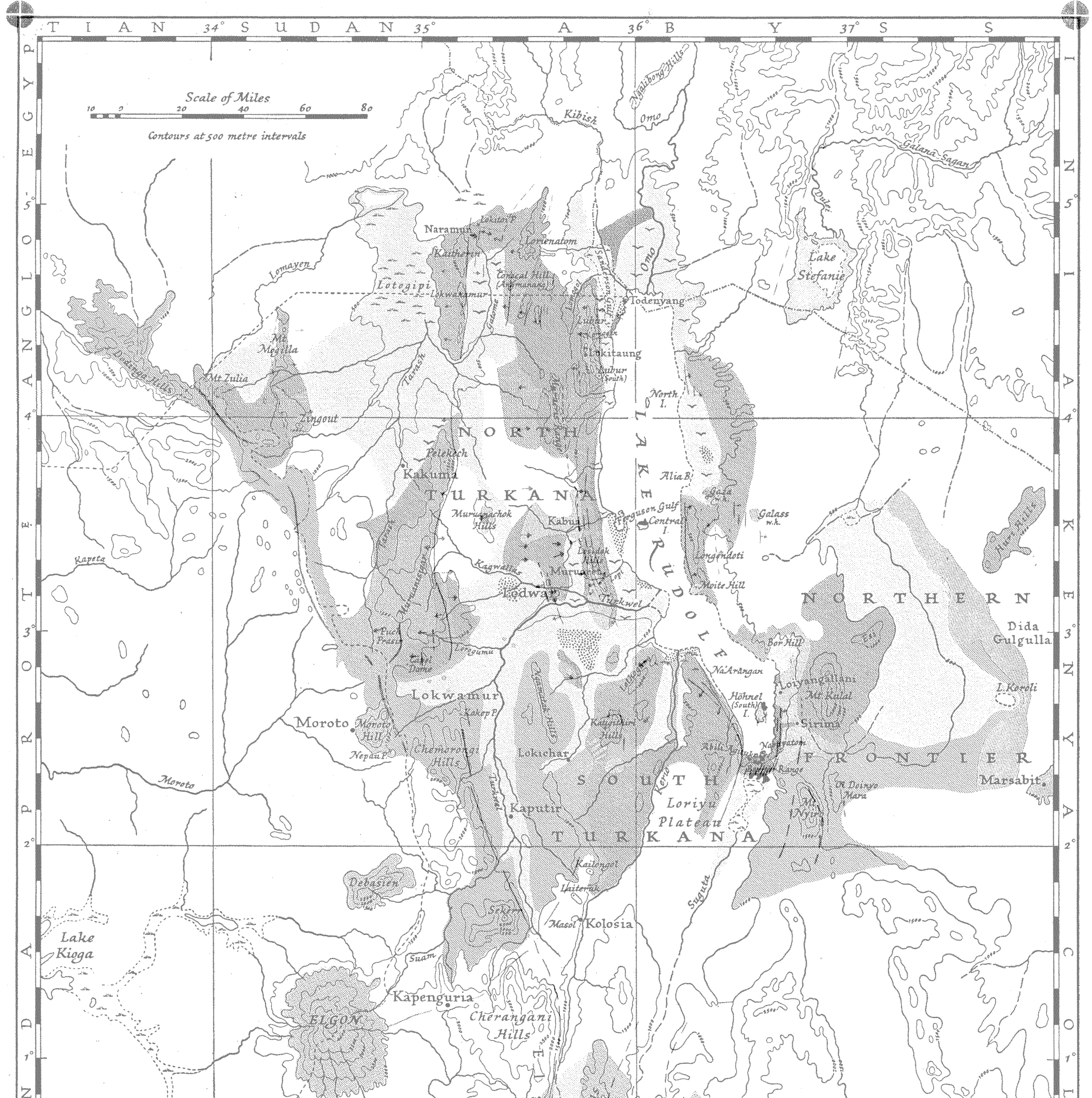


FIG. 15. The Turkana peneplain with the Ngamatak Hills 40 miles distant (infra red).

Fig. 16. The Lubar scarp looking south (photo by W. R. H. Martin).

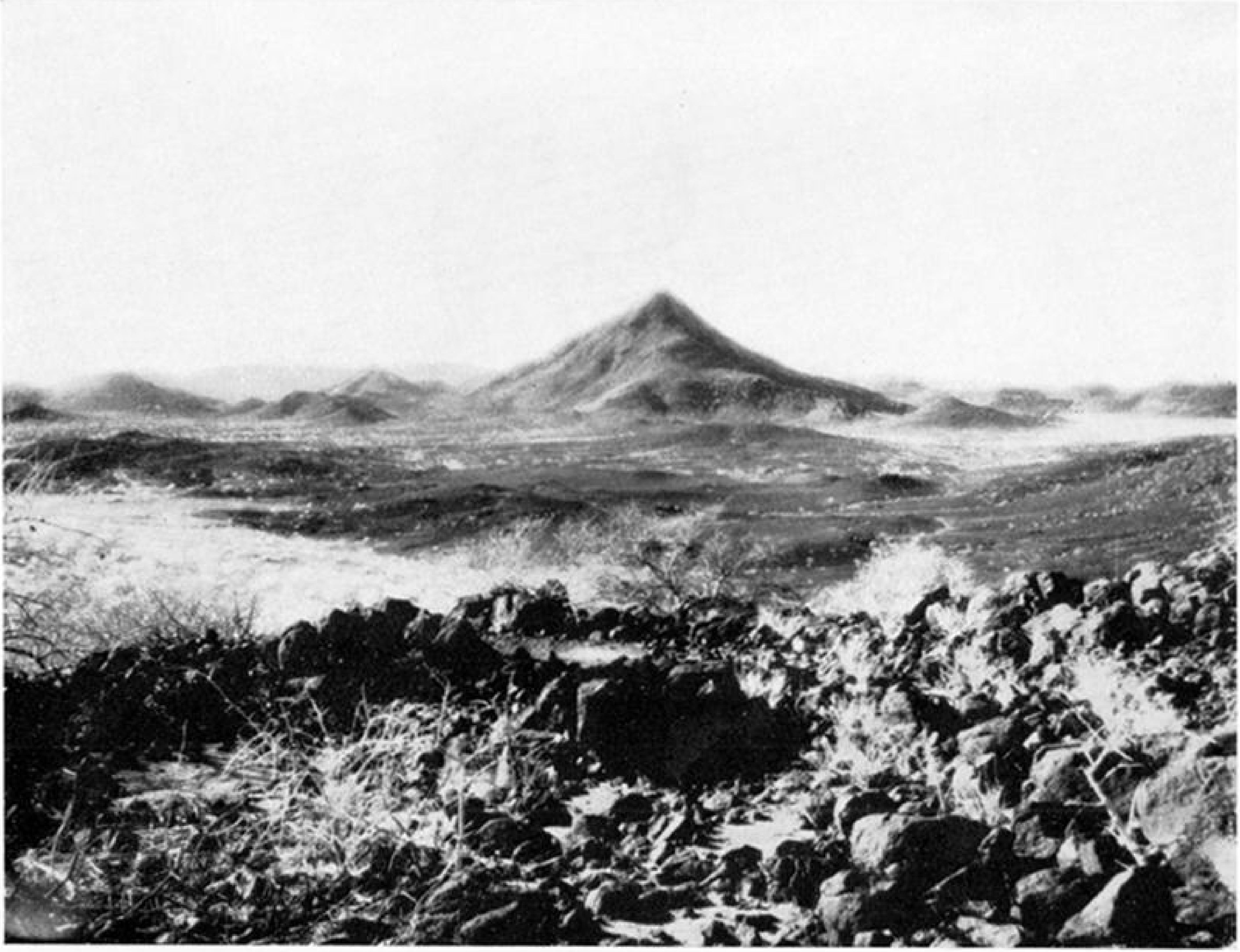


FIG. 17. Lodwar Hill from the south (infra red).

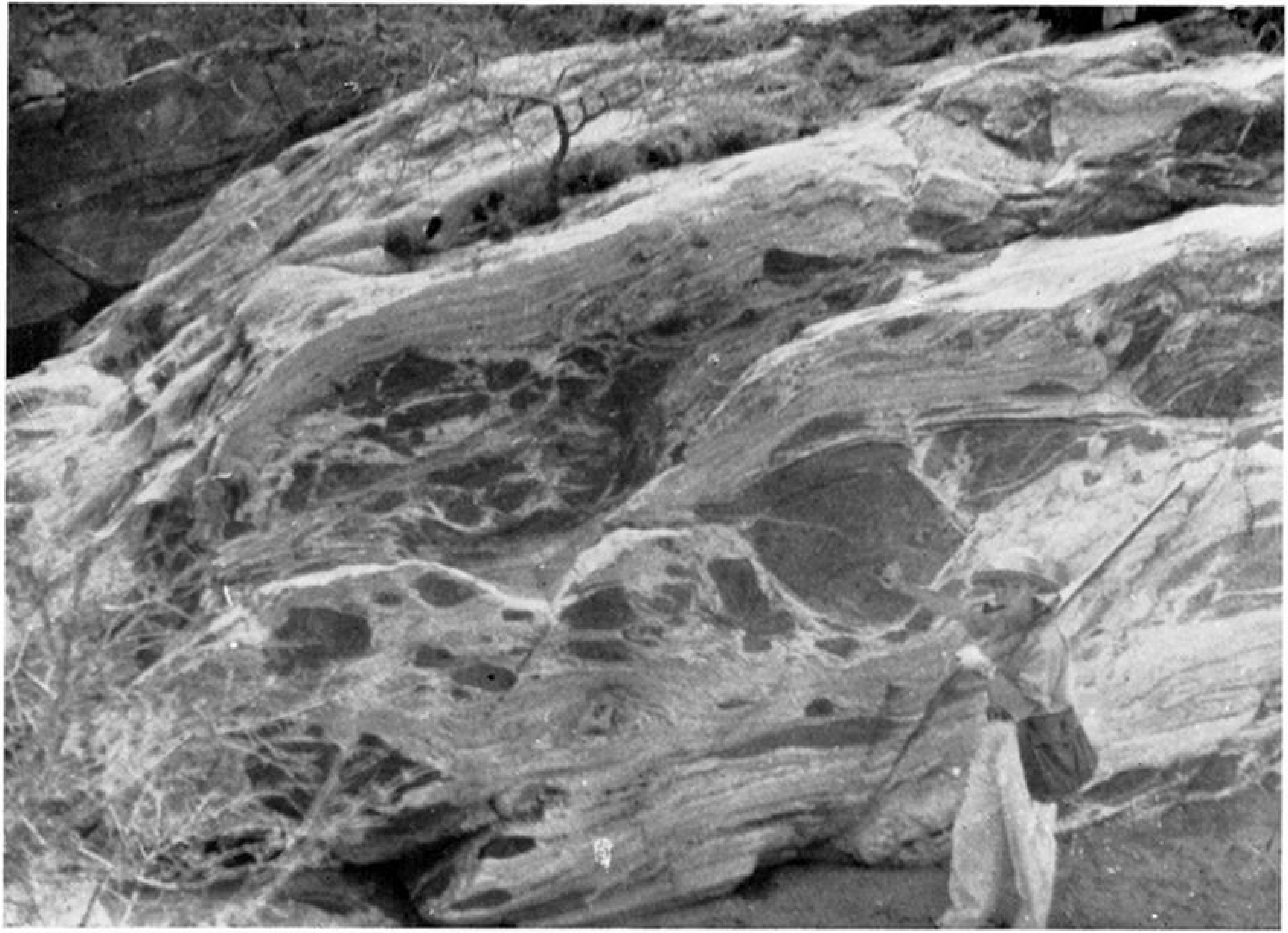
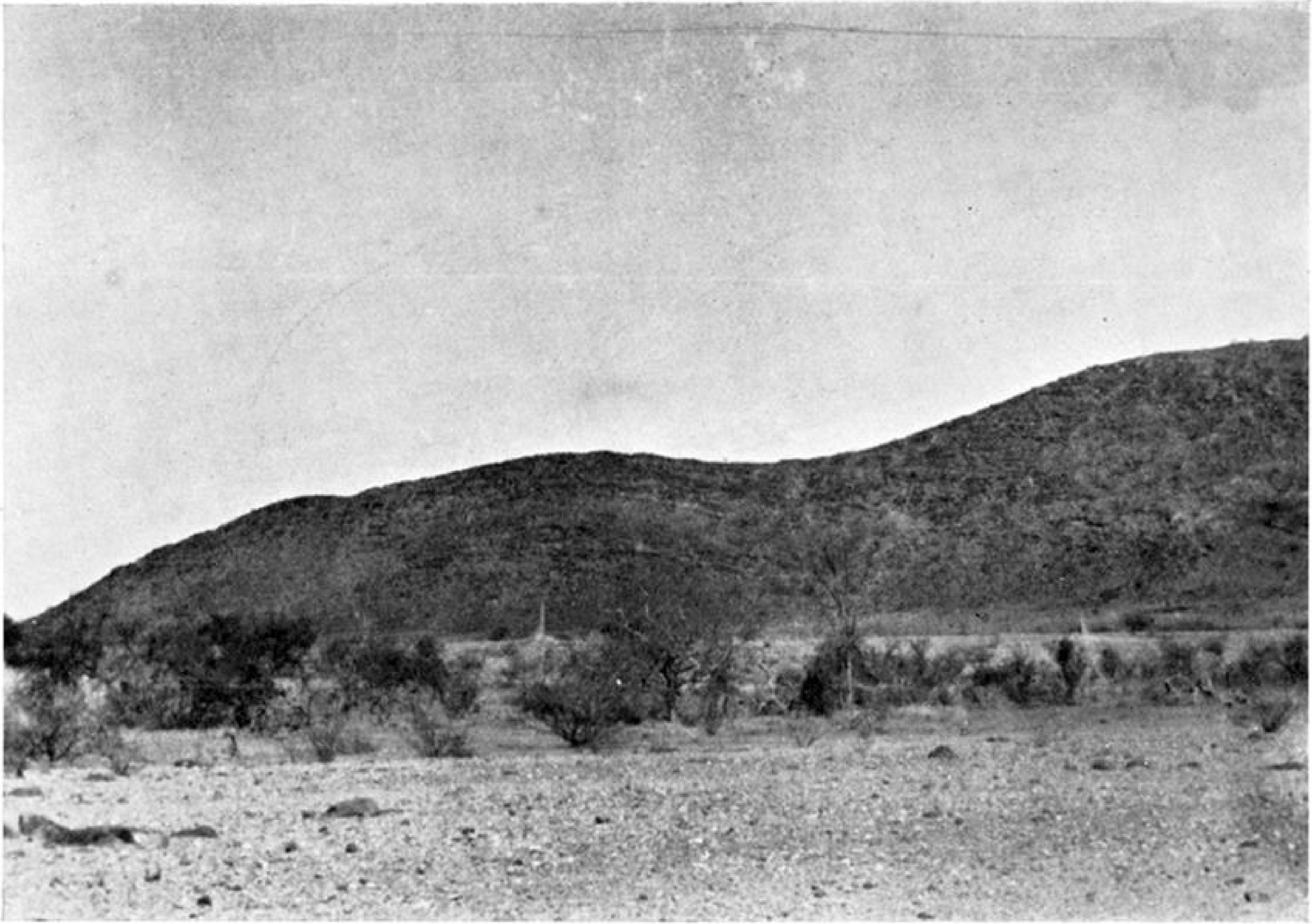


FIG. 18. Huge augen structure at the north end of Lubar escarpment.

FIG. 19. The "dyke" in Turkana Grits near the foot of the Lubar scarp east of Signal Hill.



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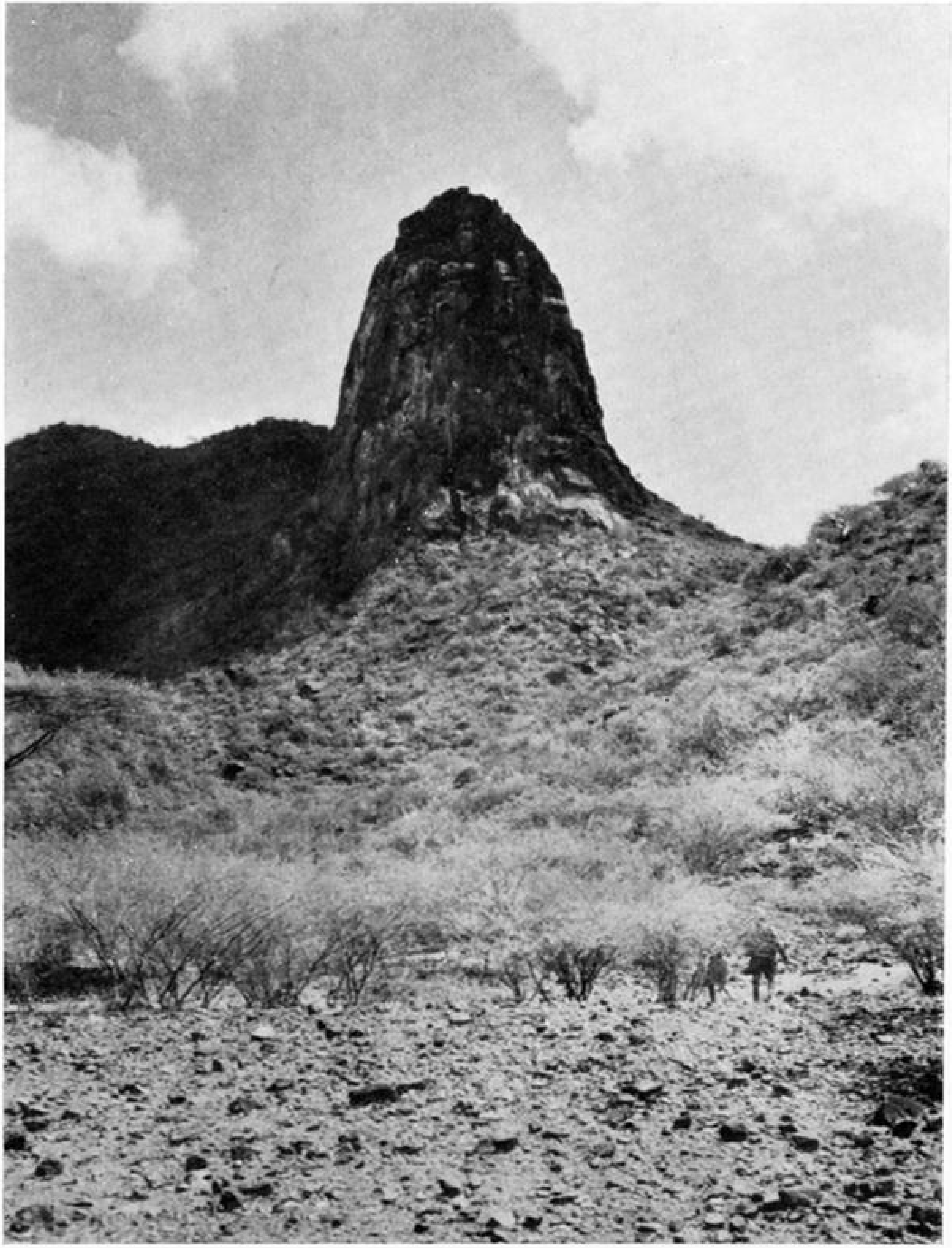

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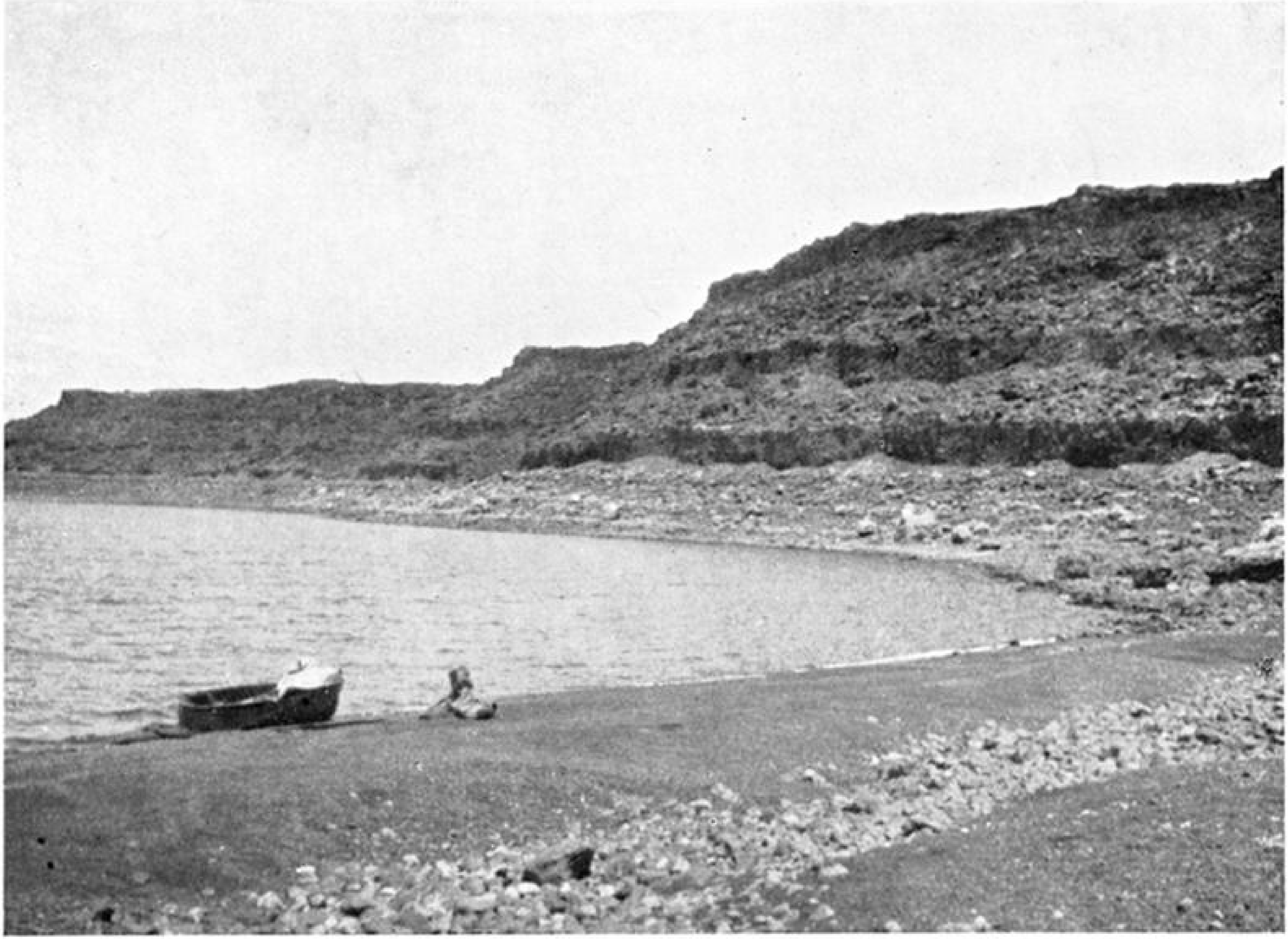

FIG. 31. The lava escarpment in North-East Bay, Höhnel Island.

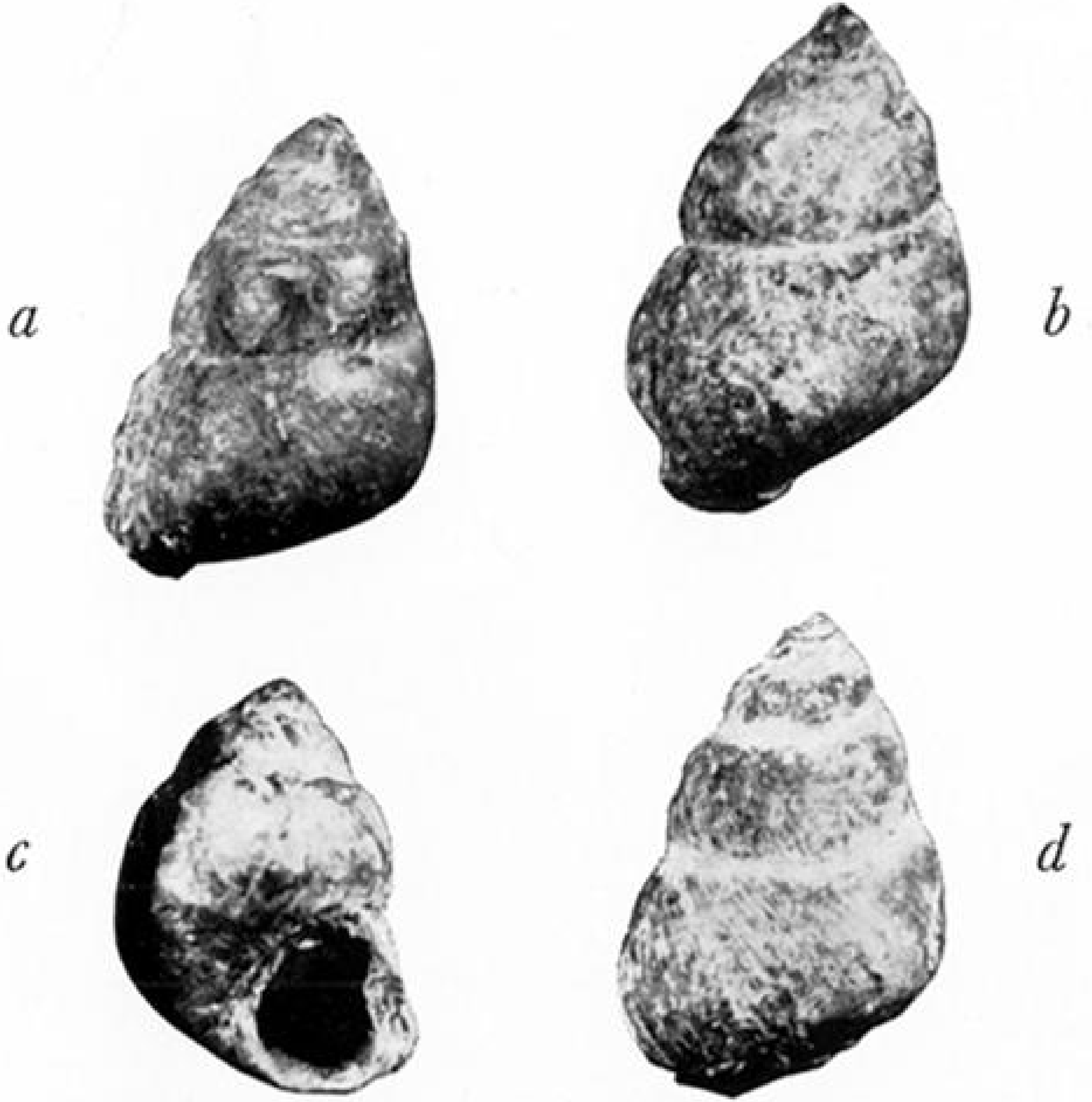

FIG. 32*a–d*. *Viviparus unicolor*, var. *rudolfianus*. (Nat. size.)

FIG. 33. *Unio (Grandidieria) abruptus*. × 2.

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	🟪	Lower and Middle Pleistocene lavas (Trachytes and basalts)
Miocene	🟧	Rhyolites
	🟫	Basalts, nephelinites, phonolites
	▨	Interbedded Grits, Magnesian Limestones and nephelinites
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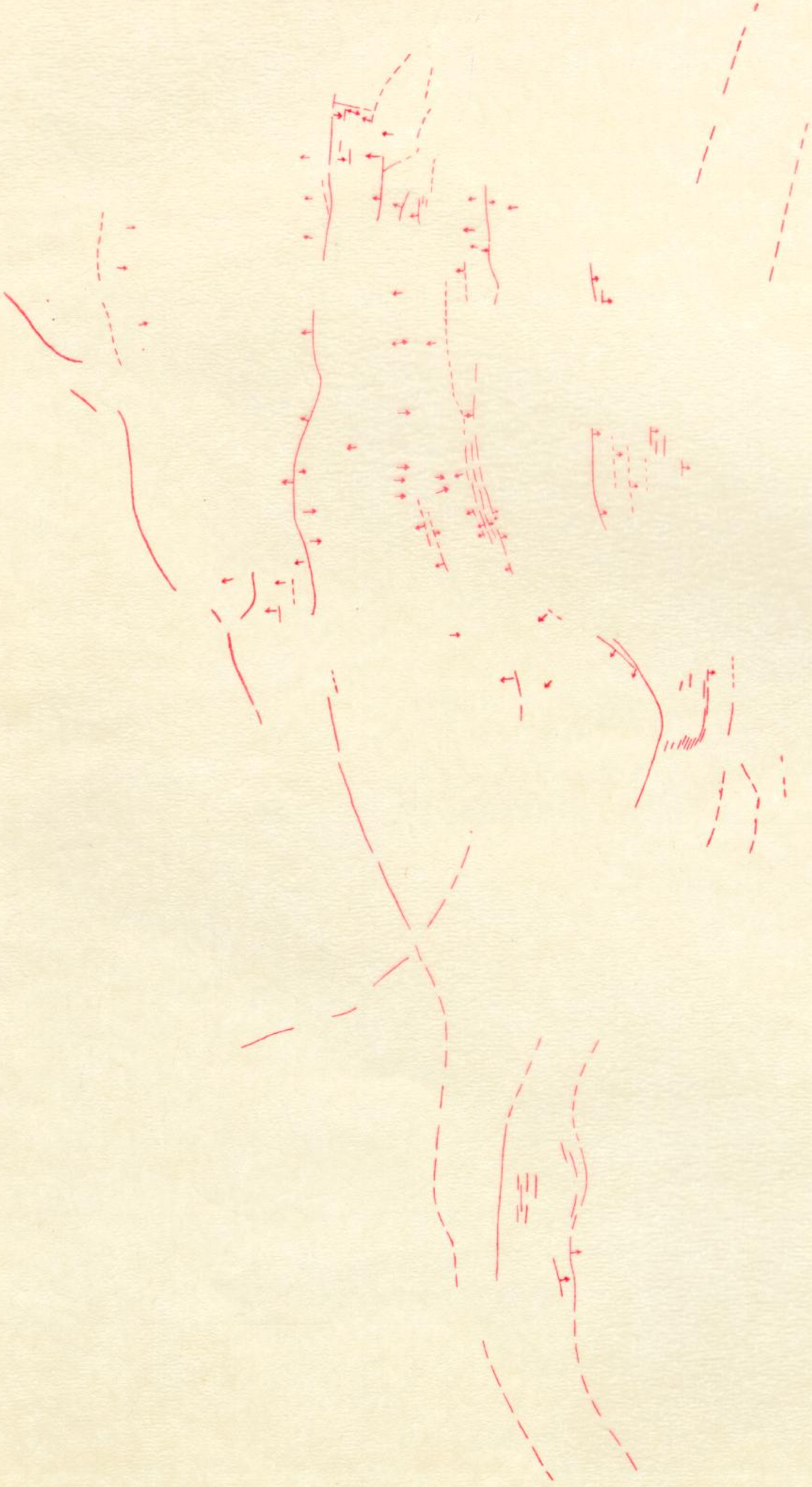
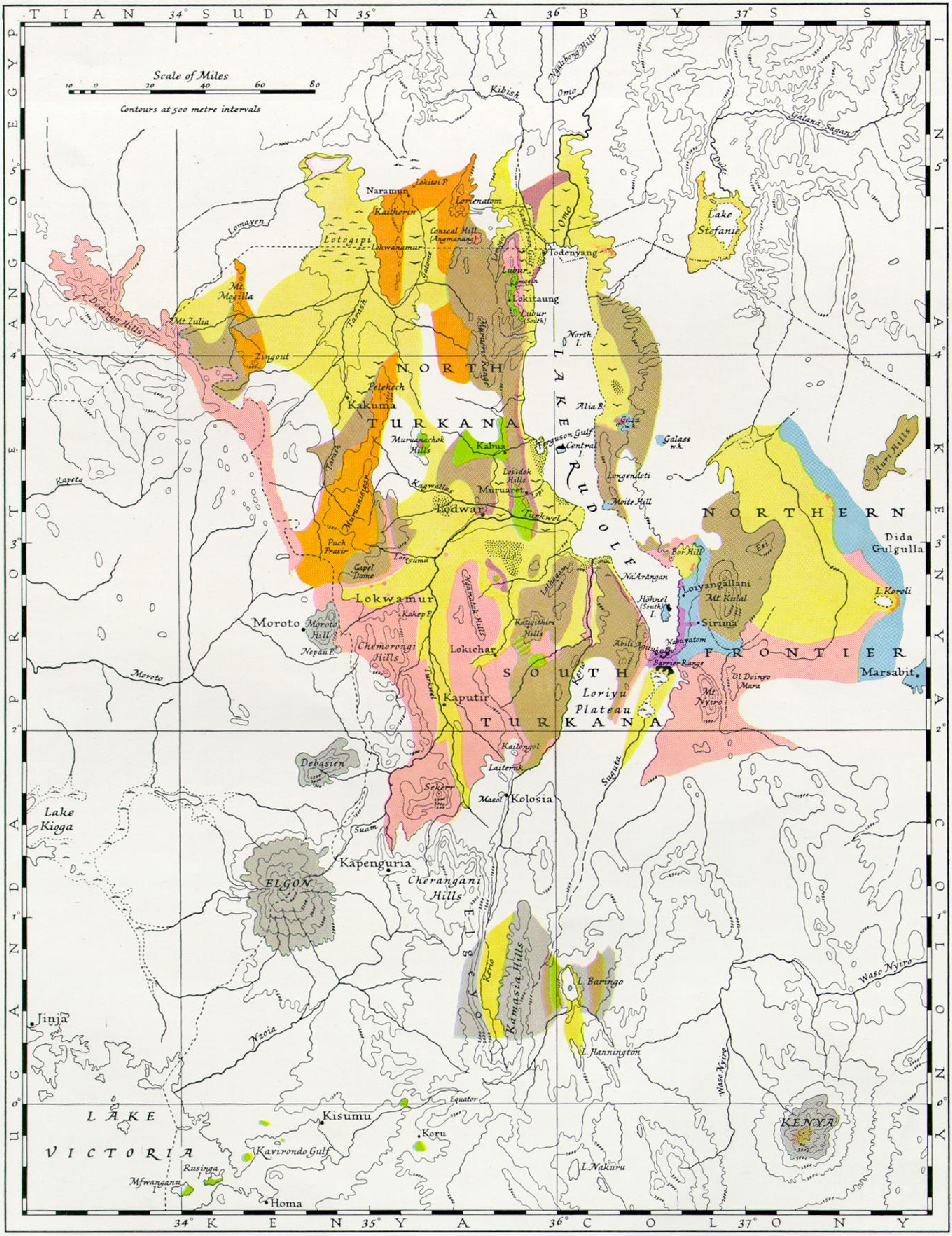


PROVISIONAL GEOLOGICAL MAP OF THE LAKE RUDOLF BASIN



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