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GEOLOGY OF THE AMBOSELI AREA

DEGREE SHEET 59, S.W. QUARTER
(With coloured geological map)

by

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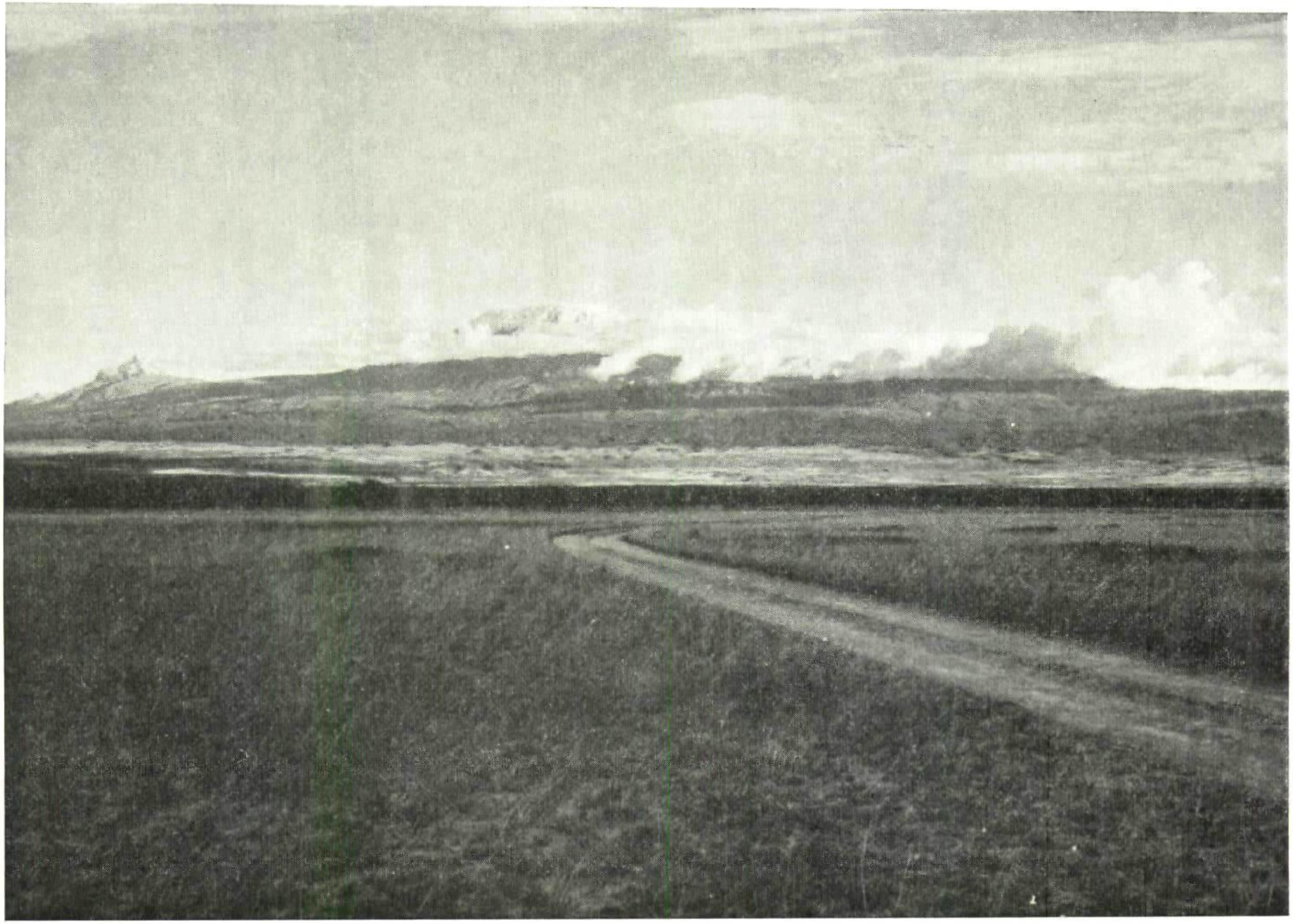

Mt. Kilimanjaro from the plains south of Ol Tukai. Snow-covered Kibo is the most recently active volcanic centre. Mawenzi (extreme left) is an eroded earlier centre. The surface in the foreground is formed by the Ol Tukai Beds

[*Frontispiece*

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ABSTRACT

The report describes the geology of an area of about 730 square miles situated in southern Kenya at the foot of Mt. Kilimanjaro. It is enclosed by longitudes 37°00′ and 37°30′E, latitude 2°30′S and the Kenya-Tanzania border. Hills in the north preserve relics of the end-Cretaceous and sub-Miocene erosion bevels, and intervening plains are part of the end-Tertiary erosion surface.

Precambrian gneisses, schists, migmatites, granulites and crystalline limestones at least 14,000 to 20,000 feet thick are exposed in the northern parts of the area. Mineral assemblages in these metasediments conform in general to the lowest part of the almandine-amphibolite facies of regional metamorphism. Complex structures result from culminations and depressions along the axes of large recumbent folds.

Pliocene to Recent volcanic rocks which attain a maximum thickness of some 3,400 feet within the area were derived from Mt. Kilimanjaro and associated parasitic vents. The earliest lavas are basalts and subordinate nephelinitic varieties, whereas the younger rocks are mainly rhomb porphyries, phonolites and trachytes. Chemical variations distinguish a strongly alkaline series from one of more mildly alkaline character.

Pleistocene lake sediments several hundred feet thick are chiefly clays, marls and impure limestones; sandy and pebbly deposits represent fluviatile facies. Quaternary superficial deposits comprise windblown silts and sands, and a variety of soils.

For some years meerschaum has been extracted from the lake beds and used in the manufacture of smoking pipes of high quality. The occurrences are described and a short account is also given of sepiolitic clays, water supplies and of the few indications of economic rocks and minerals in the Precambrian formations. The results of a special investigation of gaylussite deposits are incorporated in the report.

GEOLOGY OF THE AMBOSELI AREA

I—INTRODUCTION

General information—For the purpose of this report, the Amboseli area is defined as the Kenya part of the south-western quarter of Degree sheet 59. It covers some 730 square miles, and is bounded by the meridians 37°00′ and 37°30′E, the parallel 2°30′S and the Kenya-Tanzania boundary. The area includes a large portion of the Masai Amboseli Game Reserve, which has become popular on account of the abundance and variety of wild game, and takes its name from Lake Amboseli, a 13-mile-long featureless dusty plain that bears a few inches of water only during rainy seasons.

The Amboseli area is dominated by snow-capped Kilimanjaro, the highest mountain in Africa, with Uhuru Peak standing 19,340 ft. above sea level. The summits and crater of Kilimanjaro are situated in Tanzania, but the Amboseli area embraces the lower foothills of this impressive central type volcano which rises over 15,000 ft. above the surrounding plains.

Most of the field work was carried out between October 1959 and April 1960, and brief return visits to the area were made in 1963 and 1966. F. J. Matheson took up an investigation of the clays in the Amboseli area in 1963, and his results are incorporated in this report.

Preliminary petrological studies were completed in 1960, but more detailed work was carried out in subsequent years (Williams, 1967). Chemical analyses of four lavas were undertaken by the Geological Survey in 1963; other new analyses were provided in 1966, utilizing a research grant from University College, Nairobi.

Maps—Two preliminary plots prepared by the Survey of Kenya on a scale of 1:50,000 covering that part of the area north of 2°45′S were available for use in the field. These maps were uncontoured and showed only the limited details visible on air photographs taken in 1950, i.e. before the construction of most of the roads and tracks in the area. Additional topographic information and all geological detail were plotted on air photographs in the field and subsequently transferred to the maps, final reduction being accomplished by a photographic process. At the time of the survey no maps of a suitable scale were available to cover the country south of latitude 2°45′S and a sheet was prepared by photographically reducing a controlled mosaic of air photographs. Some distortion can inevitably be expected towards the higher ground near the Tanzania border, but the final map agrees surprisingly well with the adjacent Tanzania geological sheet which was published after the completion of the present work, and with recently published 1:50,000 contoured maps; these were released after the Amboseli sheet had been drawn, and in view of the fair measure of agreement no modification to the writer's map was considered necessary.

Form lines were drawn largely from spot-heights recorded with an aneroid barometer, a correction being made for diurnal variation. Across the flat-lying parts of the Amboseli basin accurate contouring with an aneroid is impossible and the lines shown on the map should be regarded as approximate only. Levelling along several lines was carried out by members of the Ministry of Works during an investigation of water supplies. One traverse proved a fall of 286 ft. from the Legumi Springs near the Namoloc Swamp to a point at the causeway near the north-eastern corner of Lake Amboseli. Intermediate stations along this line are not recognizable with certainty from the leveller's records and the information is of limited value. East-west levelling across Lake Amboseli showed that the surface is virtually flat and that it lies at an altitude of 3,686 ft. (taking the elevation of Meshanai Beacon to be 3,991 ft. above sea level).

The Amboseli area is now covered by a 1:250,000 sheet (SA-37-9) first published in 1965.

Communications—Those parts of the Amboseli area not underlain by lava are readily traversed by motor vehicles, hence its great popularity among visitors in search of game animals. The perfectly flat surface of Lake Amboseli itself provides a fast and comfortable line of communication in dry weather, but it becomes completely impassable to motor transport during rainy seasons when the clays support a shallow sheet of surface water.

Ol Tukai, with its two lodges, tented camp, camping ground, small shop and petrol supplies, is approached by two dry-weather roads, both of which are regularly used by visitors to the game reserve. The western route (150 miles from Nairobi to Ol Tukai) branches from the main Nairobi-Tanzania road at Namanga, circles beneath the Ngorigaishi Hills and cuts across the northern end of Lake Amboseli, with a detour around the margin of the lake available for use in wet weather. The Namanga gate into the reserve is open from 6 a.m. to 5.30 p.m. daily during the open seasons (1st June —31st October and 16th December—31st March). The alternative route links Ol Tukai with Sultan Hamud and Emali, both trading centres on the Nairobi-Mombasa trunk road; joining the road from Loitokitok about a mile beyond the eastern boundary of the area under discussion. The Leme Boti gate near the Loitokitok road is open from 6 a.m. to 5.30 p.m. The distance from Nairobi to Ol Tukai via Emali is 142 miles. A slightly shorter route via Sultan Hamud involves travelling along the East African Railways and Harbours pipeline road.

The meerschaum mine at Sinya, situated at the southern end of Lake Amboseli, is best approached by a rough track which branches from the Ol Tukai road some 10 miles from Namanga. Like many other tracks in the area, the route to Sinya should be used only in dry weather, the final few miles becoming impassable to any motor vehicle after heavy rain.

A little-used track to Kajiado via Lengesim branches from the wet weather road which follows the northern margin of Lake Amboseli; this route is not recommended as a normal approach to the game reserve. Similarly, the short route to Loitokitok from Ol Tukai should not be attempted by strangers to the area since in places the track is only poorly defined.

Several roads and tracks, constructed to provide a link between sawmills on the Kilimanjaro forest line and the rail-head at Emali, cross the volcanic rocks in the south-eastern corner of the Amboseli area. All these routes branch from the Loitokitok-Emali road between the Sinet and Kimana streams, a few miles east of Legumi Springs. At the time of the writer's survey of the Amboseli area in 1959-60 a road and a disused track led to the now-abandoned Kamwanga Sawmills situated a few miles across the border. Some time after the survey a road was constructed from the Kilimanjaro Sawmills (west of Kamwanga) to join the original route at a small hill near Lemongo Vent. This road was traversed in July 1966, and a sketched alignment is indicated on the geological map. Part of the road which once linked the West Kilimanjaro farming areas with Loitokitok is shown in the extreme south-eastern corner of the map. Travellers are warned that the section of this route between Kamwanga and the Kilimanjaro Sawmills is now motorable only with difficulty.

The central portion of the Amboseli area is covered by a confusing network of tracks. Only the more important ones are shown on the map, and even these are subject to frequent minor changes. Most of the tracks radiate from Ol Tukai and lead either to the surrounding permanent swamps, where the greatest concentrations of wild animals occur, or to local boreholes. West of Ol Tukai a narrow stretch of water at the end of the Engong Narok swamp is crossed by a causeway and small bridge. From this point a number of tracks spread out and lead to the Kitirua swamps, Lake Amboseli, Sinya, Ol Barengoi borehole, Normatior ("Observation Hill") and the Simek Furrow.

Climate—The greater part of the Amboseli area falls within a rather arid zone of south-central Kenya having a mean annual rainfall of only 10-20 in. (25.4-50.8 cm.). The 20 inch-per-year isohyet passes across the rising ground in the south-eastern corner of the area, reflecting the proximity to the high-rainfall area of Mt. Kilimanjaro.

Two rainy seasons are well defined: one extends from March to April, the other occurs in November-December. The wettest month is November, 4-8 in. (10.2-20.3 cm.) of rain falling on the plains, and 8-12 in. (20.3-30.5 cm.) across the foothills of Kilimanjaro. The mean rainfall in April is 4-6 in. (10.2-15.2 cm.), and in March and May about half this amount. The driest months are June to October, falls seldom totalling more than 0.5 in. (1.3 cm.) in those months.

II—PREVIOUS GEOLOGICAL WORK

Although situated at the foot of Mt. Kilimanjaro, an obvious attraction to many of the early travellers in the country, the Amboseli area was generally avoided by East African explorers. This was partly due to the rather arid nature of the surrounding country but perhaps mainly because of the hostile attitude of the local Masai.

In 1883 however, Joseph Thomson (1887)* travelled across the Amboseli area from west to east during the "Lytokitok" to "Donyo Erok" stage of his journey farther into the interior. On his map showing the route followed, Thomson applied the name Ngiri to this part of the country and indicated the swamps; the area was described on the map as "Sandy waste covered with water in wet season". E.A. Loftus (1951), in an account of Thomson's travels in East Africa, merely mentioned (p. 46) that the route lay across the "Njiri" plain to Donyo Erok, and there is no further description of the country traversed.

In 1951, N. J. Guest (1951, 1955) mapped the Tanzania part of the Sinya area and recorded the occurrence of meerschaum at the southern end of Lake Amboseli. Though confined to a description of the geology in Tanzania, his observations are relevant since the geological setting is identical to that encountered on the Kenya side of the border. Guest (1955, p. 2) provided the following stratigraphical succession for the Sinya Wells area:—

7. Recent argillaceous lake deposits.
6. Post-Pluvial Kilimanjaro rhomb-porphyry lava.
5. Post-Pluvial basalts.

——————Probable unconformity——————

4. Pluvial period lake deposits.
3. Secondary limestone deposit with meerschaum.

——————Unconformity——————

2. Crystalline limestone and dolomite.
1. Basement Complex, granitic gneisses.

During the present survey no evidence was found of lavas overlying lake deposits and the sediments were proved locally to overlie volcanic rocks or to be banked against them. Guest's "limestone deposit with meerschaum" (3) is clearly to be correlated with the Sinya Beds defined in the Amboseli area, and the overlying "lake deposits" (4) are equivalent to the Amboseli Clays. The "argillaceous lake deposits" (7) are perhaps to be correlated with alluvial deposits found flanking the Namanga river in Kenya.

Guest (1955, pp. 2-3) described the following well section, west of Magadini Hill and almost on the Kenya-Tanzania border:—

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* References are quoted on pp. 83-86.

	Thickness (feet)
3. Grey calcareous soil with nine inch thick band of nodular, secondary limestone; soil grades down into more calcareous mud	7
2. Greenish grey mud flecked with small calcareous nodules; three to four inch thick band of meerschaum towards the base	8
1. Secondary limestone with nodules of meerschaum	?

In the same report (pp. 2 to 4 and 8 to 10) Guest quoted chemical analyses of the rocks encountered and gave details of the determination of the true specific gravity of a meerschaum sample; calculated to the air-dry material, this was found to be 2.11. The apparent specific gravity of meerschaum is less than unity since dry samples float temporarily on water on account of their porosity. Guest concluded (p. 7) that the meerschaum is sporadically distributed in the lake beds and suggested a source of magnesium in dolomitic crystalline limestones of "Seven Sisters" Hill, situated in Tanzania.

A. P. Fawley examined Sinya Meerschaum Mine in 1955, when operations were confined to Tanzania. He found (1955, p. 2) that the mineral occurs in a folded secondary dolomitic limestone deposit and structures in the limestone were attributed to pressure from Kilimanjaro. Meerschaum appeared to follow a north-east striking zone, though a wider occurrence was expected. Meerschaum was said (p. 3) to occur as irregular and small veins that are generally lens-shaped and which vary in thickness from a fraction of an inch to 15 inches. The mineral appeared to show preferential development in areas where the host dolomitic limestones are more intensely folded, presumably because deformation provided spaces and fractures favourable to meerschaum formation. Fawley discussed the quality and classification of meerschaum and recorded the chemical composition of a number of rocks collected at Sinya. He also described the pits and the quantity of meerschaum recovered from each one and concluded (p. 10) that 1.87 lb. of meerschaum had been recovered per cubic yard of ground excavated. The figure was subdivided as follows:—

First grade meerschaum	0.47 lb. per cubic yard
Second grade meerschaum	0.75 lb. per cubic yard
Third grade meerschaum	0.65 lb. per cubic yard

P. Joubert (1957*a*, pp. 34 and 43) recorded the occurrence of bentonitic clays in the Amboseli Basin, assigning to them a volcanic origin. Partial analyses were provided for clay and surface limestone samples collected largely from the present area. In an unpublished report of the Mines and Geological Department, Nairobi the same author (1957*b*) described a further collection of clays, mostly from the Sinya District. These were subsequently examined overseas and it was reported that montmorillonite appears to be the only clay mineral present in substantial quantities. Joubert attributed folding and fracturing in the dolomitic limestones at Sinya to expansion and contraction of swelling clays during wet and dry seasons.

J. Walsh (1956) carried out a survey of Sinya Mine with the object of estimating the reserves of meerschaum in Kenya. He established the following succession:—

4. Reddish brown clay (oxidized surfaces of the dark green clay).
3. Dark green clay.
2. White hard clay with seams of meerschaum.
1. Base not seen, probably volcanics.

Walsh suggested that the meerschaum was deposited during periods when the lake was temporarily dry, and that later the deposits were intensely folded and faulted, possibly due to up-warping. The folding was believed to have caused a thickening of meerschaum seams along the axes of the folds, producing economic occurrences. He estimated that 12.4 lb. of meerschaum of all grades had been recovered per cubic yard of ground worked in Kenya up to the time of his visit, and that meerschaum of comparable quality and quantity occurs over an area of many square miles and may in fact underlie the whole of Lake Amboseli.

During 1957-58, a detailed investigation of water supplies in the Amboseli area was carried out by G. D. M. Campbell, a Ministry of Works hydrologist, and the results are set out in a number of unpublished reports. The investigation covered both ground water and surface water supplies and included a programme of shallow drilling and augering; a geophysical survey of the area was conducted by T. Bestow, a geologist of the same department. In a preliminary report Campbell (1957*a*) briefly described the general geology and water supplies of the Amboseli area. The second report by Campbell (1957*b*) included details of exploratory boreholes drilled in the north-western part of the area, between Lake Amboseli and the Ngorigaishi Hills, and a summary of the geophysical work carried out. It was concluded that a broad east-west belt of saline ground water traverses the area, underlying the central and northern parts of Lake Amboseli and the eastern and western parts of the basin. Fresh ground water is believed to flank this belt between Sinya and Ol Tukai and, to a lesser extent, around the Ngorigaishi Hills eastwards to Mesanani. Of surface water supplies, only that provided by the Olobolodi (Legumi) River was considered to be of economic value. From geophysical probes, Bestow (in an appendix to Campbell's report) concluded that Precambrian rocks appear to be covered by about 480 ft. of sediments at Lake Amboseli. Electrical depth probes in the eastern end of the basin, between Loginya and Namoloc swamps, suggested that, locally, sediments may be 600 ft. thick, resting on an irregular surface of Precambrian metamorphic rocks and possibly overlain by lava. The interpretation of the geophysical evidence from the eastern end of the basin shows little agreement with conclusions reached during the present survey.

A further report by Campbell (1957*c*) was concerned with the investigation of surface waters in the Kitenden Stream, near the Kenya-Tanzania border south of Ol Tukai. In a fourth paper the same author (1958) provided details of two exploratory boreholes, C.2804 and C.2794, drilled in the north-western and south-eastern parts of the area, and information obtained from an extensive augering programme in the basin; a number of water analyses were presented.

W. Pulfrey (1960) prepared a map to show the shape of the sub-Miocene erosion bevel in Kenya. In the Amboseli area the surface was shown at about 4,250 ft. in the north-western corner and at about 3,500 ft. along the eastern boundary of the area. A change in the direction of slope of the bevel across the Amboseli area from south-easterly to due east was indicated by the contour lines. Observations during the present survey resulted in a general eastward displacement of Pulfrey's contours for the sub-Miocene surface. The writer's views were accepted by E. P. Saggerson and B. H. Baker (1965) in a paper on the post-Jurassic erosion surfaces in eastern Kenya.

Much of the geological work carried out in the country immediately surrounding the Amboseli area, both before and after the present survey, deserves mention here since some of the information is used later in the report in discussions of stratigraphy, structure and petrogenesis.

D. L. Searle (1954) surveyed the Sultan Hamud area to the north of Amboseli, and P. Joubert (1957*a*) mapped and described the geology of the Namanga-Bissel area to the west and north-west. The Simba-Kibwezi area (Saggerson, 1963) joins the north-eastern corner of the Amboseli sheet, but the country immediately to the east of the present area has yet to be geologically surveyed.

Most of the geological work carried out in Tanzania, adjacent to the Amboseli area, has been connected with studies of Kilimanjaro. It is not the intention here to list a full bibliography, but merely to draw attention to some aspects of the previous work. Among the early explorers, H. Meyer (1900), F. Jaeger (1909) and F. Klute (1920) provided comments on the geology of Kilimanjaro. Petrological and chemical studies on the preliminary collections from the mountain were carried out by workers like J. S. Hyland (1889), L. Finckh (1902, 1906, 1914), Lacroix (1923) and F. Oates (1934), and data on felspars from Kilimanjaro were given by L. Fletcher and H. A. Miers (1887). Papers by P. C. Spink (1944) and J. J. Richard (1945) dealt with some aspects of volcanology, and N. J. Guest and D. N. Sampson (1952) gave an account of sulphur deposits in the inner crater of Kibo.

The first systematic geological work to be carried out on Kilimanjaro began in 1953 with mapping by members of the Sheffield University Kilimanjaro Expedition and representatives of the Geological Survey of Tanganyika. Preliminary accounts of the geology appeared in publications by W. H. Wilcockson (1956) and C. Downie *et al.* (1956). G. P. Leedal (1955) provided information on anorthoclase crystals from Kibo. A number of chemical analyses of Kilimanjaro lavas and related rocks were published in the Records of the Geological Survey of Tanganyika (1958, pp. 99-100). A second expedition from Sheffield and the Geological Survey continued work in 1957, and the survey subsequently undertook mapping of the areas surrounding the mountain in order to complete the Tanzania quarter-degree sheets 42, 56 and 57. Some aspects of the volcanology were dealt with by Wilcockson (1964). A geological map on a scale of 1 : 125.000 was published by the Geological Survey in 1964, and it was followed by an explanatory pamphlet (Wilcockson *et al.*, 1965) compiled by members of the expedition. Sampson (1963) wrote a summary of the geology, volcanology and glaciology of Kilimanjaro, and also (Sampson, 1966) a detailed account of Sinya meerschaum mine and the sediments occurring there. The latter work dealt with the portion of the mine in Tanzania, and the stratigraphic divisions proposed in this account of the Amboseli area were accepted and found to be represented in Tanzania. P. Wilkinson (1966) gave a summary of the geology of the Kilimanjaro-Meru region of northern Tanzania.

Various aspects of glaciology have been dealt with by E. Nilsson (1932), W. Geilinger (1936), D. W. Humphries (1959) and C. Downie (1964). Their work has been of great value in dating some of the later volcanic events on the mountain.

No detailed description of the Kilimanjaro rocks is yet in print, and only passing references have been made to the petrogenesis of this interesting suite of lavas. Downie et al. (1956, p. 830) suggested a parental magma of trachybasaltic composition. Saggerson and Williams (1964, p. 77), on the other hand, concluded that the source magma for the mildly alkaline lavas was more likely to have been of alkali olivine basalt composition, and that the source of the strongly alkaline rocks might lie close to ankaratrite in composition. A new chemical analysis of an ankaratrite from the Amboseli area was given in the same paper (Table 3, p. 67).

Few age determinations have been carried out on rocks from Kilimanjaro or the immediately surrounding areas. A figure of 0.4 million years for the Lent group is quoted by Wilkinson (1966, p. 29), and specimens from the early basalts gave figures of about 1 million years (personal communication from G. H. Curtis, of the University of California, whom the writer accompanied to the Amboseli area in 1961).

The Amboseli area has been covered by a number of small-scale geological maps, but only the geological map of Kenya, 1 : 3,000,000 Second Edition, 1962, incorporates the information presented in this report and shows the correct general distribution of metamorphic, volcanic and sedimentary rocks.

III—PHYSIOGRAPHY

The Amboseli area is readily divisible into four physiographic units:—

1. The foothills of Kilimanjaro.
2. The Amboseli basin.
3. Hills composed of Precambrian rocks.
4. A dissected plain underlain by Precambrian rocks.

The south-eastern parts of the area are occupied by volcanic rocks forming the foothills of Mt. Kilimanjaro. The ground rises gently from about 3,800 ft. O.D. to the 4,000 ft. contour where the slope increases to gradients of between 250 and 300 feet per mile. The highest ground in the area lies on the Tanzania border at an altitude of 6,400 ft. above sea level. Viewed from a distance the foothills are insignificant compared to the main mountain mass, with Kibo summit attaining an altitude of 19,340ft.

The Amboseli basin lies between lavas forming the Kilimanjaro foothills and Precambrian rocks that outcrop across the northern parts of the area (*see* Fig. 1). The basin is roughly triangular in shape with the western and south-western margins lying outside the limits of the area covered by the present survey. It narrows from west to east, where towards the apex of the triangle the basin is flanked on both sides by volcanic rocks. The surface is one of low relief, the elevation ranging from 3,686 ft. O.D. at Lake Amboseli to about 3,800 ft. around the margins of the basin. The south-central and eastern parts are marked by several permanent swamps, while the western half is dominated by Lake Amboseli, a 13-mile-long featureless plain which bears a shallow sheet of water only during rainy seasons. This north-north-easterly trending lake bed is some six miles wide at the northern end, but narrows to less than two miles near the Tanzania border; it extends across the border into Tanzania, where the margins are less well defined.

Hills composed of Precambrian rocks are confined to the extreme north-eastern and north-western corners of the Amboseli area. The Ngorigaishi Hills, in the north-west, are more prominent in the neighbouring Sultan Hamud and Namanga-Bissel areas and only the southern part of the range was examined by the writer; summit heights range from 4,100 to 4,600 ft. In the north-eastern corner of the area, Leme Boti (4,431 ft.) and Ol Doinyo Narigaa (about 4,200 ft.) are the most prominent features.

The northern part of the Amboseli area, between the hill masses, is marked by a dissected plain underlain by Precambrian rocks. The plain, which forms a watershed between the Amboseli basin and the Bissel-Kiboko drainage system, slopes down gently eastwards from 4,000 ft. to 3,800 ft. at longitude 37°20′ E. East of this meridian the ground rises again to form a pediment around Leme Boti and Ol Doinyo Narigaa at 3,900 to 4,000 ft.

Drainage—There are few permanent streams in the Amboseli area. Those draining the northern flanks of Kilimanjaro generally dry up before reaching the lower foothills of the mountain, and even in the south-eastern corner of the area gorges that carry permanent water become dry river beds within a few miles of the border. The water reappears however, from a number of springs around the southern side of the Amboseli Basin. Springs issuing from lava at the southern end of Engong Narok Swamp provide ample recharge, and following the construction of a furrow along the former dry watercourse known as the Simek a permanent flow of water has been established. Loginya and the Ol Tukai swamps apparently receive underground recharge. Namoloc Swamp, at the eastern end of the basin, is fed by the permanent Legumi Stream which rises in springs a few miles to the south. Nearby, springs also feed the Sinet Stream which flows eastwards to the Kimana Swamps in the neighbouring Loitokitok area.

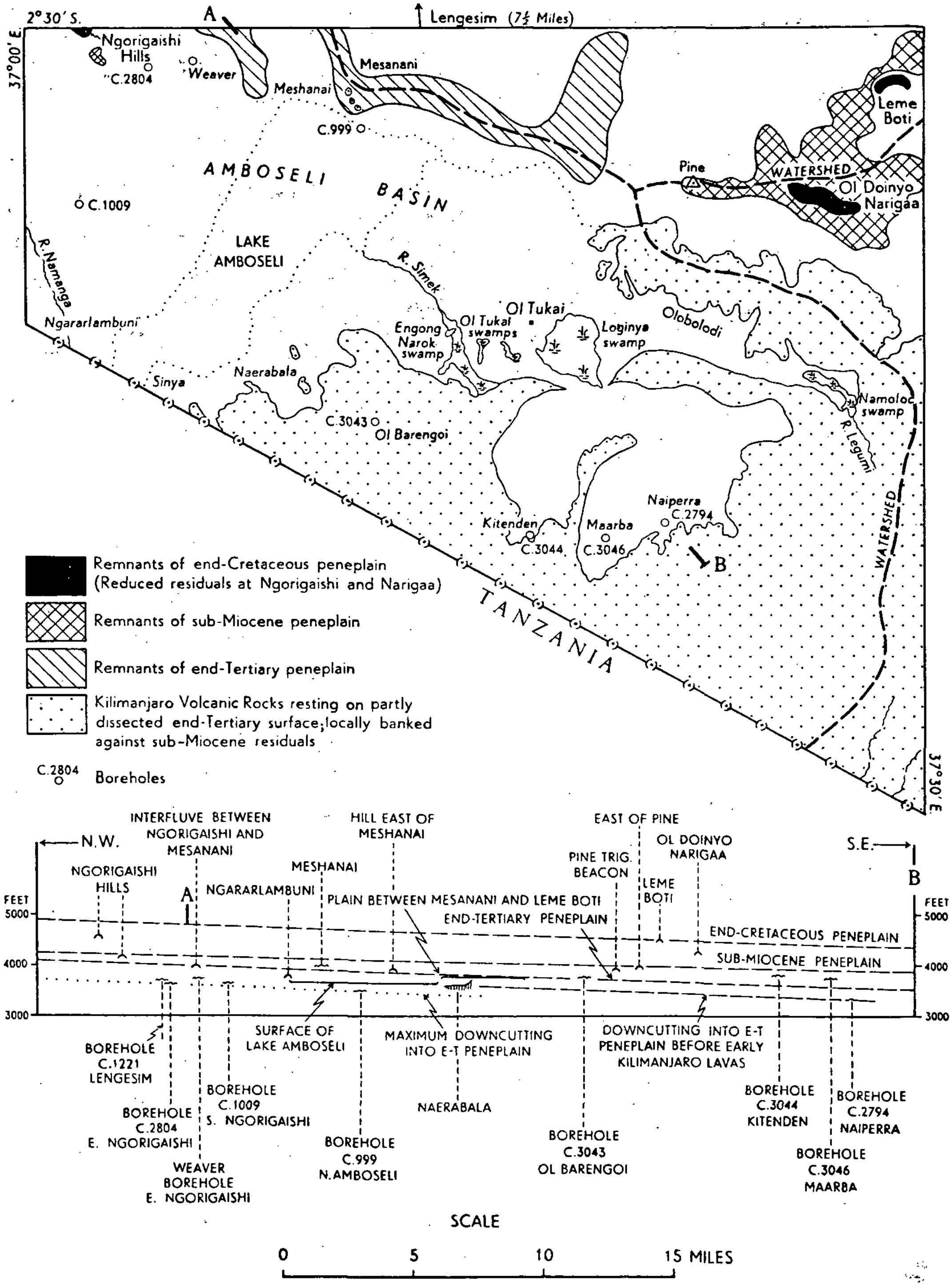

Fig. 1—Physiography of the Amboseli area, with section showing erosion bevels

A major watershed along the northern margin of the basin (*see* Fig. 1) turns southwards near Namoloc and can be traced to the Kenya-Tanzania boundary. It divides drainage into the basin from northward- and eastward-flowing systems; the latter are separated by a second watershed through the Leme Boti and Narigaa hills. Northward drainage, between Mesanani and Leme Boti, consists of seasonal streams that flow into the Bissel-Kiboko river in the Sultan Hamud area, whilst eastwards-flowing streams drain into the area between Loitokitok and the Chyulu range.

In addition to the network of deeply incised seasonal streams on the Kilimanjaro foothills the Amboseli Basin also receives drainage from the west and north-west. The Namanga River, which carries water only after heavy rain, drains a large part of the neighbouring Namanga-Bissel area. Poorly defined seasonal streams in the north-west part of the Amboseli area occupy broad alluvial valleys and have a limited catchment surface in the southern portion of the Ngorigaishi Hills and the surrounding plains.

Erosion Surfaces—Only a few remnants of erosion surfaces remain in the Amboseli area. Extensive post-Pliocene dissection, together with a thick cover of lavas towards Kilimanjaro, combine to destroy or conceal features illustrating various bevels. Moreover, the small vertical separation between different surfaces complicates the interpretation of the limited evidence available.

The higher summits of the Ngorigaishi Hills and the flat-topped hill at Leme Boti, where the surface truncates foliation planes in the Precambrian rocks, represent relics of an erosion bevel considered to be of end-Cretaceous age. In the Ngorigaishi Hills this erosion surface evidently corresponds to the 5,000 ft. bevel which Joubert (1957*a*, p. 3) referred to the sub-Miocene peneplain. In the Amboseli area the highest part of the range lies at a little over 4,600 ft. and probably represents a much reduced relic of that surface. To the east, in the neighbouring Loitokitok area, Precambrian inselbergs indicate that the end-Cretaceous surface lies at between 4,200 and 4,300 ft. and slopes down to the east-south-east. The summits of these inselbergs are roughly coplanar and indicate a marked reduction in the slopes of the bevel east of Leme Boti. This evidence is used to draw the line representing the end-Cretaceous surface in Figure 1. Low hills at Ol Doinyo Narigaa, with summits reaching 4,200 ft., are thought to represent reduced relics of the bevel.

A pediment at some 4,000 ft. around the end-Cretaceous residuals at Leme Boti and Ol Doinyo Narigaa probably represents the sub-Miocene erosion bevel, locally lying about 450 feet below the older peneplain. The southern summit at Ngorigaishi (at 4,300 ft.) is doubtfully referred to the sub-Miocene surface.

The most prominent erosion surface in the Amboseli area is clearly a continuation of the plain that extends southwards from Sultan Hamud. Saggerson and Baker (1965, p. 59) confirmed the writer's view that this plain represents the end-Tertiary bevel. It is preserved only along the watershed skirting the northern margin of the Amboseli basin where it falls from 4,000 ft. east of the Ngorigaishi Hills to 3,800 ft. midway between Meshanai and Leme Boti (*see* Fig. 1). Meshanai trigonometrical beacon is erected on an outcrop of lava but the surrounding plain of Precambrian rocks lies at about 3,900 ft. On the southern side of the Amboseli basin a borehole at Ol Barengoi showed that Precambrian rocks are overlain by lavas at a little over 3,700 ft. O.D.

Naiperra borehole on the other hand failed to locate Precambrian rocks and proved that locally the lavas extend to at least 3,340 ft. O.D.; clays encountered at the bottom of this borehole may overlie the metamorphic rocks. The lavas here evidently flowed over a portion of the surface which had already been down-cut some 200 feet.

Pulfrey (1960, Fig. 3) postulated an east-south-easterly and easterly sloping sub-Miocene bevel in the Amboseli area, drawing the 4,000 ft. contour of that bevel over Mesanani and Sinya and the 3,500 ft. contour close to the 37°30′ meridian. The author's interpretation of the erosion surface in the Amboseli and adjacent areas involves a general eastward displacement of the sub-Miocene contours from the positions indicated by Pulfrey, a maximum difference of 20 miles occurring along the northern boundary of the Amboseli area, where both the sub-Miocene and end-Tertiary surfaces are thought to slope to the south-east.

Borehole evidence in the western and north-western parts of the area shows that fluviatile sediments rest on Precambrian rocks at levels some 400 feet below the end-Tertiary peneplain. At Lengesim borehole in the Sultan Hamud area sediments rest on Precambrian surface that is there about 80 feet below local level and some 360 feet below the postulated end-Tertiary peneplain. The maximum depth of down-cutting into the end-Tertiary surface is clearly of value in estimating the floor level of the Amboseli basin and hence the thickness of sediments to be expected there.

IV—SUMMARY OF GEOLOGY

The rocks of the Amboseli area fall readily into four groups:—

1. Precambrian metamorphic rocks.
2. Tertiary to Recent volcanic rocks.
3. Pleistocene lacustrine and fluviatile deposits.
4. Quaternary superficial deposits.

1. Precambrian Metamorphic Rocks

Precambrian rocks, comprising a thick series of metamorphosed sediments, are sporadically exposed across the northern half of the area, and granitoid gneisses of the same age outcrop near the Kenya-Tanzania border west of Sinya. Elsewhere the metamorphic rocks are overlain either by lava flows from Kilimanjaro or by sediments occupying the Amboseli basin.

The original Precambrian sedimentary succession included arenaceous, argillaceous and calcareous deposits that are now represented by a variety of gneisses, granulites and schists together with broad bands of marble. The latter form the only hill features in the northern half of the area, with less resistant rock types underlying a dissected plain. In the Ngorigaishi Hills crystalline limestones are marked by numerous calc-silicate lenses and frequently by small flakes of brown or reddish brown mica. At Ol Doinyo Narigaa and Leme Boti the marble locally bears a fine sprinkling of graphite. Metamorphosed semi-calcareous sediments are represented by diopside-garnet granulites and gneisses, which at one locality are hypersthene-bearing. Garnetiferous quartzo-felspathic rocks and hornblende-garnet gneisses are believed to be metamorphosed shales, whilst biotite gneisses, biotite-garnet gneisses and hornblende-biotite migmatites represent semi-pelitic sediments. Quartzo-felspathic gneisses and granulites originated by the metamorphism of arenaceous deposits. Evidence of granitization is widespread, culminating in the local development of hornblende-biotite granitoid gneisses.

2. Tertiary to Recent Volcanic Rocks

The geology of the Amboseli area is dominated by the influence of nearby Kilimanjaro, a spectacular central volcano which was probably active from late Pliocene to Recent times.

The earliest volcanic rocks mapped are olivine basalts with minor pyroclastic intercalations. The basaltic lavas are conveniently subdivided into a lower and an upper series by flows of nephelinites, melanephelinites, ankaratrites, tephrites and phonolites. Some basalts of the lower group and all those of the upper series are characterized by the development of large felspar phenocrysts. The basalts are overlain by a second group of nepheline-bearing lavas including nephelinites, melanephelinites and ankaratrites. These lavas are followed in turn by rhomb porphyries, fine olivine-bearing trachytes and phonolities, and finally by a single flow of nepheline-rich phonolite. Parasitic vents were active at various times during the history of the volcano.

The name *Kilimanjaro Volcanic Rocks* is proposed to cover all the flows and pyroclastics derived from Kilimanjaro.

3. Pleistocene Lacustrine and Fluviatile Deposits

Much of the flat-lying ground in the central parts of the Amboseli area is underlain by sediments which may attain a maximum thickness of several hundred feet. A great deal of the material accumulated in a vast lake formed by damming of the drainage by volcanic eruptions during the Upper Pleistocene. These deposits are known as the Amboseli Lake Beds and they include impure limestones, marls and sepiolitic clays; the latter were probably derived from showers of volcanic ash falling on the lake from the still-active Kilimanjaro, or from material of volcanic origin washed into the lake from the slopes of the mountain. Facies changes occur towards the western and north-western parts of the basin, where sandy and pebbly deposits show that sediments were being supplied continuously to the lake basin from the Precambrian foundation. Towards the foothills of Kilimanjaro the lacustrine deposits grade into conglomerates containing only pebbles of volcanic rocks, indicating derivation by torrential outwash from the mountain at a time when the climate was wetter than at the present day.

The Amboseli Lake Beds are subdivided stratigraphically as follows:—

3. *Ol Tukai Beds* (silts and clays, locally diatomaceous).
2. *Amboseli Clays* (clays, calcareous clays and silty clays).
1. *Sinya Beds* (marls, clays and silty clays).

4. Quaternary Superficial Deposits

Much of the Amboseli area is mantled with Pleistocene and Recent superficial deposits. Soils include reddish-brown sandy varieties derived principally from the metamorphic rocks, black cotton soils, alluvial soils, and dusty soils overlying the volcanic rocks.

Windblown clayey silts and sands in the western parts of the area locally attain a thickness of 30 feet.

V—DETAILS OF GEOLOGY

1. Precambrian Rocks

Precambrian gneisses, schists, migmatites, granulites and crystalline limestones outcrop across the northern half of the Amboseli area, with a solitary prominent inselberg in the south near the Tanzania border at Ngararlambuni. The rocks are on the whole poorly exposed and an extensive cover of reddish-brown soil effectively conceals most of the outcrop between Mesanani and Leme Boti. Black cotton soils and reddish alluvial soils, together with unexposed fluviatile sediments that locally underlie them, infill broad valleys between the Ngorigaishi Hills and Mesanani. These valleys are largely controlled by the strike of the Precambrian rocks. Towards the Tanzania border the metamorphic rocks are blanketed by lava flows and a thick series of lacustrine sediments occupying the Amboseli basin.

Stratigraphy and Correlation

Because of the sporadic exposures numerous gaps are inevitable in any proposed stratigraphical succession, the accuracy of which depends on the correct interpretation of major structures. The following stratigraphic sequence is based on structural assumptions that are discussed in a later section of the report: —

	Approximate thickness (feet)
(8) Semi-pelitic and psammitic gneisses	2,000
(7) Crystalline limestones	750
(6) Semi-pelitic gneisses and migmatites	1,500-8,000
(5) Crystalline limestones and calc-silicate granulites	350
(4) Pelitic gneisses and granulites; subordinate psammitic gneisses	650
(3) Calc-silicate granulites and crystalline limestones	250
(2) Semi-pelitic, psammitic and subordinate pelitic gneisses	8,000
(1) Granitoid gneisses	500
	14,000-20,500

Detailed sequences established from exposures in the western, central and eastern parts of the area are shown below; some information is taken from immediately adjacent portions of the areas to the west and north.

West	*Central*	*East*
—	—	Biotite–garnet gneisses
—	—	Quartz-felspar granulites and gneisses (Sultan Hamud area)
Crystalline limestones with calc-silicate lenses (Ngorigaishi Hills)	—	Crystalline limestones (Leme Boti and Ol Doinyo Narigaa)
Hornblende-biotite migmatites.	—	Biotite-garnet gneisses
Crystalline limestones	Calc-silicate granulites	Crystalline limestones and calc-silicate granulites
—	Quartz-felspar-gneisses	—
Garnet-quartz-felspar gneisses and granulites	Garnet - quartz - felspar gneisses and granulites	Garnet-quartz-felspar gneisses and granulites.
Calc-silicate granulites (crystalline limestones at Malalda, Namanga area)	—	—
—	Hornblende-garnet gneisses	—
—	Biotite-garnet gneisses	—
—	Quartz-felspar granulites and gneisses	—
—	Biotite gneisses and schists	—
Granitoid gneisses (Ngararlambuni)	—	—

The Precambrian rocks described here are very similar to some of the metasediments of the Turoka area, about 50 miles north-west of Amboseli, to which the name *Turoka Series* was applied by Parkinson (1913, p. 539). Joubert (1957*a*, p. 32) later subdivided the Turoka Series in the Namanga-Bissel area into a lower Quartzite Group and an upper Limestone Group, and he separated the Turoka Series from underlying rocks described as the Banded Gneiss Group. This division of the Precambrian succession was adopted by Matheson (1966, p. 9) during a survey of the Kajiado area, which includes Turoka.

No quartzites were encountered in the Amboseli area but, if the crystalline limestones forming the Ngorigaishi Hills are a continuation of the limestones flanking the Maparasha Hills south-south-east of Bissel, then the Quartzite Group may in part be represented in the Amboseli area by semi-pelitic gneisses and migmatites, (6) in the succession quoted above, though these rocks are evidently mainly equivalent to the Banded Gneiss Group. It is significant that crystalline limestones at Lengarunyeni east of Namanga are underlain by quartzites and banded gneisses. The Ngorigaishi crystalline limestones are probably to be correlated with those at Leme Boti and Ol Doinyo Narigaa in the north-eastern part of the Amboseli area, but the Precambrian rocks exposed in the intervening ground are older and underlie not only the local representives of the Turoka Series but also the Banded Gneiss Group. Crystalline limestones and calc-silicate granulites are present among the older rocks and are exposed at the north end of Lake Amboseli and again at Ibulbul, near Ol Doinyo Narigaa.

The crystalline limestones of Leme Boti, Ol Doinyo Narigaa and Ibulbul can be traced into the Simba-Kibwezi area, north-east of the present sheet, and also for a limited distance into the Sultan Hamud area to the north.

Saggerson (1963, pp. 9-12) assigned three crystalline limestones and intercalated pelitic gneisses at Merueshi in the Simba-Kibwezi area to the *Kurase Series,* and proposed a correlation with the Limestone Group of the Turoka Series. The current work suggests however, that only the upper band of marble at Merueshi forms part of the Turoka Series, and the lower parts of the succession are equivalent to an attenuated Banded Gneiss Group underlain by formations not exposed in the Namanga-Bissel area. The term Kurase Series is considered an appropriate one to describe all the Precambrian rocks in the Amboseli area.

Saggerson (op. cit., p. 12) noted a strong resemblance between the rocks of the Banded Gneiss Group of the Namanga-Bissel area and those of his Kasigau Series, which overlies the Kurase Series. He also shows separately in the table the banded gneisses of Martiumisigio (Namanga-Bissel area) placing them above the Turoka Series and tentatively correlating them with the Kasigau Series. Joubert (1957*a*, p. 31) admitted the possibility of gneisses in the north-east corner of the Namanga-Bissel area being younger than the Turoka Series, and Matheson (1966, p.9) found that the same group overlies the Turoka Series in the Kajiado area but suspected an inversion of the entire sequence. The problem can now be reviewed incorporating evidence from the Amboseli area, and the writer supports Saggerson in equating the gneisses at Martiumisigio with those of the Kasigau Series, but regards the banded gneisses of Luanji, Metu and Ingito (south-western Namanga-Bissel area) as part of the Kurase Series.

For descriptive purposes, the Precambrian rocks are classified as follows:—

(1) Metamorphosed calcareous sediments:
    (*a*) Crystalline limestones with calc-silicate lenses.
    (*b*) Calc-silicate granulites and gneisses.

(2) Metamorphosed pelitic sediments:
    (*a*) Garnet-quartz-felspar granulites and gneisses.
    (*b*) Hornblende-garnet gneisses.

(3) Metamorphosed semi-pelitic sediments:
    (*a*) Biotite gneisses and schists.
    (*b*) Biotite-garnet gneisses.
    (*c*) Hornblende-biotite gneisses and migmatites.

(4) Metamorphosed psammitic sediments:
    Quartz-felspar gneisses and granulites.

(5) Granitoid gneisses.

(1) METAMORPHOSED CALCAREOUS SEDIMENTS

Variations in the lime content of original calcareous sediments is reflected in the metamorphic rock types now encountered in the Amboseli area, ranging from marbles, through diopside-garnet and diopside-hornblende-garnet gneisses to hornblende-garnet gneisses and amphibolites; these represent variations from limestones (including dolomitic varieties) to calcareous shales. For convenience the derivatives of more argillaceous rocks are described under metamorphosed pelitic sediments on a later page, and the following subdivision includes only the highly calcareous end members of the range:—

(*a*) Crystalline limestones.
(*b*) Calc-silicate granulites and gneisses.

(*a*) *Crystalline Limestones*

Metamorphosed calcareous sediments mapped in the north-western and north-eastern corners of the Amboseli area comprise coarse crystalline limestones, locally containing abundant calc-silicate knots and lenses. The western outcrops form the end of the Ngorigaishi Hills, a range composed dominantly of marble, which has already been described by Searle (1954, p. 5) and Joubert (1957*a*, pp. 9-11) in accounts of the geology of neighbouring areas. The eastern occurrences of crystalline limestones form the hills at Ol Doinyo Narigaa and Leme Boti, with lesser exposures across the flat surrounding country. Distinctive markings seen on air photographs, together with a consideration of the distribution of secondary (kunkar) limestone, permits mapping of unexposed parts of the marble bands.

In the southern part of the Ngorigaishi Hills the crystalline limestones are white or pink, medium- to coarse-grained rocks, locally enclosing many dark green pyroxene-rich calc-silicate knots and lenses which vary in size from fractions of an inch to several feet in diameter. Within the marble itself a pale green colouration is attributed to diopside; bronzy mica is often prominent. A typical specimen (59/427)* of pink crystalline limestone from the extreme south-eastern hill of the Ngorigaishi range contains sub-rounded inclusions of dark green pyroxenes some 5 to 20 mm. in diameter and local concentrations of brown mica which is sprinkled liberally throughout the rock. Pale green pyroxene occurs as irregular grains outside the calc-silicate inclusions. In thin section the carbonate is seen in plates two or three millimetres across showing cleavage and two sets of intersecting lamellar twinning; the mineral is occasionally slightly biaxial. Large crystals of colourless pyroxene ($Z \wedge c = 39°$) are seen altering to very pale green weakly pleochroic tremolite ($Z \wedge c = 20°$). Both the pyroxene and the amphibole are partly replaced by scapolite in which small flakes of calcite are prominent, causing a patchy appearance particularly in polarized light. Although penetrating intimately into the host crystals, sections of the scapolite are in optical continuity over several square millimetres. Untwinned oligoclase, with refractive indices equal to or slightly higher than that of balsam, occurs in small sub-rounded grains, and flakes of mica about 1 mm. long are prominent. The latter are pleochroic from nearly colourless to pale brown and have a negative optic axial angle of only a few degrees. Colourless grains of forsterite are rare.

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* Numbers prefixed by 59/ refer to specimens in the regional collection of the Mines and Geological Department, Nairobi.

At some localities in the Ngorigaishi Hills the crystalline limestones are marked by local concentrations of mica having a reddish-brown or coppery tint. The mica in specimen 59/429 is pleochroic from pale brown to reddish-brown and is nearly uniaxial, the negative axial angle being estimated as two to three degrees. Small occurrences of blue spinel were found by T. T. Bestow (of the then Hydraulics Branch, Ministry of Works) in similar crystalline limestones at an unknown locality in the southern part of the Ngorigaishi Hills.

At Ol Doinyo Narigaa and Leme Boti, both in the north-eastern corner of the area, white, grey or pinkish crystalline limestones commonly bear a fine sprinkling of graphite; fine flakes of brown or pale green mica are often visible in the hand specimens. Calc-silicate inclusions are rare in the eastern outcrops of marble. A typical specimen (59/496) from the eastern end of Leme Boti Hill is a coarse-grained greyish-white rock composed of crystals of calcite on an average about 4.0 mm. across. Small fine flakes of graphite are sprinkled throughout. In thin section calcite is seen in large irregular plates with scapolite occurring as intergranular crystals some two or three millimetres across or as smaller inclusions in the calcite. Grains of quartz and felspar are similarly intergranular or are present as inclusions. The felspar is untwinned, but having refractive indices close to that of balsam and being optically negative it is tentatively identified as oligoclase. Small colourless flakes of muscovite are developed in calcite or at grain boundaries. Flakes of graphite 0.5 mm. long occur throughout the slide.

A specimen (59/428) of a typical dark green calc-silicate, from a large lens enclosed by crystalline limestones near the southern end of the Ngorigaishi Hills, is composed dominantly of pyroxene which occurs in crystals four to five mm. across, though rarely attaining a length of some 15 mm. Leucocratic mottled parts of the rock comprise calcite, scapolite and dark green pyroxene, together with numerous small brownish sphenes, the larger ones being about 5.0 mm. across. Patches of a mineral having a paler green colour than the pyroxene, with which it is intimately associated, is apparently an amphibole. In a thin section of this rock anhedral crystals of pale green diopside ($Z \wedge c = 41°$) show patchy alteration to strongly pleochroic actinolitic hornblende. The amphibole is pleochroic from pale yellow-brown to dark green and has a large negative optic axial angle; maximum extinction angles ($Z \wedge c$) seen in the slide measure 13°. Irregular grains of sphene, generally 0.5 mm. or more across, occur with scapolite and calcite.

No chemical analyses of crystalline limestones from the Amboseli area are available, but Guest (1955) quoted the following analysis of a specimen from Seven Sisters Hill in Tanzania.

	Per cent
Insolubles	0.2
R_2O_3	0.1
CaO	50.7
MgO	4.7
Loss on ignition	44.2
	99.9

Searle (1954, p. 31) quoted the chemical composition of a number of crystalline limestones from the Sultan Hamud area to the north of Amboseli. Analyses of specimens from the Simba-Kibwezi area to the north-east are given by Saggerson (1963, p. 54):

(*b*) *Calc-silicate Granulites and Gneisses*

In addition to lenses of calc-silicates found locally as inclusions within outcrops of crystalline limestones, somewhat similar diopside-garnet granulites and gneisses occur in poorly exposed bands at Mesanani and west of Ol Doinyo Narigaa. The rocks at these localities differ essentially from the calc-silicate lenses in having a larger proportion of felspar, in showing better foliation, and in containing megascopic garnets; they also contain quartz and often bear micas and opaque areas. Being intercalated in a succession of pelitic, semi-pelitic and psammitic sediments, the diopside-garnet granulites and gneisses are considered to represent metamorphosed semi-calcareous sediments having a lower lime content than those encountered within the limestones.

Pale, moderately well foliated, garnetiferous pyroxene-bearing gneisses are exposed in a small watercourse three-quarters of a mile west-south-west of Meshanai trigonometrical beacon, near the northern end of Lake Amboseli. In the stream section the calc-silicate gneisses underlie quartz-felspar granulites and gneisses, and thin amphibolitic bands are developed near the contact, which is gradational. A thin section of the calc-silicate rock (59/432) from this locality shows numerous rounded pink garnets up to 1.0 mm. in diameter together with weakly pleochroic green diopside ($Z \wedge c = 46°$) and abundant microcline and microcline-microperthite. Quartz occurs as small rounded grains and as rare inclusions in garnet, where it is sometimes accompanied by chadacrysts of magnetite and apatite. The latter mineral also occurs in minute euhedral to rounded crystals throughout the rock. Rare sections of hornblende are visible, pleochroic from greenish-brown to nearly black, and also occasional flakes of brown biotite. Epidote is present in small rounded grains.

Hornblende is more prominent in pink calc-silicate gneisses exposed on a low hill beside the Ol Tukai-Sultan Hamud road some three miles west of Ol Doinyo Narigaa. A specimen (59/497) shows diopside, pleochroic from pale green to nearly colourless and having extinction $Z \wedge c = 48°$, altering to hornblende. The amphibole, which forms vermicular growths around and through pyroxene crystals, displays strong pleochroism ($X =$ pale green; $Y =$ deep green; $Z =$ deep bluish-green) and has maximum extinction $Z \wedge c = 14°$. Ragged flakes of biotite accompany and replace hornblende, whilst muscovite occurs in occasional larger flakes. Quartz, microcline and microcline-microperthite are abundant, and subordinate plagioclase has the composition oligoclase-andesine. Pink garnets attain a diameter of 2.0 mm. and ore grains are typically rimmed with leucoxene. Calcite and sphene are accessory, the latter often having leucoxene borders and abnormally small positive optic axial angles.

An unusual hypersthene-bearing calc-silicate granulite was encountered overlying quartz-felspar gneisses on a small hill some four miles west of Meshanai Beacon. The poorly exposed rocks forming the eastern slope of the hill include a greenish-black coarse granulite containing abundant red garnets. In thin section specimen (59/400) shows large pink garnets, pale green weakly pleochroic diopside altering to abundant hornblende, and anhedral grains of hypersthene that tend to occur around the larger garnets though also present elsewhere. The garnets attain a diameter of over 4.0 mm. and contain chadacrysts of apatite, diopside, oligoclase, ore and hornblende. Diopside has maximum extinction $Z \wedge c = 47°$; hypersthene is pleochroic from pale green to pink and shows no uralitic alteration. Hornblende is strongly pleochroic ($X =$ pale yellow-green; $Y =$ olive green; $Z =$ dark green) with $Z \wedge c = 17°$. Magnetite occurs abundantly throughout the rock. Other hypersthene-bearing calc-silicate granulites and gneisses have been recorded from the Kitui district (Sanders, 1954, p. 11; Saggerson, 1957, p. 10).

Maximum extinction angles ($Z \wedge c$) measured in the diopsidic pyroxenes range from 39° (colourless pyroxene in forsterite marble) through 41° (pale green diopside forming a calc-silicate lens in crystalline limestones) to 48° (pleochroic pyroxene in diopside-hornblende-garnet gneiss). This increase in the extinction angle is attributed to progressive enrichment in aluminium and iron. The increase in these elements is even more striking in the amphiboles, which range from very pale green tremolite seen in the crystalline limestones to strongly pleochroic hornblende in the calc-silicate rocks.

The mineral assemblage forsterite-diopside-tremolite indicates the dolomitic nature of the original limestones.

(2) METAMORPHOSED PELITIC SEDIMENTS

Metamorphosed equivalents of argillaceous sediments outcrop in the north-central parts of the area, where the rocks fall readily into two groups:—

(*a*) Garnet-quartz-felspar granulites and gneisses.
(*b*) Hornblende-garnet gneisses.

(*a*) *Garnet-quartz-felspar Granulites and Gneisses*

Quartzo-felspathic rocks containing abundant megascopic red garnets are best exposed near the northern end of Lake Amboseli, where two separate outcrops were mapped; these are believed to be portions of a single band displaced by faulting. Between the Ngorigaishi Hills and Meshanai Trigonometrical Beacon a north-westerly striking band of garnet-quartz-felspar granulite and gneiss can be traced from the northern boundary of the area to a small hill beside the Namanga-Ol Tukai road. Hornblende-biotite and hornblende-garnet gneisses occur locally as thin intercalations, and at many localities the rocks appear to have suffered granitization. A typical specimen (59/431) of garnet-quartz-felspar gneiss, from the northern boundary of the Amboseli area five miles north-west of Meshanai Beacon, is a pinkish-brown well foliated rock containing magnetite and numerous pink or reddish garnets commonly about 1.0 mm. in diameter. The reddish colour of the rock is largely due to pink felspars though locally it is enhanced by iron staining. The thin section shows a gneissose texture with anhedral grains of quartz drawn out parallel to the foliation and often seven to eight millimetres long. Microcline and microcline-microperthite are common, the latter containing exsolution blebs of albite. Albite, occasionally showing twinning, also occurs in anhedral grains. Small rounded pinkish garnets are common and the chief accessories are muscovite and irregular grains of ore, largely altered to limonitic oxides.

At Mesanani the rocks are often whiter than those exposed farther to the north-west, due to a smaller proportion of potash felspar. A better developed foliation produces a flaggy appearance that is particularly well displayed in exposures a mile and a quarter south-east of the trigonometrical beacon. The latter is erected on a small occurrence of olivine basalt that rests on garnet-quartz-felspar gneisses containing small flakes of muscovite.

(*b*) *Hornblende-Garnet Gneisses*

Hornblende-garnet gneisses are generally poorly exposed and outcrops were encountered only in the north-central parts of the area, where these rocks underlie quartz-felspar granulites and gneisses (though, in fact, the succession here is believed to be inverted due to recumbent folding). The hornblendic rocks represent metamorphosed shales and marls; with an increased calcareous content they probably grade laterally into calc-silicate granulites and gneisses containing diopside.

Typical well foliated, finely banded hornblende-garnet gneisses are exposed beside the Namanga-Ol Tukai wet-weather road some three miles east-south-east of Meshanai Trigonometrical Beacon. A specimen (59/403) from this locality contains hornblende, garnet and plagioclase. The amphibole, which is strongly pleochroic (X = pale greenish brown; Y = olive green; Z = bright green) with $Z \wedge c = 22°$, is occasionally seen lobing into pale pink garnet. Plagioclase has a composition in the labradorite-bytownite range. Similar rocks were seen half a mile to the east-north-east where they appear to be faulted against well exposed quartz-felspar gneisses.

(3) METAMORPHOSED SEMI-PELITIC SEDIMENTS

Gneisses and schists that represent metamorphosed semi-pelitic sediments are most commonly encountered in the eastern parts of the Precambrian outcrops, though migmatitic semi-pelitic gneisses underlie the crystalline limestones at the southern end of the Ngorigaishi Hills. All these rocks are biotite-bearing but the following subdivision for descriptive purposes is based on the appearance of megascopic garnet or hornblende:—

(*a*) Biotite gneisses and schists.

(*b*) Biotite-garnet gneisses.

(*c*) Hornblende-biotite gneisses and migmatites.

(*a*) *Biotite Gneisses and Schists*

Biotite gneisses are best seen in the north-eastern corner of the area, where they immediately underlie the crystalline limestones capping Leme Boti Hill; similar rocks overlie a band of marble north-east of Leme Boti. The two occurrences are separated by intercalated biotite-garnet gneisses into which they grade. Unexposed biotite gneisses were mapped from accumulations of boulders found north of the Ol Tukai-Sultan Hamud road, near Pine Trigonometrical Beacon and at Eremito. A small roadside quarry near the beacon exposes weathered biotite gneisses and schists, and pitting revealed similar schists at the extreme north-eastern corner of Lake Amboseli where they are overlain by thin amphibolites and quartz-felspar gneisses.

The biotite gneisses are typically medium-grained, pink, grey or pale brownish rocks with foliation generally rather poorly developed. They locally contain pink iron-stained grains of quartz and felspar that are easily mistaken for garnets on cursory examination. The pinkish gneiss (59/492) at Leme Boti Beacon contains biotite, quartz, microcline and oligoclase with rare, minute, rounded grains of epidote as inclusions in the felspar. The mica is pleochroic from pale to dark brown. A specimen (59/499) from pinkish-brown biotite gneiss boulders at Eremito contains, in addition to the above essential constituents, small flakes of muscovite, common euhedral to rounded apatite grains and ore with associated limonitic hydroxides. Near Pine Trigonometrical Beacon biotite gneisses (59/498) contain porphyroblasts of pink microcline up to 12.0 mm. in diameter. Many of the porphyroblasts, which bear microperthitic blebs of albite, are surrounded by a fine granular zone in which quartz forms myrmekitic intergrowths in oligoclase. Muscovite is common, and epidote occurs in rare small grains.

(*b*) *Biotite-garnet Gneisses*

Biotite gneisses containing megascopic pink garnets occur around the western and northern slopes of Leme Boti Hill, underlying biotite gneisses and crystalline limestones. Sporadic exposures show that biotite-garnet gneisses both underlie and overlie the Ol Doinyo Narigaa crystalline limestones. Similar garnetiferous rocks overlie quartz-felspar gneisses east of Mesanani.

Greyish moderately well foliated gneisses exposed south and south-south-west of Leme Boti Beacon contain abundant biotite and reddish garnets three to four millimetres in diameter. Specimen 59/491, collected three-quarters of a mile from the beacon, shows a mosaic texture with microcline replacing quartz and oligoclase. Biotite, pleochroic from pale to dark brown, is accompanied by occasional small subhedral to rounded grains of apatite and epidote. No garnet is visible in the section. In a pinkish gneiss

(59/490) from exposures at the roadside north-west of Ol Doinyo Narigaa, pale pink rounded garnets enclose chadacrysts of oligoclase, quartz, biotite, muscovite and ore. Biotite in this rock is pleochroic from pale yellow-green to very dark greenish-brown and muscovite is common. Microcline and oligoclase are equally prominent, the latter displaying sericitization. Quartz occurs in numerous anhedral grains and ore is bordered by limonite. Calcite and rare grains of epidote are accessories, the former being developed largely during the alteration of plagioclase.

An unusual biotite-garnet-corundum gneiss overlies quartz-felspar gneisses three miles east of Meshanai Beacon. There well foliated mesotype rocks contain abundant biotite and pinkish garnets The thin section of specimen 59/404 shows numerous grains of corundum up to 1.0 mm. long, together with biotite, microcline, oligoclase-andesine, pale pink garnet, quartz and sphene. Most of the biotite is pleochroic from yellow-brown to very dark brown but subordinate mica, closely associated with the biotite, displays striking pleochroism from blue-green to pinkish brown.

(*c*) *Hornblende-Biotite Gneisses and Migmatites*

Biotite is accompanied by abundant hornblende in migmatitic gneisses that underlie the Ngorigaishi crystalline limestone. The mottled mesotype rocks contain hornblende-rich layers that display minor contortions; quartzo-felspathic bands and lenses are common, judging by the composition of the scree material on the hill slopes. In the thin section of specimen 59/430, from the western slopes of the Ngorigaishi Hills about a mile from the southern end of the range, strongly pleochroic hornblende (X = pale yellow-green; Y = olive green; Z = dark green) shows extinction $Z \wedge c = 17°$ and is partly replaced by biotite, pleochroic from pale yellow-brown to dark brown. Oligoclase and quartz occur in anhedral grains and ore is abundant. Epidote and apatite are common accessories, the latter occasionally attaining a diameter of 1.0 mm. Calcite occurs in small interstitial plates.

Garnets were not seen in the Ngorigaishi rocks, but garnetiferous hornblende-biotite banded gneisses of similar appearance were encountered near the Namanga River, just beyond the western boundary of the present area. There better exposures show the true migmatitic nature of the rocks, which have been described in detail in an account of the geology of Namanga-Bissel area (Joubert, 1957, pp. 27-29).

(4) METAMORPHOSED PSAMMITIC SEDIMENTS

No quartzites were encountered in the Amboseli area and the only derivatives of psammitic sediments are quartz-felspar gneisses and granulites. These rocks are well exposed north-east of Lake Amboseli where a west-north-westerly striking major band can be traced for six miles. Minor occurrences were found at Mesanani, where the quartzo-felspathic rocks are underlain by calc-silicate gneisses; at the extreme north-eastern corner of the lake, overlying biotite schists; and nine-and-a-half miles east of Meshanai Beacon where the flanking rocks are obscured by extensive soil cover.

The rocks are typically well foliated, whitish or pale brown gneisses, composed of quartz, felspar and ore. The thin section of a specimen (59/405) from well exposed quartzo-felspathic gneisses three-and-three-quarter miles east of Mesanani shows a mosaic texture with quartz, microcline, subordinate oligoclase and accessory biotite, epidote and ore. Gneisses (59/433) that apparently form a thinner band about a mile to the north contain abundant microcline and microcline-microperthite replacing quartz and oligoclase. Numerous irregular grains of opaque ore are rimmed with limonite and show local alteration to leucoxene. The latter is however, best developed around crystals of sphene, which seem to have an abnormally small optic axial angle. Muscovite is a rare accessory.

(5) GRANITOID GNEISSES

A prominent inselberg at Ngararlambuni, near the Tanzania border five miles west-north-west of Sinya, is composed of well foliated pinkish granitoid gneiss containing hornblende and biotite. Specimen 59/425 shows anhedral elongated grains of quartz up to 4.0 mm. long together with microcline, microcline-microperthite, oligoclase, hornblende, biotite, muscovite and ore. The hornblende (X = brownish green; Y = olive green; Z = bright green) has maximum extinction $c \wedge Z = 30°$, and is largely replaced by biotite, pleochroic from yellow-brown or pale brown to dark brown. Muscovite is subordinate to biotite and is often associated with it.

(6) METAMORPHISM AND GRANITIZATION

The Precambrian rocks suffered intense regional metamorphism accompanied by widespread granitization, resulting in conversion of a sedimentary sequence of dolomitic limestones, sandstones, marls and shales to a thick series of crystalline limestones, gneisses and granulites. Garnet is widely developed in the metamorphosed pelitic, semi-pelitic and calcareous sediments, but the higher-grade index minerals kyanite and silimanite were not recorded. Common evidence of alkali metasomatism is indicated by the replacement of quartz and plagioclase by microcline and microcline-microperthite in the pelitic, semi-pelitic and psammitic gneisses and granulites. Locally, biotite gneisses are marked by the development of prominent microcline porphyroblasts.

In the pelitic gneisses and granulites the following typical mineral assemblage is taken to indicate the staurolite-almandine sub-facies of the almandine-amphibolite facies (*see* Turner and Verhoogen, 1960, p. 545):—

Quartz-garnet-muscovite-plagioclase

The plagioclase was determined as albite, indicating a possible local transition to the high-grade part of the greenschist facies (quartz-albite-epidote-almandine sub-facies). The common occurrence of oligoclase in semi-pelitic, psammitic and calcareous gneisses, together with the recognition of labradorite-bytownite in pelitic hornblende-garnet gneisses, confirms the suggested identification of the almandine-amphibolite facies. Microcline, which is often present in the garnet-quartz-felspar gneisses, replaces quartz and plagioclase.

The semi-pelitic gneisses commonly show the following assemblage:—

Quartz-microcline-oligoclase-biotite-epidote (-muscovite)

Psammitic gneisses and granulites contain:—

Quartz-microcline-oligoclase (-biotite-muscovite-epidote)

These conform to assemblages recorded in quartzo-felspathic rocks of the staurolite-almandine or kyanite-almandine-muscovite sub-facies (Turner and Verhoogen, 1960, pp. 546-548).

The following mineral associations in semi-pelitic gneisses arise from a combination of pelitic, quartzo-felspathic and calcareous assemblages:—

Quartz-garnet-microcline-oligoclase-biotite-epidote (-muscovite).

Quartz-oligoclase-biotite-hornblende-epidote (-garnet).

Calcareous and semi-calcareous rocks containing the following mineral combinations conform to the staurolite-almandine sub-facies (Turner and Verhoogen, 1960, p. 548):—

Calcite-diopside-tremolite-scapolite-oligoclase-phlogopite-forsterite.
Calcite-diopside-hornblende-scapolite-sphene.

Garnet-diopside-hornblende-quartz-microcline (biotite-epidote-plagioclase-calcite-sphene).

Garnet-diopside-hypersthene-hornblende-plagioclase.

These mineral assemblages in the Precambrian rocks show that the grade of metamorphism attained in the Amboseli area corresponds generally to the lowest part of the almandine-amphibolite facies (in which facies temperatures range from about 550 to 750° C. and pressures between 4,000 and 8,000 bars) though local assemblages transitional to the high-grade part of the greenschist facies and the middle part of the almandine-amphibolite facies are recorded. Similar conclusions were reached in the Mara River-Sianna area (Williams, 1964, p. 28) some 150 miles to the north-west. In the adjacent Namanga-Bissel area Joubert (1957*a*, pp. 35-38) recorded mineral assemblages conforming to the cordierite-anthophyllite, staurolite-kyanite, and almandine-diopside-hornblende sub-facies of the amphibolite facies; lower grades in the upper parts of the succession were indicated by the recognition of the chloritoid-almandine sub-facies of the albite-epidote-amphibolite facies. Assemblages comparable to those of the granulite facies were disregarded owing to evidence of chemical disequilibrium.

2. Kilimanjaro Volcanic Rocks

Volcanic rocks derived from Kilimanjaro are exposed over much of the ground south of latitude 2°40′ S. and east of longitude 37°05′ E. Lava flows also encircle and define the eastern end of the Amboseli basin, and borehole evidence discussed later shows that volcanic rocks locally form a floor to the basin. Small isolated occurrences of basalt at Mesanani, near the northern end of Lake Amboseli, probably represent local eruptions from fissures in the underlying Precambrian granulites. Cones that developed as parasitic vents on the flanks of the main volcanoes are situated mainly in Tanzania, but several occur in the Amboseli area.

No formal stratigraphic name has been proposed to cover all the volcanic rocks derived from the Kilimanjaro centres. In published summaries of the geology of the mountain, workers have used terms such as "Neogene Volcanics" or "Kilimanjaro Volcanics" e.g. Wilcockson et al., (1965, p. 2). Joubert (1957*a*, p. 34) introduced the name "Kilimanjaro Lavas" to describe olivine basalts encountered in the Namanga area west of Amboseli, referring these rocks to the Lower Pleistocene. The writer however, prefers the more general term "Kilimanjaro Volcanic Rocks" to cover the entire suite, for pyroclastic deposits are known to occur in the succession at some localities.

The contact between the volcanic rocks and the foundation of Precambrian metamorphic rocks is frequently obscured by sediments, so that only limited evidence of lava base levels is available in the Amboseli area. Mapping of the northern occurrences of lava showed that the early flows are banked against a rather irregular surface representing residual hills on an erosion surface which can be traced in neighbouring areas. The borehole (C.3043) at Ol Barengoi, south-west of Ol Tukai, proved the lava-metamorphic rock contact at 3,715 ft., O.D. Another borehole (C.2749) at Naiperra, 12 miles east-south-east of Ol Barengoi, pierced 626 feet of lava without locating the Precambrian rocks, though it is thought that the contact lies close to this depth, i.e. at about 3,340 ft. O.D.

Lava flows from Kilimanjaro spread across the Amboseli area, infilling and damming a trough which had developed from a drainage system on the south-easterly sloping end-Tertiary surface. It is considered likely that lavas originally extended beyond the confines of the Amboseli area and that they were subsequently stripped by erosion from that part of the trough north-west of the present position of Lake Amboseli. With continued downcutting of the floor of the trough the edge of the lava sheet moved back towards Kilimanjaro; later the entire basin was infilled with sediments.

Only limited borehole evidence is at present available to prove the limit of volcanic rocks beneath the cover of lake deposits. Boreholes at the northern end of Lake Amboseli penetrated Precambrian rocks beneath the sediments. At Naerabala an exploratory borehole located scoriaceous lavas at a depth of about 50 feet, whereas at a point midway between Ol Tukai and Lake Amboseli lava was encountered 33 feet below the surface. The total thickness of volcanic rocks was not proved at either locality, but it seems likely that both boreholes were drilled close to the line along which the lavas wedge-out beneath the sedimentary cover. The Naerabala site lies very close to a prominent volcanic vent, so it is conceivable that the borehole penetrated an isolated occurrence of lava, and not necessarily the main lava sheet. On the other hand solid lavas are exposed only a mile and a half away from the vent so it seems likely that these basalt flows extend, beneath the sediments, at least as far as Naerabala.

The early flows from Kilimanjaro rest on a partly dissected erosion surface which had reached maturity in Middle Pliocene times, so that volcanicity evidently commenced during the Upper Pliocene or Lower Pleistocene. This conclusion is in agreement with that reached by Wilkinson (1966, p. 28) from studies in Tanzania; he stated ". . . the earliest volcanicity is therefore not earlier than the late Pliocene".

Ages of about one million years were obtained by Prof. G. H. Curtis of the University of California (personal communication) from specimens collected at the writer's request; these came from two of the earlier flows in the Amboseli area. A specimen from the Lent Group, collected in Tanzania, gave a figure of 0.4 m.y. (Wilkinson, op. cit., p. 29): this group embraces lavas near the top of the Amboseli succession.

The youngest lavas in the Amboseli area are part of a flow which Downie (1964, pp. 7, 10) regarded as post-Pleistocene in age because eruption occurred after a glaciation tentatively correlated with the late Pleistocene Gamblian pluvial period.

The Amboseli volcanic succession is summarized below, maximum thicknesses of the various groups also being indicated.

		Maximum thickness (feet)	
(7) Phonolites	Inner Crater Group	50	
(6) Olivine phonolites trachytes and basalts	Lent Group	600	
(5) Olivine rhomb porphyries	Rhomb Porhyry Group ..	400	↑ Lavas and tuffs of the parasitic vents
(4) Nephelinites, ankaratrites and melanephelinites.	Upper Nephelinites ..	400	
(3) Felsparphyric olivine basalts and mugearitic olivine basalts.	Upper Olivine Basalts ..	900	
(2) Ankaratrites, melanephelinites, nephelinites, tephrites and phonolites.	Lower Nephelinites ..	100	
(1) Olivine basalts, felsparphyric olivine basalts, mugearitic basalts, basanites.	Lower Olivine Basalts ..	2,200	

These figures are based on observations made at widely scattered localities, so that an aggregate obtained from the table is likely to exceed the total thickness of volcanic rocks at any one site. The accuracy of an estimate of maximum total thickness in the area depends on the validity of inferences drawn from physiographic studies described earlier, for little direct evidence of the altitude of the sub-lava surface is available. The volcanic rocks probably attain a maximum thickness of some 3,400 ft. at the Kenya-Tanzania border east of the old Kamwanga-Emali road, for there the basal lava flows are considered to lie at about 3,000 ft. O.D. (Fig. 2).

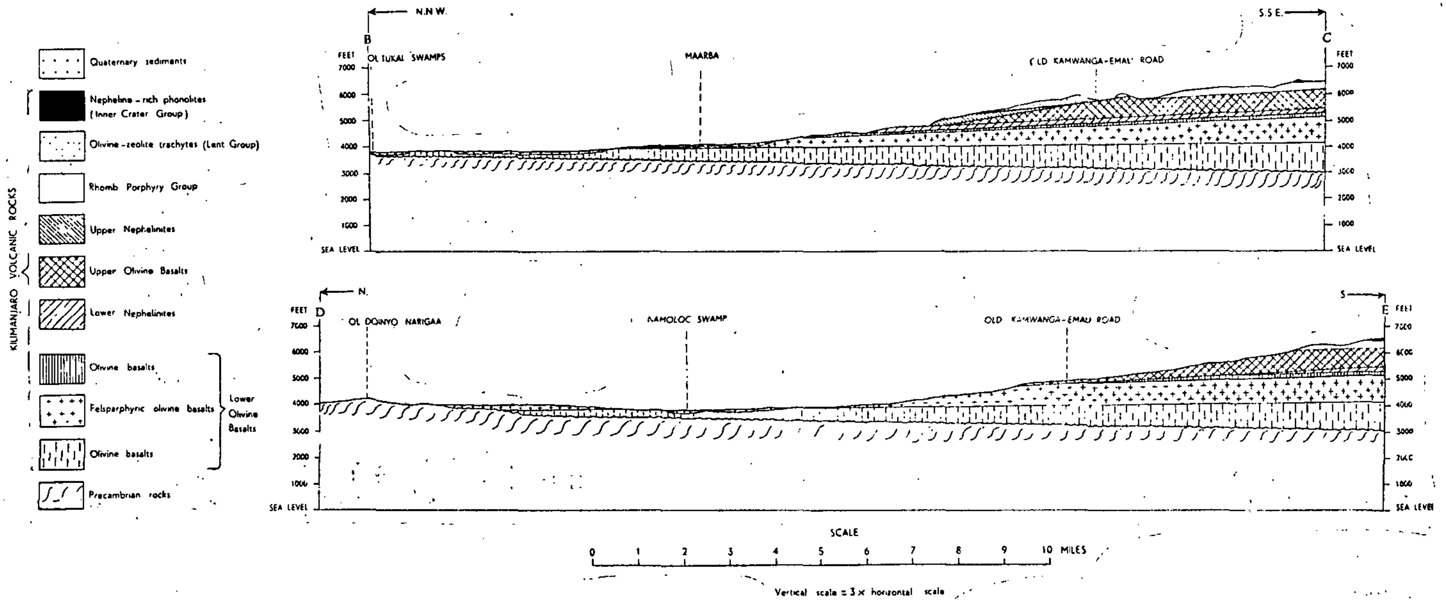

Fig. 2—Sections through the lavas in the Amboseli area. The lines of the sections are shown on the coloured geological map.

A full discussion of the correlation of the Amboseli succession with that established by workers on Kilimanjaro is given later (p. 45), and it will suffice here to note the adoption of several of the stratigraphic names used in Tanzania. The term *Inner Crater Group* is applied to nepheline-rich phonolites to stress the undoubted correlation with similar lavas across the border. Fine-grained, olivine-bearing phonolites, trachytes and basalts of the Amboseli area are together correlated with the *Lent Group* described in Tanzania, and rhomb porphyries represent a continuation of the *Rhomb Porphyry Group* mapped over a considerable area of the mountain. Some difficulty is experienced in correlating lavas underlying the rhomb porphyries with the succession established on the mountain, so new stratigraphic terms are introduced. The *Lower Olivine Basalts* and *Upper Olivine Basalts* are separated by flows of undersaturated and often felspar-free lavas here termed the *Lower Nephelinites.* The Upper Olivine Basalts are in turn overlain by a second group of undersaturated lavas to which the term *Upper Nephelinites* is applied. Some of the earlier basalts are equivalent to the *Ol Molog Group* distinguished in Tanzania.

The chief problems encountered in classifying and naming the basaltic lavas arise from difficulties in assessing (*a*) the role of zeolites and analcime in many of the rocks and (*b*) the proportion and overall composition of plagioclase more sodic than An_{50}. In the account that follows the scheme adopted for the classification of the basaltic and felspar-free lavas is that described elsewhere by the author (Williams, 1969). Some of the terms applied to the basaltic lavas in the Amboseli area are defined below:

Mugearitic olivine basalt: An olivine basalt containing sodic plagioclase as well as felspar more calcic than An_{50}. The term is used to stress the occurrence of interstitial oligoclase/potash-oligoclase in basaltic lavas.

Zeolite basanite: A olivine-bearing basaltic rock containing zeolite of presumed primary origin.

Mugearitic zeolite basanite: A zeolite basanite containing both sodic and calcic plagioclase.

Alkali olivine basalt: This term is reserved for olivine basalts containing minerals such as biotite or alkali amphiboles.

Difficulties were encountered in providing precise names for some of the trachytic and phonolitic lavas in the Amboseli area, particularly the finer-grained varieties. Chemical analyses have proved useful and the details are discussed later. Olivine is present in many of the rocks, and in some rocks zeolites evidently take the place of nepheline.

The volcanic rocks in the Amboseli area are conveniently described in approximate stratigraphic order under the following headings (symbols quoted are those used on the coloured geological map)*:—

(1) Lower Olivine Basalts

- (*a*) Olivine basalts (Plb_1)
- (*b*) Felsparphyric olivine basalts (Plb_2)
- (*c*) Olivine basalts (Plb_3)
- (*d*) Distribution and thickness from borehole evidence
- (*e*) Pyroclastic rocks

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* Full petrographic details and a discussion of the chemistry and petrogenesis of the Kilimanjaro Volcanic Rocks of the Amboseli area are provided elsewhere (Williams, 1967; 1969).

(2) Lower Nephelinites (Pln)
(3) Upper Olivine Basalts
    (*a*) Felsparphyric pyroxene-olivine basalts (Plb$_4$)
    (*b*) Felsparphyric olivine basalts (Plb$_5$)
(4) Upper Nephelinites
    (*a*) Melanephelinites (Plu$_1$)
    (*b*) Ankaratrites (Plu$_2$)
    (*c*) Nephelinites (Plu$_3$)
(5) Rhomb Porphyry Group (Plp$_1$)
(6) Lent Group
    (*a*) Olivine-zeolite trachytes and subordinate basalts (Plh)
    (*b*) Olivine phonolites (Plp$_2$)
(7) Inner Crater Group (Rvp)
(8) Lavas and tuffs of the parasitic vents (Plt)

(1) LOWER OLIVINE BASALTS (PLB$_1$ PLB$_2$ AND PLB$_3$)

The Lower Olivine Basalts are the oldest volcanic rocks seen in the Amboseli area. They must represent some of the earlier flows from Kilimanjaro and, though locally obscured by overlying sediments, are widely exposed between latitudes 2°40′ and 2°50′ S. The basalts define the eastern end of the Amboseli Basin and are the only lavas in the Kilimanjaro succession to outcrop along the northern rim of the basin, where they rest on Precambrian rocks between the Ol Tukai-Sultan Hamud road and the eastern boundary of the area mapped. Small isolated occurrences of olivine basalt at Mesanani, close to the northern end of Lake Amboseli, are probably of the same age as the Lower Olivine Basalts, though it is believed that the Mesanani lava was extruded locally along fissures in the Precambrian rocks.

The basal flows (Plb$_1$) of the Lower Olivine Basalts are correlated with olivine basalts and trachybasalts of the "Ol Molog group" mapped in Tanzania. These lavas may have been derived from the Shira centre, whereas the later lavas in the Amboseli area came from the Kibo centre.

Along the foothills of the mountain various members of the Lower Olivine Basalts are overlapped by a number of later flows, but locally they outcrop up to about 4,800 ft. Between the Likaswa Hills and Lemongo, the Lower Nephelinites overlie the basalts; at Likaswa fine-grained olivine-bearing phonolites of the Lent Group rest directly on the lower basalts; and between Lemongo and the eastern boundary of the area the Upper Olivine Basalts overlap the Lower Nephelinites to overlie the Lower Olivine Basalts. Nephelinitic lavas mapped immediately south of the Namoloc swamp have been tentatively correlated with the Lower Nephelinites encountered elsewhere (where they are clearly younger than the Lower Olivine Basalts) and it is believed that the Namoloc lavas overlie the basal member of the lower basalts.

The combined thickness of the lower basalts cannot be estimated with accuracy since the base is insufficiently exposed, but the group is probably some 2,200 feet thick in the extreme south-eastern part of the area, where it is overlain by a series of later flows. The Lower Olivine Basalts thin rapidly in a north-westerly direction from the foothills of Kilimanjaro and probably wedge out beneath the sediments approximately along a line joining the western extremities of the outcrops both north and south of the Amboseli basin (excluding the lava at Mesanani). Lavas that continue to floor the basin, beneath the sediments, west of this line are probably later flows associated with the volcanic vents of the Sinya and Kitirua districts.

The following stratigraphic subdivision of the Lower Olivine Basalts is based on the composition and size of the phenocrysts: —

(*c*) Olivine basalts (Plb$_3$).

(*b*) Felsparphyric olivine basalts (Plb$_2$).

(*a*) Olivine basalts (Plb$_1$).

(a) Olivine Basalts (Plb$_1$)

The basal flows of the Lower Olivine Basalts probably attain a maximum thickness of more than 1,000 feet. A detailed examination of these lavas between Lemomo Vent and the Likaswa Hills showed that they can be subdivided further as follows, the three types being arranged in stratigraphical order: —

Type (C) basalts: phenocrysts of olivine, pyroxene and frequently plagioclase.

Type (B) basalts: phenocrysts of olivine and plagioclase.

Type (A) basalts: phenocrysts of olivine only.

This subdivision of the earlier basaltic rocks is not indicated by different symbols or colours on the main geological map, though the margins of individual flows are marked where they form prominent features. The distribution of the various types is shown in Figure 3.

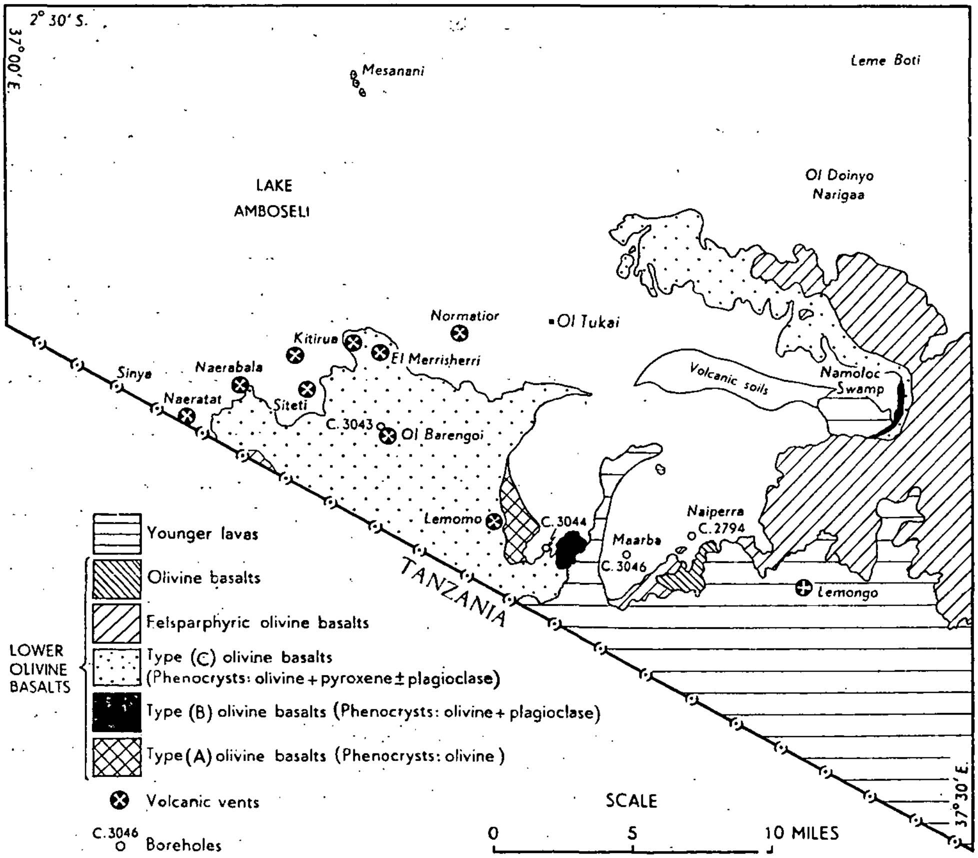

Fig. 3—Distribution of the Lower Olivine Basalts

Type (A) Basalts: These lavas are typically dark blue-grey, slightly vesicular rocks with olivine phenocrysts up to 8 mm. long. The vesicles are generally unfilled though occasionally they bear a lining of calcite or zeolite. The rocks were encountered only in two small flows east and south-east of Lemomo Vent.

The thin section of a *mugearitic olivine basalt* (59/487)* from the flow about a mile south-east of Lemomo Vent shows abundant euhedral to sub-hedral phenocrysts of colourless olivine, generally 0.5-2 mm. long, set in a holocrystalline groundmass of unorientated labradorite laths, grains of augite, ore and olivine, and needles of apatite. Some interstitial felspar is untwinned, has low relief and is optically positive: it is probably a potash oligoclase similar to that described by Macdonald (1942) in Hawaiian lavas, and by Searle (1961, p. 166) in some New Zealand basalts.

Olivine phenocrysts are less common in a *zeolite basanite* (59/488) from the upper of the two flows a mile east of Lemomo Vent. Purple-brown titanaugite, olivine, ore, calcite and labradorite (An_{69}) form a relatively coarse groundmass displaying intergranular texture. The groundmass contains rare glassy pools of a zeolite tentatively identified as chabazite. A chemical analysis of this rock is given in Table 1 (A).

Type (B) Basalts: These basalts contain tabular plagioclase phenocrysts up to 35 mm. long and some 5-10 mm. thick, together with rounded insets of olivine rarely larger than 1 mm. across. The rocks weather to shades of dark brown with some etching out of the groundmass around the prominent plagioclase phenocrysts. The lavas occur near Kitenden and also immediately south-east of the Namoloc Swamp; at both localities they are overlain by type (C) basalts.

A specimen (59/489) of *mugearitic zeolite basanite* was collected from a flow near Kitenden, some two-and-a-half miles east-south-east of Lemomo Vent. The felspar phenocrysts are optically positive with refractive indices approximately equal to that of balsam, suggesting a composition near oligoclase. The crystals have corroded margins with embayments and inclusions of the groundmass in the felspar. Microphenocrysts of olivine display marginal alteration to weakly pleochroic reddish-brown bowlingite. Two types of felspar occur as microphenocrysts; the commonest is labradorite, but a single section having corroded margins shows fine polysynthetic twinning in two directions and 2V (−) = c. 50°. Superficially it resembles anorthoclase but refractive indices are approximately equal to that of balsam, and the felspar is probably an oligoclase similar to that identified in the rhomb porphyries which are described later. The groundmass consists of labradorite (An_{62}), augite and ore, together with residual oligoclase and occasional pools of zeolite (? chabazite). The texture is intergranular.

Mugearitic olivine basalts near the Namoloc Swamp are moderately vesicular pale ash-grey lavas with plagioclase phenocrysts 5 mm. long and olivines 1-2 mm. in diameter.

Type (C) Basalts: In the third type of early basalt, megascopic pyroxenes and olivines are sometimes accompanied by plagioclase phenocrysts.

At Kitenden, at Ol Barengoi and locally north of the Olobolodi, the blue-grey compact rocks bear only phenocrysts of pyroxene and olivine, both commonly 2-3 mm. across though occasionally attaining twice that size. A specimen (59/439) of *mugearitic olivine basalt* from the plain at the base of Ol Barengoi Vent contains subhedral titanaugite ($Z \wedge c = 43°$), subhedral olivines and rare oligoclase microphenocrysts set in a groundmass of sub-parallel labradorite laths, granular pyroxene, olivine and magnetite, and skeleton crystals of ilmenite. Some optically positive interstitial material in the base has low relief and is probably oligoclase.

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* Numbers prefixed by 59/ refer to specimens in the regional collection of the Mines and Geological Department, Nairobi. Specimens in the author's collection at University College. Nairobi, are distinguished by the prefix W.

TABLE 1—CHEMICAL ANALYSES AND NORMATIVE COMPOSITIONS OF LAVAS FROM THE AMBOSELI AREA

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
SiO_2	43·38	44·57	44·72	46·82	47·14	47·10	39·98	37·15	39·72	39·88	52·54	52·87	51·97	53·29
Al_2O_3	15·04	14·62	11·87	19·69	11·90	11·90	12·27	13·92	9·49	10·25	17·61	18·24	16·33	18·28
Fe_2O_3	2·58	3·10	3·32	3·51	4·81	3·49	5·82	5·62	6·88	5·10	5·06	3·63	5·22	5·09
FeO	10·79	10·43	9·35	7·01	7·78	9·16	7·57	7·22	6·88	6·86	3·13	4·88	6·92	3·17
MgO	7·40	7·20	9·21	3·25	10·14	10·30	8·25	5·94	12·20	12·45	1·50	1·68	2·18	1·74
CaO	11·31	10·09	11·94	11·03	10·75	10·65	15·47	15·19	16·73	16·96	4·96	4·35	4·58	3·18
Na_2O	2·50	3·42	2·72	4·48	2·35	2·29	2·49	4·44	1·23	1·85	6·28	6·54	4·50	5·86
K_2O	1·27	1·19	1·36	1·96	0·69	0·69	0·74	1·33	1·09	1·10	4·27	4·19	4·17	5·33
H_2O+	0·52	0·14	0·58	0·15	0·49	0·35	1·72	1·67	1·35		0·65	0·76	1·18	1·86
H_2O-	0·23	0·06	0·42	0·08	0·26	0·23	0·61	0·81	Nil	1·19	0·17	0·39	0·61	0·54
TiO_2	3·73	3·88	3·01	2·54	3·16	3·22	3·85	4·27	3·83	3·82	1·76	1·88	1·95	1·07
P_2O_5	0·75	1·09	0·40	0·50	0·37	0·33	0·68	1·08	0·69	0·84	0·63	0·76	0·88	0·35
CO_2	0·57	0·01	0·52	3·26	trace	0·02	0·06	0·84	0·22	—	0·86	0·11	0·21	0·76
MnO	0·17	0·23	0·19	0·19	0·18	0·18	0·22	0·25	0·15	0·13	0·24	0·25	0·26	0·16
	100·24	100·03	99·61	100·47	99·86	99·91	99·73	99·73	100·46	100·10	99·66	100·53	100·96	100·67
Or	7·78	7·23	8·34	11·68	3·89	3·89	3·89	—	—	—	25·02	25·02	25·02	31·14
ab	16·24	20·96	13·62	33·01	19·91	19·39	—	—	—	—	37·47	34·58	38·25	37·20
an	25·85	20·85	16·12	16·96	19·46	20·29	20·29	13·90	16·96	16·40	7·51	7·78	11·68	7·78
ne	2·56	4·26	5·11	2·56	—	—	11·36	20·45	5·68	8·52	8·38	11·08	—	6·82
lc	—	—	—	—	—	—	0·44	6·10	5·23	5·23	—	—	—	—
di	17·22	17·62	29·75	11·16	24·70	24·50	40·54	32·66	40·74	36·12	6·48	7·05	3·43	0·22
ol	15·91	14·53	13·38	6·36	4·46	9·20	3·41	1·18	8·71	11·60	0·56	2·97	6·41	3·08
hy	—	—	—	—	12·74	10·14	—	—	—	—	—	—	0·70	
cs	—	—	—	—	—	—	—	2·24	2·41	4·47	—	—	—	—
mt	3·71	4·41	4·87	5·10	6·96	5·10	8·35	8·12	9·98	7·42	5·57	5·34	7·66	7·42
il	7·14	7·45	5·78	4·86	6·08	6·08	7·30	8·06	7·30	7·30	3·34	3·65	3·80	2·13
hm	—	—	—	—	—	—	—	—	—	—	—	—	0·70	—
ap	2·02	2·69	1·01	1·34	1·01	0·67	1·68	2·69	1·68	2·02	1·34	1·68	2·02	1·01
cc	1·30	—	1·20	7·40	—	—	0·10	1·90	0·50	—	1·90	0·20	0·50	1·70

A. Zeolite basanite (59/488), 1 m. E of Lemomo vent, Anal. J. Furst.

B. Olivine basalt (59/513), S. end of Engong Narok Swamp. Anal. H. Lloyd.

C. Mugearitic olivine basalt (W. 369), Kitenden watercourse. Anal. H. Lloyd.

D. Mugearitic olivine basalt (59/514), four miles N.E. of Naiperra. Anal. H. Lloyd.

E. Mugearitic olivine basalt (W. 287), Naiperra. Anal. H. Lloyd.

F. Mugearitic Olivine basalt (W. 364), Naiperra. Anal. H. Lloyd.

G. Analcime ankaratrite (W. 372), E. of Naiperra. Anal. H. Lloyd.

H. Biotite - perovskite - analcime melanephelinite (W. 373), E. of Naiperra. Anal. H. Lloyd.

I. Analcime-zeolite ankaratrite (59/482), S.W. of Lemongo. Anal. J. Furst.

J. Analcime-zeolite ankaratrite (59/482), S.W. of Lemongo. Anal. C. P. Wood.

K. Rhomb porphyry (W. 366), Seru. Anal. H. Lloyd.

L. Rhomb porphyry (W. 379), border 3 miles E.S.E. of BP 50. Anal. H. Lloyd.

M. Olivine - zeolite trachyte (59/504) ½ mile E. of Kamwanga Emali road.

N. Olivine phonolite (59/474) Likaswa Hills. Anal J. Furst.

The Kitenden lavas differ only slightly from those near Ol Barengoi. In a specimen (59/410) of *mugearitic olivine basalt,* from the Kitenden watercourse about 1,000 yards upstream from the dam, the zoned pale brown augite phenocrysts have cores with 2V (+) = 52° and Z c = 46°, and rims with 2V (+) = 54° and Z ∧ c = 45°. Another *mugearitic olivine basalt* (W.369) was collected upstream from Kitenden Dam from the low scarp which marks the edge of a flow overlying the one sampled above. The medium-grey lava contains phenocrysts of augite 5-6 mm. long and olivine seldom more than 3 mm. across. A chemical analysis of this specimen is quoted in Table 1 (*c*).

The type (C) lavas near the springs at the southern end of Engong Narok Swamp are medium-grey olivine basalts and mugearitic olivine basalts with phenocrysts of pyroxene up to 7 mm. long and pale green or yellow-green olivines up to 5 mm. across. The thin section of a specimen (59/513) of *olivine basalt* shows phenocrysts of pale brown augite and unaltered olivine, and microphenocrysts of labradorite (An_{68}) in a groundmass of andesine-labradorite laths, prismatic crystals and grains of pyroxene, ore and olivine granules, and slender crystals of apatite. This lava was collected for dating purposes; it gave a result of about one million years (Curtis, personal communication). A chemical analysis is given in Table 1 (*b*).

An *olivine basalt* (59/465) from a locality some three miles north-west of the Namoloc Swamp, resembles the lavas near the Engong Narok swamp in containing microphenocrysts of labradorite in addition to insets of pale brown zoned augite and olivine.

The type (C) basalts sometimes contain megascopic plagioclase in addition to olivine and pyroxene. A *zeolite basanite* (59/418) collected near the causeway that carries the Ol Tukai-Sultan Hamud road across the seasonal Olobolodi stream bed, displays tabular plagioclase phenocrysts some 10 mm. across by 1-2 mm. thick. Pyroxene, frequently appearing in euhedral crystals up to 10 mm. long, is more prominent than small altered olivines. The plagioclase in both the phenocrysts and the groundmass was found to be labradorite, and the pyroxene is a brown or purple-brown titanaugite having 2V (+) = 60° and Z ∧ c = 47°. A weakly birefringent interstitial zeolite is probably natrolite or chabazite. Calcite infills vesicles rimmed with euhedral zeolite and also runs in thin veinlets through the groundmass.

In a *mugearitic olivine basalt* (59/473) from the uppermost flow at Lemomo, both pyroxene and plagioclase are less prominent than in the lava described above, the labradorite phenocrysts seldom exceeding 3 mm. in length. The larger olivine phenocrysts are approximately 2 mm. across and are optically negative with large axial angles; smaller olivine insets are optically positive. Reddish-brown bowlingite often forms an intermediate zone or a core in otherwise clear olivine, showing that crystallization was resumed after alteration had taken place. Interstitial oligoclase in the groundmass is readily distinguished from labradorite by the difference in relief. Secondary calcite is locally abundant in the base, and a carbonate also occurs as a lining in vesicles.

(b) Felsparphyric Olivine Basalts (Plb_2)

Some of the lavas described above contain megascopic plagioclase, but the felspar is seldom conspicuous. In contrast, immediately overlying flows are notably rich in plagioclase phenocrysts.

Typical specimens of the felsparphyric basalts display closely packed tabular plagioclase phenocrysts some 10-20 mm. across and 1-2 mm. thick. These are accompanied by smaller insets of olivine and frequently pyroxene (both generally less than 2 mm. across, though locally the ferromagnesian phenocrysts attain twice that size) set in a grey, purple-grey or brownish fine-grained groundmass. The rocks exhibit a rough fracture with a tendency to crumble so that the tabular habit of the felspar is not always apparent at first glance. Weathered surfaces, on the other hand, often show clearly the coarsely porphyritic nature of the rock, with pale brown plates of felspar prominently displayed in a dark brown or reddish-brown matrix. Differential weathering of the surface occasionally leaves the plagioclase standing out from the groundmass.

In the vicinity of Naiperra felsparphyric lavas are convincingly referred to the Lower Olivine Basalts, for they are overlain by distinctive olivine basalts (Plb$_3$) and by flows of the Lower Nephelinites (Pln). The felsparphyric rocks extend from Naiperra in an unbroken outcrop which encircles the eastern end of the Amboseli Basin, continuing north-westwards from the Namoloc Swamp to within three-and-a-half miles of the Ol Tukai-Sultan Hamud road. Curtis (personal communication) reports a figure of about one million years for the age of the felsparphyric basalts east of Naiperra.

Between Naiperra and the Namoloc Swamp the lavas attain a total thickness of about 1,000 feet. Scarp features suggest the existence of at least two major flows. Along the north-eastern rim of the Amboseli basin felsparphyric olivine basalts overlie less spectacularly porphyritic lavas (Plb$_1$), probably locally overlapping the earlier flows to rest directly on Precambrian rocks, the actual contact being obscured by soils.

The thin section of a specimen (59/460) of *mugearitic olivine basalt* collected from a locality midway between Naiperra and the Namoloc Swamp shows phenocrysts of labradorite together with microphenocrysts of titanaugite, optically positive oligoclase, altered olivine. and ore set in a groundmass consisting essentially of plagioclase microlites, pyroxene and ore. Most of the interstitial material in the base is oligoclase, but a little zeolite is probably also present.

Another specimen (59/514) of felsparphyric lava from this locality came from the exposure selected by Curtis for a sample for age determination. The rock is a *mugearitic olivine basalt* with phenocrysts of labradorite (An$_{64}$) and olivine set in a groundmass of granular pyroxene and ore, tiny olivines, microlites of labradorite (An$_{66}$) and apatite needles. Interstitial optically positive felspar with low relief is probably oligoclase. Calcite amygdales are common. A chemical analysis of this rock is presented in Table 1 (*d*).

Andesine phenocrysts occur in some of the lavas and the rocks show affinities with hawaiites. In specimen 59/409 from Naiperra, for instance, the felspar phenocrysts have $\beta = 1.554$ and $\gamma = 1.561$, indicating the composition to lie between An$_{42}$ and An$_{47}$ according to the curve provided by Chayes (1952). The curves prepared by Smith (1957) to cover high-temperature modifications show a similar composition range (An$_{43}$ to An$_{48}$). Much of the felspar in the base is undoubtely labradorite, but some has a refractive index slightly less than or equal to that of balsam, is optically positive, and is tentatively identified as oligoclase or potash oligoclase. This rock may be very similar to trachyandesites of the Lower Rectangle Porphyry Group of Tanzania, in which the phenocrysts are of andesine (Wilcockson *et al.* 1965, p. 4) in contrast to the labradorite of other lavas also called trachyandesites; the nomenclature is rather puzzling, for these would appear to be trachybasalts.

The felsparphyric lavas north-west of Namoloc swamp (specimen 59/467) contain labradorite phenocrysts 20 mm. long, accompanied by small insets of titanaugite and optically negative olivines. Mugearitic olivine basalts at Ibulbul are characterized by much smaller felspar phenocrysts.

(c) Olivine Basalts (Plb$_3$)

The uppermost lavas of the Lower Olivine Basalt group are exposed only over a limited area immediately south of Naiperra borehole, where they rest on early felsparphyric basalts (Plb$_2$) and are in turn overlain by the Lower Nephelinites (Pln). The flow is probably 150 to 200 feet thick near Naiperra.

The basalts at Naiperra are medium-grey, distinctly porphyritic rocks containing phenocrysts of black or brownish pyroxene up to 5 mm. across, green, glassy olivines from 2-5 mm. in diameter, and occasional stout tabular felspar crystals up to 20 mm. long. The groundmass weathers to shades of reddish-brown, against which the phenocrysts are prominently displayed. The abundance of pyroxene and the relative paucity of felspar phenocrysts serve to distinguish these lavas from the underlying felsparphyric basalts.

The thin section of a *mugearitic olivine basalt* (59/484) collected from the end of the flow about half-a-mile east of the borehole, shows euhedral to subhedral phenocrysts of pale brown, weakly pleochroic, zoned augite. Insets of colourless olivine display marginal alteration to reddish-brown iddingsite. Labradorite (An_{63}) occurs both as large phenocrysts and also as microphenocrysts scattered throughout the felty groundmass of labradorite laths, olivine and pyroxene crystals, ore grains, and interstitial calcite. Interstitial felspar is characterized by low relief and is probably potash oligoclase.

In a specimen (W.287) of *mugearitic olivine basalt,* collected in the gorge south of Naiperra borehole, some of the plagioclase phenocrysts are as calcic as bytownite (An_{74}). The laths in the groundmass are of labradorite (An_{64}), but interstitial felspar has lower refractive indices and is probably oligoclase. In another *mugearitic olivine basalt* (W. 364), from the first gorge east of Naiperra borehole, the plagioclase phenocrysts are of labradorite (An_{68}). Optically positive interstitial felspar in the base has refractive indices approximately equal to that of balsam and is regarded as oligoclase/potash oligoclase. The chemical analyses of these two specimens are given in Table 1 (E and F).

(*d*) *Distribution and Thickness from Borehole Evidence*

The samples from percussion-drilled water boreholes (C. 3043 Ol Barengoi; C. 3044 Kitenden; C. 3046 Maarba; C. 2794 Naiperra) were studied to determine the successions in those areas. It was assumed that the presence of common fragments of a particular mineral in the samples could be taken to denote the presence of prominent phenocrysts of that mineral in the lava. The results of the study are shown diagrammatically in Figure 4 (at end).

Type (A) olivine basalts were not recognized at Ol Barengoi and Naiperra, and they were only doubtfully identified at the base of the successions established at Kitenden and Maarba, so the thickness of the group cannot be estimated.

Type (B) basalts form the greater part of the successions at Kitenden and Maarba, but are evidently not represented at Ol Barengoi and Naiperra. They seem to attain a maximum thickness of 315 feet at Maarba.

Type (C) olivine basalts reach the greatest thickness at Naiperra, where 465 feet is indicated by the borehole. 75 feet was proved at Ol Barengoi, and only 35 feet and 15 feet at Maarba and Kitenden respectively.

The felsparphyric olivine basalts (Plb_2) are best represented at Naiperra, where felspar-rich lavas and tuffs overlying type (C) basalts attain a thickness of 80 feet. The felsparphyric basalts dwindle to 25 feet at Maarba, and are absent at Kitenden and Ol Barengoi.

(*e*) *Pyroclastic Rocks*

Minor intercalations of pyroclastic rocks among lavas of the Lower Olivine Basalts were proved in the boreholes at Kitenden, Maarba and Naiperra (Fig. 4), but no exposures of tuffs and ashes were located during mapping. The boreholes penetrated only the lower half of the succession, and there is no way of assessing the role of pyroclastic rocks in the upper part of the basaltic group.

A major tuff bed, some 40 feet thick, was located in the felsparphyric olivine basalts (Plb_2) at Naiperra, but its lateral extent is unknown. A less significant intercalation of tuff occurs in the type (C) basalts between Naiperra and Maarba. Volcanic ashes occur at several horizons in the type (B) basalts between Maarba and Kitenden, one bed of pale grey ash at Kitenden evidently being some seven to eight feet thick. The type (A) basalts were encountered only in the final few feet in two of the boreholes, so that the succession is insufficiently known to determine the role of pyroclastic rocks.

(2) LOWER NEPHELINITES (PLN)

The Lower Nephelinites are exposed in two areas, being concealed elsewhere by overlapping later flows; they attain a total thickness of about 100 feet. South of Naiperra, between the Likaswa Hills and Lemongo Vent, ankaratrites and rare phonolites rest on the middle and upper members of the Lower Olivine Basalts (i.e. Plb_2 and Plb_3) and are overlain by felsparphyric pyroxene-olivine basalts (Plb_4, the earliest flows of the Upper Olivine Basalts) and by melanephelinites (Plu_2) of the Upper Nephelinites.

Perovskite nephelinites immediately south of the Namoloc Swamp are tentatively referred to the Lower Nephelinites. The field relationships are not well displayed at that locality, but it is believed that the nephelinitic rocks overlie at least the basal flows of the Lower Olivine Basalts. The nephelinites evidently grade westwards into nepheline-zeolite tephrites, which show rather puzzling relationships towards nearby felsparphyric lavas: the contact between these flows is either a fault or, and this seems more likely, the tephrites occupy an erosional hollow in the felsparphyric basalts.

(*a*) *Ankaratrites*

Representatives of the Lower Nephelinites exposed south of Naiperra are medium-grey porphyritic ankaratrites containing only euhedral phenocrysts of black or dark brown pyroxene commonly 5 mm. or more across. The lavas are compact and bear only a few small vesicles and occasional brownish or yellowish amygdales about 2 mm. in diameter. East of Naiperra borehole the ankaratrites contain slightly larger pyroxenes and some varieties bear megascopic olivines.

A specimen of *analcime-zeolite ankaratrite* (59/408), collected from the base of the flow in the gorge immediately south of Naiperra borehole, has euhedral to subhedral pyroxene phenocrysts together with smaller insets of ore and apatite in a fine, felty groundmass consisting of prismatic crystals and grains of pyroxene, grains of ore, apatite, iddingsite (after olivine), rare small flakes of biotite, and interstitial nepheline, analcime and zeolite. The zoned, pale-brown weakly pleochroic augite phenocrysts have maximum extinction angles $Z \wedge c = 51°$. Interstitial colourless to very pale-brown zeolite is optically positive with a small optic angle and is tentatively identified as chabazite. The biotite is strongly pleochroic in shades of reddish-brown.

Two analyses of an analcime-zeolite ankaratrite (59/482) are quoted in Table 1 (I and J). This specimen comes from the Upper Nephelinites, and it differs from the rock described above in containing megascopic olivine. It is more fully described on a later page.

Another specimen of *analcime-zeolite ankaratrite* (W. 376) came from the spur just over a mile east of Naiperra borehole. An *analcime ankaratrite* (W. 372) from the same locality contains numerous pyroxenes 7-8 mm. long and altered olivines 2 mm. across set in a dark brownish-grey groundmass. In thin section this rock shows phenocrysts of pale-brown augite, grains of ore and an occasional colourless olivine with a thin rim of reddish brown iddingsite. Nepheline, analcime and small flakes of yellow-brown biotite accompany prismatic pyroxenes and grains of ore and altered olivine in the rather fine groundmass. A chemical analysis of specimen W.372 is quoted in Table 1 (*g*).

(*b*) *Melanephelinites and Nephelinites*

Some specimens of the lava east of Naiperra borehole are olivine-free. They contain pyroxenes up to 12 mm. long and rare biotite phenocrysts 10 mm. across in a medium-grey matrix. The thin section of a *biotite-perovskite-analcime-melanephelinite* (W. 373) shows numerous phenocrysts of pale-brown augite and crystals of ore in a groundmass of augite, ore, biotite, apatite, nepheline and perovskite. Pools of calcite are often fringed with euhedral analcime, and analcime also occurs interstitially throughout the base. Biotite phenocrysts were not cut by the section. A chemical analysis is given in Table 1 (*h*).

The lavas south of the Namoloc Swamp are grey and greenish-grey rocks which display square and rectangular sections of nepheline about 2 mm. across and more numerous phenocrysts of black pyroxene of about the same size. The thin section of a *perovskite-zeolite nephelinite* (59/485) from the eastern end of the outcrop shows numerous euhedral to subhedral phenocrysts of zoned pyroxene, together with nephelines, some of which display turbid alteration. Several crystals of strongly pleochroic brown amphibole are also present. These phenocrysts are accompanied by microphenocrysts of ore, sphene, perovskite, and apatite. Small prisms of greenish aegirine-augite and pale purplish titanaugite are visible in the groundmass. Nepheline occurs in euhedral crystals and in interstitial pools in association with a colourless zeolite. Ore, apatite and sphene are also present in the groundmass, and a little interstitial analcime was doubtfully identified. The zoned pyroxene phenocrysts frequently consist of pleochroic purple-brown titanaugite cores with green aegirine-augite rims; rare reversals are also seen, optically positive aegirine-augite ($X \wedge c = 35°$) being rimmed by titanaugite. The amphibole phenocrysts have X = yellow, Y = brown, Z = dark yellow-brown, and the small extinction angle $Z \wedge c = 2°$ indicates kaersutite. One 3 mm. long, rounded crystal is mantled by a reaction rim of opaque ore, and bears inclusions of titanaugite, apatite and ore. Angular microphenocrysts of mauve-brown perovskite show weak birefringence and complex twinning and occasionally attain a length of 1 mm. The aegirine-augite in the groundmass has $X \wedge c = 31°$ and occurs either as separate crystals and grains or as a rim to titanaugite. The optically negative zeolite associated with nepheline has birefringence 0.009-0.010.

(*c*) *Tephrites*

Towards the western end of the outcrop at Namoloc the perovskite-zeolite nephelinites described above grade into *nepheline-zeolite tephrites*. In specimen 59/486 there is no megascopic nepheline and a thin section shows phenocrysts of subhedral purple-brown titanaugite ($Z \wedge c = 54°$), rounded strongly pleochroic kaersutite ($Z \wedge c = 4°$), and scattered grains of ore. In the groundmass, nepheline and zeolites adopt an interstitial habit towards prisms and grains of titanaugite, plagioclase microlites, and ore grains. Rare crystals of sphene occur in the matrix, and calcite is rather common in interstitial pools and thin veinlets.

(*d*) *Phonolites*

Occasional boulders on the spur east of Naiperra borehole contain euhedral phenocrysts of nepheline up to 5 mm. across, together with small pyroxenes and rare crystals of felspar 7-8 mm. long. These minerals are set in a pale-grey mottled matrix. The felspar extracted from a nepheline-rich phonolite (W. 375) showed the optical properties of sanidine. In thin section, only nepheline and pyroxene phenocrysts are visible in a groundmass of alkali felspar laths, nepheline, pyroxene, amphibole, aenigmatite, ore, sphene and apatite. The amphibole is pleochroic from reddish-brown to yellow-brown.

These lavas superficially resemble nepheline-rich phonolites of the Inner Crater Group, but the Naiperra rocks differ chiefly in containing pale green augite phenocrysts in contrast to the aegirine reported in lavas of the Inner Crater Group. Furthermore, no amphibole, aenigmatite or sphene is visible in Inner Crater Group phonolites of the Amboseli area.

(3) UPPER OLIVINE BASALTS (PLB_4 AND PLB_5)

The Upper Olivine Basalts are characterized by abundant tabular plagioclase phenocrysts. They are exposed across the south-eastern corner of the Amboseli area, outcropping generally south of a line between the Likaswa Hills and Ropet; no representatives were found beyond the foothills of Kilimanjaro. These upper basaltic lavas rest on flows of the Lower Nephelinites between the Likaswa Hills and Lemongo, and on felsparphyric lavas of the Lower Olivine Basalts between Lemongo, Ropet and the eastern boundary of the area. They are overlain by the Upper Nephelinites west of Lemongo; by olivine phonolites at the Likaswa Hills; by olivine-zeolite trachytes where the Kamwanga road approaches the border. The total thickness of the group is believed to be some 900 feet.

Prominent pyroxene phenocrysts accompanying plagioclase in the lower flows provide a convenient basis for subdivision of the Upper Olivine Basalts into:—

(*b*) Felsparphyric olivine basalts.

(*a*) Felsparphyric pyroxene-olivine basalts.

(a) Felsparphyric Pyroxene-olivine Basalts (Plb_4)

These basal lavas of the Upper Olivine Basalts probably attain a maximum thickness of some 150 to 300 feet. East of the Likaswa Hills the rocks are felsparphyric olivine basalts, whereas in the Ropet district zeolite basanites become more common than genuine basalts, though no distinction can be made in hand specimens. Small scarp features in the Ropet district indicate the presence there of at least two separate flows, accounting for the widening of the outcrop near the eastern boundary of the area.

Plagioclase phenocrysts in these lavas are typically 10-20 mm. long and 1-3 mm. thick, though in finer-grained varieties mapped south-south-east of Ropet the felspar plates rarely exceed 5 mm. across and are correspondingly thinner than those seen elsewhere. Pyroxene phenocrysts vary from 5-10 mm. across, and green glassy olivines from 2-5 mm. in diameter, only occasionally attaining the upper limit. Alteration of olivine is particularly noticeable in the basalts of the Ropet district.

An *olivine basalt* (59/479) from a locality some three miles east of the Likaswa Hills contains large plates and microphenocrysts of labradorite, subhedral phenocrysts of pale-brown or purple-brown titanaugite, and rounded insets of olivine displaying marginal alteration to reddish-brown bowlingite. The groundmass consists of andesine-labradorite laths, and granular pyroxene, ore and olivine.

Phenocrysts of olivine, titanaugite, ore and labradorite are accompanied by a few microphenocrysts of andesine in a *mugearitic olivine basalt* (59/510) from Ropet. Both labradorite and subordinate optically positive oligoclase occur in the groundmass together with pyroxene, ore and olivine.

(b) Felsparphyric Olivine Basalts (Plb_5)

Felsparphyric lavas containing no megascopic pyroxene occur in at least two thick flows totalling some 600 feet between Lemongo and the Tanzanian border; similar rocks were mapped east of the Likaswa Hills. In all the specimens examined an alkaline tendency is indicated by the presence of biotite in the groundmass.

The rocks bear numerous plates of plagioclase about 15-20 mm. long and 1-2 mm. thick, and occasional rounded olivines rarely larger than 1 mm. in diameter; the groundmass is medium-grey. The coarsely porphyritic nature of the rock causes a rough, crumbly fracture, and in general appearance the lavas are similar to other felsparphyric basalts in the area. They differ from the earlier felsparphyric lavas, however, in containing biotite and/or amphiboles.

A *mugearitic olivine basalt* (59/478) from a locality some four miles east of the Likaswa Hills contains phenocrysts of labradorite, olivine and ore. Numerous small flakes of nearly uniaxial reddish-brown biotite are conspicuous in a groundmass of plagioclase microlites, pyroxene, ore, olivine, brown amphibole and interstitial optically positive felspar, probably oligoclase.

Biotite, pleochroic from pale yellow-brown to a distinct yellow-brown or pinkish brown, is prominent in the groundmass of a *mugearitic olivine basalt* (59/509) from a locality about a mile south-east of Lemongo Trigonometrical Beacon. The mica is closely associated with an amphibole (c.f. kataphorite) displaying pleochroism from very pale yellow-green or nearly colourless to pale-pinkish or purplish-brown. The optic angle is large, and $Z \wedge c = 30°$. Felspar laths in the base are probably andesine or labradorite but much of the interstitial felspar has low relief and is evidently oligoclase.

(4) UPPER NEPHELINITES (PLU_1, PLU_2 AND PLU_3)

Flows, described here as the Upper Nephelinites, attain a total thickness of 300 to 400 feet south-west of Lemongo vent. These lavas overlie the Upper Olivine Basalts and rest locally on the Lower Nephelinites west of Lemongo. They are overlain by fine-grained olivine-zeolite trachytes and basalts of the Lent Group, and they are considered to be older than the rhomb porphyries.

The rocks closely resemble those of the lower nephelinitic group already described, though no felspar-bearing varieties occur among the upper lavas. Biotite is present in the lower and middle flows of the Upper Nephelinites, but olivine is confined to middle members.

The Upper Nephelinites are subdivided stratigraphically as follows:—

(*c*) Nephelinites

(*b*) Ankaratrites

(*a*) Melanephelinites

(*a*) *Melanephelinites* (Plu_1)

The lowest flows of the Upper Nephelinites are best exposed in the scarps about three miles south-south-east of Naiperra where the lavas are nearly 300 feet thick. They are medium-grey to ash-grey compact rocks containing slender euhedral pyroxene phenocrysts commonly 4 mm. long; they tend to be lighter in colour than most of the basalts in the area.

Zoned pyroxenes in a *biotite-zeolite-analcime melanephelinite* (59/480) from the end of the flow two miles west of Lemongo, have pale brown cores ($2V (+) = 57°$; $Z \wedge c = 44°$) and purple-brown rims ($2V (+) = 56°$; $Z \wedge c = 57°$). Apatite occurs in small euhedral crystals, often as inclusions in the pyroxene but also as microphenocrysts throughout the groundmass, where it tends to be concentrated about large irregular ore grains. The groundmass consists essentially of numerous crystals and granules of brownish augite, fine granular dendritic ore, occasional clusters of zeolite crystals showing traces of polysynthetic twinning, and interstitial nepheline and analcime. Small flakes of biotite, pleochroic from almost colourless to reddish-brown, indicate affinities with ankaratrites. Vesicles are lined with weakly birefringent, uniaxial negative chabazite/gmelinite which occasionally shows prismatic cleavages.

(*b*) *Ankaratrites* (Plu_2)

Lavas that differ essentially from the basal flows in containing olivine phenocrysts in addition to pyroxenes are represented only by accumulations of tough, rounded boulders on the spur two and a half miles south-west of Lemongo Vent. The uniformity of composition of the boulders is taken as evidence that they were formed *in situ*. No estimate can be given of the thickness of the ankaratrite flow.

The dark grey, dense rocks contain phenocrysts of yellow-green glassy olivine varying from 3-10 mm. in diameter, and black pyroxenes up to 10 mm. across but more commonly half that size. The rocks weather to shades of medium-brown with a characteristic mottling caused by the phenocrysts.

The thin section of an *analcime-zeolite ankaratrite* (59/482) from a locality three miles south-west of Lemongo Trigonometrical Beacon, shows numerous large phenocrysts of pyroxene and olivine together with abundant ore grains, set in a fine, granular groundmass of pyroxene, ore, nepheline, zeolites and biotite. The euhedral to subhedral titanaugite phenocrysts are strongly zoned, usually with pale brown cores ($Z \wedge c = 54°$) and thin pleochroic purple-brown rims ($Z \wedge c = 56°$), though reversals of this arrangement are seen. Interference figures indicate an increase in the optic axial angle from centres to rims of the crystals. The subhedral colourless olivines have $2V (+) = 85°\text{-}90°$. Biotite in the groundmass is strongly pleochroic from pale yellow or nearly colourless to rich reddish brown or orange-brown, and is locally abundant around olivine phenocrysts. Brown pyroxene in the base has $Z \wedge c = 42°$. Nepheline, analcime and zeolites are developed interstitially. Two chemical analyses of this rock are quoted in Table 1 (*i* and *j*).

(*c*) *Nephelinites* (Plu_3)

Occasional boulders of *melilite-melanite-perovskite nephelinite* (59/481) are found across the ankaratrite outcrop south-west of Lemongo Vent. The greenish-grey boulders, with prominent euhedral nepheline phenocrysts up to 5 mm. square, present a strong contrast to the dark ankaratrites found at this locality. A thin section of specimen 59/481 shows phenocrysts of nepheline, melilite and pyroxene accompanied by microphenocrysts of perovskite and ore in a holocrystalline groundmass composed essentially of green pyroxene, nepheline, melilite, melanite, ore, perovskite, analcime and zeolites. Many of the pyroxene phenocrysts are zoned with purple-brown titanaugite cores and rims of aegirine-augite displaying pleochroism in shades of green and brown. The optic sign of the soda-pyroxene was found to be either positive or negative, with a moderate to large optic angle; $X \wedge c = 38°$. The pyroxene in the matrix is green pleochroic aegirine-augite, occasionally having colourless cores. Weakly birefringent purple-brown perovskite showing complex polysynthetic twinning occurs both as microphenocrysts and as small grains in the groundmass. Nepheline is characteristically euhedral, displaying square and rectangular sections in both phenocrysts and groundmass crystals. The melilite phenocrysts are zoned, the rims showing stronger birefringence than the cores of the crystals. This is thought to indicate an increase in the soda content of the melilite towards the margins, and it is significant that the melilite phenocrysts are surrounded by granular soda-pyroxene. Analcime and unidentified zeolites form interstitial patches in the base.

(5) RHOMB PORPHYRY GROUP (PLP_1)

Coarsely porphyritic lavas, containing abundant rhomb-shaped phenocrysts of felspar (said to be anorthoclase or simply alkali felspar) were described in the succession of volcanic rocks extruded from the Kibo centre of Kilimanjaro (e.g. Wilcockson, 1956, p. 223; Wilcockson *et al.* 1965, p. 5). The lavas were referred to as rhomb porphyries, and further subdivision was effected on the basis of phenocryst size and the presence or absence of megascopic nepheline.

The field term rhomb porphyry was adopted during mapping in the Amboseli area and, in the absence of a more informative name, it was subsequently retained to describe distinctive olivine-bearing rocks which show mineralogical affinities with trachytes and mugearites and yet chemically often resemble phonolites. The lavas attain a thickness of some 400 feet and are typically pale-grey and often highly vesicular rocks, with whitish felspar phenocrysts up to 30 mm. long showing characteristic rhomb-shaped sections.

The rhomb porphyries overlie felsparphyric lavas of the Upper Olivine Basalts and are overlain by fine-grained flows of sparsely porphyritic lavas (termed olivine-zeolite trachytes; they correspond to the Lent group of Kilimanjaro) and by a single flow of nepheline-rich phonolite belonging to the Inner Crater Group.

The thin section of specimen 59/501, collected from an exposure near the Tanzanian border four and a half miles south-east of the disused Kamwanga-Emali road, shows large euhedral phenocrysts and rare microphenocrysts of a felspar superficially resembling anorthoclase, together with microphenocrysts of olivine and a felspar having the appearance and some of the optical properties of oligoclase. These minerals are set in a felty holocrystalline groundmass of felspar, pyroxenes, ore, olivine, analcime, chabazite, apatite and biotite.

The felspar phenocrysts are zoned, and in some sections show fine polysynthetic twinning in two directions. The optical properties in Table 2 were measured on grains, variations in the values probably indicating derivation from different zones in the crystal. Determinations on phenocrysts from a similar rock (59/503) are included for comparison.

TABLE 2—OPTICAL PROPERTIES OF FELSPARS FROM RHOMB PORPHYRIES OF THE AMBOSELI AREA

	59/501					59/503			
	(i)	(ii)	(iii)	(iv)	(v)	(i)	(ii)	(iii)	(iv)
α	1·539	1·546	1·544	—	—	1·540	1·545	—	—
β	—	1·550	1·550	—	—	—	—	—	—
γ	1·548	1·555	—	—	—	—	—	—	—
2V(–) ..	—	—	68°	70°	72°	—	—	71°	73°
Extinction on (010)..	—	—	4°	—	6·5°	—	5°	—	—

The distinction between alkali felspar and plagioclases at compositions with approximately equal calcium and potassium contents is somewhat arbitrary, but the phenocrysts in these rocks are probably to be regarded as oligoclases with low optic angles, rather than anorthoclases with abnormally high refractive indices. An investigation of alkali felspars from some volcanic rocks from Kenya and northern Tanzania by Häkli (1960, p. 106) showed that the refractive indices of An-bearing anorthoclases are approximately the same as those of plagioclases containing an equal amount of anorthite. The range of refractive indices measured in the two specimens is $\alpha = 1.539$ to 1.546. In plagioclases this would correspond (Chayes, 1952, pp. 95-96) to a composition ranging from An_{22} to An_{35}. A value around 70° for the optic angle suggests a high-temperature form of oligoclase. The composition is likely to be about An_{27} according to data given by J. R. Smith (1956). Fletcher and Miers (1887) analysed a felspar from a Kilimanjaro rock evidently similar to the specimens under discussion. The composition of the felspar was quoted as Ab_{52} An_{25} Or_{23}, but the mineral had $\beta = 1.5373$ and $2V (-) = 60°44'$, both values being considerably lower than those recorded in felspars from specimens 59/501 and 59/503.

Some microphenocrysts of felspar in specimen 59/501 display fine albite twinning, with the small extinction angles associated with oligoclase. The olivine in microphenocrysts is optically negative with a large axial angle. Analcime and a zeolite (c.f. chabazite) occur in interstitial pools in the groundmass together with prismatic crystals and rounded grains of augite and greenish aegirine-augite, grains of olivine, occasional subhedral crystals of apatite, irregular grains and dendrites of opaque ore, and small flakes of reddish-brown biotite. Nepheline was not positively identified.

Specimen 59/503 was collected from a small outlier of rhomb porphyry resting on felsparphyric olivine basalts beside the disused Kamwanga-Emali road, about a mile and a half from the Tanzanian border. The lava at this locality has a rough fracture and is blue-grey and finely vesicular, with felspar phenocrysts displaying rectangular or rhombic sections 15-20 mm. long. Under the microscope the phenocrysts show extinction angles of 3° on fine albite twinning. Refractive indices measured on grains are quoted in Table 2. Microphenocrysts of olivine, apatite and ore are accompanied by optically negative oligoclase having maximum extinction angles on albite twins of 6°. The groundmass contains plagioclase microlites, fine granular ore, pyroxene and olivine, and interstitial analcime and zeolite. Nepheline was doubtfully identified. Rare amygdales are composed of analcime.

Vesicular lavas at the northern end of the Maarba outcrop contain rhomb-shaped felspars about 10 mm. long. The rocks have a characteristic rough surface caused by the differential weathering of phenocrysts and groundmass. Vesicles are lined with calcite. The thin sections of specimens 59/472 and W. 335 from this locality show large rounded phenocrysts of felspar resembling anorthoclase, but having refractive indices close to that of balsam. The crystals contain numerous inclusions, the most prominent being irregular ore grains and occasional olivines. Small olivines, ore grains and crystals of apatite accompany the felspars in a fine groundmass of felspar microlites, and grains of ore and pyroxene. Interstitial material is mainly optically positive felspar (oligoclase) with some analcime.

Less vesicular rocks occur at the southern end of the Maarba outcrop. The analysis of a specimen of rhomb porphyry (W. 366) from Seru is quoted in Table 1 (*k*). The chemical data for another rhomb porphyry (W. 379) from Endoinet are given in the same table (*l*). This rock came from exposures in Tanzania very close to the border. The locality falls within an outcrop mapped by workers in Tanzania as nepheline rhomb porphyries; these lavas are said to contain nepheline phenocrysts as well as felspars and they were referred to the Caldera Rim Group. No megascopic nepheline was seen in any of the Amboseli rhomb porphyries and the mineral is not visible in the exposures from which W. 379 was collected. The norm (Table 1) shows however, considerably more nepheline than that of specimen W. 366 from Seru.

(6) LENT GROUP (PLH AND PLP$_2$)

Fine-grained lavas of the Likaswa Hills, and others which occur farther east where the Kamwanga-Emali road crosses the border, have all been referred to the Lent Group. The Lent Group was defined in Tanzania, where it comprises aphyric trachyandesites, trachytes and phonolites which originated as eruptions from fissures and centres on the flanks of Kibo (Wilcockson *et al.*, 1965, p. 5).

The fine-grained lavas near the Kamwanga road are olivine-zeolite trachytes and subordinate olivine basalts, whereas the flows forming the Likaswa Hills are olivine phonolites. The age relationship between the trachytes, basalts and phonolites cannot be established from observations in the Amboseli area alone, and insufficient detail on work in Tanzania is at present available. An age determination carried out on a specimen from the Lent Group gave a result of 0.4 million years (Wilkinson, 1966, p. 29).

(a) *Olivine-zeolite Trachytes and Subordinate Basalts* (Plh)

Very fine-grained flows about 300 feet thick occur on both sides of the Kamwanga-Emali road near the Tanzanian border. They overlie lavas of the Rhomb Porphyry Group and rest locally on the Upper Nephelinites and late flows of the Upper Olivine Basalts. These trachytes and basalts are seldom well exposed, and the outcrop as mapped is based mainly on the occurrence of numerous boulders and float fragments of the distinctive lava. An indication however of the accuracy with which the margins of the flows were located in poorly exposed ground can be obtained by comparing the geological map of the Amboseli area with the Kilimanjaro-Moshi sheet published by the Geological Survey of Tanzania; the trachyte-basalt outcrop agrees very closely with that of the Lent Group mapped independently in Tanzania.

The fine-grained trachytes are grey and blue-grey dense rocks with very rare felspar phenocrysts. Specimen 59/504, from a locality half a mile east of the disused Kamwanga road and the same distance from the border, contains microphenocrysts of olivine, apatite and ore set in a very fine groundmass of pyroxene, olivine, ore, felspar microlites, biotite, zeolite and analcime. No felspar phenocrysts are visible in the thin section, but fragments from a 10 mm. long crystal in the hand specimen were extracted for examination. No twinning was seen in 010 cleavage flakes but extinction occurs at 6° from the 001 cleavage. $2V\ (-) = 54^\circ$ to 64° and the following refractive indices were measured: $\alpha = 1.530$; $\beta = 1.534$. These optical properties agree closely with those recorded in phenocrysts from fine-grained phonolitic lavas of the Likaswa Hills, and the felspar is probably to be regarded as potash-oligoclase. Reddish-brown biotite is frequently developed around olivine microphenocrysts in this rock, and the mica also occurs as small flakes in the groundmass. A zeolite (c.f. chabazite/gmelinite) and analcime are confined largely to clear pools in the groundmass. A chemical analysis of specimen 59/504 is given in Table 1 (*m*).

No felspar phenocrysts are visible in a slightly coarser specimen (59/505) collected from lavas exposed along the Kenya-Tanzania border between boundary pillar No. 50 and the Kamwanga road, but oligoclase occurs as microphenocrysts together with olivine and apatite. Felspar laths in the groundmass show combined Carlsbad-albite twinning and were also identified as oligoclase. Olivine, pyroxene and ore, together with common pools and interstitial patches of zeolite (c.f. gmelinite) and analcime, make up the remainder of the groundmass. Calcite is rimmed by gmelinite in rare amygdales.

The difficulty in classifying the lavas represented by specimens 59/504 and 59/505 can be summarized as follows. Mineral composition alone does not provide an entirely satisfactory basis for classification, because the rocks are all fine-grained. Furthermore the determination of the composition of felspars, particularly those of the groundmass, is not easily accomplished by optical methods. The detection of felspathoids and zeolites in the finest rocks is similarly troublesome. Nevertheless, optical studies indicate a composition for the lavas somewhere in the basanite-trachybasalt-mugearite range. Chemical analysis of one of the rocks shows the SiO_2 percentage to be lower than trachytes and higher than basalts and basanites. Phonolites are excluded on account of the small amount of normative nepheline, and trachybasalts on the grounds of poor agreement in the percent of K_2O and CaO. The K_2O content of the analysed rock suggests strong affinities with trachytes and phonolites. The place of nepheline is evidently taken by zeolite and analcime, so the term "Zeolite trachyte" is proposed.

Fine-grained basaltic lavas which are considered to form part of the Lent Group were encountered at three localities. They are difficult to distinguish from the fine-grained trachytes in the field so the two types are not separated on the geological map.

Large boulders of *alkali olivine basalt* (W. 386) are associated with rhomb porphyries near the Kilimanjaro Sawmills road about a mile from the Tanzania border. The boulders were probably derived from flows of the Lent Group which form the higher ground to the east. The basalt is a medium-grey, fine-grained rock containing numerous tiny crystals of labradorite 0.5 mm. long set in a groundmass of calcic plagioclase, augite, olivine, biotite, ore and a little unconfirmed analcime.

Occasional basalt boulders occur across the rhomb porphyry outcrop where the Kilimanjaro Sawmills road crosses the Tanzanian border. A specimen (W. 388) of *porphyritic olivine basalt* has phenocrysts of olivine 4 mm. across, and augite 8 mm. long in a medium-grey groundmass of plagioclase laths, augite, ore and olivine.

A few boulders of fine *mugearitic olivine basalt* were found across the ankaratrite outcrop south-west of Lemongo Trigonometrical Beacon. Specimen 59/483 contains phenocrysts of labradorite 2 mm. long, euhedral olivines about 1 mm. across, and small insets of ore. These are accompanied by rounded microphenocrysts of amphibole in a matrix of plagioclase laths and granular augite, olivine and ore. The olivine phenocrysts are largely altered to iddingsite and they bear inclusions of apatite. The amphibole (X = pale brown; Y = orange-brown; Z = yellow-brown) is surrounded by a dark, iron-rich reaction rim. Plagioclase in the groundmass shows small extinction angles and has refractive indices close to that of balsam; it is tentatively identified as oligoclase.

(*b*) *Olivine Phonolites* (Plp_2)

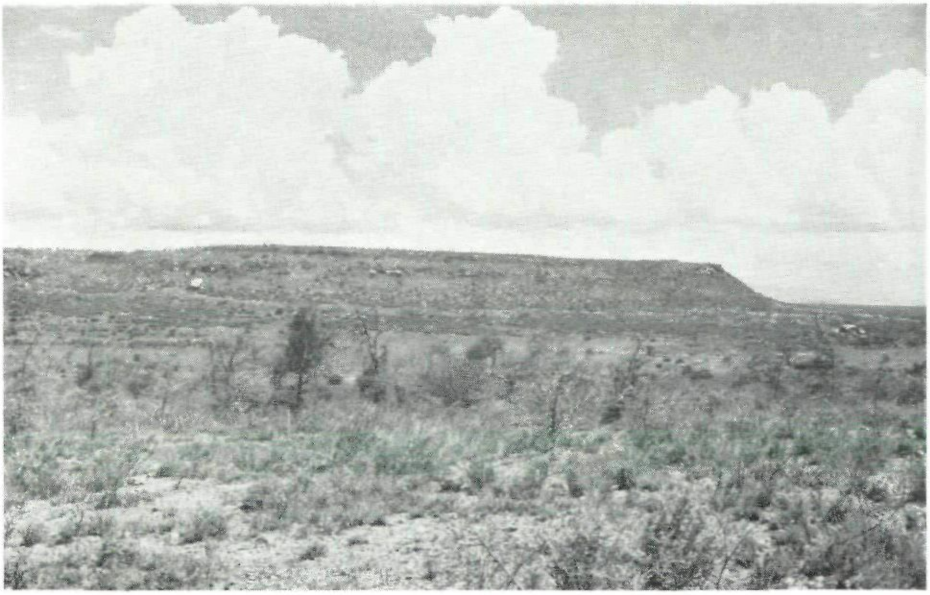
Fine-grained phonolitic lavas forming the Likaswa Hills are some 600 feet thick. They rest on members of both the Lower and the Upper Olivine Basalts, and on flows of the Rhomb Porphyry Group. In the field the phonolites were tentatively correlated with other fine-grained lavas (described above as olivine-zeolite trachytes and basalts) but subsequent studies brought out significant differences between the Likaswa rocks and those which outcrop farther east. Extremely fine-grained lavas were described simply as phonolites in early accounts of the geology of Kilimanjaro (e.g. Wilcockson, 1956, p. 223); later the term Lent Group was introduced to cover a variety of fine-grained flows.

The Likaswa phonolites are grey or greenish grey, fine-grained, sparsely porphyritic rocks exhibiting conchoidal fracture. Specimen 59/474, from the north-eastern end of the hills, contains an occasional 5 mm. long felspar phenocryst and a few smaller euhedral pyroxenes. The rock displays fine flow structure and is mottled with rounded and angular pinkish or brownish patches from 5 to 10 mm. across. Under the microscope it shows a porphyritic texture, with rare euhedral phenocrysts of olivine and apatite and subhedral grains of magnetite, set in a fine groundmass bearing microphenocrysts of felspar, pyroxene and amphibole. Neither pyroxene nor felspar phenocrysts occur in the thin section, but grains of both were extracted from the hand specimen for examination. The pyroxene has 2V (+) = c. 60° and is greyish-brown in some of the thicker fragments.

Some felspar grains resemble anorthoclase in having fine lamellar twinning in two directions. The optical properties of the felspar from specimen 59/474 are summarized in Table 3. Values quoted by Mountain (1925, p. 336) and Fletcher and Miers (1887, p. 132) for other unusual Kilimanjaro felspars are shown for comparison, together with some of the optical properties of the phenocryst felspar in a fine-grained olivine-zeolite trachyte (59/504) and a nepheline-rich phonolite (59/502) from the Amboseli area. and felspars from the Kapiti Phonolite (Smith, 1950, pp. 9-10).

PLATE I

(a) Lake Amboseli. A view across the dry lake bed towards the Ngorigaishi Hills



(b) Leme Boti, a flat-topped remnant of the end-Cretaceous erosion surface. The hill is composed of Precambrian crystalline limestones and gneisses

PLATE II—THE AMBOSELI LAKE BEDS AT SINYA

(a) The Amboseli Clays resting on marls belonging to the Sinya Beds. The shallow depth to the water table is indicated by flooding in the excavation

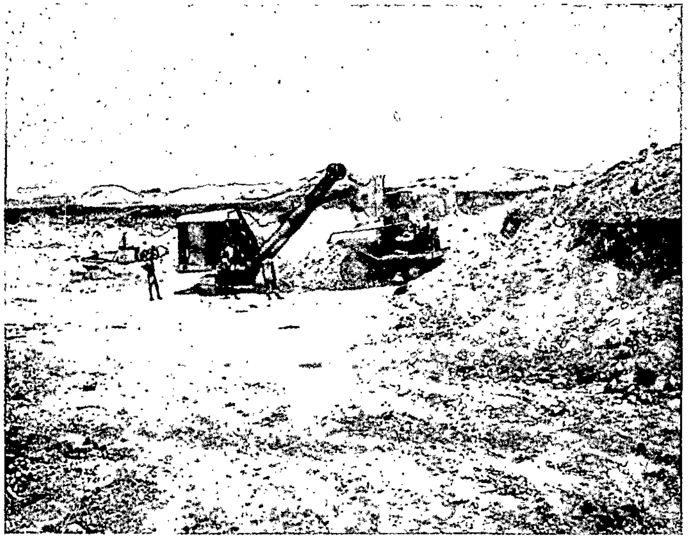
(b) The Amboseli Clays with basal conglomerate (marked by the outstretched hand) overlying meerschaum-bearing Sinya Beds

PLATE III—STRUCTURES IN THE AMBOSELI LAKE BEDS AT SINYA

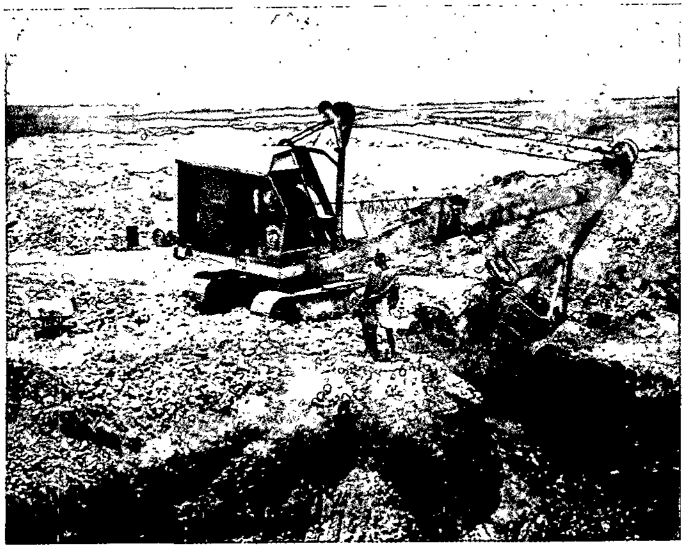
(a) Folds in the Amboseli Clays. The basal conglomerate is being indicated in the anticline on the left. Traced to the right, the conglomerate becomes horizontal and is unaffected by the second anticline in the overlying clays

(b) Low-angle fractures in the Amboseli Clays and the Sinya Beds. The basal pebble bed of the Amboseli Clays is being indicated on the left; to the right of the fracture, it passes between two beds of blocky clay

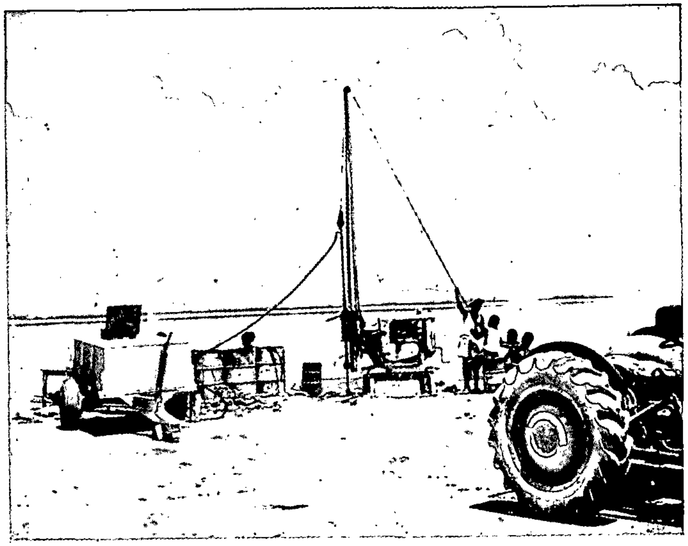
PLATE IV



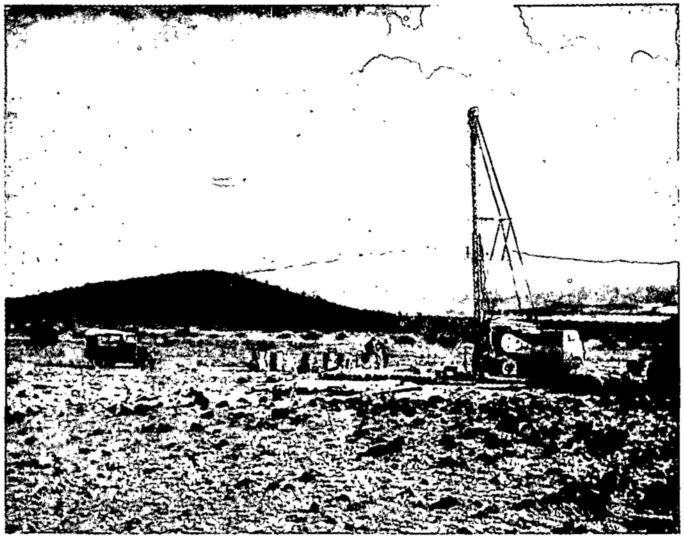
(a) Open-cast mining of meerschaum at Sinya



(b) Open-cast mining of meerschaum at Sinya



(c) Drilling an exploratory borehole in the middle of Lake Amboseli during the survey



(d) Drilling for water (borehole C.3043) at Ol Barengoi

TABLE 3—OPTICAL PROPERTIES OF FELSPARS FROM LAVAS OF THE LENT GROUP, AND FROM OTHER LAVAS FOR COMPARISON

	(*a*)			(*b*)	(*c*)				(*d*)	(*e*)	(*f*)	(*g*)	
α ..	1·530	—	—	1·528	1·530	—	—	—	1·525	1·533	—	1·527	—
β	1·535	—	—	1·534	1·534	—	—	—	1·528	1·537	1·5373	1·533	—
γ	1·538	—	—	—	—	—	—	—	1·530	1·539	—	—	—
2V(—) ..	—	55°	57°	66°	—	54°	60°	64°	50°	60°	60° 44′	—	42°–48°
Extinction (001) ..	—	—	—	—	—	—	—	—	—	0·5°	—	7·5°	—
Extinction (010) ..	5°	—	7°	7°	6°	—	—	—	—	5·1°	—	—	—

(*a*) Phenocryst, olivine phonolite (59/474), Likaswa Hills, Amboseli area.
(*b*) Phenocryst, olivine phonolite (59/475), Likaswa Hills, Amboseli area.
(*c*) Phenocryst, olivine-zeolite trachyte (59/504), east of Kamwanga road, Amboseli area.
(*d*) Phenocrysts, nepheline-rich phonolite (59/502), near Kenya-Tanzania border south-east Amboseli area.
(*e*) Phenocryst, rhomb pophyry, Kilimanjaro (Mountain, 1925, p. 336).
(*f*) Felspar, Kilimanjaro, (Fletcher and Miers, 1887, p. 132).
(*g*) Felspars, Kapiti Phonolite, north-east of Kajiado (Smith, 1950, pp. 9-10).

Fletcher and Miers (op. cit. p. 131) give the following chemical analyses of felspar crystals examined:

	(i)	*(ii)*	*(iii)*	*(iv)*	*(v)*
Silica	60·52	61·03	62·59	61·74	62·17
Ferric oxide	2·96	1·63	—	—	—
Alumina	22·29	23·71	23·06	23·98	23·52
Lime	2·77	2·91	2·86	2·94	2·90
Magnesia	trace	trace	—	—	—
Soda	6·48	6·83	6·70	6·91	6·80
Potash	4·63	4·38	4·79	4·43	4·61
Loss on ignition	0·18	0·24	— —	—	—
	99·83	100·00	100·00	100·00	100·00

Columns (i) and (ii) show the analyses of two loose crystals; (iii) and (iv) are derived from these analyses by excluding the iron (which is present as visible inclusions in the felspar) and the loss on ignition. Column (v) is the mean of (iii) and (iv). Fletcher and Miers (op. cit. p. 132) note that, if expressed as a mixture of anorthite, microcline and albite, the felspar is represented as:

$An_1Or_{0.94}Ab_{2.11}$ (i.e. $Ab_{52}An_{25}Or_{23}$)

Mountain (op. cit. p. 343) quoted the following lime, soda and potash percentages for Mt. Kenya Kenyte and Kilimanjaro rhomb-porphyry, together with the value for the same oxides in the phenocrysts in these rocks:

	MT. KENYA		*MT. KILIMANJARO*	
	Kenyte	*Phenocryst*	*Rhomb-porphyry*	*Phenocryst*
CaO	2·04	2·01	2·13	2·84
Na_2O	8·81	7·22	8·76	6·65
K_2O	5·27	4·71	5·75	4·50

Spectrographic analysis of felspar from a phenocryst in specimen 59/474 showed an appreciable content of soda, lime and potash. This confirms its identification on optical properties as potash oligoclase or calcic anorthoclase.

Among the microphenocrysts in specimen 59/474, felspars show Carlsbad or rare fine albite twinning; pyroxene has $Z \wedge c = 46°$, and is optically positive; a soda-amphibole (c.f. kataphorite) is strongly pleochroic from pale or yellowish-brown to reddish-brown, has extinction $Z \wedge c = 28°$ and $2V (-) \doteqdot$ c. 60°. The fine groundmass is composed of small granules of pyroxene, undetermined felspar microlites, a fine sprinkling of ore, brown kataphorite, and interstitial nepheline and analcime. The latter also occurs in occasional small pools in the groundmass.

A chemical analysis of specimen 59/474 is given in Table 1 (*n*), for comparison with the olivine-zeolite trachyte (59/504) from Amboseli, Table 1 (*m*).

Specimen 59/475, also from the north-eastern end of the Likaswa Hills, contains blue-grey ovoids in the greenish-grey base, which bears rare small phenocrysts of felspar, pyroxene and olivine. In thin section the rock shows parallel orientation of felspar microphenocrysts, with indications of flow around finer-grained portions of the groundmass that correspond to the ovoids seen in hand specimen. The groundmass consists of granules of greenish pyroxene, felspar microlites, grains of ore and brown pleochroic kataphorite, together with interstitial nepheline and analcime. Small amygdales contain analcime, calcite, and rarely a zeolite.

Mineralogically and texturally the phonolites closely resemble other fine-grained lavas encountered in the Amboseli area and described as olivine-zeolite trachytes. In the trachytes however "potash oligoclase" is accompanied by optically positive plagioclase, and biotite takes the place of kataphorite seen in the phonolites.

Near the locality from which specimen 59/475 was collected the phonolites bear medium-grained felspathic inclusions averaging about four inches across and showing ragged but sharp contacts with the host lava. Under the microscope these inclusions (59/476) are seen to consist of a mosaic of felspars, anhedral pale yellowish green olivines, an occasional large flake of brown biotite, small granules of pyroxenes and ore, and accessory apatite. The felspar is dominantly anorthoclase showing fine polysynthetic twinning in two directions; some untwinned grains have larger optic angles than the anorthoclase and the refractive indices are probably slightly higher. The felspathic aggregates were regarded in the field as altered Precambrian inclusions, but it seems more likely that they are cognate inclusions.

(7) INNER CRATER GROUP (RVP)

The Inner Crater Group is represented in Kenya only by a small tongue of nepheline-rich phonolite about 50 feet thick, overlying the rhomb porphyries in the south-eastern corner of the Amboseli area; it marks the end of a narrow flow that is more prominent on the Tanzanian side of the border. These phonolites are the youngest rocks in the Amboseli volcanic succession and they were, in fact, the last lavas to be erupted from the Kilimanjaro centres. The flows were extruded from the ring fracture of the Kibo caldera floor and spilled over the lower parts of the rim, principally to the north-east (these are the flows that reach the Amboseli area), but also to the west and south-west.

A post-Pleistocene age for flows of the Inner Crater Group was indicated by Downie (1964, pp. 7, 10) who found that eruption of the phonolites occurred after the Main Glaciation (correlated with the later Pleistocene Gamblian pluvial period) but before the Little Glaciation (correlated with the post-Pleistocene Makalian pluvial period).

The lavas in the Amboseli area are medium-grey porphyritic rocks having a greenish tinge that is particularly noticeable on weathered surfaces. Euhedral phenocrysts of colourless, white, or yellowish nepheline (commonly 2 mm. across, but occasionally twice that size) exhibit rectangular and hexagonal sections. They are accompanied by occasional glassy felspar phenocrysts and rare pyroxenes up to 2 mm. long, all set in a fine-grained, grey groundmass.

The thin section of a specimen (59/502) collected from the flow a few hundred yards from the Tanzanian boundary shows euhedral phenocrysts of nepheline together with microphenocrysts of greenish pyroxene, ore and apatite set in a fine groundmass consisting essentially of pyroxene, ore and nepheline. The subhedral aegirine-augite crystals rarely attain a length of 1 mm. They exhibit pleochroism from pale olive-green to pale brown, are optically positive, and show extinction angles $X \wedge c = 37°$. Apatite occurs in slender prisms up to 0.5 mm. long. The groundmass is very fine-grained with nepheline occasionally visible in small rectangular sections, though more commonly it displays an interstitial habit towards pyroxene and ore. Calcite occurs in fine veinlets, and analcime was doubtfully identified in the groundmass. No felspar phenocrysts were cut by the section, so grains were extracted from the hand specimen for examination. The following optical properties were recorded: $\alpha = 1.525$; $\beta = 1.528$; $\gamma = 1.530$. $2V (-) = 50°$. These values are compared with those for felspars from other Kilimanjaro lavas, and with felspars from the Kapiti Phonolite, in Table 3.

The lavas of the Inner Crater Group were originally described (Wilcockson, 1956, pp. 223-4) as "nephelinites or nepheline phonolites with conspicuous glassy nepheline and pyroxene phenocrysts in a glassy or micro-crystalline matrix". Later the lavas were described (Wilcockson *et al.* 1965, p. 6) as nepheline-rich aegirine-phonolites. No chemical analyses of Inner Crater Group lavas from the Amboseli area are available.

(8) LAVAS AND TUFFS OF THE PARASITIC VENTS (PLT)

Numerous small parasitic cones are scattered around the flanks of Kilimanjaro, their zonal distribution suggesting an association with fracture belts (Wilcockson, 1956, p. 226). Some of these vents occur in the Amboseli area, but there are too few to demonstrate convincingly any linear arrangement (*see* Fig. 3). Most of the vents lie in a zone between Sinya and Normatior, near the contact between early flows from Kilimanjaro and overlying sediments of the Amboseli Lake Beds. The latter are often banked against scoriaceous lavas forming the cones, concealing any flows that might have originated from them. Extensive flows of olivine basalts and ultrabasic lavas from parasitic vents have been reported from parts of Kilimanjaro (Wilcockson, op. cit., p. 226) where most of the cones have well preserved craters and consist of lavas and pyroclastics. Having glacial deposits interbedded at some localities, the cones are believed to be of Pleistocene age. On the Saddle, between Kibo and Mawenzi peaks, they are all older than the last main glaciation and include flows of nepheline rhomb porphyry similar to the lavas of the Caldera Rim Group, with which they are thought to be contemporaneous.

The degree of erosion of the vents in the Amboseli area, where original craters are rarely distinguishable, together with variations in the composition of the constituent lavas, suggest that eruptions were not contemporaneous and that some of the cones are older than the Upper Pleistocene. Lemongo Vent, for instance, is composed of highly vesicular felsparphyric olivine basalt mineralogically similar to lavas of the Upper Olivine Basalts of the main volcanic succession. Ol Doinyo Siteti Vent, on the other hand, is composed of vesicular olivine melanephelinites or ultrabasic lavas, the eruption of which was more likely to have coincided with flows of nephelinitic lavas from the main centres. Both Normatior and Ol Barengoi Vents are composed of olivine basalts bearing no megascopic felspar, and extrusion may have been contemporaneous with flows of the Lower Olivine Basalts. In neither cone is there any recognizable crater.

Irregular vesicles in purplish lavas forming Lemongo Vent measure up to 20 mm. across and bear only a little zeolitic material as a lining. Plagioclase phenocrysts in the *felsparphyric olivine basalt* (59/507) from the trigonometrical beacon have a labradoritic composition. Olivine insets are altered to bowlingite and iron ore, and pyroxene occurs only as rare yellowish phenocrysts. The groundmass consists dominantly of very fine ore with a sprinkling of pyroxene granules.

At Ol Barengoi Vent purplish rather compact *olivine basalts* bear occasional streams of small vesicles and prominent pyroxene phenocrysts. In thin section specimen 59/438 shows phenocrysts of pyroxene and olivine together with microphenocrysts of labradorite. Pyroxene, ore and calcic plagioclase form a groundmass in which vesicles are infilled with calcite, analcime and a zeolite.

No felspar was seen in the *ultrabasic lavas* (59/436) from Ol Doinyo Siteti but a little interstitial nepheline was doubtfully identified in the base. Yellowish, strongly zoned pyroxenes occur as phenocrysts, together with olivine that is largely replaced by ore. Granules and small prisms of pyroxene and grains of ore form the groundmass. Similar olivine-bearing ultrabasic lavas collected from the Pleistocene volcanic rocks of the Chanler's Falls area, north-east of Mt. Kenya, were found to occur as nepheline-free patches in olivine melanephelinites (Williams, 1966, pp. 37-8).

Pyroclastic material is nowhere conspicuous in the volcanic succession mapped in the Amboseli area. Subordinate tuffs and ashes were encountered on the slopes of the cones, and ash forms the matrix of gravel deposits that occur south-east of Lemongo Vent. Similarly, the matrix of conglomerates that overlie the Lower Olivine Basalts south and south-east of Loginya Swamp is composed of material that is largely derived from ash and tuff.

(9) CORRELATION

Although volcanic rocks of approximately the same age as those described in this account occur in several surrounding areas, the Amboseli succession can be correlated directly only with the main Kilimanjaro sequence immediately to the south.

The ground east of the Amboseli area has yet to be mapped, so that the extension of the Kilimanjaro Volcanic Rocks in that direction is not known in detail. A Recent age has been assigned to basaltic lavas forming the Chyulu range in the Simba-Kibwezi area, mainly because the volcanic centres there have suffered little erosion (Saggerson, 1963, p. 31). The lavas which continue eastwards into the Loitokitok area from Amboseli are considered to be late Tertiary to Pleistocene in age. Future mapping will undoubtedly show that these flows are overlain by the volcanics of the Chyulu range.

Pleistocene basalts and basanites (the analcime basanites and olivine basalts of Simba, and the olivine basalts of Ngatatema) occur north-east of Amboseli in the Simba-Kibwezi area (Saggerson, op. cit.), but they were derived from local vents and do not represent an extension of the Kilimanjaro flows though they were probably erupted contemporaneously.

Lavas in the Namanga-Bissel area, west of Amboseli, were variously named basalts, analcime basalts and analcime basanites (Joubert, 1957*a*, pp. 7, 34) but from the published descriptions the writer favours the term olivine analcimite for these rocks. It is not clear at present whether these lavas are equivalent to the Lower Olivine Basalts of the Amboseli area, or to one of the groups characterized by felspar-free rocks.

Volcanic rocks in the Taveta area, south-east of Amboseli, are chiefly olivine basalts overlain by olivine soda-trachytes, together constituting the Rombo Series (Bear, 1955, pp. 29-32). These rocks were evidently derived from the Mawenzi centre of Kilimanjaro, whereas the Amboseli flows came predominantly from the Kibo centre. Felspathoidal lavas, including olivine-, perovskite-, and melilite-bearing nephelinites, occur only as float blocks in the Taveta area and their precise origin is uncertain (Bear, op. cit., pp. 32-3).

A comparison of the volcanic succession in the Amboseli area with that established in Tanzania for the main part of Kilimanjaro (Table 4) shows a number of obvious correlations. These are even more convincingly indicated by the map (Fig. 5) covering the northern flanks of the mountain and the adjacent part of the Amboseli area. This map was prepared by combining the results of the present work with the published Kilimanjaro-Moshi sheet (1 : 125,000); only minor modifications to geological boundaries were necessary along the Kenya-Tanzania border.

The nepheline-rich phonolites (12) of the Amboseli area are undoubtedly equivalent to similar lavas (*j*) of the Inner Crater Group. These lavas flowed from Kibo caldera in Recent times and the correlation establishes the correct stratigraphic position of the Amboseli phonolites as the youngest volcanic rocks mapped during the present study.

Distinctive fine-grained lavas (11) of phonolitic, trachytic and basaltic composition are clearly to be correlated with trachyandesites, trachytes and phonolites (*g*) of the Lent Group. Rhomb porphyries (10) that underlie the fine-grained lavas in the Amboseli area are equivalent to flows of the Rhomb Porphyry Group (*f*) mapped in Tanzania, where the sequence is much thicker. Rhomb porphyries (*i*) with nepheline phenocrysts (Caldera Rim Group) and others (*h*) with relatively small felspar phenocrysts (Small Rhomb Porphyry Group) are not represented in the Amboseli area; they overlie the Lent Group in Tanzania.

TABLE 4—CORRELATION OF THE AMBOSELI VOLCANIC SUCCESSION WITH THE MAIN KILIMANJARO SEQUENCE

SHIRA CENTRE	*AMBOSELI AREA*	*KIBO CENTRE*	
	(12) Nepheline-rich phonolite...... (50 ft.)	(*j*) Nepheline-rich aegirine phonolites (+425 ft.)	(Inner Crater Group).
		(*i*) Rhomb porphyries with nepheline phenocrysts (630 ft.)	(Caldera Rim Group).
		(*h*) Rhomb porphyries with relatively small felspar phenocrysts (700 ft).	(Small Rhomb Porphyry Group).
	(11) Fine-grained olivine phonolites, olivine-zeolite trachytes and olivine basalts (600 ft.)......	(*g*) Aphyric trachyandesites, trachytes and phonolites (1,000 ft.).	(Lent Group).
	(10) Olivine rhomb porphyries...... (400 ft.)	(*f*) Rhomb porphyries (2,000 ft.)	(Rhomb Porphyry Group).
(vi) Nephelinites	(9) Nephelinites (8) Ankaratrites (7) Melanephelinites } (300–400 ft.)	(*e*) Trachyandesites (1,000 ft.)	(Upper Rectangle Porphyry Group).
(v) Agglomerates and basic lavas	(6) Felsparphyric olivine basalts...... and mugearitic olivine basalts (600 ft.)	(*d*) Trachyandesites (1,200 ft.)	(Upper Trachyandesite Group).
(iv) Trachybasalts	(5) Felsparphyric pyroxene-olivine basalts and mugearitic types (300 ft.).	(*c*) Trachyandesites (2,000 ft.)	(Lower Rectangle Porphyry Group).
(iii) Melanephelinites and ultramafic lavas.	(4) Ankaratrites, melanephelinites, nephelinites, tephrites and phonolites (100 ft.).		
	(3) Mugearitic olivine basalts (200 ft.).	(*b*) Aegirine-rich trachytes (300 ft.)	(Lava Tower Trachyte Group).
(ii) Trachybasalts and basalts.	(2) Felsparphyric lavas (mugearitic olivine basalts and hawaiites) (1,000 ft.)	(*a*) Trachyandesites (+200 ft.)	(Lower Trachyandesite Group).
(i) Olivine basalts and trachybasalts (Ol Molog Group)	(1) Olivine basalts; mugearitic olivine basalts; zeolite basanites (1,000 ft.).		

......indicates correlation.

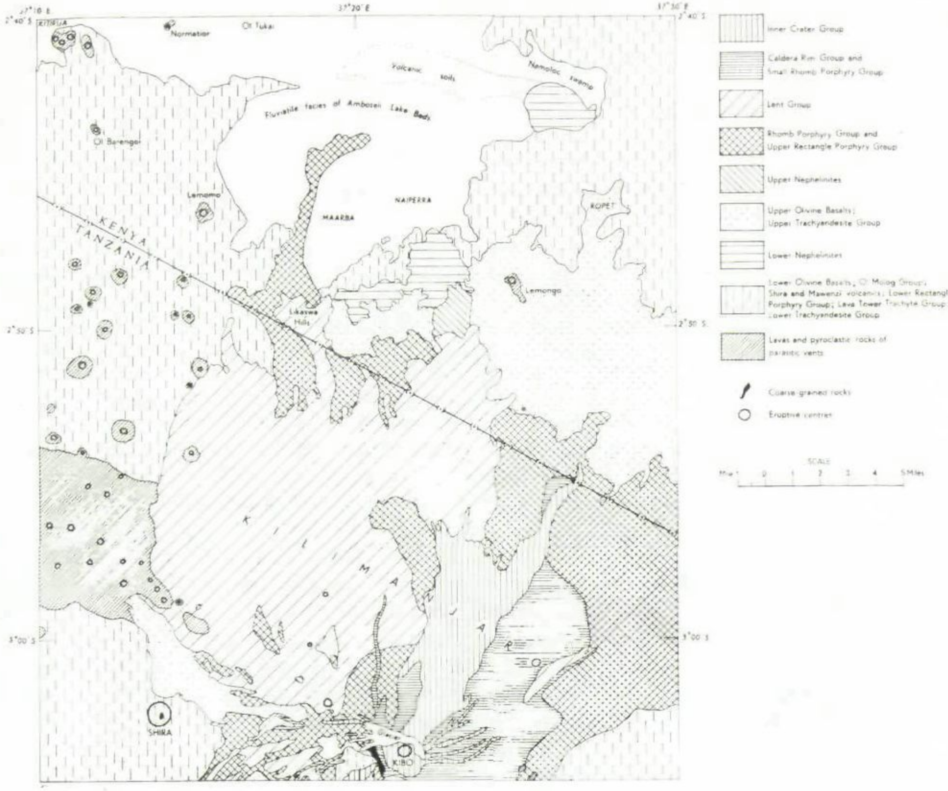


Fig. 5—Correlation of volcanic rocks across the Kenya-Tanzania border

Felspar-free felspathoidal lavas (7), (8) and (9) constitute the Upper Nephelinites of the present work. The flows have a rather restricted occurrence and they are evidently not exposed in Tanzania, where many of the earlier lavas are obscured by rhomb porphyries and by fine-grained flows of the Lent Group.

In Tanzania the rhomb porphyries are underlain by a series of lavas originally described as trachybasalts (e.g. Wilcockson, 1956, pp. 223-4), but later identified as trachyandesites (Wilcockson *et al.*, 1965 p. 4). Correlation of some of these lavas with part of the basaltic sequence established in the Amboseli area seemed likely, but until the publication of the geological map of Kilimanjaro no firm proposals could be made. Now however, sufficient evidence is available to show that trachyandesites (*d*) of the Upper Trachyandesite Group are equivalent to felsparphyric olivine basalts (6) of the Upper Olivine Basalts (*see* Fig. 5). Wilcockson *et al.* (op. cit.). state: "Lavas on the northern slopes of the mountain approaching the Amboseli Plain are probably to be correlated with the upper trachyandesite group".

Basaltic and basanitic lavas (1), (2) and possibly (3) of the Lower Olivine Basalts are evidently to be correlated with olivine basalts and trachybasalts of the Ol Molog Group of Tanzania: these lavas may have been derived from the early Shira centre (Wilcockson *et al.*, op. cit., p. 3). There are evidently no representatives in the Amboseli area of the Lower Rectangle Porphyry Group, the Lava Tower Trachyte Group and the Lower Trachyandesite Group of the Kibo succession.

Activity at the Shira centre had ceased before eruption from Kibo of lavas of the Upper Trachyandesite Group, but the possibility of correlation of flows of the Lower Nephelinites (4) with melanephelinites (iii) or nephelinites (vi) of the Shira succession cannot be excluded. Petrographic studies suggest however, a common origin for lavas of the Lower and Upper Nephelinites, so all the flows are tentatively assigned to the Kibo succession.

(10) CHEMISTRY AND PETROGENESIS

Chemical analyses of a selection of lavas from the Amboseli area and the C.I.P.W. norms are quoted in Table 1. A detailed discussion of the chemistry of these rocks, including comparisons with other East African lavas and with similar types from other parts of the world, is given in another account (Williams, 1969) which also deals with the petrogenesis of the Kilimanjaro rocks; only a summary of the conclusions is presented here.

It was found that in a standard A-F-M diagram most of the Amboseli-Kilimanjaro rocks plot close to the trend of the Hawaiian alkalic suite, though hypersthene-normative lavas (e.g. those represented by analyses, E, F and M) fall on the Hawaiian tholeiitic trend. In plots of CaO, MgO and SiO_2 against the "solidification index" $\left(\frac{MgO}{MgO + FeO + Fe_2O_3 + Na_2O + K_2O} + 100\right)$ and in a von Wolff diagram, two trends were distinguished in the Kilimanjaro lavas: one is characterized by strongly alkaline ankaratrites and melanephelinites, and the other by alkali olivine basalts, trachybasalts/trachyandesites, trachytes, rhomb porphyries and some phonolites (i.e. the olivine phonolites of the Lent Group and possibly also the nepheline-rich phonolites of the Inner Crater Group). The two trends are displayed in the triangular diagram $SiO_2 - Na_2O + K_2O + Al_2O_3 - CaO + MgO + FeO$ (Fig. 6).

Some olivine-free phonolites in Amboseli are regarded as differentiates from a strongly alkaline nephelinitic magma because they show mineralogical affinities with nephelinites and nepheline tephrites with which they are closely associated in the field. The Amboseli rhomb porphyries, on the other hand, are olivine-bearing and show mineralogical affinities with mugearites and olivine trachytes, though chemically they resemble fine-grained olivine phonolites of the Lent Group. In variation diagrams, the rhomb porphyries plot between trachybasalts and olivine-free phonolites of the Inner Crater Group. The latter are tentatively regarded as the ultimate differentiates from an alkali basalt magma, for they are mineralogically distinct from the phonolites derived from nephelinitic magma.

Variation diagrams consistently indicate an ankaratritic source for the strongly alkaline series, and a parental magma of alkali olivine basalt composition for the mildly alkaline rocks. The close association in northern Tanzania and southern Kenya of volcanics of these two series led Saggerson and Williams (1964, p. 78) to conclude that the parental magmas were both derived from a common source in the mantle, differences in the products of partial melting of peridotitic mantle material being attributed to variations in temperature and pressure. There is now general agreement that nephelinitic magmas originate at greater depths than those of normal basaltic composition, and also that the composition of extrusive material depends to some extent on the rate of migration of magma to the surface.

A comparison of Kilimanjaro with other East African volcanic centres shows that the focus of strongly alkaline (nephelinite-phonolite) activity moved from eastern Uganda and western Kenya to northern Tanzania at the end of Miocene times. Pliocene to Recent strongly alkaline centres in northern Tanzania and southern Kenya tend to lie along the western and central parts of the Rift Valley, whereas the volcanoes near the eastern margins (e.g. Kilimanjaro, Meru, Ngong, Ol Esayeiti and Olorgesailie) are

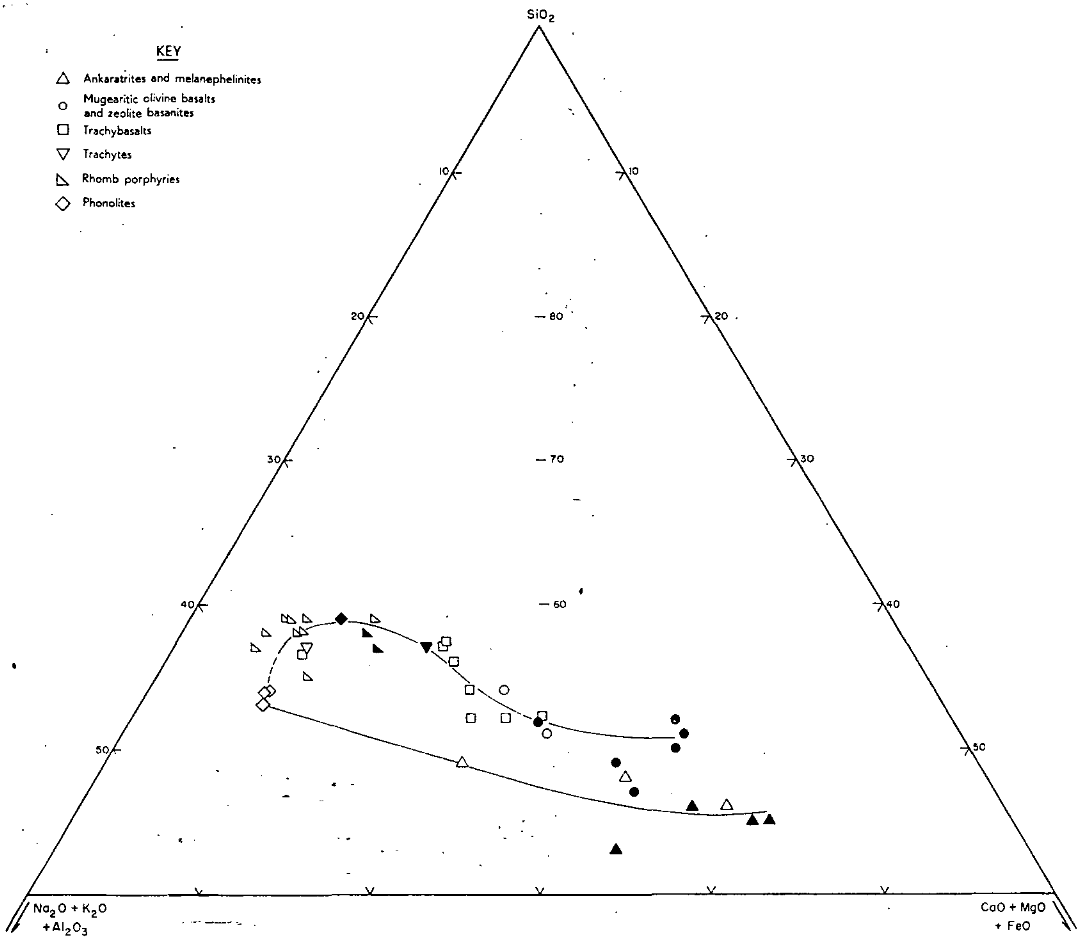


Fig. 6—Diagram showing differentiation trends in the Kilimanjaro volcanics. Solid symbols represent Amboseli lavas, open symbols rocks from Tanzania

characterized by the association of strongly and mildly alkaline suites. In seeking an explanation for this distribution pattern, it is perhaps significant that down-warping often plays a more important role than faulting in determining the eastern margins of the Gregory Rift Valley.

3. Amboseli Lake Beds and Fluviatile Deposits

A thick series of Pleistocene sediments, consisting essentially of lacustrine clays, marls and silts, occupy a broad east-west trending basin in the Amboseli area. The basin is bounded by Precambrian rocks to the north and by Kilimanjaro Volcanic Rocks to the south. Lavas also define the eastern and north-eastern parts of the trough but the western margin lies outside the present area. Facies changes occur west and north-west of Lake Amboseli and the sediments there consist dominantly of coarse fluviatile deposits obscured by alluvium and windblown silts. The lake beds also grade into conglomeratic deposits south of Loginya Swamp. At the time of the present survey the extent and nature of the sediments in Tanzania were largely unknown, but they were later investigated by Sampson (1966).

The surface of the sedimentary basin is one of extremely low relief so there are few natural sections exposing the deposits and most of the information recorded came from boreholes, hand-auger holes, wells and excavations. Most detail is available in the Sinya district where shallow opencast mining of meerschaum provides excellent sections. Some of the boreholes which penetrated the sediments were drilled during an investigation of water supplies; others were drilled in the course of the present survey; a few were drilled by F. J. Matheson during a subsequent examination of the clays.

The maximum depth of the sedimentary basin has not been proved but physiographic studies described earlier suggest that the deposits infill a trough cut some 400 feet into the end-Tertiary peneplain and that locally the sediments may attain a thickness of about 300 feet.

A borehole (C. 999) close to the northern end of Lake Amboseli penetrated 185 feet of sediments overlying Precambrian rocks; the surprising thickness at this point illustrates the steep nature of the margin of the basin. Samples from another borehole (C. 1009) situated between the Namanga River and the Ngorigaishi Hills and near the western boundary of the Amboseli area, show that it pierced coarse fluviatile deposits to a depth of at least 80 feet below the level of Lake Amboseli. At the southern end of the present dry lake bed a hole drilled during the survey proved more than 95 feet of lacustrine sediments without locating either the floor of the basin or deposits indicating its close proximity. Another hole, drilled at Naerabala close to the volcanic vent, showed that locally the sediments rest on lava at 66 feet below the surface.

The eastern half of the basin is believed to be comparatively shallow, though a borehole (C.3045) north of Ol Tukai pierced sediments to a depth of some 60 feet below the level of Lake Amboseli without locating the floor of the trough. On the other hand a borehole drilled by Matheson about a mile and a half north-west of Ol Tukai airstrip encountered lava at only 33 feet below the surface; it may have located a buried volcanic cone. Another hole drilled by Matheson to a depth of 49 feet east of Loginya Swamp, where the sedimentary cover was thought to be much thinner because of the proximity of exposed volcanic rocks, failed to locate the floor of the trough.

Difficulties were often experienced in logging and correlating with certainty successions in rapidly varying sequences of clays, the compositions of which were largely unknown. Most of the deposits range in colour from pure white to green, grey, brown and black; bluish and yellow clays are rare. Because the colours tend to fade as the clay dries they are best recorded from damp material. The whiter clays are generally highly calcareous but at some localities a diatomaceous content is partly responsible for pale colours. The clay itself in green, brown and black sediments is typically non-calcareous, but the deposits often contain small calcareous inclusions. The compositions of the clays are discussed in a later section of the report which deals with the economic geology.

The name "Amboseli Lake Beds" was proposed by Joubert (1957*a*, p. 34) to describe Pleistocene lacustrine deposits in the south-eastern parts of the Namanga-Bissel area. The sediments were considered to represent waterlain pyroclastic material derived from Kilimanjaro.

The following stratigraphical subdivision of the Amboseli Lake Beds in the present area is based on lithological changes and the recognition of unconformities in the succession:

3. Ol Tukai Beds.
2. Amboseli Clays.
1. Sinya Beds.

(1) SINYA BEDS

The Sinya Beds, the basal formation of the Amboseli Lake Beds, comprise whitish marls (containing meerschaum at Sinya), clayey limestones, clays and silty clays which attain a total thickness of more than 60 feet. Only the upper parts of the succession have been investigated, for the beds are generally overlain by thick developments of the Amboseli Clays. Doming is largely responsible for the natural outcrops of the Sinya Beds at the type locality, near the Kenya-Tanzania border at the southern end of Lake Amboseli, and a minor dome causes a reappearance of similar marls and clays at Naerabala about three miles east of Sinya. Drilling at a locality two miles north-east of Naerabala proved the occurrence of calcareous clays which are tentatively correlated with the Sinya Beds; they are overlain by 25 feet of sediments assigned to later formations. Extensive drilling and augering in other parts of the Amboseli basin failed to reveal successions that match those recorded between Sinya and Kitirua and it is concluded that the Sinya Beds, if developed there, are covered by appreciable thicknesses of later sediments.

Facies changes undoubtedly occur within the Sinya Beds, similar to the lateral lithological variations observed in the overlying formations, and it is not unlikely that the marls and clays grade into silts, sands and gravels, particularly towards the western and north-western parts of the area where only coarse fluviatile deposits were encountered during drilling.

Sinya

The Sinya Beds are best observed at the type locality where fresh sections down to the shallow water table are being revealed continually during opencast mining of meerschaum. At the time of the survey the water table at Sinya stood some 10 to 15 feet below the surface, but exceptionally heavy rain in 1961-62 caused a substantial rise in the water level.

Fig. 7 (at end) shows the distribution in March 1960 of workings and exploratory trenches in that part of Sinya Mine situated in Kenya. A number of boreholes and hand-auger sites are also indicated and the successions recorded from these and from the excavations are presented in Figure 8 (at end): (*a*) and (*b*) show the details obtained during the survey while (*c*) was constructed by the writer from information provided by F. J. Matheson.

Excavations at Sinya generally show a variable thickness of white or off-white rather rubbly marl or clayey limestone in which bedding is seldom well defined. Harder limestones are exposed in the opencast workings farther south in Tanzania indicating a facies change in that direction. Along the Kenya part of the axis of the dome, which is marked by a low topographic feature with a north-north-easterly trend, the marl is exposed at the surface or is obscured by only a few inches of silt or superficial limestone, but away from the central parts of the dome the Sinya Beds are unconformably overlain by the Amboseli Clays, the base of which is marked by a thin but persistent pebble bed.

Mining has shown that meerschaum is present chiefly in the marl/limestone bed, though derived fragments of the mineral are found in some of the overlying deposits. The meerschaum occurs in pockets, lenses and lenticular seams having a completely random orientation and distribution within the host rock. Further details of the deposit and the mining methods employed are given in a later section of the report, and this discussion is concerned mainly with the thickness and structure of the meerschaum-bearing bed.

Excavations at Sinya proved more than 23 feet of marl without locating the base, and at the time of the survey this was considered to be nearly the maximum thickness to be expected in the centre of the dome, for an equivalent thickness of white marl had been located by drilling to the west. Matheson subsequently drilled to a depth of 43 feet close to the long axis of the dome, encountering only "clay with carbonate and meerschaum" (section M.3, Fig. 8); if this is all to be correlated with the marl bed established elsewhere it indicates a marked thickening of the bed in the centre of the dome.

Although the marl sometimes has a pale green tinge, green colours are more typical of non-calcareous clays, some of which overlie the meerschaum-bearing bed but are in turn overlain by the basal conglomerate of the Amboseli Clays. These green clays frequently appear in the cores of synclinal folds that are truncated by the unconformity and they are often characterized by the abundant development of parallel cylindrical inclusions of hard white calcareous material. These may represent fossilized roots, though no internal structure is visible. Where bedding can be seen in the clay the "roots" are perpendicular to it. They seldom exceed an inch in diameter or a few inches in length, and they often bear short "rootlets". Similar inclusions were found in green and grey beds in the Amboseli Clays.

Sections (A) to (G) in Fig. 8 (at end) illustrate the westward dip of the Sinya Beds, which is accompanied by a marked thickening of the unconformably overlying Amboseli Clays. A trench section (F) shows the dip of the unconformity to be 4° which, if maintained, would result in the basal conglomerate lying at over 100 feet at (B). Drilling at (B), whilst failing to locate with certainty the pebble conglomerate, established an almost uninterrupted development of white calcareous clay/marl between 61 and 84 feet below the surface. This bed is provisionally correlated with the meerschaum-bearing marl exposed in the core of the dome, and a thin gritty limestone bed pierced at a depth of 43 to 44 feet is thought to represent the pebble bed. The following succession in the Sinya Beds west of the dome is based on the above tentative correlations:—

Lithology	*Approx. Thickness (Feet)*
4. White and pale grey calcareous clays	3
3. Green and pale green clays with thin intercalated beds of grey clay and brown silty clay	14
2. White marl with thin intercalated beds of brown silty clay and pale green clay	23
1. Pale green and pale khaki-coloured clays	+14
TOTAL ..	+54

Sections (H) to (L) in Figure 8 show the successions along the eastern flanks of the Sinya Dome. The occurrence of meerschaum in some of the marls exposed at the surface led to an early misinterpretation of the structure, but detailed examination later showed that the marls contain only fragmentary meerschaum, probably eroded from the central parts of the dome; the deposits are assigned to the Ol Tukai Beds. The basal conglomerate of the Amboseli Clays was doubtfully identified some 16 feet below the surface at (I). No meerschaum was identified however, in the cores from Matheson's boreholes (M.5) and (M.7), where the Sinya Beds are probably about 32 feet below the surface. The Sinya Beds east of the dome are probably represented by the following sequence:—

Lithology	*Approx. Thickness (Feet)*
2. Green and pale grey clays (locally containing calcareous fragments)	2–4
1. Grey-brown and brown silty clays with thin beds of grey clay ..	+14
TOTAL ..	+18

The total succession here may be equivalent to (3) in the sequence proposed for the Sinya Beds west of the dome, in which case the clays and silty clays overlie the meerschaum-bearing marl, which was not pierced.

Neither the basal conglomerate of the Amboseli Clays nor the underlying Sinya Beds were located in a borehole at (T) at the northern end of the dome. Drilling was finally abandoned in white calcareous clays encountered at a depth of 24 feet. Matheson's borehole (M.4) pierced similar white clays from 20 to 31 feet below the surface, underlain by a thin gritty bed which is correlated with the basal conglomerate of the Amboseli Clays. The succession in the Sinya Beds north of the dome is therefore as follows:—

Lithology	*Approx. Thickness (Feet)*
3. Grey clays	6
2. Green clays	4
1. Grey and white calcareous clays with thin intercalations of green clay	+27
TOTAL ..	+37

Matheson located a thin bed of grey, gritty clay at a depth of 17 feet in borehole (M.6) near the southern end of the dome. This is taken as the basal bed of the Amboseli Clays, and the barren marls exposed in sections (M) to (P) are assigned to that formation and to the Ol Tukai Beds. The meerschaum-bearing marls in the following succession in the Sinya Beds were encountered in borehole (M.6) at a depth of nearly 40 feet:—

Lithology	*Approx. Thickness (Feet)*
3. Grey clays	9
2. White clays and sepiolite mudstones	12
1. Grey and white calcareous clays	+9
TOTAL ..	+30

Naerabala

The Sinya Beds are re-exposed in the core of a minor dome some three-and-a-half miles east of Sinya, near the small volcanic vent at Naerabala. Measured sections in the sediments, at localities outside the Sinya area, are summarized in Figure 9 (at end): the sites are shown in Figure 10. Exploratory trenching at Naerabala proved 15 feet of marls and clayey limestones similar to those found at Sinya, without exposing the base. Trenches show that rather hard clayey limestones are overlain by white marls and pale green clay and that the sequence is unconformably overlain by the Amboseli Clays at the base of which is developed a thin basal conglomerate. Sections (14), (9) and (15) in Figure 9 (at end) illustrate the unconformity. The beds at (14), including the pebble bed, dip northwards (i.e. towards Lake Amboseli) at 20°. Only a few fragments of meerschaum were recovered from the marl and limestone at Naerabala, though more detailed work is required before rejecting the locality for mining.

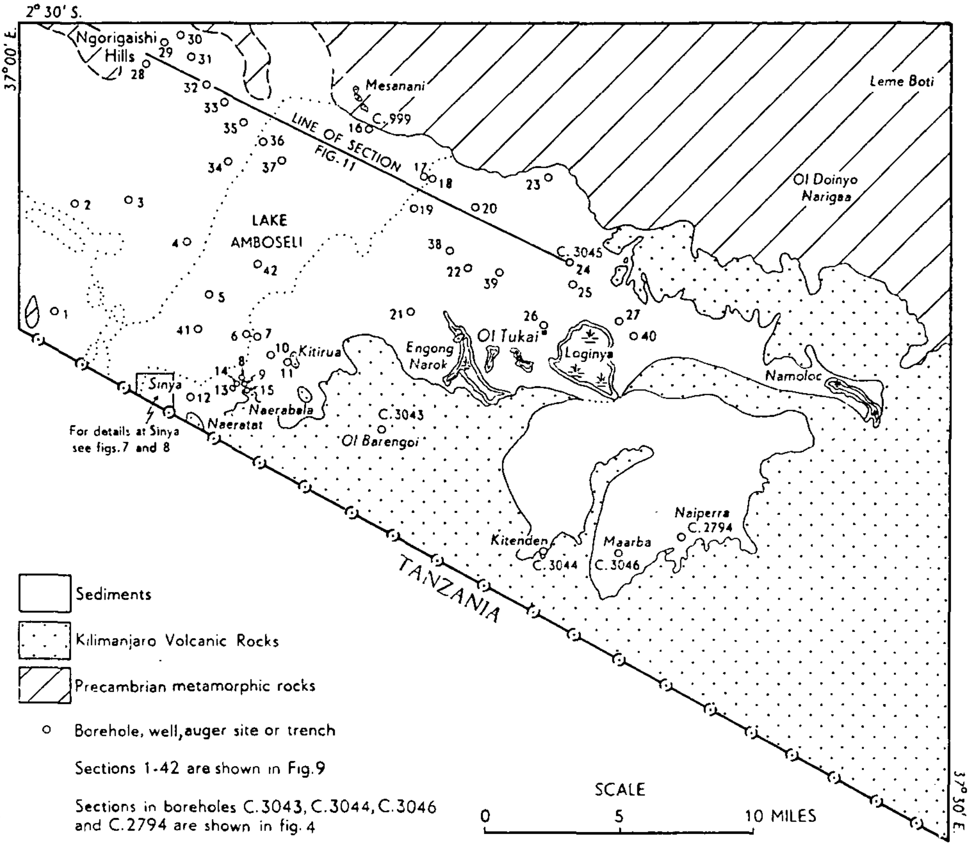


Fig. 10—Distribution of boreholes, wells and auger sites in the Amboseli area. Details of sections are given in Figs. 4 and 9

During the survey a hole was drilled near section (14) to determine the thickness of limestone and marl and to establish a more complete succession. The sequence is shown at (8) in Figure 9, and although the pebble bed was not identified from samples its position can be inferred by correlation with trench sections. The borehole proved that locally some 50 feet of Sinya Beds rest on scoriaceous lavas. The succession in the Sinya Beds at Naerabala is as follows:—

Lithology	*Approx. Thickness (Feet)*
8. Whitish marl	1
7. Pale green clay	4–8
6. White marl and powdery marl	6
5. Hard white clayey limestone	8–15
4. Pale grey clay	10
3. Dark grey-green clay	7
2. Pale green clay	8
1. Grey-brown clay	+2
TOTAL	46–57

Kitirua

No exposures of the Sinya Beds were found at Kitirua but the succession recorded in a borehole drilled about a mile-and-a-half north-east of Naerabala vent included 35 feet of white calcareous clays that are correlated with the meerschaum-bearing marl and limestone at Sinya and Naerabala. The unconformity separating the Amboseli Clays and the Sinya Beds is believed to lie at a depth of about 25 feet below the surface at the Kitirua drilling site; the complete succession established is shown at (10) in Figure 9. The Sinya Beds here are probably banked against the scoriaceous lavas associated with the Kitirua vents, but the borehole pierced 84 feet of sediment without locating volcanic rocks. The succession in the Sinya Beds at Kitirua is as follows:—

Lithology	*Approx. Thickness (Feet)*
3. Green and pale green clays	11
2. White calcareous clays with thin intercalated beds of green clay	35
1. Green, brown and whitish clays	+11
TOTAL ..	+57

(2) AMBOSELI CLAYS

The Amboseli Clays rest with marked unconformity on the Sinya Beds, the contact being marked locally by the development of a basal conglomerate about 18 inches thick. This pebble bed is clearly recognizable in excavations at Sinya and Naerabala, but was not conclusively identified during drilling and augering. Matheson located a thin gritty bed in several boreholes and this is tentatively correlated with the pebble conglomerate, but in many borehole sections the position of the unconformity can only be inferred by comparison with sequences in nearby artificial exposures.

The Amboseli Clays probably attain a maximum thickness of some 200 feet and the formation includes a variety of clays, calcareous clays and silty clays.

Sinya

The Amboseli Clays are well displayed in excavations in the Sinya district where the basal conglomerate and the overlying deposits show visible dips away from the central parts of the dome. Drilling was undertaken in the rapidly thickening clays around the flanks of the dome in the hope of locating the pebble conglomerate: results tended to be disappointing in this respect, but sufficient stratigraphical information was obtained to determine with some confidence the position of the unconformity between the Sinya Beds and Amboseli Clays.

Figure 7 (at end) shows the inferred original outcrop of the basal pebble bed of the Amboseli Clays, together with provisional isopachytes for the combined clays and overlying Ol Tukai Beds; the latter probably seldom exceed five feet in thickness over the area of the map. Detailed sections in the Amboseli Clays at Sinya are given in Figure 8 (at end).

The basal conglomerate ranges from six inches to two feet in thickness and is easily recognized in weathered trench sections where it assumes a distinctive texture; in freshly cut sections it is not always easily separated from marls and limestones of the Sinya Beds but close examination reveals the pebbly nature of the bed. The rounded to subrounded pebbles range from a few millimetres to more than 40 mm. in diameter, but most commonly they measure 10-20 mm. across. They vary in composition from white marl and clayey limestone to porcellaneous grey clays and meerschaum. The pebbles, together with small, rounded grains of garnet and quartz, are set in a white or pale grey matrix of calcareous clay. The conglomerates probably grade into finer deposits away from the central parts of the dome, a fact which would explain the difficulty in identifying in boreholes the unconformity between the Sinya Beds and the Amboseli Clays.

The following succession in the Amboseli Clays was established by drilling west of the Sinya dome:—

Lithology	*Approx. Thickness (Feet)*
6. Greenish clays	8
5. Pale grey and whitish calcareous clays	6
4. Green clays with a thin intercalated bed of pale grey clay	12
3. White marl	4
2. Green clays	6
1. White calcareous clays (with pebble bed at the base)	5
	41

The clays rest on the Sinya Beds and are overlain by a few feet of silt or silty clay that is tentatively referred to the Ol Tukai Beds. Matheson recorded 18 feet of green clay with intercalations of grey, overlying "white clay with carbonate and sepiolite mudstone" which attains a thickness of more than 16 feet. The pebble bed was not located, but may have been pierced at the base of the white clay where no core was recovered.

North of the dome the succession in the Amboseli Clays is as follows:—

Lithology	*Approx. Thickness (Feet)*
3. Green clays with thin intercalated beds of brown and grey clays	22
2. Grey marl	1
1. Whitish calcareous clay	+3
TOTAL	+26

The clays here are overlain by a thin cover of wind-blown silts that form low dunes nearby. Matheson's borehole (M.4) proved a thin bed of gritty clay at the base of white calcareous clays some 30 feet below the surface; this gritty bed is tentatively correlated with the pebble bed.

East of the dome isolated trenches failed to locate any appreciable thickness of marl that could be correlated with the meerschaum-bearing bed exposed in the core and an exploratory borehole had to be abandoned before it proved the suspected marl bed at depth. The pebble bed however, was doubtfully identified during augering and drilling so the following succession evidently represents the Amboseli Clays:—

Lithology	*Approx. Thickness (Feet)*
3. Green, grey and brown clays	8
2. Pale grey calcareous clays	4
1. Brown, grey and green clays (with pebble bed at the base)	3
TOTAL	15

Matheson later found a thin bed of grey, gritty clay (which he correlated with the pebble bed) at a depth of about 30 feet. This borehole was also abandoned before proving any meerschaum-bearing sediments.

The clays east of the dome are overlain by a thin bed of marl bearing fragments of meerschaum, and by pale brown silts; these sediments are referred to the Ol Tukai Beds. The cover of marl and silt thins towards the small dry lake bed immediately east of the mine workings and there the Amboseli Clays form the surface.

Naerabala and Kitirua

The Amboseli Clays are absent across the dome at Naerabala, but trenches on the flanks show the basal beds dipping about 20° towards the lake. A correlation of sections recorded both east and west of Naerabala (Fig. 9) illustrates the thickening of the Amboseli Clays in those directions, while, to the south, the deposits are evidently banked against the volcanic rocks of Naerabala Vent. The Amboseli Clays are not exposed in the Kitirua district but drilling proved their presence beneath the Ol Tukai Beds. Multi-coloured clays near the base of the western vent at Kitirua are tentatively referred to the Amboseli Clays.

At Naerabala the succession is as follows:—

Lithology	*Approx. Thickness (Feet)*
3. Whitish calcareous clay	6
2. Green clay	5
1. Grey and pale grey clays (with thin basal pebble bed)	2
TOTAL ..	13

The following comparable sequence was recorded from the borehole at Kitirua:—

Lithology	*Approx. Thickness (Feet)*
4. White calcareous clay	4
3. Whitish calcareous clay	6
2. White calcareous clay	4
1. Grey calcareous clay (with basal pebble bed)	2
TOTAL ..	16

A trench section (12) in Figure 9 three quarters of a mile north of Naeratat volcanic vent and midway between Naerabala and Sinya, suggests that green clays overlie the successions proposed for Naerabala and Kitirua.

Lake Amboseli

The Amboseli Clays immediately underlie the entire surface of the dry lake bed, being concealed by only a few inches of windblown silts. In the centre of the lake drilling proved 20 feet of green and grey-green clays (bearing gaylussite crystals in the upper beds) without locating the base. More silty clays were encountered towards the south-eastern, north-eastern and north-western margins of the lake; this is undoubtedly in part a facies change, although at Nenkereri (north of Naerabala), at least 23 feet of brown and green silty clays probably overlie the gaylussite-bearing bed of dark green clay seen in the centre of the lake (*see* sections 5, 6 and 7 in Figure 9). Since the basal beds of the Amboseli Clays approach the surface in the Naerabala and Kitirua districts, it appears that the silty deposits occupy the core of a local basin.

Matheson drilled to a depth of 90 feet at a site in the southern half of Lake Amboseli, establishing the following general succession:—

Lithology	*Approx. Thickness (Feet)*
4. Black, grey and green clays with gaylussite	26
3. Green, black and dark grey clays	26
2. Pale grey and white clays	21
1. Green clays	+17
TOTAL ..	+90

In the north-eastern corner of the lake the Amboseli clays are represented by green, brown and grey silty deposits that are perhaps overlain by purer green and grey-green clays (*see* sections (17), (18) and (19) in Figure 9). The following succession was recorded in an exploratory borehole drilled some 2,000 feet east of the shoreline of the lake, which is here marked by a low feature defining the extent of the overlying Ol Tukai Beds:—

Lithology	*Approx. Thickness (Feet)*
4. Pale green clays	6
3. Grey-green and brownish-green silty clays and pale grey clay ..	4
2. Pale green calcareous silty clay	12
1. Brown, green, and pale grey silty clays	+18
TOTAL ..	+40

In the north-western part of Lake Amboseli 45 feet of green clays and silts were proved, without locating the base.

East of Lake Amboseli

Between the eastern margin of the lake and the Ol Tukai district little is known of the nature of sediments underlying the Ol Tukai Beds that form the surface. Locally diatomaceous clays of the Ol Tukai Beds are underlain by at least five feet of pale green and brown silty clays, and these deposits are provisionally referred to the Amboseli Clays which are here believed to lie at 15 to at least 85 feet below the surface, depending on the depth of the basin containing diatomaceous deposits (*see* sections (18), to (27) in Figure 9). In sections (20) and (23), recorded near the northern margin of the Amboseli Basin, no diatomaceous sediments were recognized and the separation of the Ol Tukai Beds and Amboseli Clays is purely arbitrary, the latter being taken to include more than 25 feet of silty clays.

Fluviatile Facies of the Amboseli Clays

Fluviatile deposits (conglomerates, gravels, sands, silts and clays) located by drilling near the northern shore-line of Lake Amboseli, towards the Ngorigaishi Hills and also near the western boundary of the area, clearly represent, at least in part, lateral equivalents of the Amboseli Clays (Figs. 9 and 11). In several boreholes the fluviatile deposits were found to rest on Precambrian rocks, and in those places the lower parts of the successions recorded are presumably to be correlated with the Sinya Beds. The uppermost beds may represent a facies of the Ol Tukai Beds.

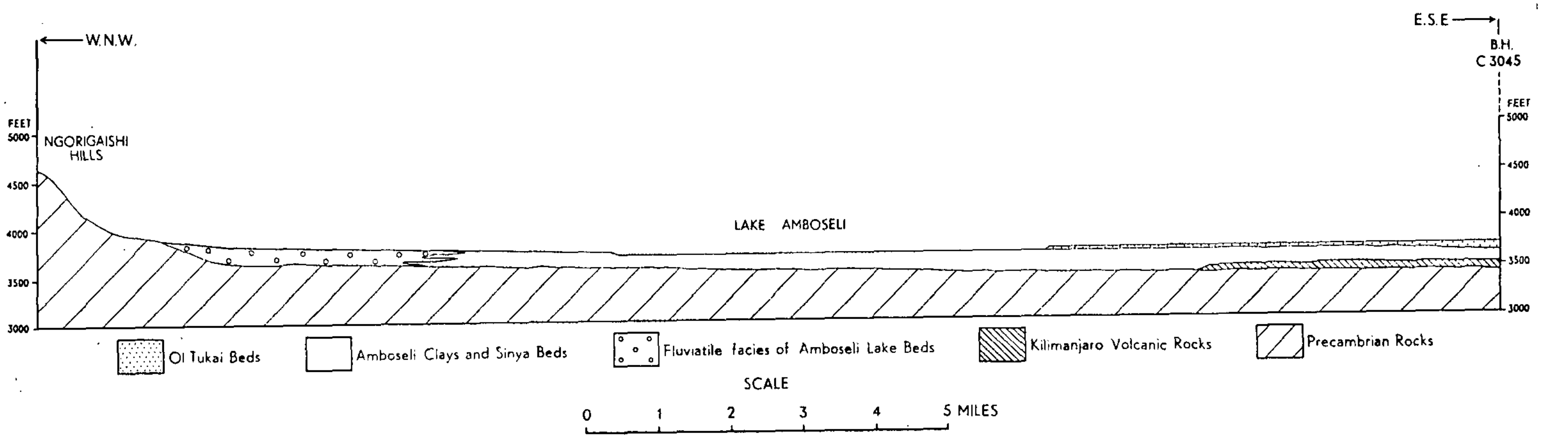


Fig. 11—Section through the sediments in the north-western part of the Amboseli area. The line of section is shown in Fig. 10

(3) OL TUKAI BEDS

The Ol Tukai Beds form a low feature marking the eastern shore-line of Lake Amboseli, and they conceal underlying sediments completely in the eastern half of the basin. The deposits attain a thickness of more than 80 feet north of Ol Tukai where pale grey diatomaceous clays are overlain by silts, clays and superficial limestones. These sediments probably rest unconformably on the Amboseli Clays. Along the eastern shore-line of the lake and towards Kitirua and Naerabala the formation is represented by calcareous silts and thin surface limestones which probably seldom exceed a total thickness of ten feet. At Sinya thin developments of silts, clays, marls and limestones are tentatively referred to the Ol Tukai Beds. The deposits at Sinya and Naerabala locally overlap the Amboseli Clays to rest directly on the Sinya Beds on the flanks of the domes. Towards the Ngorigaishi Hills, the western boundary of the area, and the foothills of Kilimanjaro, the clays and silts grade into coarse fluviatile deposits.

Ol Tukai District

In the type area the Ol Tukai Beds infill a basin which had probably been cut in older sediments by torrential floods from the northern slopes of Kilimanjaro. The deposits thin rapidly towards Lake Amboseli and they are banked against Precambrian rocks to the north and against lavas to the east; southwards the beds grade into conglomerates.

The base of the Ol Tukai Beds in the type area is taken arbitrarily as the base of diatomaceous deposits, and underlying sediments are referred to the Amboseli Clays (*see* Figure 9, sections (18) to (27)).

The following succession was established in borehole C.3045 where the Ol Tukai Beds attain a maximum known thickness:—

Lithology	*Approx. Thickness (Feet)*
4. Pale grey calcareous silts	15
3. Olive-green clay	10
2. Grey green, pale green and brown clays, locally containing siliceous nodules, plant remains and calcareous fragments . .	10
1. Pale grey diatomaceous clays with rare beds of white diatomite and thin intercalated beds of dark green clay; brown siliceous nodules common; fish remains in the lower parts	+45
	+80

Between Ol Tukai and Kitirua the diatomaceous deposits become more silty and ultimately lens out, to be replaced by pale brown, green and whitish calcareous silts and silty clays. Northwards brown and green silts replace the diatomaceous clays in the vicinity of Precambrian rocks, and westwards towards Lake Amboseli pale grey, greenish, white and brown calcareous silts represent the Ol Tukai Beds. In the neighbourhood of Ol Tukai airstrip pale grey diatomaceous silty clays now form the surface, but the ground was formerly capped by a bed of superficial limestone. This cover has been largely eroded but there remain a number of circular pedestal-like outcrops of limestone standing about two feet above the surface, and undercut at the base.

Kitirua-Naerabala-Sinya

Clays, marls and silts which form a thin but extensive cover between Kitirua and Sinya are referred to the Ol Tukai Beds because they rest with slight angular unconformity on typical representatives of the Amboseli Clays. Sections (12) to (14) in Figure 9 illustrate the unconformity at Naerabala, and various sections in Figure 8 show the way in which the Ol Tukai Beds infill slight irregularities in a former surface at Sinya.

Pale grey calcareous clays and silts form a distinct pavement around the western side of the vent north of Ol Doinyo Siteti and the sediments contain basalt pebbles, unidentifiable bone and shell fragments and silicified plant remains. Towards the lake, brown calcareous silts bear fragments and pebbles of limestone, and at the shore-line these deposits grade into white powdery marls with a thin cap of superficial limestone. At Naerabala, brown calcareous silts and clays overlie the Amboseli Clays while at Sinya similar deposits are accompanied by white and grey marls and clayey limestones. Some of the deposits at Sinya contain fragments of meerschaum, and surface marls were confused with the main meerschaum-bearing bed during the early stages of mining. Mapping subsequently showed the importance of distinguishing between sediments containing primary meerschaum and those bearing fragmentary material derived by erosion of older beds in the core of a dome. The presence of meerschaum fragments in the Ol Tukai Beds shows that doming must have been well advanced before the deposition of those sediments.

Kitenden-Maarba-Naiperra

A great deal of the ground between Kitenden and Loginya and Namoloc Swamps is littered with well rounded lava pebbles derived from conglomerates which are evidently the lateral equivalents of the clays and silts of the Ol Tukai District. The conglomerates are sporadically exposed at Maarba but the best evidence of thickness of the deposits comes from samples collected during drilling of the boreholes at Kitenden, Maarba and Naiperra (*see* Fig. 4). The conglomerates attain a thickness of 85 feet at Kitenden where they rest on lavas forming part of the oldest division of the Lower Olivine Basalts. The pebbly deposits are 30 feet thick at Maarba and 60 feet at Naiperra and at both localities the sediments rest on felsparphyric lavas of the Lower Olivine Basalts.

West of Lake Amboseli

Substantial thicknesses of fluviatile deposits were encountered during drilling west of Lake Amboseli (*see* Figs. 9 and 11). The sediments clearly represent a fluviatile facies of the Amboseli Lake Beds, but they cannot be accurately subdivided and correlated with the three formations proposed for the lacustrine deposits. A borehole (C.2804) near the Ngorigaishi Hills, for instance, located Precambrian rocks at about 3,620 feet O.D. (*see* section (28) in Figure 9), i.e. about 65 feet below the level of the clays forming the present surface of Lake Amboseli. Much of the sediment penetrated by this borehole must be regarded as the lateral equivalent of the Amboseli Clays, and is described earlier as such, but some of the gravels towards the top of the succession are perhaps to be correlated with the Ol Tukai Beds. Similarly some of the sands and gravels proved by borehole C.1009 south of the Ngorigaishi Hills are likely to represent a fluviatile facies of the Ol Tukai Beds.

(4) SEDIMENTARY SUCCESSION IN TANZANIA

Between 1961 and 1963, (i.e. after the preparation of the present report) D. N. Sampson carried out a survey of an area in Tanzania immediately south of Amboseli. The results of the survey were incorporated in the geological map of the Kilimanjaro-Moshi area (Special Sheet, Geological Survey of Tanzania) published in 1965. In the course of this work the meerschaum-bearing sediments of the Tanzania portion of Sinya mine were investigated in detail and a separate account of the results was subsequently published (Sampson, 1966). The latter paper quotes many chemical analyses of the sediments.

The stratigraphical succession proposed in the present report was found to apply also in Tanzania and the three-fold subdivision of the Amboseli Lake Beds was adopted, though a correlation of upper sediments with the Ol Tukai Beds of the Kenya succession was regarded as tentative. The following succession was established (Sampson, *op. cit.*, p. 24) from observations in the southern part of Sinya mine:—

		Maximum observed thickness
		feet
? Ol Tukai Beds	Impure limestones and marls	12
	..........unconformity..........	
	Green thixotropic clays	7
	Limestone conglomerate	0.6
Amboseli Clays	..........unconformity..........	
	Green thixotropic mudstones	7
	..........unconformity..........	
	Sepiolitic mudstones and limestones	8
Sinya Beds	Dolomitic lacustrine limestones	24
		(*base not seen*)

The dolomitic lacustrine limestones were described as hard, poorly bedded rocks. They are the main host rocks for the meerschaum and they are to be correlated with the whitish marls in the Kenya dome, where the beds are known to be at least 23 feet thick, and are underlain by pale green and khaki-coloured clays.

The sepiolitic mudstones and limestones forming the upper eight feet of the Sinya Beds in Tanzania are evidently the lateral equivalents of green, grey and brown clays and pale calcareous clays of the Kenya dome.

The Amboseli Clays in Tanzania consist of green thixotropic mudstones unconformably overlain by similar clays with a thin limestone conglomerate at the base. The unconformity in the Amboseli Clays has not been recognized in Kenya.

Thin developments of impure limestones and marls in Tanzania are tentatively correlated with the Ol Tukai Beds mapped in Kenya.

(5) ORIGIN OF THE DEPOSITS

Mapping and correlation of the various deposits comprising the Amboseli Lake Beds and their fluviatile equivalents were based on some of the more obvious physical and chemical properties of the rocks, e.g. colour, grain size and carbonate content. Most of the pale-coloured clays are calcareous; green and brown clays sometimes contain small inclusions of carbonates, but the clays themselves are non-calcareous. These characters were adequate for field studies of the sediments, but detailed laboratory investigations are required to establish the compositions of the deposits. At an early stage in investigations chemical analyses proved the dolomitic nature of the clayey limestones and marls, and chemical work also proved the surprisingly high magnesia content of clays originally regarded as bentonites. Subsequent studies by X-ray techniques showed that some of the deposits are sepiolitic clays rather than bentonitic varieties.

The origin of much of the material occupying the central parts of the Amboseli basin is still conjectural, but it seems likely that the sepiolitic clays were derived from volcanic ashes which showered down across the former lake. A notable feature of many of the sediments is the high magnesia content. Guest (1955) looked to the Precambrian crystalline limestones for a source of magnesia, but Sampson (*op. cit.*, p. 30) drew attention to the fact that chemical analyses of the marbles west of Sinya indicate an abnormally low MgO content; magnesia-poor crystalline limestones also occur in the Sultan Hamud area, north of Amboseli (Searle, 1954, pp. 27-31). The writer is in complete agreement with the conclusions reached by Sampson, who regarded the volcanic rocks as a source not only of the magnesia, but also of lime.

The postulated derivation of the purer clays and marls from volcanic ashes explains the facies variations observed in the deposits, for normal clastic material would be expected in quantity only where streams entered the original lake. A change in composition in the ashes, from varieties rich in calcium carbonate to types having a high magnesia content, is indicated by the essential difference in composition of the Sinya Beds and the Amboseli Clays. Explosive volcanic activity had probably diminished or ceased by the time of deposition of the Ol Tukai Beds, which are characterized by diatomaceous deposits.

4. Quaternary Deposits

A variety of Quaternary superficial deposits was encountered in the Amboseli area. They conceal much of the Precambrian outcrop, often mantle occurrences of lacustrine and fluviatile sediments and are frequently developed across volcanic rocks. Many of the deposits accumulated during Recent times but some date back to the Pleistocene. They comprise alluvial soils, sandy soils, dusty volcanic soils and windblown clayey silts and sands.

Alluvial Soils of the Namanga River

Dark, clayey alluvial soils flank the Namanga River and extend from the western boundary of the area to the southern parts of Lake Amboseli. They are apparently flood deposits, overlying both lacustrine and fluviatile facies of the Amboseli Clays, and were deposited in Recent times immediately preceding the final desiccation of the lake. The alluvial sediments are marked by a sprinkling of quartz grains, and the difference in lithology between these soils and purer clays forming the lake surface is readily appreciated when attempting to motor across them in wet weather—the Amboseli Clays produce a treacherous, slippery surface and often bear a few inches of water for long periods after rain; the alluvial soils become waterlogged and incapable of supporting the weight of any vehicle.

Reddish-Brown Sandy Soils

Precambrian rocks in the area are largely concealed by a mantle of reddish-brown sandy soils that are best developed between Mesanani and Leme Boti. An apron of similar superficial deposits around the southern end of the Ngorigaishi Hills effectively conceals coarse, fluviatile sediments and grades imperceptibly southwards into pale brown, windblown clayey silts. The reddish-brown soils contain numerous grains of quartz, garnet, hornblende and felspar and were formed *in situ* on weathered gneisses and granulites. Across outcrops of marble, sandy soils are accompanied by occurrences of kunkar limestone. The soils and superficial limestones formed throughout Pleistocene and Recent times, the more extensive developments coinciding with remnants of the end-Tertiary peneplain.

Black Cotton Soils and Reddish-Brown Alluvial Soils

Seasonal watercourses and areas of poor drainage across the plains underlain by Precambrian rocks are often marked by the development of black cotton soils and reddish-brown alluvial soils. These deposits are most prominent between Pine Trigonometrical Beacon and Ibulbul, where they occupy a broad shallow depression between lavas forming the north-eastern rim of the Amboseli Basin and the hills of Precambrian rocks at Ol Doinyo Narigaa, completely concealing the lava-metamorphic rock contact. Similar deposits are found in swampy areas across the Amboseli Lake Beds, notably along the north-eastern margin of the basin and north-west of Loginya Swamp. Where they overlie lacustrine sediments, these soils formed during Recent times; elsewhere, they probably range from Pleistocene to Recent in age.

Reddish-Brown Volcanic Soils

Reddish-brown dusty soils, often littered with lava boulders, overlie volcanic rocks, and south of Naerabala vent they probably also rest on lacustrine sediments. Volcanic soils are shown on the geological map only where insufficient evidence is available to determine the nature of the underlying lavas.

Windblown Clayey Silts and Sands

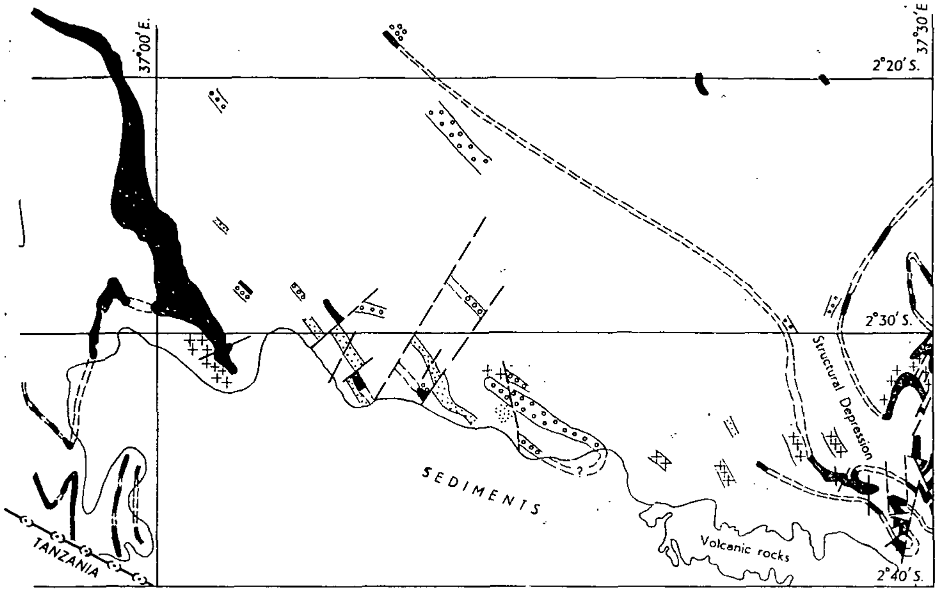
Pale brown, wind-transported clayey silts and fine sands containing grains of quartz, garnet, hornblende and magnetite attain a maximum thickness of some 30 feet immediately west of Lake Amboseli. Drilling in these poorly consolidated deposits showed that they rest on green Amboseli Clays at the level of the lake surface. They apparently thin westwards to overlie coarse fluviatile sediments that, in the higher part of the succession, are thought to represent a fluviatile facies of the Ol Tukai Beds (*see* sections (3) and (4) in Figure 9). Thin garnet-rich beds occur intercalated in sands near the northern end of the line of dunes flanking the lake, while to the south, near the Tanzania border, dune sands rest on both limestones (doubtfully referred to the Ol Tukai Beds) and on dark alluvial soils of the Namanga River delta. North of Sinya Mine low dunes rest on the Amboseli Clays and separate the lake proper from a minor dry lake bed east of the dome.

VI—STRUCTURE

1. Structures in the Precambrian Rocks

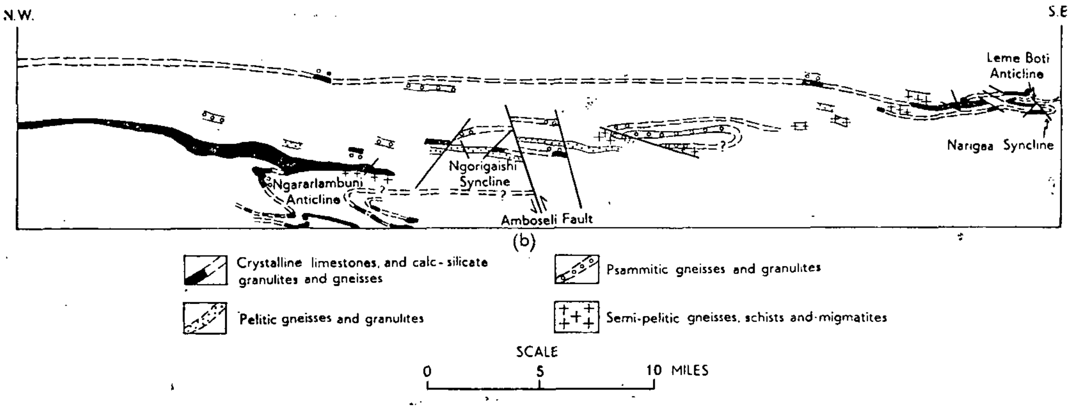
The Precambrian rocks in the Amboseli area have been subjected to at least one phase of intense folding and faulting. Compressional forces, acting largely from the south-east, resulted in the development of large-scale recumbent folds, the axial planes of which were later displaced by N.E.-S.W. faults. The fractures include both normal and reverse faults as well as minor thrusts. Locally culminations and depressions in the plunge of the recumbent folds complicate the structural pattern, resulting in the production of irregular closed outcrops. A more detailed structural study of this part of Kenya will be required to deduce with certainty the origin of gentle crossfolds but there is no evidence within the area mapped to show that they are related to more than one period of folding.

The metamorphic rocks in the Amboseli area are largely concealed by lavas, by sediments occupying the central basin and by an extensive mantle of superficial deposits, so that even in the north the correct interpretation of major structures depends primarily on the accuracy with which isolated outcrops are correlated. Figure 12 (*a*) shows the distribution of exposures and the inferred outcrops of some of the major bands in parts of the Amboseli, Sultan Hamud and Namanga-Bissel areas. The tectonic profile, Figure 12 (*b*) constructed by projection on to a plane normal to the average plunge direction of lineations, illustrates the recumbent nature of folds in the Precambrian rocks and the effect of faulting.



(a)

Fig. 12 (a)—Map of the northern section of the Amboseli area and adjacent areas, showing the distribution of exposed Precambrian rocks and the inferred continuation of some outcrops



(b)—Transverse profile of the area included in (a). The plane of projection strikes 126° and dips at 74° to the south-west

Structural data recorded during the survey are recorded in Figure 13, which also shows the axial planes of major folds. Also incorporated in Figure 13 is a stereogram of lineations and poles to foliation planes measured in Precambrian rocks, showing that folds plunge at low angles to the north-east. The average plunge is 16° in the direction 036°, though a slight scatter of lineations indicates local swinging of the fold axes. Weiss (1958) carried out a detailed structural analysis of Precambrian rocks at Turoka, some 50 miles north-west of the Amboseli area, and concluded that folds there plunge at 20° in the direction 062°. Poles to foliation planes show an even more marked scatter than do the lineations in the stereogram. This is also partly related to a swing in the fold axes, but further complication is introduced by reversed dips in the north-eastern corner of the area that are related to culminations and depressions on the fold axes.

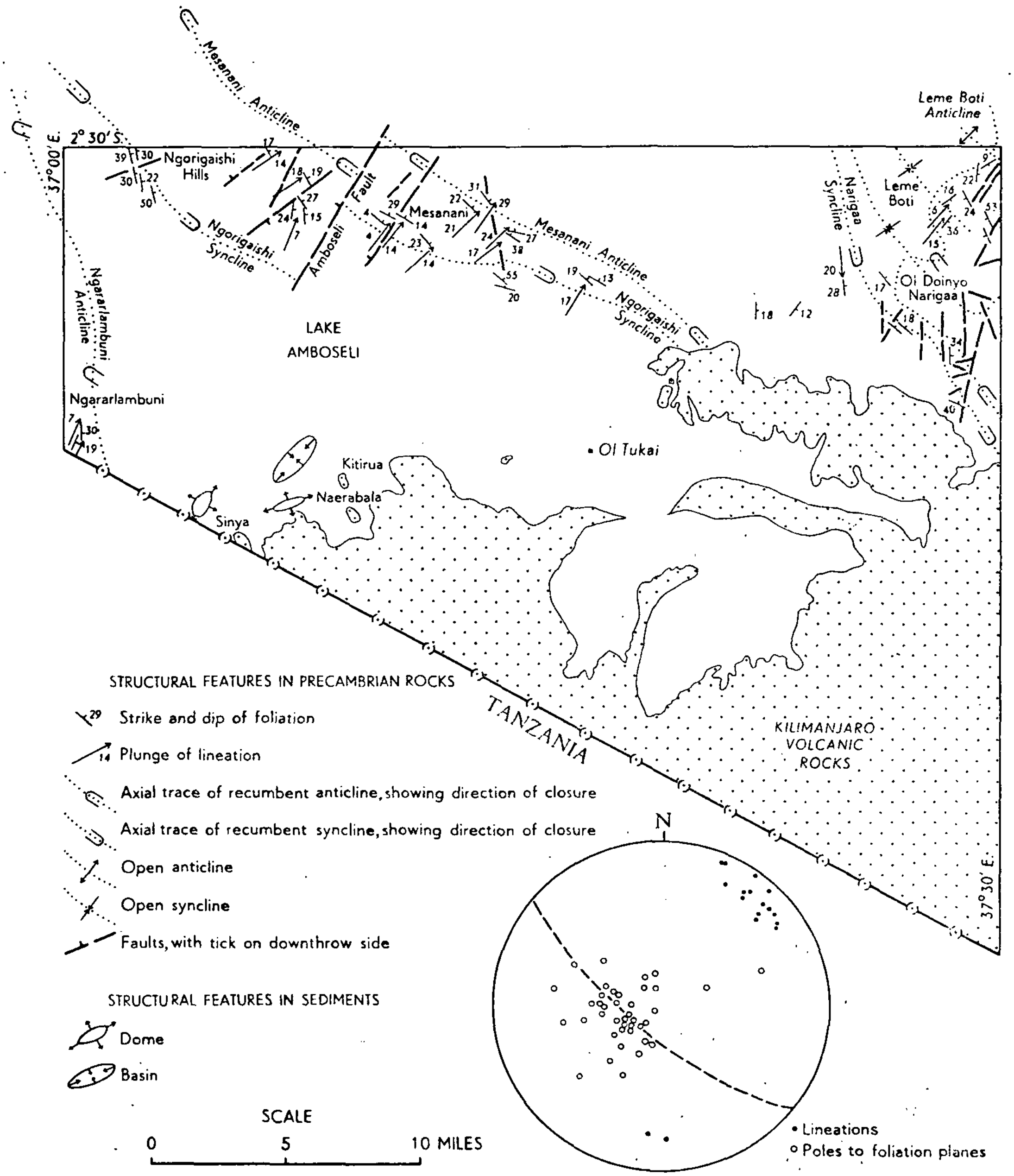


Fig. 13—Structural map of the Amboseli area, and stereographic projection of structural data from Precambrian rocks

The structural complexity in the neighbourhood of Leme Boti is well illustrated by the outcrop shapes of crystalline limestone bands. These limestones are reasonably well exposed in the areas already mapped and continuations of the outcrops are readily followed by the distinctive markings seen on air photographs. The photographs also enable an accurate forecast to be made of limestone outcrops in the unsurveyed Loitokitok area lying immediately to the east of the Amboseli area. Rock types flanking the marble bands are generally poorly exposed and over large areas are unknown so that they offer little assistance in the unravelling of the geological structures. Saggerson (1963, p. 48) has already provided a map showing the disposition of the limestone outcrops in the south-western part of the Simba-Kibwezi area and the south-eastern corner of the neighbouring Sultan Hamud area, indicating the probable correlation of a number of isolated exposures of marble. This map is reproduced here (Fig. 14) together with a southward extension based on the evidence recorded during the present survey. The repetition of Saggerson's work is essential to a clear understanding of the structure involved.

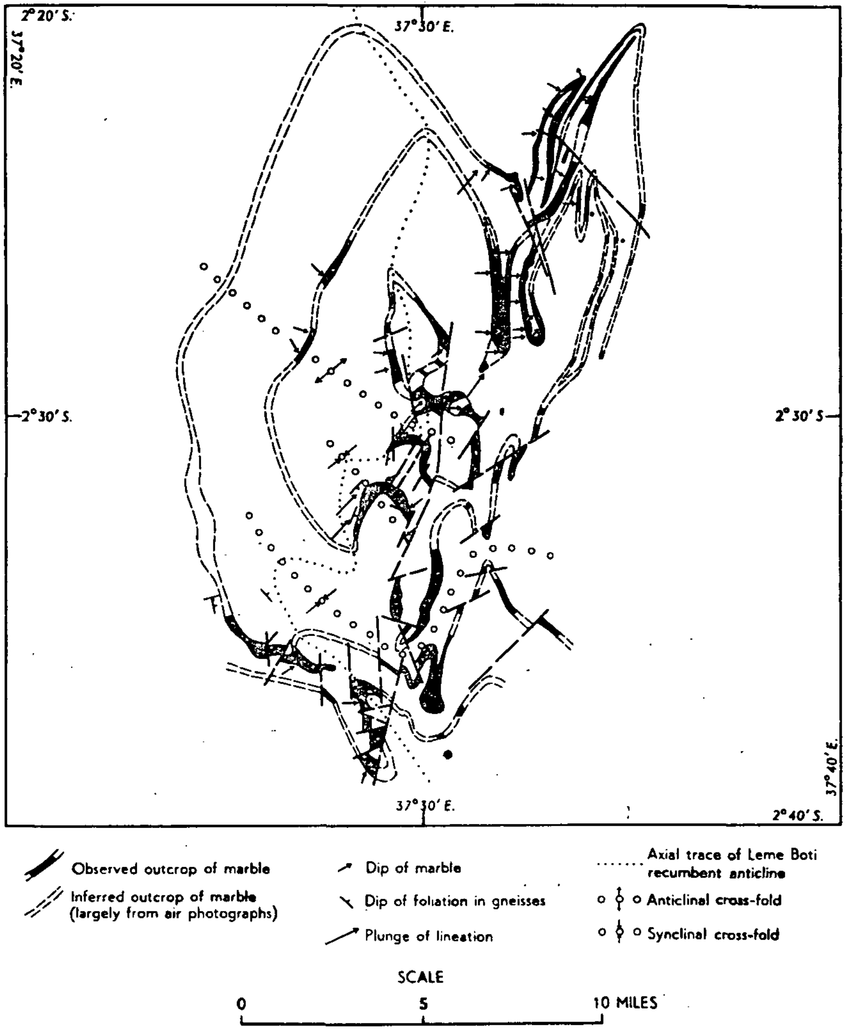


Fig. 14—Map showing the distribution of crystalline limestones in the north-eastern part of the Amboseli area and adjacent parts of the Sultan Hamud, Simba-Kibwezi and Loitokitok areas. Information north of latitude 2° 30′ S. is taken from a diagram by Saggerson (1963, p. 48)

Culmination in the regional plunge has the effect of completely closing the outcrops of individual bands at the hinge-line of a recumbent fold (Fig. 15), the ultimate form of the outcrop on a plane surface varying with the depth of erosion of the structure. Gentle refolding would, of course, produce the same outcrop shape as a series of culminations and depressions, but no cross lineations were recorded within the structures in the present area, and the lineation pattern remains simple in contrast to that encountered in, for instance, the Mara River-Sianna area of south-western Kenya (Williams, 1964, p. 34) where refolding was demonstrated.

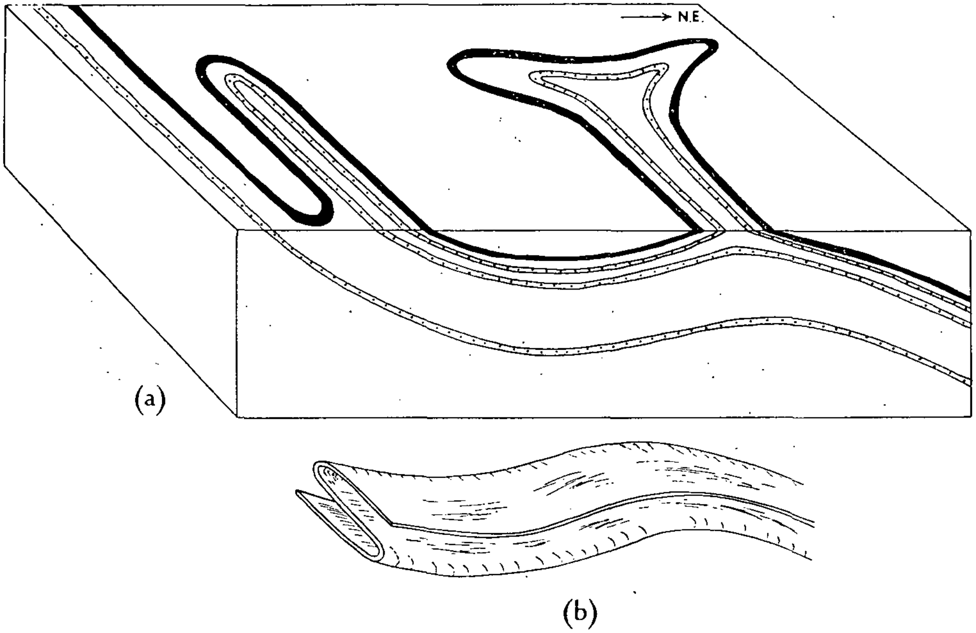


Fig. 15—Simplified block diagram illustrating the outcrop form produced by erosion of recumbent folds having a plunge depression and culmination

The best evidence of a major culmination comes from the area north-east of Leme Boti. There a closed limestone outcrop displays dips to the east, north-east and south, sharp closures of the marble band occurring at the hinge-line of the north-easterly trending recumbent anticline (the Leme Boti anticline); an indentation in the western part of the outcrop marks the trace of the culmination. The Leme Boti limestone, lying stratigraphically higher than the band mentioned above, probably also has a completely closed outcrop, though complex folding has resulted in a series of structures having axial traces trending north-north-east. These are apparently recumbent folds, a gentle plunge (or a series of minor culminations and depressions) accounting for the unusual elongation of the outcrop parallel to the direction of lineation. A steepening of the plunge has the effect of swinging the outcrops from this north-north-easterly trend to a north-westerly orientation that characterizes the Precambrian rocks elsewhere in the Amboseli area, in part of the Sultan Hamud area to the north (Searle, 1954), and throughout the Namanga-Bissel area to the west (Joubert, 1957*a*).

A major structural depression, the Narigaa depression, occurs south of Leme Boti, between the limestones forming Leme Boti Hill and those exposed at Ol Doinyo Narigaa. The outcrops at these two localities probably constitute part of the same band of marble, repetition being effected by the depression. At Ol Doinyo Narigaa the limestones trend generally north-westerly, parallel to the regional strike of Precambrian rocks in the north-central and north-eastern parts of the Amboseli area. Gentle dips and outcrop forms in the Narigaa Hills indicate recumbent folding with a plunge to the north-east. East of the present area the axial traces of folds tend to assume a more north-south orientation, probably in response to a shallower plunge near the Narigaa depression.

Culminations and depressions occur in the vicinity of concentric structures mapped in Precambrian rocks of the southern Machakos area (Baker, 1954, p. 21), and there is some disturbance in the regional north-easterly lineation pattern around similar concentric structures in the Sultan Hamud area (Searle, 1954, p. 24). North-westerly trending open folds occur in the south-western part of the Sultan Hamud area, and Matheson (1966, pp. 30-1) found cross-structures trending slightly west of north in the Kajiado area. The structural complexity encountered at Leme Boti forms part of a disturbed zone separating areas of north-easterly trending folds from a part of eastern Kenya in which the north-westerly Mozambiquian trend is dominant (*see* Saggerson *et al.*, 1960, pp. 344-5). It is perhaps significant that Kilimanjaro is situated at the southern end of this transitional zone.

2. Structural Setting of Kilimanjaro

The geological setting of Kilimanjaro was briefly described by Wilcockson (1956, pp. 219-20), who drew attention to the situation of the volcano near the intersection of two main structural zones: one is a prominent north-north-westerly trend indicated by the Lelatema and Pangani faults, and the other is represented by an east-north-easterly line of major volcanoes including Esimingor, Monduli and Meru. Prominent zones of parasitic vents fall into two main groups. One trends approximately west-north-west and includes the North Shira, Rombo and Saddle zones; the other group includes the nearly north-south Kilema and Lolgaria-Loosoito zones. The parasitic cones in the Amboseli area, between Lemomo, Kitirua and Naeratat, represent a continuation of the Lagumishera zone described by Wilcockson *et al.* (1965, p. 7); the trend seems to be approximately north-south.

Prominent north-north-westerly aligned faults (i.e. parallel to the Lalatema and Pangani faults) were mapped in the Namanga-Bissel area (Joubert, 1957*a*, p. 39), but this trend is poorly represented in the Amboseli rocks. North-easterly trending fractures in the Namanga-Bissel area are parallel to several small faults mapped between the Ngorigaishi Hills and Mesanani during the present work: changes to a more prominent north-north-easterly direction (north of Lake Amboseli and at Leme Boti) and to north-south (at Ol Doinyo Narigaa) correspond to similar swings in the Precambrian lineation pattern.

Pleistocene-Recent volcanic vents in the Simba-Kibwezi area, north-east of Amboseli, are concentrated along lines corresponding to north-west—south-east and north—south fault-trends (Saggerson, 1963, pp. 31-50), so the structural control for volcanoes in the Chyulu range is apparently very similar to that responsible for the alignment of the Kilimanjaro parasitic vents.

3. Structures in the Amboseli Lake Beds

The main structural features in lacustrine sediments that occupy the Amboseli basin are shown in Figure 13. At Sinya and Naerabala doming causes the only natural exposures in Kenya of the Sinya Beds, the basal formation of the Amboseli Lake Beds. At the south-eastern end of Lake Amboseli evidence from drilling and augering suggests the existence of a local basin in the clays, though it is not known whether the feature has a structural or erosional origin.

At Sinya small-scale structures in marls and clayey limestones were studied in some detail during an investigation of meerschaum occurrences in the Sinya Beds. No homogeneity was found in the fold patterns recorded from trench sections and open-cast workings where small flexures show trends varying from east—west to north-west—south-east, with plunges to the west, north-west and south-east at up to 25°. The dome has a long axis trending north-north-east parallel to the direction of elongation of Lake Amboseli, and parallel to faulting and fold plunges in the Precambrian rocks of the area. The majority of the trenches run parallel to the long axis of the dome so that the existence of folds plunging in that direction are less readily appreciated. There is some evidence that the minor flexures radiate outwards from the core of the dome. The orientation of the Naerabala dome is not as clearly displayed as that at Sinya but it probably trends approximately east-north-east and here the direction of elongation might have been determined by its proximity to a volcanic vent. A third dome occurs in Tanzania at the southern end of Lake Amboseli; it has a similar orientation to the one at Sinya, but the axis is offset about three-quarters of a mile to the west, so that the three features display an *en echelon* arrangement.

Folding in the Amboseli Clays is never as intense as that seen in the underlying Sinya Beds and the unconformity separating the two formations is often marked by a surface truncating structures in the earlier sediments. The basal pebble bed of the Amboseli Clays dips off the dome at between 4° and 20° (*see* Plate II (*b*)), the higher dips generally being to the north at both Sinya and Naerabala. Clay and marl beds above the unconformity are usually parallel to the pebble bed and show corresponding dips so that doming of the sediments could not have entirely preceded the deposition of the Amboseli Clays; on the other hand thinning of clay beds towards the core of the dome suggests that deposition of the Amboseli Clays was contemporaneous with doming. Rarely, dips of up to 40° were observed in beds above the unconformity. At the locality illustrated by Plate III (*a*) the pebble bed and the overlying clays are folded by the anticline on the left, whereas the pebble bed is horizontal and only the overlying clays are anticlinally folded on the right.

Fractures are common in the Sinya Beds, and have locally controlled meerschaum formation. They are less frequently seen in the overlying Amboseli Clays, though at one locality (Plate III (*b*)) small low-angle thrust-like fractures displace the Sinya Beds, and also the basal pebble bed and at least part of the clay resting on it. Some of these fractures may be related to slumping.

The deposits in Tanzania contain harder limestones than those on the Kenya side of the border, making the beds more suitable for structural studies. Sampson (1966, p. 28) concluded that the earliest folding took place along north-westerly trending axes giving rise to symmetrical folds in the Sinya Beds. This was followed by folding along north-easterly trending axes producing an anticlinal ridge which was subsequently, or contemporaneously, affected by north—south gentle folds to give domes and troughs.

VII—GEOLOGICAL HISTORY

Following a period of regional metamorphism and intense folding, during which the Precambrian rocks were thrown into a series of large recumbent structures, the Amboseli area was subjected to several cycles of erosion which effectively removed all evidence of deposition or volcanic activity before late Tertiary times. Evidence of three distinct phases of peneplanation is preserved in the Precambrian rocks. The last bevel is regarded as part of the end-Tertiary surface that matured in Middle Pliocene times. It was upon this surface, already partly dissected by a major river system, that the early Kilimanjaro lava flows poured out during late Pliocene or Lower Pleistocene times.

The first flows to reach the Amboseli area were basaltic lavas that infilled irregularities in the end-Tertiary surface; the flows spread across it and were locally banked against residual hills representing remnants of an earlier erosion surface, the sub-Miocene bevel. Ashes were ejected from the volcano periodically, but this phase of activity at Kilimanjaro was evidently one characterized by quiet extrusion of lavas. The early flows, which were probably derived from the Shira centre on Kilimanjaro, extended successively farther across a south-easterly sloping plain. Occurrences of olivine basalt resting on Precambrian rocks at Mesanani, near the north end of Lake Amboseli, may represent outliers of early flows from the mountain, but it is considered more likely that the lava at this locality was extruded locally from fissures. Some of the outlying parasitic vents were probably active at this stage in the history of Kilimanjaro.

The early basaltic lavas infilled and dammed a drainage system that had developed on the end-Tertiary surface; this represented a primitive Pangani River fed by streams draining the high ground extending from Namanga, through Kajiado to the Machakos area. The present Pangani River rises in the volcanic mountain masses of Kilimanjaro and Meru and flows southwards and south-eastwards entirely in Tanzania. Its former headstreams, partly diverted by river capture by a tributary of the Athi River and partly cut off from the main river by volcanic rocks, are now found in the infilled valleys carrying the Kajiado-Bissel and Namanga seasonal streams. Damming of the Pangani headwaters by the Lower Olivine Basalts probably diverted the streams along the margins of the newly formed lavas, resulting in their erosion and a migration of the outward edge of the outcrop back towards Kilimanjaro. Downcutting into the Precambrian rocks led to the formation of a widening trough. At the same time there was some erosion of the lava sheet between Lake Amboseli and the present position of the Namoloc Swamp, resulting in the formation of a broad valley which, however, never succeeded in breaching the lavas in the Namoloc area, though some overflow of flood-waters may have occurred through the Ibulbul Gap.

During the erosion of the Amboseli trough, eventually to a level some 400 feet below the end-Tertiary surface, continued activity at Kilimanjaro resulted in the outpouring of lavas that were more viscous than the earlier flows and never extended as far from the volcano as the Lower Olivine Basalts. These later lavas flowed from the Kibo centre and were marked by the extrusion first of thin flows of analcime-zeolite ankaratrites, biotite-perovskite-analcime melanephelinites, and nepheline-zeolite tephrites. These were immediately followed by felsparphyric basaltic lavas (the Upper Olivine Basalts) not unlike some of those forming the basal flows from the mountain. During this period there was probably further parasitic vent activity in the Amboseli area, resulting in the formation of a number of small cones of tuffs and scoriaceous lavas, among them Lemongo Vent south-east of Naiperra. Following the extrusion of the Upper Olivine Basalts, flows that reached the area from Kibo centre show a brief return to a phase of eruption of strongly alkaline lavas, rock types including biotite-zeolite-analcime melanephelinites, melilite-melanite-perovskite nephelinites, and analcime-zeolite ankaratrites; these constitute the Upper Nephelinites. There followed a period of eruption of coarsely porphyritic lavas containing rhomb-shaped felspar phenocrysts (the Rhomb Porphyry Group) succeeded by fine-grained olivine-zeolite trachytes, olivine phonolites and olivine basalts of the Lent Group. The flows became progressively more viscous and occurences of the lavas are found only in the higher parts of the foothills near the Kenya-Tanzania border. The remaining parasitic vents probably formed during this period of volcanic activity, which ranged from Middle to Upper Pleistocene. Some of the cones may have been built up along the flanks of the Amboseli trough, near the edge of the eroded Lower Olivine Basalts, and flows from the vents probably spread across part of the floor of the basin. A single small tongue of nepheline-rich phonolite, exposed on the Tanzanian border, has been correlated with Recent lavas forming the Inner Crater Group at Kibo summit of Kilimanjaro.

During the Upper Pleistocene the damming of the middle parts of the Pangani River system was completed and, in the Amboseli area, downcutting was replaced by a period of deposition in the trough. The Namanga and Kajiado-Bissel rivers carried in great quantities of sand, silt and coarse gravel, which were deposited in the western and north-western parts of the basin. At the same time northward drainage from the newly formed Kilimanjaro mass resulted in the introduction of quantities of fine ash and volcanic debris into the lake. Showers of ash probably fell across its surface during periods of activity associated with the formation of the late parasitic vents on the flanks of the mountain.

Lacustrine sedimentation in the Amboseli basin commenced with the deposition of the Sinya Beds, the lower parts of which were not pierced during drilling in the area so that the nature of the basal sediments is unknown. The formation has a proved thickness of more than 60 feet at the southern and south-eastern end of Lake Amboseli where the sediments are banked against lavas. Farther off-shore the deposits probably accumulated to a maximum thickness of over 100 feet. In the parts of the succession investigated the Sinya Beds consist of green, brown, grey and white clays overlain by a bed of dolomitic marl and clayey limestone. The calcareous deposits, which vary in thickness from 14 to 35 feet, are in turn overlain by green, grey and brown clays (the latter often silty) and a thin upper bed of white and pale grey calcareous clays. The alternation of sepiolitic clays and calcareous deposits possibly represents a change in the composition of pyroclastic material.

Following the deposition of the Sinya Beds a period of temporary aridity caused a regression or complete desiccation of the lake. Minor earth movement produced small fold structures in the sediments so that later deposits, which accumulated during reflooding of the eroded surface, rest with a marked unconformity on the Sinya Beds. The overlying Amboseli Clays probably attain a maximum thickness of some 200 feet immediately east of the present lake bed. The formation includes green, brown and grey sepiolitic clays with white calcareous clays near the base, which is marked locally by a thin pebble bed. At Sinya and Naerabala deposition of basal beds of the Amboseli Clays was accompanied by a disturbance in the floor of the basin, causing doming of earlier sediments and resulting in the Sinya Beds now being exposed at the surface. Towards the margins of the lake, silty clays give way to coarse fluviatile deposits carried in by the Namanga and Bissel rivers.

Further desiccation of the lake was followed by deposition of the Ol Tukai Beds, which at the type locality are over 80 feet thick and apparently infill a local basin eroded in the Amboseli Clays by torrential floods from the northern flanks of Kilimanjaro. The lacustrine facies of the Ol Tukai Beds includes over 45 feet of diatomaceous clays overlain by grey, green and brown clays and pale grey calcareous silts. Coarse fluviatile deposits which accumulated at the same time as the Ol Tukai Beds are found in the western and north-western parts of the area, where they complete the infilling of the river valleys draining into the lake; conglomerates and pebble sheets, up to 85 feet thick, overlie lavas of the Lower Olivine Basalts between Kitenden and the Loginya and Namoloc swamps. These fluviatile sediments contain an assortment of lava pebbles and were deposited by flood waters entering the basin from the northern flanks of Kilimanjaro.

Throughout Pleistocene and Recent times reddish-brown, sandy soils, black cotton soils and reddish alluvial soils formed across exposed Precambrian rocks in the northern parts of the area, the alluvial soils occupying seasonal watercourses and depressions that developed on the plain. At the same time reddish-brown dusty soils were formed by the decomposition of volcanic rocks in the southern parts of the area. Immediately preceding the final desiccation of Lake Amboseli in Recent times dark, clayey alluvial soils were deposited by the Namanga River during periods of flood. These soils are locally overlain by wind-blown clayey silts and sands that accumulated along the western shore-line of the lake. Dunes some 30 feet high rest on the Amboseli Clays at the edge of the lake and extend westwards to form a thinner cover over fluviatile deposits. Minor dune formation occurred at the southern end of the lake, isolating a small sheet of water east of Sinya.

VIII—ECONOMIC GEOLOGY

The chief minerals of economic importance in the Amboseli area are associated with the lake beds. Meerschaum has been mined for some years and, more recently, interest has been shown in the gaylussite deposits of Lake Amboseli. Preliminary investigations of the clays, however, have proved disappointing. No encouraging signs of mineralization were seen during reconnaissance traverses across the poorly exposed Precambrian rocks. Similarly, mapping of the volcanics failed to reveal rocks or minerals which are likely to be of economic value. Pyroclastic material is greatly subordinate to lavas; welded tuffs, which are used extensively as building stones in many other parts of Kenya, were not encountered. Surface water supplies and ground water conditions in the Amboseli area were not investigated in detail during this survey because a great deal of information was already available.

1. Meerschaum

The only known economic deposits of meerschaum in the Sinya district are mined where the basal formation of the Amboseli Lake Beds outcrops at the surface as a result of doming in the sediments. Sinya Mine, owned and operated by the Tanganyika Meerschaum Corporation Ltd. of Arusha, lies astride the Kenya-Tanzania boundary at the southern end of Lake Amboseli. Shallow open-cast mining is distributed between the two countries and the meerschaum, after preliminary cleaning and trimming, is transported by road to a factory in Arusha, where it is used in the manufacture of a variety of pipes, pipe-bowls and insert bowls for briar pipes. A process has been perfected whereby fragmentary meerschaum can be converted into reconstituted blocks suitable for pipe manufacture. Other commercial uses are continually under investigation. The mine is 95 miles by road from Arusha, 130 miles from Nairobi, and is situated some 26 miles east of Namanga, a small trading centre on the trunk road linking Nairobi with Tanzania.

Meerschaum is sporadically distributed throughout a folded and fractured bed of lacustrine marl and clayey limestone forming part of the Sinya Beds, outcrops of which give rise to two low topographic features, one in Kenya and the other in Tanzania. The Kenya dome, with maximum topographic relief of some ten feet, has a long axis trending approximately north-north-east, and the feature is about 2,500 feet in length and 700 feet wide. It is bounded to the east and west by dry lake beds and to the north by a line of low dunes separating Sinya from Lake Amboseli. To the south the feature flattens gradually into a plain extending across the inter-territorial boundary and here any continuation of the marl outcrops is obscured by a thin cover of clays, silts and superficial limestone. In Tanzania the outcrop of the Sinya Beds is offset some 4,200 feet to the west, the long axis of a second dome there trending north-east. A study of air photographs suggests that the outcrops of marl and limestone in the core of the Tanzania dome cover an area at least three times the size of that in Kenya. Furthermore there is the possibility of an even more widespread development of the Sinya Beds at workable depth southwards and south-westwards. D. N. Sampson (1966) has given a very detailed account of the Tanzania part of the mine area.

Meerschaum is found principally within the marl and limestone in the form of pockets, lenses and lenticular seams having a completely random orientation and distribution. Individual occurrences vary in size from half-inch thick seams to pockets, the largest of which was said to measure some 35 feet by 12 feet horizontally and 10 feet in depth.

This pocket produced about 300 bags of meerschaum (i.e., some 19,500 lb.) and was situated in clayey limestones in Tanzania. A single block of meerschaum recovered in 1961 measured some 54 in. × 37 in. × 15 in. Where bedding in the host rock is clearly defined (the marl in particular commonly displays a rubbly, broken appearance so that structural features are obscure) there appears to be some preferential development of meerschaum in the cores of small folds, along their limbs and generally in zones of greatest contortion. Small fracture planes are not uncommon and may locally have controlled the meerschaum formation; seams of meerschaum that occupy such fractures occasionally show lineated surfaces that suggest some movement after the formation of the mineral. Mining to date has proved no connexion between lithological variations (i. e. from marl to limestone) within the host sediments and the quality or quantity of meerschaum recovered. Though meerschaum has occasionally been found in less calcareous clays, it is believed that the mineral is largely confined to a single bed of marl and limestone. The clay content of this bed shows a decrease when traced southwards into Tanzania, and although the facies change seems to be unimportant so far as the meerschaum content is concerned it naturally affects the ease of excavation. Whereas the marl is readily excavated, removal of the harder limestone frequently requires initial blasting. A cursory examination of the Tanzania workings suggests that the limestone might have a lenticular form within the marl bed.

Early hand digging of the deposits has now been abandoned in favour of mechanical excavation, the machines in use being capable of working to a depth of 17 feet below track level using a boom and bucket. Working below this level is accomplished by first digging out a large pit with a ramp and subsequently excavating in the floor. The depth of mining at Sinya is largely controlled by a water table, which in years of normal rainfall is encountered some 12 feet below the surface, so that the maximum depth of working is approximately 27 feet with the equipment now in use. The second level of excavation is carried out beneath the water.

Once a pocket of meerschaum has been located during excavation the mineral is removed in blocks by hand digging to prevent unnecessary breakage. In addition, hand picking from each bucket of spoil removes any blocks and larger fragments. The spoil is then transported to a dump situated beyond the limit of immediate mining operations. These accumulations of spoil contain vast reserves of fragmentary meerschaum available for use in a recently introduced process leading to the production of reconstituted blocks suitable for pipe manufacture. It will be appreciated that immediate back-filling of workings is undesirable until a plant has been designed to remove all fragmentary meerschaum from the spoil and until mining to the maximum possible depth has been carried out.

Three grades of meerschaum are recognized at the mine:—

No. 1—Blocks suitable for pipe manufacture (i.e. larger than 4 × 2 × 2 inches).

Inserts—Blocks too small for the manufacture of a pipe bowl and stem, but suitable for the production of insert bowls for briar pipes and separate bowls of lower grade pipes (larger than 2 × 1½ × 1½ inches).

Smalls—Material suitable for the manufacture of reconstituted blocks.

In addition to workable meerschaum, two other varieties are found during mining. "Shrinker", which is identical to meerschaum in the wet state when recovered, develops numerous conchoidal fractures during drying and is unsuitable for pipe manufacture. "Baruti", though somewhat similar to meerschaum, is denser and harder than the pure mineral. Sampson (1966, p. 29) gives the following chemical analyses of these varieties:—

	1	2	3	4
SiO_2	52·51	52·39	53·28	54·82
TiO_2	0·13	trace	trace	trace
Al_2O_3	0·87	1·49	0·53	0·19
Fe_2O_3	0·45		—	—
FeO	0·40	1·08	0·38	0·12
MnO	0·01	—	—	—
MgO	22·49	22·18	24·29	26·22
CaO	0·81	0·17	0·10	0·88
Na_2O..	0·65	0·56	0·60	0·78
K_2O	0·65	1·02	0·35	0·44
H_2O-	12·01	10·70	11·38	8·79
H_2O+	9·48	8·77	8·90	8·08
P_2O	0·04	0·05	0·04	0·15
TOTAL ..	100·50	99·41	99·85	100·47

1. Meerschaum (X/7696/2), Sinya Mine. Collected by T. C. James. Anal. G. Luena.
2. Meerschaum ("Block"), Sinya Mine. Collected by D. N. Sampson.
3. Meerschaum ("Shrinker"), Sinya Mine. Collected by D. N. Sampson.
4. Meerschaum ("Baruti"), Sinya Mine. Collected by D. N. Sampson.

Pipe Manufacture

Most of the meerschaum recovered at Sinya is used in the production of a wide range of smoking pipes. These were originally manufactured at a factory in Nairobi, but in 1961 the Tanganyika Meerschaum Corporation Ltd. transferred its head office and factory to specially designed premises in Arusha, Tanzania. The new pipe factory is said to be one of the most modern of its kind in the world and is the result of intensive experiments aimed at perfecting processes capable of bulk production of high-quality meerschaum pipes.

A brief history of the corporation, including an account of some of the early difficulties encountered in pipe manufacture and methods by which they have been overcome, was given by its managing director, Mr. A. G. Clough (1958). The article is accompanied by plates illustrating stages in manufacture. Dry slabs of meerschaum are first cut into blocks of suitable sizes, skill and experience being required to exclude flaws in the mineral without undue waste. Bowl and stem are cut by machines and the latter is threaded for subsequent insertion of the mouthpiece. The rough article is then trimmed by hand, sandpapered and waxed, and finally calcined to produce a finished pipe of exceptional durability without destroying the smoking quality associated with traditional fragile meerschaum pipes.

A process has recently been perfected whereby a powder produced from meerschaum fragments can be converted into reconstituted blocks suitable for pipe manufacture. The process adopted is said to differ from that used overseas for a similar purpose, and it is claimed that the local product (to which the trade name *Arcon* has been applied) is superior to Austrian and American reconstituted material in being completely stable in water and in having physical properties (density and porosity) closer to those of natural meerschaum.

Other Uses

Although the demand for Amboseli meerschaum pipes on a worldwide market exceeds the supply of raw material from the mine, other uses for the mineral are constantly being investigated. It is unlikely that pipe manufacture will be replaced as the sole use for first-grade block meerschaum but vast reserves of fragmental material are available. The surplus remaining after allowing a portion for reconstitution processes might find a ready market locally or overseas. Meerschaum has already been used in limited quantities in the cosmetics industry as a constituent of face packs, and in the preparation of a powder grease-spot remover. Its use as a gas absorbent, particularly in acetylene cylinders, has been entertained and uses as a filtering medium have been suggested.

Reserves of Meerschaum

Owing to the sporadic and random distribution of the mineral, meerschaum reserves in the Amboseli area cannot be calculated directly from observations at Sinya, though a clear understanding of the stratigraphy and structure is essential to any estimate.

Sampson (*op. cit.* pp. B 32-33) quoted the figure of 8-12 ounces of meerschaum recovered per ton of host rock removed up to the time of his survey, and gave the figure of over one million tons of host rock within the scope of the present equipment. He pointed out that since much of the earlier working had been selective the average future yield might be somewhat lower.

2. Gaylussite

(By F. J. Matheson, B.Sc., Ph.D., F.G.S. Geologist)

Gaylussite is a hydrated double carbonate of sodium and calcium with the composition $Na_2CO_3.CaCO_3.5H_2O$. It is colourless, crystallizing in the monoclinic system with a perfect prismatic cleavage. The crystals are commonly flattened wedge shapes but sometimes additional material has grown on the side of a crystal in a herring-bone pattern. The hardness is between two and three on Mohs' scale and the specific gravity 1.93-1.95.

The surface of Lake Amboseli is covered by one or two feet of fine reddish or yellowish silt which is probably partly waterlain and partly wind-borne in origin. When dry it develops small polygonal sun cracks. Immediately below it there are a few inches of black clay, which sometimes contains calcium carbonate, overlying a generally black clay which contains gaylussite. The host clay is in places dark green, especially towards the west where less abundant gaylussite crystals are found in a grey clay below the black or green clays. The gaylussite-bearing clay is underlain by a pale green clay along the southern, eastern and western shores of the lake. To the north-east the host clay continues in the lake but the gaylussite dies out. Along the western and southern sides of the lake the top one or two feet of the gaylussite-bearing clay is richer in large crystals than the lower part; these large crystals however, frequently enclose a considerable proportion of clay. In some holes a barren band three to six inches thick occurs near the middle of the gaylussite-bearing clay. When exposed to the air the gaylussite weathers to form a thin film of calcium carbonate covering the crystals and a layer of carbonate coats the surface of the clay. The surface of the south-western part of the lake is obscured by alluvial silt brought down by flood waters from the Namanga River.

It was originally intended to sample the entire deposit at 500-yard intervals with provision for intermediate holes at 250-yard intervals, and odd numbers were used for the pits at 500-yard intervals, even numbers being left for the intermediate points. Time was limited, so the greater part of the deposit was sampled at 1,000 yard intervals with pits at 500 yards near the margins in order to delimit its extent more accurately. The extent of the deposit and the location of the pits is shown on Figure 16. At each completed pit a representative sample was taken throughout the thickness of gaylussite-bearing clay, including any richer or barren layers. The thicknesses of overburden and gaylussite-bearing clay were measured and are recorded in Table 5. Five kilograms of each sample were fed into a centrifugal separating machine in a continuous flow of water to free the gaylussite crystals from the enclosing clay. The gaylussite was collected on a 30-mesh screen and its final dry weight converted into the percentages in Table 5.

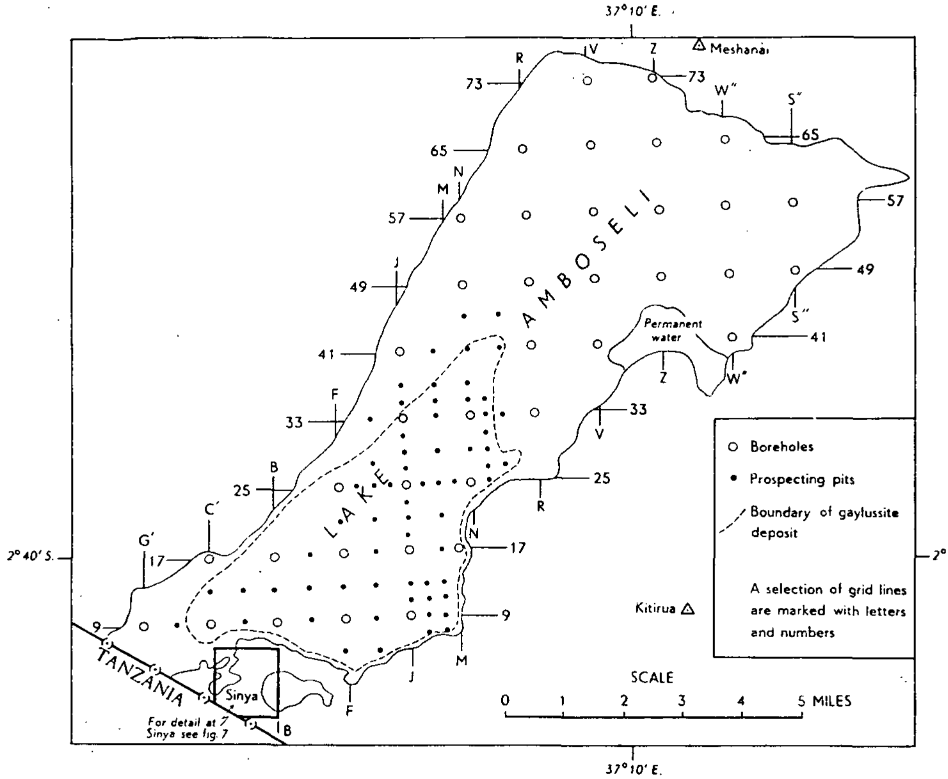


Fig. 16—Sketch map showing prospecting pits and boreholes used in investigations of gaylussite and clays in the Amboseli area

TABLE 5

No. of pit	Overburden (feet)	Gaylussite-bearing clay (feet)	Area assigned (sq. yds.)	Percentage of gaylussite	Reserves (long tons)
C'9	0–5¼	5¼–10¼	1,070,000	20	617,000
C'13	0–6¾	6¾– 9	650,000	20	168,700
A'9	0–2½	2½– 9½	750,000	19	575,300
A'13	0–5½	5½– 9½	1,000,000	22	507,400
A'17	0–4	4 – 5½	600,000	20	103,800
B 9	0–1½	1½– 6	900,000	20	467,100
B13	0–3	3 – 9½	1,000,000	22	888,000
B17	0–3½	3½– 5½	1,000,000	20	230,000
B21	0–4¾	4¾– 6¾	600,000	14	96,870
D 5	0–2	2 – 4	600,000	10	69,200
D 9	0–1¼	1¼– 3½	1,000,000	22	214,100
D13	0–1¼	1¼– 8¼	1,000,000	28	807,400
D17	0–1½	1½– 7¾	1,000,000	24	864,800
D 2	0–2½	2½– 6	1,000,000	23	464,100
		D25	unknown due to	water	

TABLE 5—(*Contd.*)

No. of pit	Overburden (feet)	Gaylussite-bearing clay (feet)	Area assigned (sq. yds.)	Percentage of gaylussite	Reserves (long tons)
F 5	0–1¼	1¼–10¼	900,000	11	513,900
F 9	0–1¼	1¼–10	1,000,000	15	756,800
F13	0–1¼	1¼– 7¼	1,000,000	19	684,700
F17	0–1	1 – 4¾	1,000,000	10	432,600
F21	0–1¾	1¾– 4½	1,000,000	10	158,600
F25	0–1½	1½– 5½	562,500	20	259,400
F27	0–1½	1½– 5¼	312,500	19	128,400
G25	0–1¾	1¾– 4¾	468,750	16	129,700
H 5	0–1¾	1¾– 4	750,000	12	116,800
H 9	0–1½	1½– 8	1,000,000	12	449,900
H13	0–1¼	1¼– 9¼	1,000,000	13	599,600
H17	0–1	1 – 5	1,000,000	10	230,600
H21	0–1¼	1¼– 4	1,000,000	10	158,600
H25	0–1	1 – 3¼	500,000	10	79,290
H28	0–1	1 – 2¼	700,000	12	121,100
I25	0–1	1 – 3¾	437,500	13	81,980
J 9	0–1½	1½– 7¾	562,500	13	269,600
J11	0–1	1 – 7	375,000	13	189,700
J13	0–1¾	1¾– 7½	562,500	14	261,100
J17	0–1½	1½– 5¼	750,000	10	158,500
J19	0–1¼	1¼– 4½	500,000	10	93,670
J21	0–1¼	1¼– 3½	500,000	10	64,860
J23	0–1½	1½– 2¾	437,500	11	41,630
J25	0–1	1 – 3	250,000	12	34,600
J27	0–1½	1¼– 3¾	437,500	8	50,460
J29	0–1½	1½– 3¾	500,000	6	38,920
J31	0–1¼	1¼– 3	500,000	12	95,150
J33	0–1½	1½– 4	400,000	12	69,200
K 7	0–1½	1½– 6¾	325,000	14	137,700
K 9	0–1½	1½– 7½	250,000	7	60,540
K11	0–1½	1½– 7¼	250,000	11	91,160
K13	0–1½	1½– 6½	375,000	13	140,600
K25	0–1¼	1½– 4	437,500	7	30,900
L 7	0–1¼	1½– 4½	152,500	10	28,560
L 9	0–1½	1½– 6½	350,000	10	100,900
L11	0–2	2 – 6¼	325,000	10	80,280
L13	0–1½	1½– 6¼	375,000	12	123,200
L17	0–1½	1½– 7	750,000	12	285,400
L21	0–1¾	1¾– 5	1,062,500	14	278,600
L25	0–1¾	1¾– 2¾	500,000	9	29,940
L29	0–1¾	1¾– 4¼	1,000,000	5	72,070
L33	0–2¼	1¼– 5	750,000	5	59,460
L35	0–1½	1½– 3½	375,000	3	12,620
L37	0–1¾	1¾– 3½	281,250	1	2,838
M13	0–1½	1½– 6½	175,000	9	45,400
M15	0–1½	1½– 6¼	220,000	14	84,350
M17	0–1¼	1¼– 6¼	325,000	13	122,300
M25 ..	0–1½	1½– 5	500,000	15	144,900

TABLE 5—(*Contd.*)

No. of pit	Overburden (feet)	Gaylussite-bearing clay (feet)	Area assigned (sq. yds.)	Percentage of gaylussite	Reserves (long tons)
N25	0–1	1 – 4½	468,750	7	63,370
N28	0–1¾	1¾– 3½	750,000	9	68,110
N33	0–2	2 – 4¼	562,600	11	80,280
N35	0–1½	1½– 4	375,000	12	64,860
N37	0–1½	1½– 3¼	318,750	1	7,251
N41	0–1½	1½– 3¼	500,000	4	20,180
O25	0–2¼	2¼– 4½	158,750	10	12,990
O27	0–2	2– 4¼	250,000	15	48,650
O29	0–2	2 – 4¾	285,000	13	58,730
O31	0–1½	1½– 4½	250,000	5	21,620
O33	0–1¾	1¾– 4	250,000	5	16,215
O35	0–2	2 – 4	450,000	5	25,950
P27	0–2	2 – 3½	400,000	8	27,680
P41	0–1½	1½– 3½	600,000	4	24,220
TOTAL ..			45,373,750		14,811,654

To ascertain whether gaylussite particles of —30-mesh were lost some duplicate samples were passed through a 60-mesh screen and it was found that 1.4 per cent extra gaylussite was collected from a sample which had yielded 14 per cent from the 30-mesh screen.

Each sample pit was regarded as representative of the area in its vicinity both for depth of ore and percentage of gaylussite. For pits at 1,000-yard intervals the area taken is 1,000,000 square yards, and for one at 500-yard intervals 250,000 square yards. Where a pit is separated from its neighbours by 1,000 yards in one direction but by 500 yards in another the most appropriate rectangular area has been assigned to the pit. Near the margins of the deposit the area assigned to the most appropriate pit was calculated.

The total depth in yards of gaylussite-bearing clay in each pit was used since sampling was representative and the percentage of gaylussite applies to the total thickness. The density of representative samples of gaylussite and clay was measured when wet because the samples passed through the centrifuge were not dried after collection. The average density figure used for the calculation was 2.3.

The original percentages obtained in the field were used for the calculation of reserves, but if —30-mesh particles can be collected during working the amount of gaylussite recoverable could be 10 per cent higher than the figure given.

Calculation was carried out for each pit as follows:—

$$\frac{\text{Area assigned} \times \text{thickness} \times \text{percentage} \times 1.73}{100} = \text{Reserves (Long tons)}$$

The figure 1.73 is the conversion factor for expressing one cubic yard of ore in long tons, assuming the density to be 2.3.

Over the whole deposit of approximately 15 square miles a figure of 14,811,654 tons of gaylussite were proved and this could be brought up to approximately 15 million tons if an area of 550,000 square yards assigned to pit D 25 (not sampled due to flooding) is similar in gaylussite content to the surrounding pits. Allowing for the recovery of 30-mesh particles during working of the ore this figure could be increased to 16,500,000 tons. In several pits the base of the gaylussite-bearing clay was not seen owing to the influx of water or the depth proving too great for hand digging.

To indicate the tonnages of gaylussite available in areas of different richness the following table was constructed: —

Percentage	*Area assigned (Square yards)*	*Reserves (Tons)*
1–5	5,175,000	262,424
6–10	11,750,000	2,079,970
11–15	15,130,000	5,358,660
16–20	7,313,750	3,364,800
+20	6,000,000	3,745,800
TOTAL	45,373,750	14,811,654

Percentages of five and under occur only in the north-eastern part of the deposit where the thickness of ore is small. It is of interest that in the range between six and ten per cent the great majority of the reserves shown above are accounted for by ore containing ten per cent gaylussite, for which the figures are 1,668,600 tons in an area of 7,831,250 square yards.

Over the lake surface proper, the overburden averages 1 ft. 6 in. in thickness but ranges down to one foot and up to two feet in places. The alluvium in the south-west increases the total overburden to about five feet on average but is greater in the north-west and less in the south-east near the lake. The alluvium covers an area of 6,670,000 square yards and conceals an estimated 2,975,820 tons of gaylussite.

3. Clays

It had been suggested that many of the clays at Amboseli were bentonites, i.e. sodium montmorillonite. The term bentonite was originally applied to clays of volcanic origin from eastern Wyoming and western South Dakota, the prominent feature of the material being its ability to swell to many times its original volume when mixed with water. The name was later extended to cover a variety of non-swelling clays and is now generally accepted as the rock name for material composed essentially of clay minerals of the montmorillonoid group (usually montmorillonite, less commonly beidellite).

Mineralogical and x-ray diffraction tests made on a variety of clay specimens from Amboseli by Mineral Resources Division of the Institute of Geological Sciences, London, showed the main clay minerals present in all specimens submitted to be sepiolite and illite, and in only a few samples was a montmorillonoid detected. Other common constituents identified were dolomite and calcite. The occurrence of minor amounts of halite points to a saline environment, and efflorescences developed on dried clay specimens proved to be trona.

Partial chemical analyses of Amboseli clays, as compared with Wyoming bentonite, are as follows: —

	per cent 1	2	3	4
SiO_2	45·70	42·02	41·32	57·98
CaO	9·70	5·62	6·25	1·92
MgO	5·52	10·12	10·57	3·24
Na_2O+K_2O	3·96	6·84	6·42	1·35

Anal. 1–3, W. P. Horne, Mines and Geological Dept., Nairobi.
4. A. G. Van Eman.

1. Amboseli Clay, S.W. of lake
2. Amboseli Clay, N.W. of lake
3. Amboseli Clay, centre of lake
4. Bentonite, Medicine Bow, Wyoming

Swelling tests carried out by F. J. Matheson on 72 specimens from pits and boreholes sunk during the gaylussite investigation already described, and other excavations around Lake Amboseli, gave swelling indices varying from 15 to 93, the overall average being 32. Tests on samples of Wyoming and North African bentonites, carried out at the same time, gave swelling indices of 153 and 135 respectively. A full account of Matheson's work is contained in an unpublished report (R15/07/29A) of the Mines and Geological Department, Nairobi.

The Amboseli clays therefore prove to be sepiolites contaminated in varying degrees by carbonate minerals and other impurities. Although not in such demand as bentonite, pure sepiolite has a number of commercial uses, but the fine carbonate minerals in the Amboseli clays would be almost impossible to separate because of the poor filtration characteristics of the clay in suspension.

4. Minerals in Precambrian Rocks

Few rocks or minerals of possible economic value were encountered in the Precambrian rocks of the area. Marble occurs in the north-western and south-eastern parts of the Amboseli area but the limestones are generally dolomitic. More favourably situated magnesia-poor crystalline limestones occur in the neighbouring Sultan Hamud area (Searle, 1954, pp. 27-31). Marble is quarried at Turoka in the Kajiado area for use as monumental stone and lime is manufactured by calcining limestones from the same area. Being less accessible, the Amboseli rocks are less likely to be considered for similar purposes.

Small occurrences of blue *spinel* have been reported from the southern parts of the Ngorigaishi Hills, though the mineral was not encountered during the present survey. Numerous grains of *corundum* were found in a specimen of biotite-garnet gneiss collected three miles east of Meshanai Beacon. Exposures at this locality are poor and the extent of the gneiss outcrop and its overall corundum content are unknown.

5. Water Supplies

The central and east-central parts of the Amboseli area are well provided with permanent water in the form of swamps. Engong Narok Swamp receives visible recharge from several small springs at its southern end but the Ol Tukai and Loginya swamps apparently have sub-surface recharge. A permanent sheet of water at Namoloc is fed by the Legumi stream that rises nearby at a series of clear springs issuing from basalt. A mile and a half to the east springs feed the Sinet Stream, which flows eastwards into the neighbouring Loitokitok area. Several permanent streams enter the Amboseli area from the flanks of Mt. Kilimanjaro, but these invariably dry up within a few miles of the Tanzania border.

Groundwater conditions in the Amboseli area have been studied in some detail by officers of the Ministry of Works Hydraulics Branch. Details of the investigations are given in a number of unpublished reports by Campbell (1957*a*, 1957*b*, 1957*c* and 1958). Chemical analyses of ground and surface waters in the area are presented in Table 6 and the localities from which the analysed samples were collected are shown in Fig. 17.

WATER ANALYSES—AMBOSELI AREA

(*Parts per million*)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Alkalinity (as $CaCO_3$)																		
Carbonate ..	40,000	100·0	1,600	29,200	Nil	38·0	Nil	Nil	324·0	52·0	Nil	6,000	328·0	10·0	36·0	Nil	Nil	Nil
Bicarbonate ..	16,000	2,300	3,640	6,800	624·0	1,609	1,214	875·0	594·0	281·0	456·0	6,400	1,095	348·0	493·0	203·0	202·0	131·0
Ammonia																		
Saline	0·6	1·4	3·84	0·48	Nil	0·09	0·36	0·30	0·06	trace	0·12	trace	0·112	trace	—	trace	trace	trace
Albuminoid ..	0·8	0·13	1·12	1·14	trace	—	—	—	0·96	0·03	0·03	0·288	0·096	0·336	—	trace	trace	trace
Oxygen absorbed (4 hr. at 80°F) ..	—	—	—	—	—	0·43	4·74	2·90	2·56	0·96	0·90	13·4	8·4	4·2	—	—	—	—
Chlorides (as Ct) ..	19·0	3·45	14·1	34·5	13,800	664·0	365·0	469·0	105·0	27·0	53·0	8,100	335·0	101·0	155·0	6·0	5·0	3·0
Sulphates (as SO_4)..	22,700	2,710	5,780	18,220	1,407	765·0	399·0	1,057	trace	55·0	5·0	1,036	8·0	25·0	17·0	trace	trace	trace
Nitrites (as NO_2) ..	2,050	272·0	860·0	1,993	present	present	present	present	present	present	present	Nil	Nil	present	—	Nil	Nil	Nil
Nitrates (as NO_3) ..	Nil	Nil	Nil	Nil	present	present	present	present	present	present	Nil	Nil	Nil	Nil	—	—	—	Nil
Calcium (as Ca) ..	Nil	Nil	Nil	Nil	1,820	—	—	—	—	—	—	—	—	—	2	Nil	Nil	—
Magnesium (as Mg.)	—	—	—	—	1,665	—	—	—	—	—	—	—	—	—	1	—	—	—
Iron (as Fe) ..	trace	trace	trace	trace	1·5	0·1	0·1	0·1	6·4	3·6	0·40	1·6	1·6	0·4	—	—	—	0.4
Silica (as SiO_2) ..	23·0	3·0	3·0	2·5	25·0	16·0	36·0	36·0	16·0	30·0	40·0	2·0	2·0	48·0	—	0·4	0·7	25·0
Fluorides (as F) ..	140·0	6·7	11·8	102·0	1·3	3·8	1·3	3·4	3·1	3·0	1·1	31·0	7·1	1·6	2·1	1·2	1·0	0·2
Total hardness ..	10·0	30·0	10·0	10·0	11,360	10·0	40·0	50·0	10·0	10·0	20·0	20·0	10·0	30·0	—	36·0	30·0	—
Total solids ..	118,877	7,470	14,060	78,690	25,300	7,635	2,620	3,400	2,175	1,110	745·0	27,720	2,270	670·0	810·0	305·0	270·0	200·0
pH	7·9	8·1	7·9	8·1	6·5	8·1	7·9	7·7	8·3	8·1	8·1	8·3	8·3	8·1	9·0	7·9	7·9	6·7

1. Pivot borehole, N.W. part of Lake Amboseli.
2. Compass borehole, N.W. of Lake Amboseli.
3. Safeseat borehole, N.W. of Lake Amboseli.
4. Shore borehole, N.W. part of Lake Amboseli.
5. Borehole C2804, N.W. of Lake Amboseli.
6. Auger site No. 14, N.E. part of Lake Amboseli.
7. Auger site No. 10, N.E. part of Lake Amboseli.
8. Auger site No. 11, N.E. part of Lake Amboseli.
9. Auger site No. 6, Simek delta.
10. Auger site No. 7, Simek delta.
11. Auger site No. 9, Simek delta.
12. Auger site No. 1, Nenkereri.
13. Auger site No. 4, Nenkereri.
14. Auger site No. 5, Nenkereri.
15. Sinya (Fawley, 1955, p.3).
16. Naiperra borehole C2794 (sample 1).
17. Naiperra borehole C2794 (sample 2).
18. Legumi River, Namoloc.

NOTE.—All analyses, except No. 15, from Campbell (1957*b* and 1958).

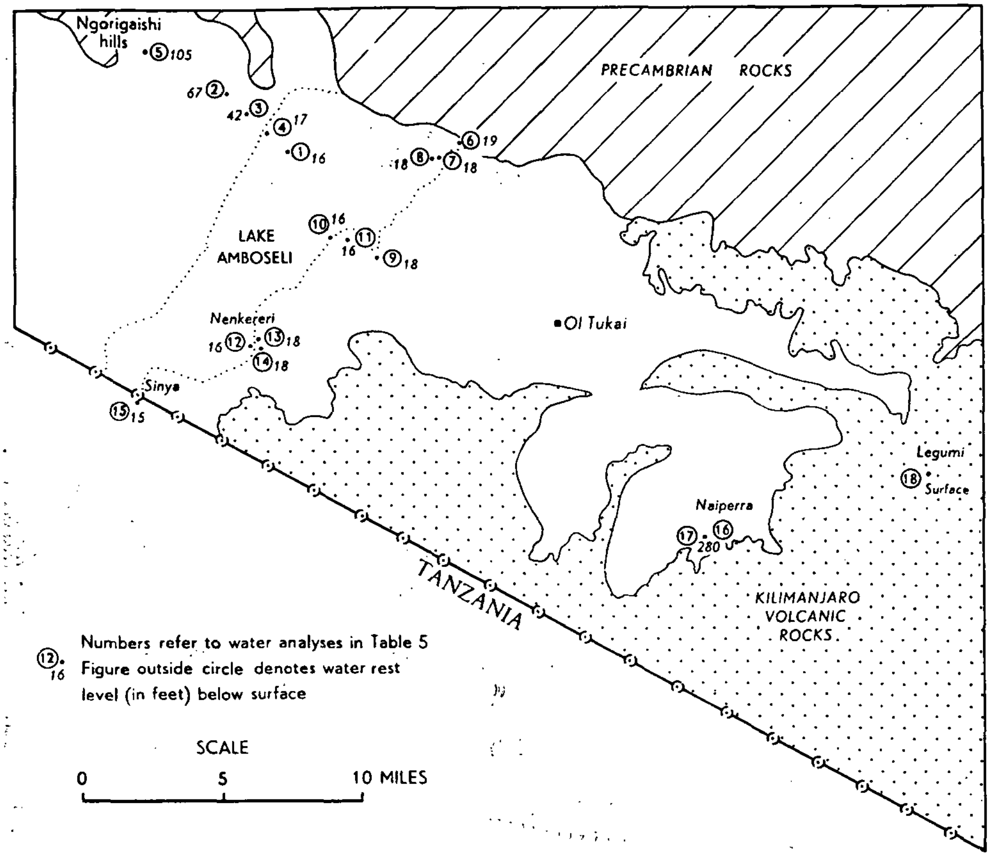


Fig. 17—Localities of analysed water samples

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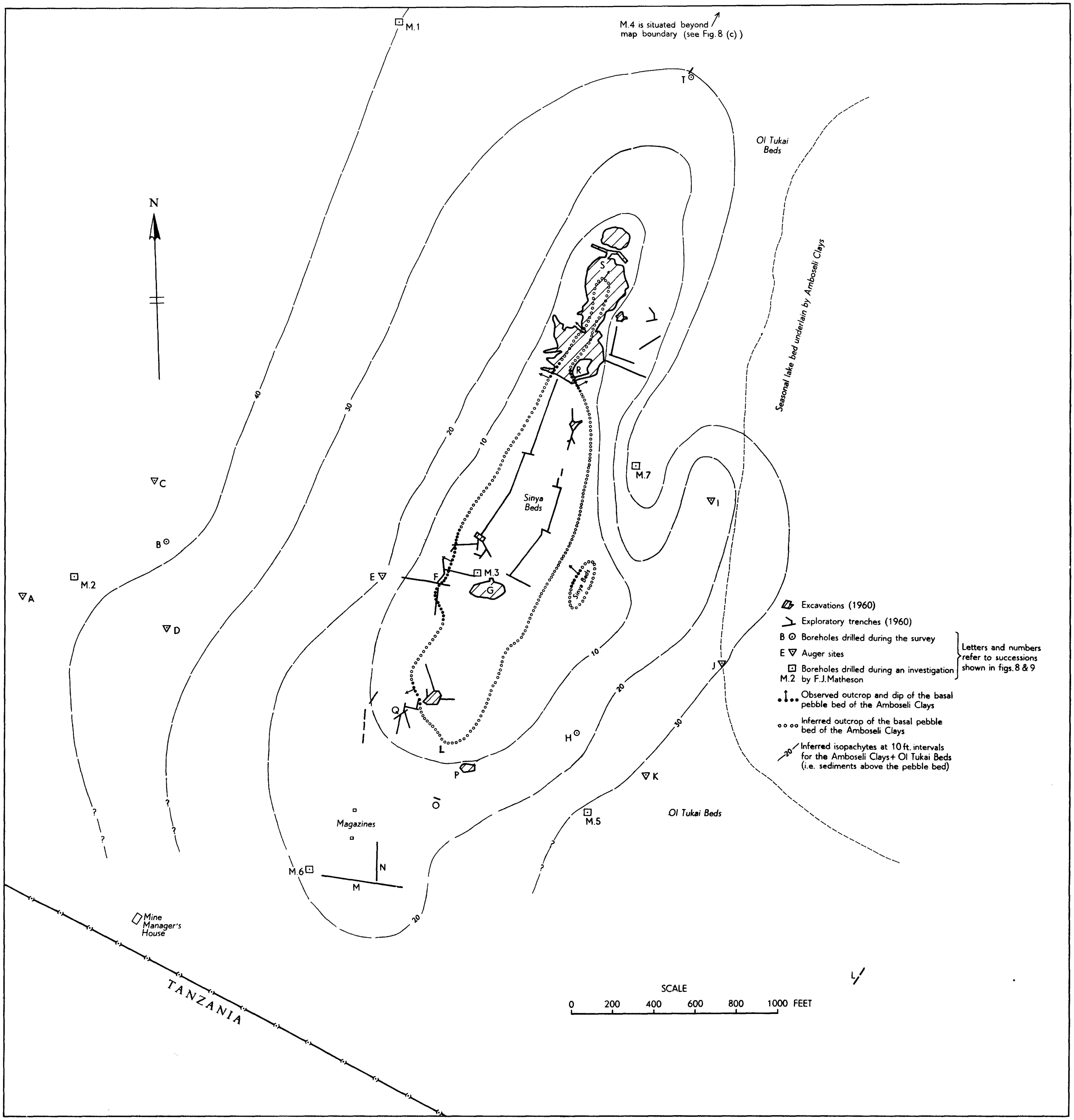


Fig. 7 Map of the Sinya dome Amboseli area.

15818 c

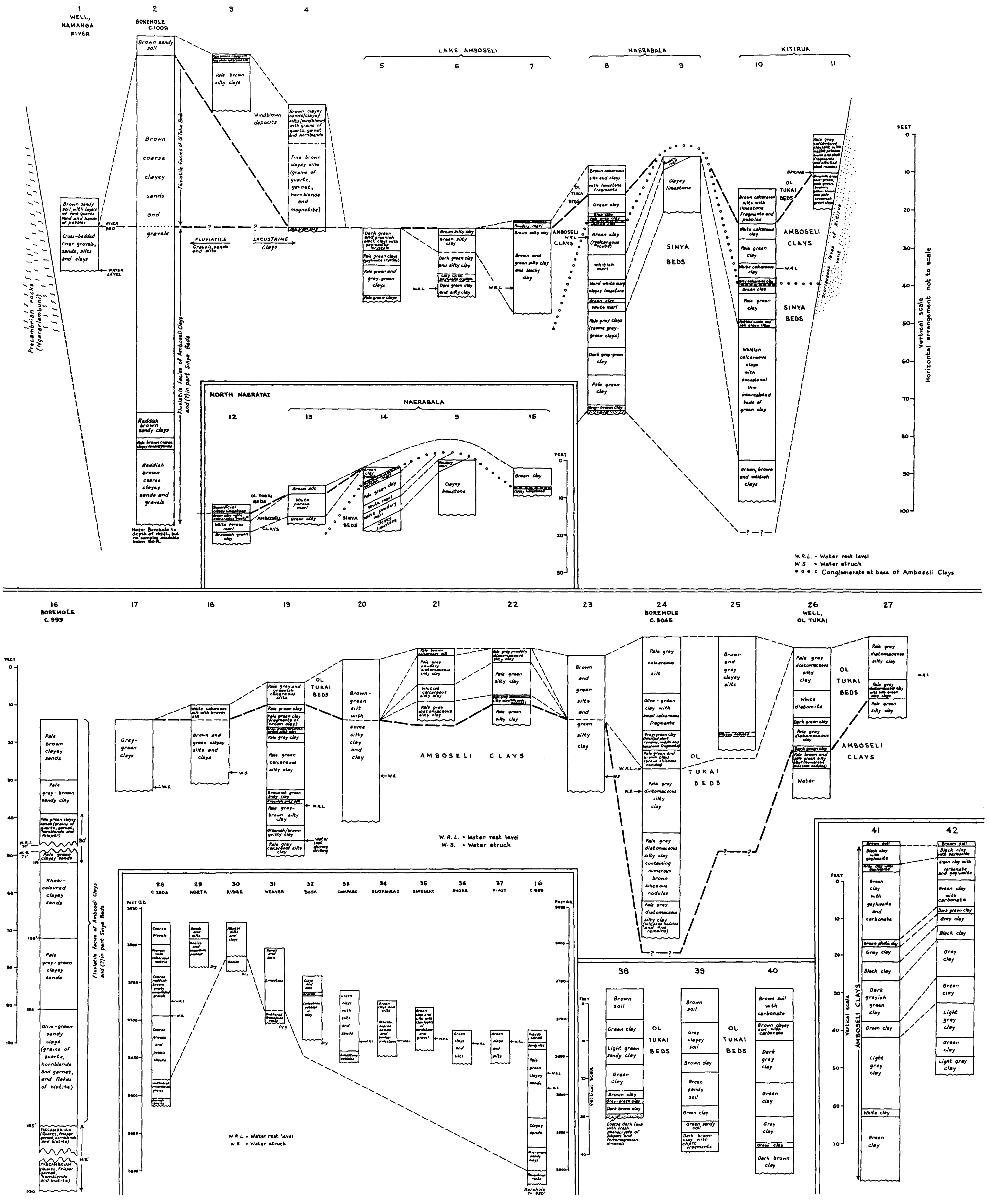
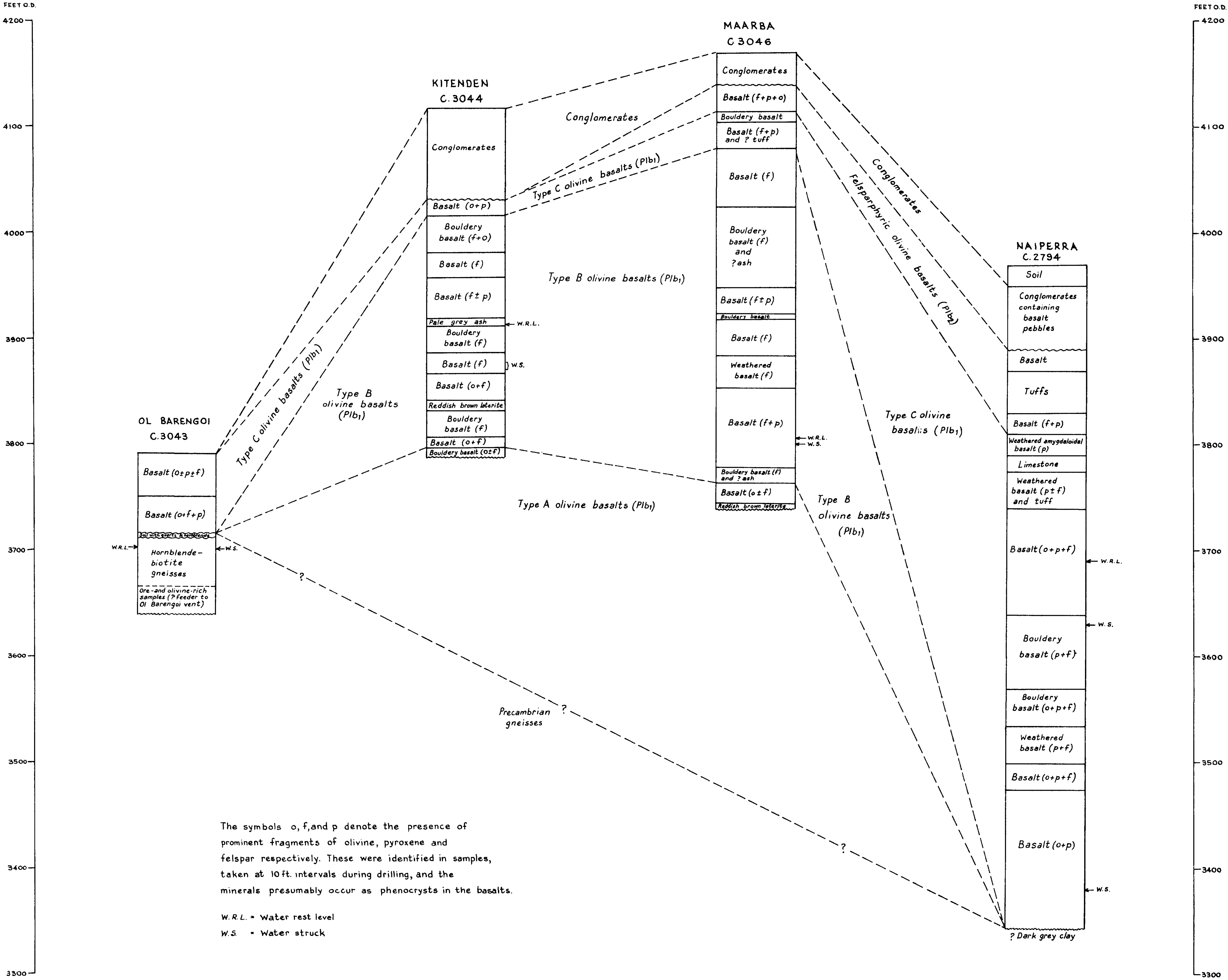


Fig. 9 Correlation diagrams Amboseli Lake Beds.

15818 a



The symbols o, f, and p denote the presence of prominent fragments of olivine, pyroxene and felspar respectively. These were identified in samples, taken at 10 ft. intervals during drilling, and the minerals presumably occur as phenocrysts in the basalts.

W.R.L. = Water rest level

W.S. = Water struck

Fig. 4 Borehole sections in the lavas of the Amboseli area.

15818 b

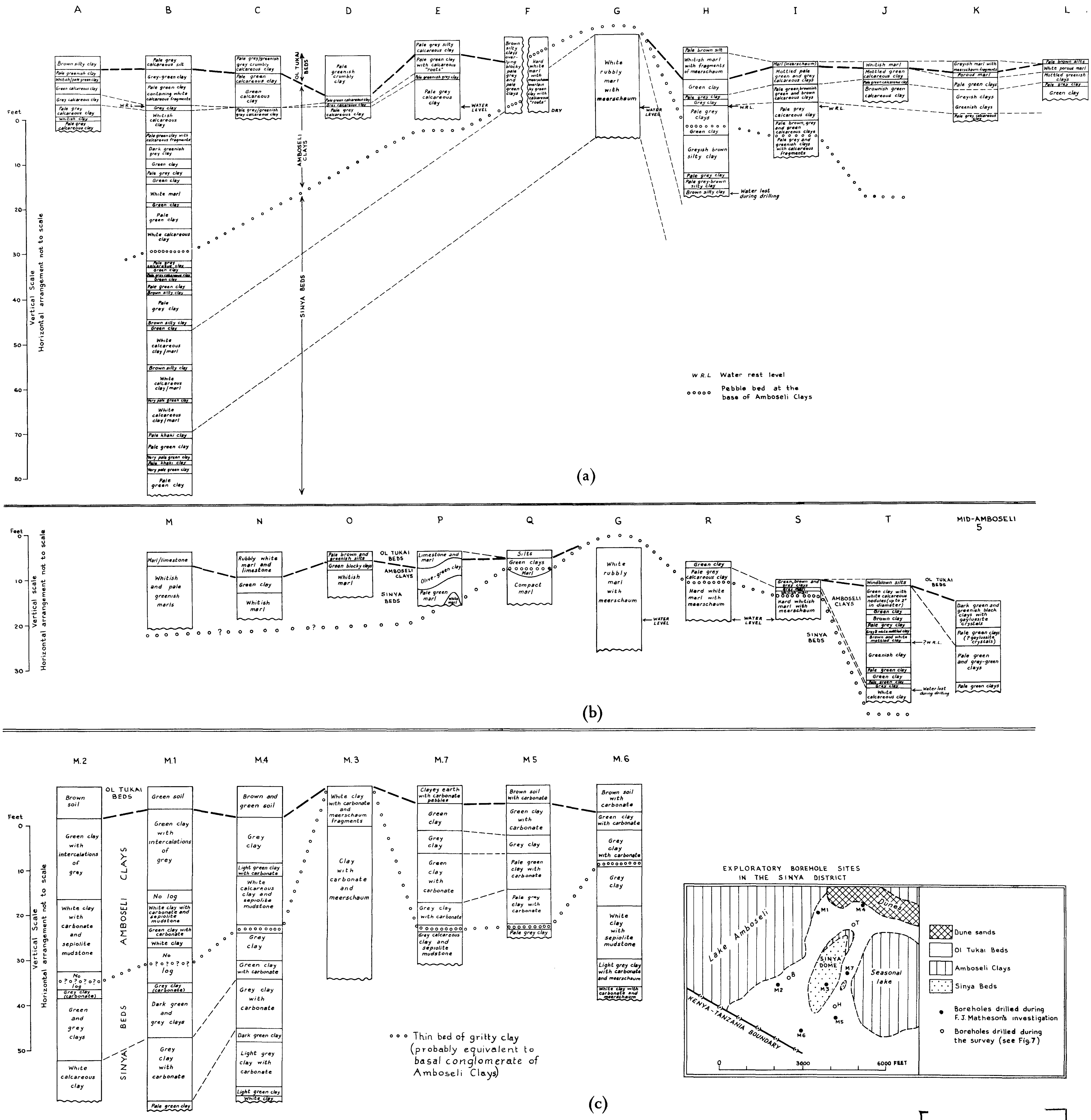


Fig. 8 Correlation diagrams Sinya Beds, Amboseli area.