MINES AND GEOLOGY

GEOLOGY
OF THE
MAGADI AREA

DEGREE SHEET 51, S.W. QUARTER
(with two coloured maps)

by

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FOREWORD

The Magadi soda lake is one of the natural wonders of the world. It was first examined by geologists in the early years of the twentieth century but, until the present survey was carried out by Mr. Baker, no comprehensive mapping or geological examination had been carried out over the area as a whole. As the rocks of the area, apart from lake beds, consist almost entirely of late Tertiary and Pleistocene lavas, the expectancy of finding mineral deposits was small. Yet Magadi has provided more mineral wealth for Kenya than any other part of the Colony. Between 1916 and 1953 nearly two million tons of soda ash were produced, and between 1933 and 1953 nearly a quarter of a million tons of common salt as well as other products were obtained. The soda deposits have a remarkable advantage in so far as they are not a wasting asset as are most minerals that are mined; as is shown in the report, the lake is receiving increments of salts at a rate greater than that at which they are being removed.

Various theories have been put forward to account for the unusual accumulation of salts at Magadi, but none has accounted fully for the powerful effect of the weathering of the volcanic rocks in the Rift Valley over long periods, nor for the leaching of the weathered products by rain and the accumulation of the solutions so formed in the lowest part of the valley. A theory, put forward as the "surface leaching hypothesis" is embodied in the report and accounts for these important factors. The hypothesis does not lose sight of the fact that the hot springs at Magadi are vital in producing and maintaining the soda deposits. It is a corollary that were that part of the Rift Valley not a volcanic region, it is unlikely that the deposits would have accumulated.

The Olorgesailie prehistoric site lies in the northern part of the Magadi area. An account of the geology of the lake beds that occupy this prolific site, with its many levels on which prehistoric man left his tools, is given in the report, but the various artifacts are not described as it is known that a full account of the prehistory of the site is in preparation elsewhere.

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Chief Geologist.

Nairobi,
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GEOLOGY OF THE MAGADI AREA

I—INTRODUCTION

The Magadi area as defined for the purpose of this report is the south-west quarter of Degree Sheet 51 (Kenya Colony) bounded by latitudes 1° 30′ and 2° 00′ S. and longitudes 36° 00′ and 36° 30′ E. It is some 1,200 square miles in extent. The area was formerly in the Masai Extra-Provincial District but is now in Southern Province, that part east of the Nguruman escarpment being administered by the District Commissioner, Kajiado, while the part west of the Nguruman escarpment is administered from Narok.

Field work in the area was done between the 11th. of April and October the 24th. 1952.

Climate and Vegetation.—With the exception of the upper part of the Nguruman escarpment at the western margin of the area, the climate is dry and hot as the rainfall figures below suggest.

Rainfall at Magadi

(Taken from the records of the East African Meteorological Department)

	1950	1951	1952	1953	Average for 28 years
	inches	*inches*	*inches*	*inches*	*inches*
Magadi (altitude 1,983 feet) . .	12·70	22·11	14·35	10·33	14·56

Almost all the rainfall is concentrated in two "rainy" seasons, March to April and in December, and often occurs as a result of isolated storms accompanied by strong winds from the east and north-east. Humidity is moderate to low, varying from 27 to 50 per cent of saturation. Shade temperatures vary from 72° F. in the cloudy season and are usually between 95° F. and 105° in the dry season, the maximum so far recorded being 109° F.

The low rainfall, high daily temperatures and the character of the prevailing lava bedrocks combine to produce a semi-arid landscape. Soil of any thickness is generally found only in the fault-troughs, which are infilled with lake beds or alluvium. The lava surfaces are boulder strewn or rocky with only rare patches of yellow-brown silty soil. The vegetation is limited to stunted thorn bushes and small patches of grass, but watercourses are marked by lines of isolated trees. In the larger basins like the Koora plain, the plain east of Ol Doinyo Nyiro, and the Kwenia Swamp, which are the centres of small internal drainage systems, and in the low-lying ground adjacent to the Uaso Nyiro river, the soil tends to be dark and supports a more luxuriant vegetation. These dark soils are related to "black cotton soil" and exhibit large deep cracks when they dry up in the hotter months.

At the base of the Nguruman escarpment, at the outer margins of the alluvial fans of the Oloibortoto and Endosapia perennial rivers, are belts of dense forest and undergrowth which remain green throughout the year. The only cultivation in the area is found in this zone. A small area of fields clustered about a village called Kalemma is found on the alluvial fan of the Endosapia river. The village is a settlement of *Wasonjo*, members of a northern Tanganyika tribe. The Kalemma *Wasonjo* have much in common with the Masai, who inhabit the rest of the area, and show considerable skill in using the Endosapia water in irrigating their fields. They have no cattle on account of the tsetse fly that infest the forest zone, and the Masai are rarely seen west of the Uaso Nyiro for the same reason. The Magadi Soda Company has a small plantation irrigated by the waters of the Oloibortoto river. In it are grown banana, orange, grapefruit and papaiya trees.

The Soda Company has till recently cut much of the forest in the vicinity of the bridge over the Uaso Nyiro for use in firing the kilns in their factory.

Indigenous peoples.—Apart from the few *Wasonjo* at Kalemma village referred to previously, the inhabitants of the area are nomadic Masai. They are not numerous on account of the poor nature of the grazing for their cattle and the paucity of water during the greater part of the year.

Communications.—All the roads in the area have been built by the Magadi Soda Company and are maintained in unusually good condition. The principal roads are the Magadi-Olorgesailie-Ngong-Nairobi road and the Magadi-Uaso Nyiro-Oloibortoto dam-site road. These are gravel surfaced and are only impassable during very heavy rains. The Magadi-Uaso Nyiro road crosses the surface of the soda lake by a causeway, which is liable to subside when the trona is softened by solution. Branching off from the Magadi-Uaso Nyiro road are several partly overgrown tracks formerly used by trucks carrying firewood to Magadi. The principal ones are shown on the map since they were cleared for the present survey.

Leading southwards from Magadi factory to the southern end of the lake and on towards Shombole is a rough motor-track suitable for robust vehicles only. A further track leads northwards from Magadi factory along the eastern margin of the lake and then along the base of the Magadi "trough" to the northern boundary of the area. It is only passable with great difficulty.

In addition to the above tracks several motorable routes were discovered into otherwise inaccessible parts of the area. These routes are only practicable to small four-wheel-drive vehicles. One such route extends from mile 15½ (from Magadi) on the Magadi-Nairobi road southwards along the Koora plain to Koora railway station, and thence southwards along a narrowing fault-trough to the southern boundary of the area. The west bank of the Uaso Nyiro is motorable from a point six miles north of the bridge as far south as Lake Natron. A rough track was made extending from a point five miles east of the Uaso Nyiro bridge, northwards along the east bank of the Uaso Nyiro for 14 miles. It is also possible to motor over most of the country comprising the alluvial flats of the Uaso Nyiro in the south-western part of the area.

Place-Names.—Most of the place-names quoted on the map are Masai, but some others are included that have originated through the activities of members of the Magadi Soda Company, as some of the names they have used have found their way on to other published maps.

Considerable difficulty was experienced in determining Masai names, firstly because it was only rarely that one encounters Masai in the area, secondly because the Masai only appear to name the largest mountains and rivers. Many of the alluvium-filled troughs were called *Karamat* or *Karamatian* and it is assumed that this means a "plain" and has been omitted from the maps except in one or two places. An alternative name for the *Uaso Nyiro* (= small muddy river) appears to be *Ngare Nyiro* (= the mud-coloured water).

The name Magadi probably originated from the Masai word *magad* meaning bitter. The *i* suffix probably came to be added through the use of the word in Kiswahili.

Methods of Mapping and Maps used.—The 1:125,000 map accompanying this report was compiled by the writer entirely from air photographs. Ground control was provided throughout the area by plane-table surveying. Some place-names and form-lines were taken from the 1:250,000 Boundary Commission map, G.S.G.S. No. 1764. This latter map is sketchy and represents the only previous attempt at large-scale surveying.

As is often the case in arid areas the air-photographs proved very useful in that lines of geological structure could be discerned on them. This was particularly so in the case of the innumerable almost uneroded Pleistocene fault escarpments. Furthermore, the difference of shade in lava and lake-bed areas shows up extremely well on the photographs.

Field operations in the area were limited by lack of roads and the scarcity of water. It was only possible to make two porter *safaris* into the difficult north-west corner of the area and much of the northern boundary was not visited. The north-western and south-eastern corners of the area were not visited and the geology of those parts shown on the map is tentative.

II—PREVIOUS WORK

J. W. Gregory (1921, p. 179)* briefly records the early work done in the Magadi area A. Fischer, the first European to visit the area, passed along the foot of the Nguruman escarpment in April, 1883, and noted the abrupt cliffs and banded terraces (Fischer, 1884, pp. 58, 60, 75 and 76; and 1885, p. 199). He collected specimens of gneiss and basalt which were described by Mügge (1885, pp. 577, 605). Kaiser (1898, p. 322) reported basalt flows in the Nguruman district, his rocks being described by Künzli (1901, pp. 150–160, 163–164) as basalts, some with olivine.

According to *Magadi Calling*, a booklet published by the Magadi Soda Company, Lake Magadi was surveyed by Major F. Burnham in 1904 and later, in 1908, by J. S. Coates, a Colonial Office geologist. A report based on the work of Coates was published in 1923 (*see* Anonymous, 1923), and gives several analyses of trona, lake liquors, spring waters and rocks from Magadi.

Parkinson's work in the Magadi area is the most detailed geological work published to date (Parkinson, 1913). He described the fault escarpments and horsts or fault blocks in the Magadi region and recognized that Lake Magadi lies in the lowest part of the faulted Rift Valley floor. He noted the wide distribution of lacustrine sediments which extend eastwards from the lake and occur at different levels in various fault troughs, and explained this by regarding the faulting as being contemporaneous with lake sedimentation. Parkinson described local silicification along fault-lines and silicification of lake-beds in the Magadi trough. He collected specimens of a fossiliferous limestone from the escarpment west of the south-west lagoon of the lake, the fossils being identified by R. B. Newton of the British Museum. Parkinson found other fossils which were dated as post-Pliocene in age by Newton, in a 100-foot shaft in lake-beds north of Koora Station. Parkinson speculated on the origin of the salts of the springs, concluding that they are derived by leaching of alkaline lavas. This aspect of his work is more fully discussed in the section dealing with the alkaline springs (p. 55).

J. W. Gregory (1921, pp. 178–183) visited Magadi and traversed from the Kedong basin towards Olorgesailie and Ol Doinyo Nyegi and on to Magadi, and finally along the railway towards Kajiado. He obtained rock specimens from the Nguruman escarpment which were described as quartzite, gneiss, nepheline augitite, olivine basalts and nepheline tephrite. He recognized that the upper part of the Nguruman escarpment is composed of Basement System rocks and that it is formed by two distinct faults.

As a result of his observations Gregory suggested the following volcanic sequence for the Magadi area:—

phonolitic trachyte
analcite basalt (in the east)
olivine basalt (in the east)
phonolitic rhyolite
augitite
nepheline tephrite.

In 1932 J. A. Stevens, at that time a chemist of the Magadi Soda Company, wrote a paper (unpublished) entitled "Lake Magadi and its alkaline springs". This paper deals with the location, temperature and composition of the numerous alkaline springs at the lake margin; the contents of Lake Magadi; and contains valuable chemical analyses of spring waters, lagoon liquors and various salts. Much of the information in the section on alkaline springs (p. 51) in this report is taken from Stevens's paper.

Dr. R. M. Shackleton, formerly of the Mines and Geological Department, Kenya, wrote a short report (unpublished) on the Olorgesailie Prehistoric Site in 1944. His work followed the discovery in 1942 by Mrs. Leakey, wife of Dr. L. S. B. Leakey, Curator of the Coryndon Museum, Nairobi, of numerous hand-axes and other artifacts which have subsequently been shown to belong to the Acheulean culture. Dr. Shackleton's report deals with the succession of lake-beds in the vicinity of the Site and with the geology of the surrounding country. He showed that the artifacts frequently lie on former land surfaces.

*References are quoted on p. 79.

Dr. Shackleton continued his work on the Olorgesailie lake-beds during a subsequent visit to Kenya, and it is hoped that his paper on the detailed geology will be published in due course. Dr. Leakey, who has made an examination of the artifacts from the Site, read a short paper summarizing its history and some of its more interesting features before the First Pan-African Congress on Prehistory in 1947 (Leakey, 1952, p. 209).

J. A. Stevens and P. C. Spink (1946) wrote a short account on the geography of the Nguruman escarpment in the neighbourhood of the Endosapia river. They also described lake beds, tuffs and agglomerates seen during a journey from Magadi to Suswa, which lies about 22 miles north of the northern boundary of the present area.

In 1951 Dr. B. N. Temperley, formerly of the Mines and Geological Department. Kenya, wrote a report (unpublished) on investigations in the vicinity of Lake Magadi, This report deals primarily with the search for liquors rich in common salt, carried out in an attempt to assist the Magadi Soda Company, but Dr. Temperley made some geological observations on the sequence of lake beds in the Magadi trough and discussed the origin of the salts and springs. Many aspects of Dr. Temperley's work are discussed in later sections of the present report on the evaporite and on the alkaline springs.

A general account of the soda deposits and the method of processing at the Magadi factory was given by L. A. Lyons in 1952.

T. H. White published a short account of the High Magadi beds in 1953 and described the fossils in them. He was of the opinion that repeated flooding of the Magadi area, "over a period of perhaps half a million years", might account for the extraordinary purity of the soda deposits in the lake, having led to frequent recrystallizations.

Since 1927, when the present Magadi Soda Company was formed, much information has been gained by members of its staff and, by courtesy of the Company, has been made available for use in this report. Chemical analyses, a short report on diatomite deposits, the report by Stevens (1932) on the lake and springs and sundry unpublished papers on water-supply have been made available by the Company together with technical information on plant and treatment processes. This valuable information has been drawn on freely by the writer and is acknowledged wherever possible.

III—PHYSIOGRAPHY

The area mapped covers the greater part of the width of the Rift Valley and includes the western boundary faults. The Nguruman escarpment, which forms the western wall of the Rift Valley, descends to the east by moderate slopes from an altitude between 6,000 and 6,500 feet to a platform at about 4,500 feet, after which it drops spectacularly to the floor of the Valley. The upper part is clearly an old escarpment, consisting of deeply dissected Basement System rocks, while the lower scarp is young, precipitous, and relatively recently formed in volcanic rocks. Several perennial rivers that descend the escarpment have built up alluvial cones of considerable size; some of these extend several miles from the base of the escarpment on to the valley floor.

The Rift Valley floor is broken by small fault escarpments, which are so numerous that the country is broken into table- and step-like strips with intervening troughs, all generally narrow and all trending a little east of north. The floor of the valley descends, with many steps due to the escarpments, from east and west down to the deepest trough which is central in the area and occupied in its more southerly part by Lake Magadi. The floor of the valley declines southwards at a rate of approximately fifty feet per mile and the "horsts" and "troughs" are similarly tilted, though locally they are level or even tilted northwards. The surfaces of the horsts and troughs are generally featureless being composed of originally flat-lying plateau lavas of Pleistocene age on which erosion has had little effect beyond the cutting of shallow impersistent stream channels.

From west to east the principal depressions in the Rift Valley floor are the Uaso Nyiro valley, the Kordjya plain, the Magadi trough, the Koora plain and the Kwenia plain. The Uaso Nyiro depression is occupied by the perennial Uaso Nyiro; the northern part of the depression is a tectonic basin through which the river flows in a deep gorge, while the lower part is the alluvial plain of the Uaso Nyiro. The Kordjya plain, though not great in area, is the alluvium-filled plain formed by internal drainage into a fault basin on the lava surface.

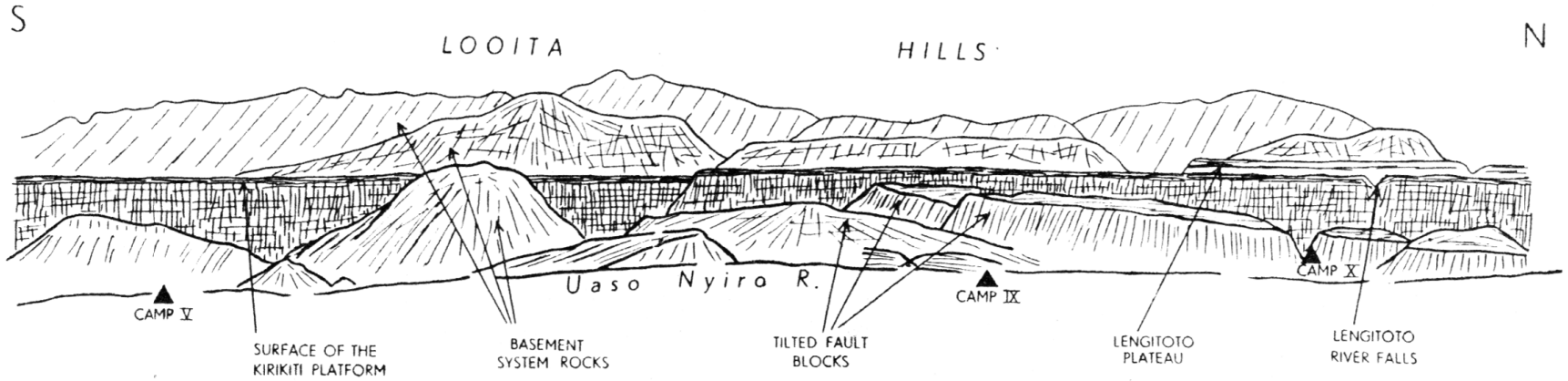


Fig. 1.—Sketch of the northern part of the Nguruman escarpment viewed from a ridge seven miles north of En Doinyo Nyiro.

The Magadi trough is occupied in its southern part by Lake Magadi, which at 1,977 feet is the lowest part of the area being described; it is bounded by fault escarpments and traverses the area completely from north to south.

Also traversing the area is the Koora plain and its eastern branch the Kwenia plain. Both originate from the Legemunge plain to the north of Olorgesailie mountain; the Koora plain passes west and the Kwenia plain east of Olorgesailie. Both plains narrow to the south and are delimited by fault escarpments.

Rising from the Rift Valley floor are several isolated volcanic mountains—Olorgesailie 5,780 feet, Ol Doinyo Nyegi 3,835 feet, Shanamu 4,400 feet, and minor hills such as Kisamis and Koriamat. The oldest of these and the only one to show appreciable denudation is Olorgesailie. Its streams are at a late youthful stage of dissection but the volcano-like profile is clearly discernible from a distance. The other hills mentioned are relatively young in geological age and are almost uneroded. Ol Doinyo Nyegi stands up as a dome-like mountain with cliffs on its eastern and western sides due to faulting.

The principal flowing river in the area is the Uaso Nyiro, the head-waters of which rise on the south-west of the Mau range west of the Rift Valley. The Uaso Nyiro carries a considerable volume of water during the rains due to its large catchment area on high ground and is one of the few large rivers in the Colony to rise outside the Rift Valley and to flow into and end in it.

Right bank perennial tributaries of the Uaso Nyiro flowing off the Nguruman escarpment are (from north to south) the Lengitoto, the Endosapia and the Oloibortoto rivers. The Lengitoto river has spectacular falls some 350 feet high at the point where it descends from the Naimithigirya plateau, while the Endosapia and Oloibortoto rivers have cut deep gorges into the escarpment and have many minor falls and rapids in their descent to the valley floor. Only the Lengitoto flows into the Uaso Nyiro in the dry season; the others pass underground into their alluvial fans.

The Turoka river in the south-east corner of the area rises in the hills south-west of Kajiado and descends several small escarpments before turning south into the Kabongo depression. It flows during the rains only and has a wide sandy bed. When in spate it forms a lake in the Kabongo depression which sometimes persists through two or three dry seasons after exceptionally heavy rains. Also rising in the east is the Ol Keju Nero river which descends several escarpments east of Olorgesailie, passes round the north end of the mountain and down the Koora plain to the west and finally is lost in the Koora plain north-east of Koora railway station.

Streams on the grid-faulted area are seasonal and consequent in character; they flow either into Lake Magadi or into small alluvium-filled basins of internal drainage caused by faulting.

In the north-western part of the area there are some unusual small-scale topographical features on the lava surface. The surface here is of relatively low relief and consists of small hills, plateaux and groups of isolated "tors", none of these features being higher than two hundred feet above the level of the surrounding country. Many of the hills have well-marked defiles running across their upper parts, the defiles sometimes crossing and giving the hills the appearance of a large "hot cross-bun", as they were named by Temperley in his unpublished report on the Magadi area (1951). The plateaux, which vary in size and shape, frequently have grassy defiles along their edges. Not all have marginal defiles, and where the defiles occur they do not always continue all round the plateaux. While the plateaux are sometimes several miles across the "hot cross-buns" are never more than two hundred and fifty yards in diameter. The tor topography is reminiscent of that well known from granite country. Isolated ridges and hills are topped by piles of large rounded boulders resting on top of one another.

These structures are found to be composed of the same lava—a highly porphyritic trachyte, distinctive in appearance from all other lavas in the area. This lava extends over almost the entire width of the Rift Valley, most of it out-cropping some distance to the north of the present area. Wherever it is seen it is clearly distinguishable at a distance by the

uneven character of its surface and by the structures mentioned which are found on it. Since the structures are so unusual and since they appear to have formed as a result of erosion rather than volcanic action or tectonic influence their origin will be discussed here.

Temperley (1951) originally discovered the structures while examining aerial photographs of the north-western part of the area. He concluded that the structures, in particular the defiles, may have been formed by local subsidence following upon the removal of underground soluble or easily eroded material. This suggestion was based on the possibility that there might be underground salts in the form of evaporite beds interbedded in the lavas of the district or below the porphyritic trachyte. The fact that the structures are limited to the area of outcrop of one lava suggests that they are due to some inherent peculiarity of the lava rather than to subsidence. Furthermore there is no evidence for the existence of any lake beds, evaporites or other deposits apart from a local, impersistent bole immediately below the porphyritic trachyte lava.

There are several features of the porphyritic trachyte outcrop which distinguish it from the other lavas in the area. They are:—

1. The lava outcrops only on the hills, tors, "hot cross-buns" and plateaux; between the outcrops are moderately level plains of soil;
2. The soil between the features is deep but in two places where streams have cut channels in it in shallow basins the underlying plateau trachyte outcrops;
3. The surface of the shallow soil-filled basins between plateaux is level in their central parts but slopes up towards the lava outcrops;
4. Where the porphyritic trachyte is cut by faults the escarpment so formed when seen *en face* is irregular in outline, indicating that the topography was probably already developed to a large extent before the faulting.
5. Small exposures of the porphyritic trachyte are surrounded by numerous small fragments of broken rock, felspar cleavage fragments and dark streaks of ferromagnesian minerals on the soil.
6. In all exposures the lava is found as sub-rounded fragments and boulders, these being pitted and cracked far more than other lavas in the area.

All the above observations suggest that the lava has undergone and is still undergoing rapid erosion and disintegration, possibly as the result of diurnal variations of temperature. Moreover, the most southerly outcrops of the lava are probably outliers of considerable relief resting on the plateau trachyte and partly buried under their own detritus. Stream channels near to two of the "hot cross-buns" at the northern margin of the area indicate that the slope of the hill sides, which is approximately 40°, continues downwards beneath the soil to at least one hundred feet below adjacent plain level and that only the upper parts of these unusual structures are visible at the present day.

Since a careful examination of the structures does not reveal any tectonic cause for the defiles and since there is abundant evidence that erosion working on the easily disintegrated rock has been responsible for the development of the broad land-forms on the porphyritic trachyte, it is suggested that erosion may also be responsible for the development of the defiles. The defiles are not orientated in any preferred direction and are frequently curved, particularly the plateau defiles. In the group of plateaux near the Uaso Nyiro, however, and in other groups of structures to the north of the area mapped, the defiles in some cases locally trend in similar directions and this suggests that they may be eroded along major joints. There is also a possibility that they may be structures originated by local variations in direction and rate of flow when the lava was extruded. Temperley (1955) has suggested that the "hot cross-bun" and plateau structures are pressure tumuli and plateaux formed by the up-doming of the solidified lava crust as a result of the inflow of additional molten lava into the still unconsolidated interior of the flow. Such structures have been observed on a much smaller scale in the recent lavas of Hawaii. The defiles in structures of such origin would be formed by the cracking open of the lava crust along lines of maximum tension i.e., radially on the pressure domes (tumuli), along the crests and radially near the ends of ridges, and along the margins of the plateaux.

IV—SUMMARY OF GEOLOGY AND GEOLOGICAL SUCCESSION

The oldest rocks in the area are the gneisses, quartzites and schists of the Basement System, a formation which is generally considered to be Archæan in age. The Basement System rocks are confined to the upper slopes of the Nguruman escarpment where they form a dissected strike ridge. The Nguruman escarpment was formed as a result of two periods of faulting, the movements taking place along the same plane south of the Oloibortoto river, but probably along new lines north of the river. The first movement down-threw the Basement rocks about 1,500 feet to the east and was followed by a period of erosion of the escarpment so formed. A series of olivine basalt lavas (the Kirikiti Basalts) was erupted on the down-throw side of the fault and inundated the lower part of the escarpment. These basalts were isolated as a ledge on the escarpment by the second movement of the Nguruman Rift fault, which threw down the rocks to the east another 1,500 feet.

In the eastern part of the area a volcano of central type (Olorgesailie) built up a pile of lavas consisting of augitites, trachyandesites, alkali trachytes and nephelinites. The age of these volcanic rocks relative to the Kirikiti basalts cannot be determined, but since olivine basalts similar to the Kirikiti Basalts (Ol Keju Nero and Singaraini Basalts) occur resting on Olorgesailie lavas, the Kirikiti Basalts are tentatively correlated with them and thus appear as younger than the Olorgesailie lavas in the table of geological succession.

There is evidence that the faulting on the east side of the Rift Valley did not begin until after the Olorgesailie vulcanicity, for nephelinites similar to those forming the upper part of Olorgesailie have been found in the upper part of the escarpment between Singaraini and Ngong.

The floor of the Rift Valley must at this time have been partly covered by basalts of Kirikiti, Ol Keju Nero and Singaraini types with the extrusives of Olorgesailie lying below. The extensive period of extrusion of plateau-type alkali trachytes then ensued, with the result that the greater part of the valley floor was covered by up to twenty flows of these uniform lavas. Resting conformably on the plateau trachyte in the north of the area is the orthophyre-trachyte, a distinctive rock closely allied to the plateau trachytes in composition but differing greatly in appearance and mode of weathering. The plateau trachyte vulcanicity was brought to a close by the formation of a number of small ash and scoriaceous lava cones, all small with the exception of Ol Doinyo Nyegi

On the almost level surface of alkali trachytes a thin layer of lake beds (the Oloronga Beds), consisting principally of reworked volcanic dust and debris, was deposited.

Grid-faulting which is so easily discernible at the present day followed the deposition of the Oloronga Beds. Numerous sub-parallel faults cut the Rift Valley floor and resulted in a general downfaulting of the central strip which is now occupied by Lake Magadi. Several subsidiary fault troughs were formed and lake sediments accumulated in them. The Olorgesailie lake beds, which contain Acheulian artifacts and fossils of Middle Pleistocene age, accumulated as diatomaceous clays, while in the Uaso Nyiro depression fine silts and clays accumulated. Cherty rocks consisting largely of silicified bedded clays were laid down in the Magadi fault-trough, though deposition of these beds may well have begun before the grid-faulting episode was ended (*see* p. 81).

Subsequent minor faulting with associated tilting affected the Olorgesailie lake beds and also tilted the Uaso Nyiro beds westward.

A further period of lake deposition was confined principally to the Magadi trough and the Uaso Nyiro basin. Elsewhere lacustrine gravels and clays were deposited in fault troughs. In the Magadi trough fine silts and clays (the High Magadi Beds) were laid down to a level 40 feet higher than the present surface of the lake. Later these beds were partly eroded from the trough, principally by wind action. Finally, the onset of alkaline spring activity, together with the accumulation of muds during the wetter periods, resulted in the deposition of a series of beds of sodium carbonates intercalated with clays. These form the Evaporite Series which is still in process of formation at the present day.

The geological succession in the area is indicated in the following table:—

	Geological Succession
Recent	Evaporite Series—Boulder beds
	——— erosion ———
Upper Pleistocene . .	High Magadi Beds—Uaso Nyiro alluvium
	———minor faulting and erosion———
Middle Pleistocene . .	Olorgesailie Lake Beds—*Chert Series—Ngare Nyiro Beds
	——— grid faulting—erosion ———
	Oloronga Beds
	Minor volcanic vents—Ol Doinyo Nyegi Volcanics
	Orthophyre trachyte
Lower Pleistocene . .	Plateau alkali trachytes
	———rift faulting—second Nguruman fault———
	Lengitoto Trachyte and underlying sediments
Pliocene (?)	Ol Keju Nero Basalts—Kirikiti Basalts
	Olorgesailie volcanics
	———first Nguruman fault—erosion———
	——— erosion ———
Archæan	Basement System

V—DETAILS OF GEOLOGY

1. Metamorphic Rocks—Basement System

Schists and gneisses of the Basement System are only found in the western part of the area on the higher slopes of the Nguruman escarpment. Basement System rocks outcrop extensively, however, immediately to the west of the area and the summit ridges of the Looita and Lebetero hills, which form the crest of the Nguruman escarpment, are all composed of these rocks.

At all points but two, the Basement system rocks pass out of sight below the Kirikiti volcanics. They are exposed below the Kirikiti platform at a point two and a half miles north-west of the site of camp V which is on the central reach of the Uaso Nyiro. Another place where they are exposed is in the gorge of the Oloibortoto river, the most powerful river which descends the Nguruman escarpment in the area, and which has cut a deep gorge exposing Basement rocks in the bottom. The sketch (Fig. 2) below indicates the relationship between the Basement System rocks in the upper part of the escarpment and the Kirikiti volcanics along the Oloibortoto gorge. The section exposed in the Oloibortoto gorge is most instructive and contains the only exposures seen in the area of a fault separating Basement System and volcanic rocks. The fault breccia is approximately 100 feet wide and consists largely of almost white, fine-grained, angular quartzite fragments cemented by cryptocrystalline white quartz mylonite, though small rather rounded lava fragments are also found in its eastern part. The quartzite fragments vary greatly in size from large blocks to small fragments. The breccia is traversed by curved fractures dipping between 40° and 50° to the east. On the surfaces of these fractures a series of strong vertical grooves and slickensides are developed. In the lavas immediately east of the fault-zone irregular, more or less vertical, crush-zones a few inches wide are seen to be orientated in a north-south direction.

About 40 yards west of the fault breccia well-bedded muscovite-quartzites are exposed in the river-bed striking at 213° and dipping at 10° eastwards. The quartzites are veined by thin concordant quartz stringers carrying books of muscovite up to one inch in diameter. A well-defined lineation due to the orientation of muscovite flakes on bedding planes plunges at 8° towards the south-east.

*Subsequent work has shown that the Chert Series occurs lower in the succession. *See* Appendix, p. 81

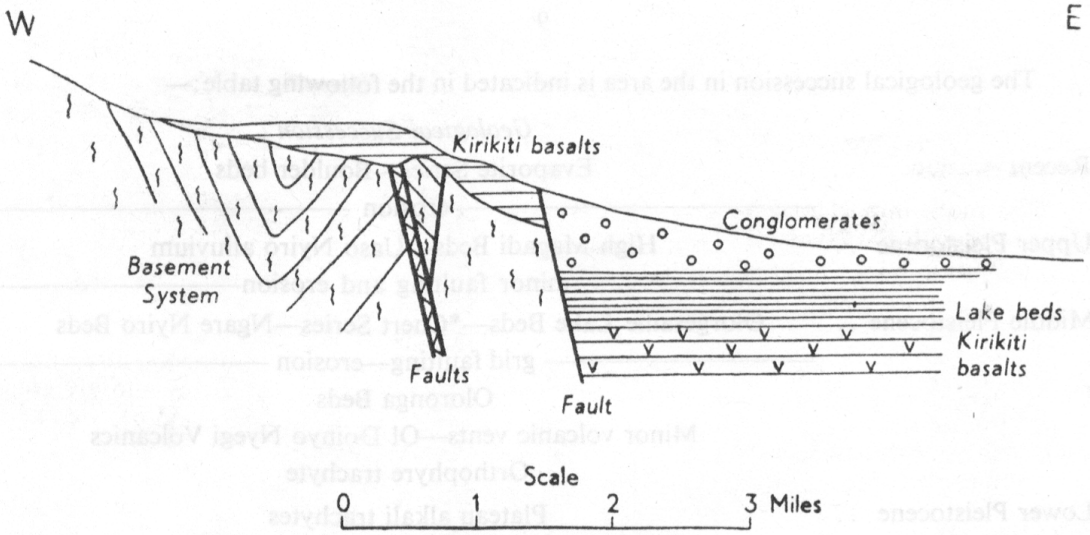


Fig. 2.—Diagrammatic section along the Oloibortoto river gorge.

Towards the west the quartzites become thin-bedded and interbedded with slips of muscovite-quartz schist. The dip is generally steep and towards the east-north-east. The last accessible exposure upstream in the gorge indicates that the quartzite rocks grade westwards into laminated micaceous gneisses containing quartz, felspar and biotite with subordinate muscovite. The gneisses contain pegmatitic pods and streaks and the laminations and foliation dip at 78° to the east-north-east.

Descending from the ridge immediately to the north of the Oloibortoto gorge one or two prominent ribs of muscovite quartzite can be followed from near the summit of the ridge to the river below. They strike 6° west of north and dip at 31° to the east. The rocks are well bedded and apparently unaffected by their proximity to the fault. They are reddish brown on weathered surfaces, rather fine-grained, and have an abundance of slightly greenish muscovite flakes visible on bedding surfaces.

The Basement System rocks to the immediate north of the Oloibortoto river were not visited, but their structure is visible on air photographs. They dip steeply to the east as in the Oloibortoto section and strike a few degrees west of north.

The unnamed river descending from the southern part of the Naimithigirya plateau, some six miles north-north-west of Kalemma, exhibits an interesting section. Here the platform of Kirikiti basalts is narrow and, at a point about one mile north of the section, Basement System rocks are exposed in the face of the lower escarpment. In the river the lower part of the section shows alluvial boulder beds with occasional exposures of Kirikiti basalts, but just past the entrance of the gorge there are exposures of migmatitic biotite gneisses dipping 22° to the east, and striking some 15° west of north. Further to the west the gneisses vary in dip and strike and small shatter-zones point to the proximity of a fault The shatter-zones, all narrow, hade westwards at angles near 68°, which is contrary to expectations. On numerous bedding planes a lineation is seen to pitch gently southwards at about 12°.

The rocks above the Basement System gneisses are conglomerates consisting of boulders of metamorphic rocks, followed by sandstones and further conglomerates. Details of the section are not available because the cliffs are inaccessible. The Kirikiti series lies with strong unconformity on the eastward slopes of the Basement System rocks, in accord with observations made in the Oloibortoto section.

One mile north of the river section described, two miles west of the centre point of air photograph 415/5047, flaggy biotite gneisses outcrop in a small stream-bed about half-way up the lower escarpment. They dip at some 69° eastward and the rock type and dip are maintained up to the level of the Kirikiti basalts. The contact with the lavas is not seen but exposures of augite basalt were found forty yards from the Basement System rocks. Actually in contact with and overlying the gneisses in the valley are alluvial conglomerates and cross-bedded sands.

Petrographically the Basement System rocks are similar to those described from other areas. One of the muscovite-quartzites (51/385)* carries an unusually large amount of sphene. It has numerous small interstitial flakes of muscovite and small irregular grains of microcline. The quartz grains are clear and exhibit uneven extinction due to strain or to recrystallization.

The more important features of the Basement System rocks are: the parallelism of their strike with the Nguruman escarpment, and their predominant easterly dips.

2. Volcanic Rocks

(1) The Volcanic Rocks of the Olorgesailie Area

Olorgesailie is the highest mountain in the part of the Rift Valley described in this report. The southern and northern summits rise to 5,780 and 5,752 feet respectively and are connected by a narrow ridge. The western slopes are steeper than those in the east, due to faulting along the west side of the mountain and to its being tilted westwards. The westward tilt is indicated by the fact that the fault-block of plateau trachytes south of the mountain is also tilted, the plateau trachytes and the faulting being younger than the Olorgesailie volcanics. Inliers of lavas similar to those that form the bulk of Olorgesailie occur on Shanamu to the west, and on two small hills north-east of Shanamu that project above the level of the surrounding plateau trachytes.

As seen in the gorge about one mile north-east of Shanamu the volcanics dip at approximately 35° to the west. Conglomerates and silts overlying the Shanamu volcanics with strong unconformity are also seen in this gorge.

Olivine basalts, described as the Ol Keju Nero Basalts in a later section, overlie the lower lavas of Olorgesailie on the northern and parts of the eastern margin of the mountain. These lavas, although described separately, may have originated from small vents on the flanks of Olorgesailie and so be part of the Olorgesailie vulcanicity.

(a) Olorgesailie Volcanic Series

Lack of time during mapping made a comprehensive survey of Olorgesailie impossible and work on the mountain was confined to reconnaissance traverses on the northern and north-western slopes up to the northern summit. Specimens were also collected from the lower eastern and south-eastern slopes. It is therefore possible only to give petrographic descriptions of the larger lava flows making up the succession.

So far as the structure is concerned all the evidence points to the mountain being a normal central volcano, composed for the greater part of lavas with little inter-bedded fragmentary material. Dips in the lava sheets are normally quaquaversal about a point situated between the north and south summits.

At the base of the mountain at its north-west side a small hill of lava rises out of a large alluvial outwash fan. The lava is hard and mottled dark and light grey in colour. In thin section (specimen 51/366) it is seen to resemble trachytes found in the small outlying mass of Olorgesailie lavas east-north-east of Shanamu hill. The rock carries glomeroporphyritic clusters of ragged anorthoclase phenocrysts and small rare green augite microphenocrysts set in a dusty matrix of augite granules, opaque iron ores and small tabular potash felspar crystals showing Calsbad twinning. One group of opaque ores is roughly hexagonal in outline and suggests complete oxidation of a basaltic hornblende crystal. The rock is thus a variety of alkali trachyte similar to the lavas of the small outlier by the roadside which occurs about a mile north-west of this hill.

On the north-west slope of Olorgesailie, on a spur running north-westwards, the lower lavas are seen to be similar to that already described. In a small stream gorge about 600 feet above the level of the base of the hill an agglomerate bed 75 feet thick was seen. It consists of lava fragments up to several inches across in a matrix of brown ash, and there is no semblance of bedding. Above the agglomerate up to an altitude of 3,830 feet are augite trachytes and varieties similar to pyroxene trachytes of the southern ridge of Shanamu hill. They grade upwards into highly porphyritic alkali trachytes without visible augite, which are similar to lavas at the base of the north-west slope of the mountain. At 4,410 feet trachytes with augite micro-phenocrysts are again common; the augite is always subordinate to the phenocrysts of alkali felspar.

*Numbers 51/385, etc. refer to specimens in the regional collections of the Geological Survey, Nairobi.

On nearing the north summit of Olorgesailie the rock type changes to a hard green-grey lava with abundant waxy greenish grey nepheline phenocrysts. No felspars are seen in hand specimen (51/367). This nepheline-rich lava forms the north summit of Olorgesailie and extends some distance down the slopes on the upper parts of the spurs. The specimen taken from the summit of the ridge (specimen 51/367(2)) shows large idiomorphic nepheline phenocrysts with zones of aegirine-augite inclusions near their margins. Smaller nepheline phenocrysts with more rounded outlines do occur but they usually show at least one good crystal face. Well-formed aegirine-augite micro-phenocrysts are common and smaller paler grains of aegirine-augite and needles of aegirine occur in a trachytoid groundmass of alkali-felspar microlites. Sphene is a common accessory mineral.

Specimens collected by Shackleton indicate the presence of the nephelinite over a considerable area on the northern slope of the mountain. A thin section of a specimen collected from 4,330 feet on the northern slopes (specimen 51/13) shows numerous idiomorphic nepheline phenocrysts together with small aegirine-augite micro-phenocrysts in a pale green matrix consisting largely of fine-grained aegirine in a colourless isotropic base. Twinned sphenes are common and reach four millimetres in length. Specimen 51/27, collected by Shackleton on the north slope of the mountain, is similar to the preceding one—the nepheline, however, is traversed by numerous cracks containing a brown amorphous substance.

At the base of the eastern side of the mountain, the lowest rocks exposed above the alluvial fans stretching from the bottom of the slope are dark grey, compact non-porphyritic olivine basalts. An example of these rocks, specimen 51/431, contains labradorite (An_{55}) felspar, and much granular pale brown augite and a few colourless olivines. The basalt is similar to the Ol Keju Nero basalts and may belong to that series.

Higher on the eastern slopes exposures are of dark grey trachytes with numerous tabular felspar phenocrysts visible in hand-specimen. They resemble trachytes found on South Shanamu.

The Olorgesailie volcanics are overlain by members of the Ol Keju Nero basalts at the north base of Olorgesailie, but in other places they are overlain by the plateau trachytes. The writer believes that the Ol Keju Nero basalts represent a last local phase of the Olorgesailie vulcanicity, but since they cannot be traced to vents on the mountain their derivation is uncertain. The Ol Keju Nero basalts are locally overlain by members of the upper part of the plateau trachyte series and thus are older than them. Since their derivation is uncertain though their place in the volcanic sequence is known they are treated below as a separate series.

(*b*) *Shanamu*

Shanamu hill is aligned in a north-south direction and consists of two parallel ridges separated by a shallow "col". Both its western and eastern sides are steep, and the result of faulting. Structurally, therefore, the hills are due to block-faulting and represent an up-standing inlier of Olorgesailie volcanics between two valleys, the upper Koora valley on the east and the Nengeba valley to the west, both these valleys being covered by lake beds or alluvium.

At the southern extremity of the Shanamu ridge, near the pass crossed by the Magadi road, exposures at the base of the hill show plateau trachyte lavas abutting against a sloping surface of porphyritic trachyte of Olorgesailie type. This lava is exposed as a rather fissile rock with rare vesicles and common small felspar phenocrysts. The matrix of the rock (specimen 51/349) is dark grey, and has a sheen due to the presence of numerous felspar microlites. Under the microscope the rock is seen to contain euhedral tabular anorthoclase phenocrysts with slightly corroded terminal faces. Rare small pale green micro-phenocrysts of aegirine-augite are also seen, sometimes associated with opaque iron ore grains. The groundmass consists of orthoclase microlites arranged in fluidal and stellate patterns. Specks of opaque ores are also common but no ferromagnesian minerals, apart from small granules of aegirine-augite, are seen in the groundmass. The rock has the constitution of an alkali trachyte, but is quite distinctive from the plateau alkali trachytes, being more porphyritic, darker in hand-specimen, and lacking cossyrite such as is almost always found in the latter rocks.

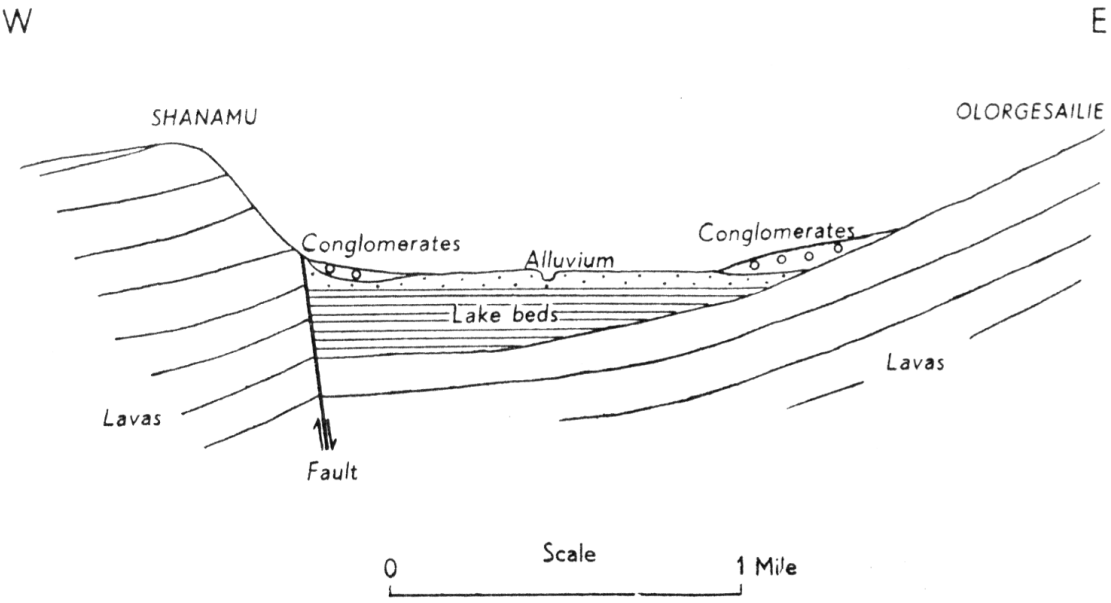


Fig. 3.—Diagrammatic Section through Shanamu hill.

On the summit of the southernmost hill comprising the Shanamu ridge are rocks similar to that described above; the thin section (51/354) shows that the anorthoclase phenocrysts are somewhat ragged and sometimes show very fine lamellar twinning. Some of the phenocrysts have a narrow marginal zone showing a smaller extinction angle than the main part of the crystal, the marginal zone being free of twinning. The zone is probably due to deuteric alteration. Aegirine-augite is more common as microphenocrysts and as granules in the groundmass than in the exposures near the Magadi road, and several strongly pleochroic brown hornblende crystals margined by dusty opaque ores are also present.

The small outlier of Olorgesailie lavas by the roadside a few miles north-east of Shanamu is composed of lava similar to that described above. A thin section (51/430) shows anorthoclase phenocrysts exhibiting fine "cross-hatch" twinning, some of the crystals being arranged in glomero-porphyritic groups. Corroded margins are common on the anorthoclase and some have a narrow zone of dusty inclusions near their margins. Several "basaltic" hornblende phenocrysts crowded with densely packed opaque grains are present and can be diagnosed by their pseudo-hexagonal outlines, and there are occasional sphene phenocrysts. The groundmass is somewhat richer in augite than in the previously described rocks and the felspar microlites are shorter and make up a smaller proportion of the rock.

On the south-west side of the inlier north-east of Shanamu the plateau trachytes are seen to overlie the trachytes that form the hill. The contact is not well exposed, but the disposition of exposures shows that the surface of the older trachytes was undulating and weathered before the deposition of the plateau trachytes.

The upper part of the southern ridge of Shanamu hill is composed of the trachyte already described. On descending the eastern side of the ridge exposures of a distinctive porphyritic basalt are found about half-way down the hillside and about one mile south-east of the summit. The basalt clearly underlies the trachyte but the contact is not exposed. The rock (specimen 51/355) contains many augite phenocrysts set in a vesicular fine-grained brownish grey matrix. In thin section the augite phenocrysts are seen to be euhedral, pale mauve, and feebly pleochroic, and are probably titaniferous. The margins of some individuals are darker than the cores. The augite phenocrysts often contain inclusions of opaque iron ores and the groundmass contains bright red-brown iddingsite and tabular microphenocrysts of andesine (ca. An_{48}). The matrix consists of felted andesine prisms, augite, iddingsite and opaque iron ores.

The sequence in the stream section immediately south-east of the eastern summit of Shanamu shows that basalts with phenocrysts of augite are common in the succession of lavas. The lowest rocks are basalts similar to that already described. Interbedded in the

sequence are fine-grained types and others, with few or no augite phenocrysts that grade by increase in porphyritic felspars into glomeroporphyritic andesine basalts. Specimen 51/356 is an example of these. In hand-specimen the rock is non-vesicular with glomeroporphyritic felspars and brown spots in a dark grey matrix. Under the microscope the porphyritic felspars are seen to occur in clusters of tabular, occasionally zoned, crystals showing albite twinning. The larger individuals are andesine (An_{53}), while the micro-phenocrysts of the matrix are somewhat more sodic (An_{47}). The matrix is rather richer in felspar laths than the basalts but contains the same minerals, i.e. granular augite, opaque iron ores, andesine microlites and iddingsite.

Overlying the lavas without augite phenocrysts are basalts rich in augite phenocrysts, approximately 30 feet thick. Such rocks are found from this point, which is 530 feet above the road, up to the east summit of Shanamu. Interbedded with these lavas are thin agglomerate beds consisting of fragments of similar lavas in a fine tuffaceous matrix. The upper series of lavas is rather more fine-grained and contains a higher proportion of felspar phenocrysts than the lower lavas. The rock of the summit (51/358) is micro-vesicular with small felspar and augite phenocrysts in a hard dark grey matrix. The augite phenocrysts are from 5 to 8 millimetres long. The felspar micro-phenocrysts are andesine (An_{49}) and occur as albite and carlsbad-albite twins of tabular habit, lying in a groundmass of plagioclase prisms, brown augite granules and iron ore grains. A few variable-sized olivine crystals, altering to iddingsite, are also present. Several vesicles filled with calcite occur in the slide. The rock appears to be transitional between the specimen 356 and the augite-rich olivine basalts.

The section in the gorge about one mile north-east of Shanamu shows a sequence of lavas and agglomerates dipping westwards. At the mouth of the gorge at the level of the upper Koora valley are exposures of lava similar to the trachytes at the southern end of the Shanamu ridge. In thin section the rock (specimen 51/362) is found to be composed of groups of rather stout irregular anorthoclase phenocrysts in a micro-crystalline trachytic matrix. Brown micro-phenocrysts of basaltic hornblende are common and are surrounded by loosely compacted coronas of small crystals of greenish pyroxene associated with granular opaque oxides. Much rarer are small pale greenish grey augite phenocrysts, while minute granules of augite are common in the groundmass which consists of felspar needles with trachytic arrangement and specks of iron ore. There are rare sphene microphenocrysts.

In the main part of the gorge a sequence of five lavas with porphyritic augites is seen to be interbedded with agglomerates composed of blocks of rock of a similar type. The lavas dip at variable angles westwards and are all between 3 and 15 feet thick. The sixth lava which locally forms the surface is about 30 feet thick and resembles some members of the plateau trachyte series, although it is clearly part of the Shanamu sequence. In hand-specimen this rock (51/363) is medium grey and highly vesicular, the interior of the vesicles being olive green. Felspar phenocrysts up to 5 millimetres in size are very rare. In thin section the rock resembles the plateau trachytes even more closely. Microphenocrysts of alkali felspar are numerous and consist of stout complex-twinned orthoclase crystals, frequently containing zones of inclusions near their margins. Extinction is gradational from one side of the crystal to the other. The small short tabular felspars of the matrix seem to be orthoclase also. Associated with the orthoclase of the groundmass are flecks of brown cossyrite and rare granules of pale green augite.

At the north-western end of the gorge the volcanic series is overlain with strong unconformity by conglomerates and brown silts. Projecting above the silts in the stream-bed at the north end of the gorge is a most unusual rock. In hand-specimen (51/365) the rock is compact and hard and is crowded with rounded felspar phenocrysts which vary from one to eight millimetres in size. The rock also contains small xenoliths of lighter-coloured lava. The matrix of the rock is dark grey and contains scattered ferromagnesian minerals up to three millimetres in size. As seen under the microscope the felspar phenocrysts are rather ragged anorthoclase crystals, which frequently have sutured and lobate margins due to resorption by the matrix. They are variable in size, and exhibit fine lamellar and cross-hatch twinning. Many are patchily replaced by calcite. Several rounded basaltic hornblende crystals that have been partly resorbed by the groundmass are present. A few porphyritic brown biotite crystals with resorbed and darkened margins were recognized in addition, while well-formed pale green augite phenocrysts are common. All the above minerals, together with scattered large iron ore grains, occur as phenocrysts of various sizes in a

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fine-grained ore-speckled translucent groundmass consisting principally of microcrystalline felspar. The various phenocrystic minerals are anhedral with the exception of the augite and biotite. It is probable that almost all of them are xenocrysts. or that the lava represents the mixing of two rather different magma types.

A xenolith occurring in the thin section described above is about one centimetre in diameter and consists of well-formed interfelted tabular orthoclase crystals. The crystals are extensively replaced by calcite spots and stringers and the interspaces between them are filled with calcite. A few acicular aegirine-augite crystals and occasional basaltic hornblende crystals occur in association. The xenolith probably represents a fragment of deep-seated alkaline rock carried up and extruded with the lava in which it occurs. It suggests that carbonate metasomatism may have occurred in the deeper parts of Olorgesailie volcano.

(2) Ol Keju Nero Basalts

These basalts outcrop in the Ol Keju Nero river to the south-west of the Olorgesailie prehistoric site. The section exposing the lavas is about one mile long and shows five superposed flows with various interbedded fragmental deposits. The whole sequence has a variable dip of 10° to 15° to the west-north-west. The basalts also outcrop in the upper part of the scarp north-east of the Olorgesailie prehistoric site. The succession established in the valley is:—

	feet
(Plateau trachytes)	
7. Fine-grained scoriaceous black lava	thin
6. Agglomerates, ashes, volcanic grits and gravels	35
5. Red-brown olivine basalt	?
4. Weathered lava breccia	2–3
3. Reddish grey olivine basalt	?
2. Dark grey compact basalt	a few feet
1. Highly scoriaceous red-weathered basalts	*c.* 200
(Olorgesailie lavas)	

The lowermost lavas are exposed in the eastern part of the section. The third flow, which occurs in a part of the river running through steep cliffs, has a blocky outcrop and contains lines of vesicles. Some evidence of the existence of north-south fracture-zones were seen in this lava.

The reddish grey lava (bed 3, specimen 51/439), when examined in thin section, is seen to be a fine-grained basalt with rather rare mircophenocrysts of augite and common rounded bodies of a red-brown mineral set in a micro-crystalline dusty matrix. The red brown mineral has the lamellar structure, parallel extinction and moderate axial angle of iddingsite, an alteration product of olivine. The rock is therefore a partly altered olivine basalt. The red-brown lava overlying the lava breccia has small augite phenocrysts in a glassy matrix. In thin section this rock (specimen 51/440) shows well-formed very pale green augite phenocrysts set in a dark iron-ore-clouded matrix containing spots of red-brown iddingsite.

The fragmental beds in the upper part of the sequence are bedded agglomerates, ashes and volcanic grits and gravels about 35 feet in thickness. Kunkar limestone beds up to one inch thick are common in the brown grit in the middle part of the succession. The thin scoriaceous black lava overlying the ashes and agglomerate in the western end of the section overlies trachytic lavas of the Olorgesailie Series.

On the crest of the fault escarpment about one mile north-east of the Olorgesailie prehistoric site basaltic lavas form the upper part of the ridge south of the road. North of the road, however, the basalts are overlain by a highly porphyritic trachyte similar to that forming the uppermost lava of the plateau trachyte series. The basalt underlying the trachyte is a highly vesicular rock with a sheen of small plagioclase felspars visible in the dark brownish grey matrix. In thin sections (51/434 and 51/435) the rock is seen to contain tabular andesine-labradorite micro-phenocrysts in a granular matrix consisting of augite, iron ore and small plagioclases. In the matrix are several skeletal crystals of altered iddingsite, some individuals

being almost opaque. The iddingsite contains greenish fibrous relics which may represent serpentinized olivine. Several specimens collected by Shackleton during his survey are of basalts from the Ol Keju Nero river—they are similar to those already described and include specimens 51/22, 51/21, and 51/20. Another of Shackletons specimens (51/28) from the scarp north-east of the Prehistoric site is of a basalt similar to the specimens collected by the writer at the same locality and confirms that, whereas the basalts in the river section carry no microscopically recognizable plagioclase felspars, plagioclase microphenocrysts are common in the basalts of the scarp north-east of the Prehistoric site.

The Ol Keju Nero basalts are seen to overlie the northern terminal flows of the Olorgesailie volcanic series. They also are overlain by the orthophyric trachyte of the Plateau Trachyte Series and by other trachytic lavas east of Legemunge. The Ol Keju Nero basalts are therefore intermediate in age between the Olorgesailie and the Plateau Trachyte Series. A further series of basaltic lavas occurs in the area—the Kirikiti Basalts—which form the step-like ledge on the Nguruman escarpment, and basalts also outcrop near Singaraini railway station. It is probable that the Singaraini and Ol Keju Nero basalts are contemporaneous since they are both overlain by the plateau trachytes. Whether these basaltic series in the eastern part of the area can be correlated with the Kirikiti basalts in the west is open to speculation. Nevertheless the Kirikiti basalts are also older than the plateau trachytes and it can be stated that after the close of the Olorgesailie vulcanicity basalts were erupted over a wide area in the Rift Valley and must have covered a large part of its floor. After the eruption of these basalts faulting took place along the Nguruman escarpment and along the Kwenia trough and probably also to the east of the area, on a line west of Turoka railway station.

(3) Kirikiti Basalts

The Kirikiti platform has already been described as a ledge some one to three miles wide forming the lower part of the Nguruman escarpment. The inaccessibility of both the northern and southern section of the Kirikiti platform did not allow the writer to make as thorough a survey of these parts of the escarpment as could be wished. Sufficient evidence was seen, however, in the best sections available, to make it clear that the Kirikiti basalts rest against the lower part of a pre-existing fault escarpment of Basement System rocks, and that a further movement along the earlier fault-line in the south and along new fault-lines north of the Oloibortoto river, left a ledge of the basalts on the lower part of the Nguruman escarpment and downfaulted the rest of the series, which is of unknown extent, into the floor of the Rift Valley. Previous to the eruption of the Kirikiti basalts the Nguruman escarpment was approximately half its present height, having been formed by faulting and having suffered extensive erosion so as to give its scarp face a moderate to steep eastward slope. After the eruptions the floor of the then Rift Valley must have been covered over an extensive area by basaltic lava flows to a depth, at the western side, of at least 1,000 feet.

There is evidence that near the Nguruman escarpment, where numerous streams must have descended the slope, considerable thickness of conglomerates, sands and silts were laid down at intervals during the eruption of the basalts, with the result that conglomerate and sand lenses are interbedded in the Kirikiti basalt sequence. At the entrance to the lower end of the Oloibortoto river gorge a small cliff shows the following section:—

	feet
8. dark grey basalt	12
7. quartzite conglomerate	20
6. yellow sandstone with grey grit in upper part	15
5. conglomerate of quartzite pebbles	6
4. yellow-brown grit and sandstone	7
3. conglomerate of quartz and quartzite pebbles	4–8
2. light brown current-bedded sandstone with pebbles	5
1. fine-grained dark grey basalt	4–6

Further up the gorge, up to the fault breccia separating the Kirikiti lavas from the Basement System quartzites, are hard fine-grained dark grey basalts, which are probably higher in the sequence than the members of the succession given above. One of these, specimen 51/394, is seen in thin section to contain numerous clear crystals of olivine, together with crystals of pale purplish brown augite, opaque iron ores and plagioclase felspars.

Ascending the escarpment about one mile south of the entrance to the Oloibortoto gorge the lower part of the escarpment is found to consist of scree and rolled alluvial boulders near stream-channels. The lowest exposures of rock *in situ* are at 2,774 feet O.D. and consist of grey fine-grained lava with no phenocrysts but rare amygdales. In thin section (specimen 51/389) the rock is revealed as a rather fine-grained equigranular olivine basalt with labradorite, augite, olivine and iron ore. Similar rocks continue upwards to 3,264 feet O.D. where the lava (specimen 51/390) is a basalt similar to those below but is rather more coarse-grained and has calcic andesine plagioclase (An_{49}); the rock also contains iddingsite in which one or two relic olivines can be seen. The rocks at the edge of the escarpment (specimen 51/391) are exactly similar to those previously described, being typical olivine basalts with the olivine partly altered to iddingsite.

The upper surface of the Kirikiti platform, which is at an altitude of 4,298 feet O.D. at the point climbed, is flat and level and has occasional outcrops of olivine basalt. The platform is approximately two miles wide at this point and the ground west of it slopes upwards at an increasingly steep angle to the forested upper slopes of the Nguruman escarpment. Although that part of the escarpment was not visited, since it is just to the west of the area being described, outcrops of Basement System gneisses are discernible on the upper slopes.

Traversing up the narrow ridge immediately north of and overlooking the entrance to the Oloibortoto gorge, rocks similar to those described above are found. Although the exposures in the face of the escarpment are not sufficiently good to enable one to discern individual lava flows, it is possible to distinguish a bedded sequence when the escarpment is viewed from a point a few miles to the east. The lava flows are then seen to be regular and level, their surfaces being parallel to the upper surface of the Kirikiti platform.

The river section up the escarpment west of Camp V on the Uaso Nyiro passes along the north side of a tilted fault-block of Kirikiti lavas. At the north-eastern extremity of the fault-block are fine-grained grey olivine basalts. These rocks are traversed by curious curved joints partly infilled with dirty white kunkar limestone. The whole of the fault-block is built of at least three superposed basaltic lavas with intervening brecciated and reddened weathered zones. On entering the gorge in the Nguruman escarpment proper, at the north-western end of the fault-block, the basalts are seen to overlie migmatitic gneisses of the Basement System. The cliffs at this part of the gorge are too steep to climb, but viewing the cliffs from below it seems as if the Basement System surface, which slopes eastwards, is overlain by a succession of several hundred feet of alternating conglomerates and sands. High up in the cliff, near the top of the Kirikiti platform, are one or two lava flows. Specimens obtained from scree at the base of the cliff suggest that these lavas are olivine basalts similar to the others described.

The character of the Kirikiti platform changes somewhat in the northern part of the area. The main Kirikiti fault which is responsible for the scarp at the east edge of the platform splits into several distinct faults which trend north-eastwards and finally amalgamate again east of Leshuta, where the fault is along the gorge of the Uaso Nyiro. East of the Naimithigirya plateau the westernmost fault of the system lowers the plateau surface considerably and tilts it eastwards. This eastward tilt is maintained as far east as the Uaso Nyiro where the lava surface rises again. The structure of this part of the area east of the Naimithigirya plateau is that of a tectonic depression with the west side of the basin raised somewhat by faulting. The platform of the ledge descends by a series of outward tilted steps instead of being a single high cliff-like scarp as is the case in the rest of the area. The sequence of lavas in the tilted fault-blocks south of Leshuta is clearly seen in a number of sections in streams flowing off the Naimithigirya plateau down to the Uaso Nyiro. In several of these sections two distinctive lavas occur separated by a variable thickness of red earth. The upper lava, a basalt, has a spheroidal type of weathering which is characteristic throughout its outcrop, while the lower lava is cut by curved joints filled with kunkar limestone. The intervening red earth also contains more or less vertical kunkar limestone veins which are cut off by the upper "spheroidal" basalt. In the sections south of Leshuta both the "spheroidal" and "veined" basalts together with the red bed dip at gentle angles eastwards in sympathy with the surface of the ground.

On traversing up the Lengitoto river towards the west two basalts are seen to overlie the red bed. In the main scarp bounding the Naimithigirya plateau on the east at least eight horizontal superposed lava sheets can be seen in a vertical cliff. On climbing this escarpment

a mile or two south of the Lengitoto river waterfall, at one of the few places where it is possible to get up the scarp face, the rocks at the base of the escarpment are seen to be dark grey compact basalts.

The surface of the Naimithigirya plateau, which is at an altitude of 4,500 feet O.D., is level and has few exposures. The plateau continues westwards outside the area and finally abuts against the lower slopes of a strike ridge of Basement System rocks. The uppermost lava of the Kirikiti series, which forms the Naimithigirya plateau surface, is an olivine basalt (51/417) which is very similar to the Kirikiti olivine basalts near the Oloibortoto gorge. The rock contains olivine partly or completely altered to iddingsite, augite, labradorite and iron ore. It is non-porphyritic, grey and massive in hand-specimen.

(4) Lengitoto Trachyte and Associated Sediments

To the north of the Lengitoto river there is a low plateau, the Lengitoto plateau, standing up from the Naimithigirya plateau. It is bounded by a distinct scarp about 150 to 200 feet high and is composed of a lava overlying tuffaceous silts, which rest on the Kirikiti basalts. The sediments consist of approximately 100 feet of beds, the upper part of the sequence being exposed and consisting of buff clays, and laminated green and white tuff which is current-bedded in parts. The overlying lava (specimen 51/419) is a hard pale greenish grey rock showing faint colour-mottling but no vesicles or phenocrysts. In thin section the rock shows a marked similarity to the plateau alkali trachytes, its groundmass being identical with that of the widespread alkali trachytes described in the following section. The rock contains dusty stout tabular orthoclase crystals of rather ragged habit which are usually twinned on the carlsbad law. These form approximately 70 per cent of the rock by volume. The ferromagnesian minerals, which are intersertal to the felspars, are green ægirine, kataphorite pleochroic from pinkish brown to greenish brown, and strongly pleochroic brown to almost opaque cossyrite.

The occurrence of a trachyte lava resting on the Kirikiti basalt series suggests that it may be the lowermost member of the Plateau Trachyte Series which was erupted previous to the faulting of the Kirikiti platform. The rest of the plateau trachytes occur on the floor of the Rift Valley at a much lower level, where they were erupted subsequent to the Kirikiti faulting and where they are assumed to overlie the Kirikiti basalts.

(5) The Plateau Trachyte Series

The Plateau Trachyte Series consists of alkali trachyte lavas which are widespread throughout the area. They are well exposed in all the fault escarpments throughout the central part of the area, and in these escarpments it is frequently possible to trace individual lava sheets for many miles. The megascopic and microscopic features of the rocks remain the same over large areas of outcrop and the constancy of their characters and the evidence that the lavas are widespread makes it probable that the same lava outcrops over most of the area covered by the series. In some of the larger escarpments the presence of up to ten or eleven distinct superposed lava sheets, and the regularity with which the uppermost lavas recur in nearby escarpments, suggests that there is little lateral variation in the thickness and number of the lava flows. This widespread regularity of members of the series, and the fact that no vents from which they could have been erupted have been discovered, suggests that the series is composed of plateau-type lavas that may have welled up quietly through fissures.

The lavas of the Plateau Trachyte Series are seen to overlie all the preceding lava series in various sections of the area. Their contact with the Kirikiti basalts was, however, not observed, although the contact could probably be found in the upper reaches of the Uaso Nyiro south-east of Leshuta.

The surface of the ground covered by the lavas of the Series consists, on the up-standing fault-blocks, of lava debris, rubble and, over considerable areas, of bare rock. The soil is a light brown dust and is confined to depressions in the lava surface. Grass is scant and low thorn bushes are scattered. Exposures are therefore excellent and the numerous fault escarpments offer opportunities to examine vertical sections. Surface structures in the lavas are often seen and lineation due either to lines of vesicles or to a preferred orientation of the long axes of the vesicles are often seen. In general, surface exposures are highly vesicular and brecciated, while cracks and curved flow layers indicate the rough nature of the original lava surface. In small escarpments the surface irregularities frequently give way a few feet below

the upper surface of the lava flow to massive rock traversed only by rather closely spaced horizontal joints and much more widely spaced vertical joints. Many of the outcrops of the trachytes are slabby while only a few consist of fissile or massive rocks. The exposures are usually weathered to a black or deep brown colour and a few inches below ground surface the lava fragments are often coated with dirty kunkar limestone. On weathered surfaces rather scattered characteristically yellow-brown felspar phenocrysts are usually visible but no other minerals are discernible with the naked eye.

On clean unweathered surfaces the trachytes are seen to be fine-grained, the matrix being a medium greenish or brownish grey colour sometimes being mottled in lighter and darker shades. Scattered clear, often yellowish, idiomorphic felspar phenocrysts about a quarter to a half centimetre in size are seen. Some specimens are rather lighter grey than most and others have a reddish tinge, but generally speaking the rocks of the group are very similar in both macroscopic and microscopic characters.

In thin section the uniformity throughout the rocks makes it unnecessary to describe individual specimens, the group characteristics of the commonest types are described in the next few paragraphs followed by descriptions of varieties.

Three generations of felspars are discernible—phenocrysts of 6 to 8 millimetres size, micro-phenocrysts which reach $1\frac{1}{2}$ to 2 millimetres, and the felspars of the groundmass which vary somewhat but are approximately 0·1 to 0·3 millimetres in size. Since the phenocrysts are rather rare, there being usually only one or two visible per square foot of surface area of the rock, they are rare in the thin sections. Twinning is rather rare but when it occurs it is according to the Carlsbad law. The phenocrysts are probably anorthoclase.

The felspars of the groundmass and the micro-phenocrysts are anorthoclase which is evidently rich in sodium, as is indicated by the norms calculated from analyses of members of the series from near Lake Magadi. The micro-phenocrysts are more common than the phenocrysts, and are rather ragged in outline, showing only one or two crystal faces. Extinction is undulose in many examples, and an ubiquitous feature is a dusty zone of included prisms of ægirine near the margins of the crystals. This feature is so common that it is diagnostic of the Plateau Trachytes. The felspars of the groundmass are small and comprise approximately 60 to 70 per cent of the volume of the rock. They are rather stout tabular crystals commonly with a rectangular outline and frequently have dusty inclusions in their centres or, where the groundmass felspars are rather larger than usual, as in specimen 51/320 (S.W. lagoon, Magadi) they have a zone of dusty inclusions. The zone of inclusions tends to be in the central part of small crystals and occurs more towards the margins in larger individuals.

Intersertal in the groundmass of felspars are green ægirines occurring as small, usually elongated, crystals. The ægirine is rather variable in quantity and in the majority of the specimens is associated with cossyrite and kataphorite, but in some cases it is the sole ferromagnesian mineral, while in others cossyrite is the predominant dark mineral. The cossyrite is almost opaque in some rocks and has an ophitic relation to the felspar in the groundmass. Angular grains of opaque iron ores are rather rare in these rocks. Quartz was found in four rocks, viz. specimens 51/323, 51/331, 51/332 and 51/412, from the south-west lagoon, from the south-east lagoon, from six miles east of the south-east lagoon, and from the south end of the Koora trough respectively. The quartz occurs as interstitial grains, usually in groups, in the matrix of the rocks. The presence of quartz in the norms of the rocks analysed (p. 20) suggests that small amounts of this mineral may be widespread in the trachytes. The observed occurrences of modal quartz are, however, in specimens from near the southern boundary of the area, and it is possible that the plateau trachytes are represented locally by quartz trachytes. The general petrographic character of the trachytes and the occurrence of quartz in some of them suggests correlation with the Limuru quartz trachytes of the area west of Nairobi (cf. Shackleton, 1945, table opp. p. 6 and Sikes 1939, p. 22).

The textures of the groundmasses of these rocks vary from trachytoid almost to granular, the determining factor being the degree of elongation of the felspar crystals. The rocks are probably most nearly related to the kalitrachytes described by Johanssen (1937, pp. 18–20) as consisting principally of potash felspars, sodic pyroxenes and one or other sodic amphibole. They are referred to by the more general name of alkali trachyte for the purposes of this report.

Coates (*see* Anonymous, 1932, pp. 435, 440) collected several specimens of lavas near Lake Magadi and these were analysed with the results tabulated in the following table. The rocks were identified as soda-pitchstone (A) and soda-trachytes (B, C, D, E) by the writer of the paper, but they are all alkali trachytes in the sense used for the present work.

ANALYSES OF ALKALI TRACHYTES FROM THE VICINITY OF LAKE MAGADI

	A	B	C	D	E
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
SiO_2	59·41	59·38	61·24	60·25	63·81
Al_2O_3	12·03	10·84	13·53	10·87	12·76
Fe_2O_3	4·53	3·92	4·52	5·08	4·74
FeO	3·93	4·28	3·36	3·50	1·65
MgO	0·63	0·89	1·06	0·83	0·57
CaO	1·39	3·31	1·98	2·73	0·40
Na_2O	6·37	5·60	4·95	6·29	5·67
K_2O	4·36	5·01	3·86	4·77	5·12
H_2O	4·05	3·14	2·50	1·25	2·67
CO_2	tr	1·30	0·35	1·06	0·18
TiO_2	0·81	0·81	0·99	0·88	0·69
P_2O_5	1·06	1·00	0·99	1·62	1·58
SO_3	0·27	0·04	0·09	0·08	0·24
Cl	0·05	0·007	0·02	0·06	tr
MnO	0·65	0·35	0·34	0·83	0·31
TOTALS ..	99·54	99·877	99·78	100·10	100·39

Anal.: Imperial Institute.

NOTE.—Subtraction of oxygen equivalent to chlorine was not made in the original analyses No alteration has been made here as the equivalents do not exceed 0·014 per cent.

NORMS

	A	B	C	D	E
Q	7·74	6·78	15·29	11·40	15·53
or	26·05	29·50	22·80	28·35	30·01
ab	37·73	28·85	40·08	29·32	37·20
an	—	—	1·66	—	—
ns	—	1·00	—	—	—
di	0·69	2·06	—	—	—
hy	2·98	7·99	4·28	7·94	0·20
ac	12·47	11·05	—	12·46	6·00
mt	0·23	—	6·50	1·16	3·94
il	1·52	1·52	1·82	1·67	1·22
ap	2·35	2·34	2·35	3·70	2·35
cc	—	2·90	0·80	1·60	0·40
C	—	—	0·81	—	—
hl	0·12	0·20	0·06	0·24	—
th	0·42	0·07	0·14	0·14	0·42
nc	—	—	—	0·76	—

A—From one mile north-north-east of "Needle Rock"
B—From near Magadi Hospital
C—From two miles south of Magadi golf-course
D—From three miles north of the south-west lagoon hot springs
E—From half a mile west of the north end of "Little Magadi" lake.

The norm of analysis C shows excess alumina and a high figure for albite, with a lack of acmite in consequence. It is possible that the divergence of this norm from the others is due, in part, to analytical inaccuracies.

Varieties of the plateau trachytes are found in a number of places but the variations are only slight and do not alter the naming of the rocks. The thin section of specimen 51/326 (from three miles west of Koora) shows the presence of one or two rather large twinned augite crystals and has rather a higher proportion of dark minerals than usual. In specimen 51/324 (from the S.W. Lagoon, Magadi) there are again occasional micro-phenocrysts of augite, and in the matrix cossyrite occurs with ægirine-augite, and kataphorite is also present.

In the northern part of the area a distinctive lava covers a considerable amount of ground. This lava, which is an *orthophyre-trachyte*, conformably overlies the uppermost members of the Plateau Trachyte Series, and is the lava on which the "tor" and "hot cross-bun" surface structures are found (*see* p. 7). Both in the scarp north of En Doinyo Nyiro and in the scarps at the northern end of the Legemunge plain there are sections showing the orthophyric trachyte resting with conformity on the alkali trachytes, there being no intervening sediments.

The areas of outcrop of this lava can always be clearly observed from a distance because of the distinctive surface features to which it gives rise. The surface is much more rough than in any other part of the area, soil cover is more extensive and thick, and through the soil the lava outcrops as piles or large rounded boulders resembling "tors". The appearance of the orthophyre-trachyte is similar wherever it is seen; the surfaces of the boulders are weathered dark brown or black and the numerous large felspar phenocrysts, which make up about 50 to 60 per cent of the rock by volume, protrude from the weathered surfaces. In hand-specimen clean surfaces of the rock are light to medium grey in colour, sometimes with brownish tinges. The felspar phenocrysts, the cleavage faces of which impart a sheen to the rock are of much the same colour as the groundmass, and do not stand out by virtue of their colour as one might expect. The rock is usually only vesicular at its lower contact but hand-specimens appear to be rather porous, having numerous minute angular cavities in the groundmass, which is rough to the touch. On striking with a hammer small rocky outcrops usually disintegrate into small angular fragments, and, as has been mentioned in the discussion of the surface structures, the exposures appear to be subject to extremely rapid weathering.

In thin sections the rocks show little variation. The felspar phenocrysts (as in specimen 51/401, from two miles west of the two "hot cross-bun" structures) are anorthoclase and reach over one centimetre in size. They frequently occur in glomero-porphyritic aggregates, the individual crystals having rounded outlines. Smaller phenocrysts are frequently idiomorphic and are often traversed by cracks or spotted with dusty inclusions. A wide variety of twinning phenomena is found: indistinct lamellar twinning is rather rare but cross-hatch twinning is more common, particularly in the euhedral anorthoclase phenocrysts of specimen 51/314 (north of Kisamis). The felspars are characteristically iron-stained on cracks and, rarely contain small augite inclusions.

The groundmass is somewhat similar to that of the plateau trachytes. Pale green augite microphenocrysts are quite common; they are anhedral and vary considerably in size. The matrix is felspathic and consists largely of small stout prisms of alkali felspar which rarely show Carlsbad twinning. The crystals vary considerably in perfection of crystal form. In all slides, particularly in specimen 51/402 from a point north-east of the two "hot cross-bun" structures, some of the felspars are rather angular in outline, but the majority show a semblance of rectangular outlines. Red-brown cossyrite is the ubiquitous dark mineral of the groundmass. In specimen 51/402 it is seen mantling green augite, but generally it occurs as shards and wisps in the matrix. One or two rutile crystals as well as magnetite and apatite occur in the same thin section as accessory minerals, and in some slices secondary calcite is present in small amounts.

The orthophyre-trachyte occurring on the top of the scarp north-east of the Olorgesailie prehistoric site differs somewhat from the usual type. In hand-specimen (51/433) the rock is highly porphyritic and weathered to a dark reddish brown colour. In thin section, however, it is seen to have the same minerals and textures as those described above. The pale green augites are rather larger and better formed and the anorthoclase phenocrysts are of rounded

irregular outline with lobes of the groundmass penetrating into them. They are dusty with minute inclusions near their margins and in the vicinity of cracks. The groundmass, which consists of subhedral rather granular alkali feslpars, contains numerous small opaque iron ore grains. The orthophyre-trachyte on this scarp directly overlies Ol Keju Nero basalts.

(6) Ol Doinyo Nyegi Volcanics

Ol Doinyo Nyegi, the second largest mountain in the area after Olorgesailie, rises to 3,835 feet above sea-level and some 1,000 feet above the level of the surrounding country. It is more or less hemispherical in outline and is conspicuous from the main road to Magadi because of the cliffs and lines of lava clearly visible on its western flank. The mountain, which is a volcano, is almost cut in half by a fault down-throwing to the east, the eastern third of the mountain being buried below the sediments filling the Koora valley. A fault has also thrown down a small part of the west side of the mountain, giving rise to the cliffs there. The structure of the volcano is indicated in Fig. 4.

The mountain is constructed of more or less hemispherical sheets of porphyritic obsidian of varying thickness, separated, on the south-west slopes, by beds of brown to yellow-brown scoriaceous ash. The ratio of glassy lava to ash in the south-west slope of the hill is about one to three. The cliffs on the west side are composed of black obsidian with prominent devitrified brown laminations. The obsidian contains numerous phenocrysts of orthoclase in the form of rather stout prisms about a quarter of an inch long. On the south-west slopes eight distinct obsidian flows of which the fourth and the eighth are the thickest are visible in the hillside. The eighth is some 200 feet thick, at the same horizon as the obsidian which forms the cliffs on the western slope and may be composed of several flows.

The slope of the upper part of the hill on the western side conforms to the surface of the "main obsidian" band, as the eighth and thickest lava may be termed. On approaching the summit ridge the slight rise to the summit is found to be composed of a laminated pale and dark brown highly vesicular porphyritic glass. In thin section this rock (specimen 51/336) is found to consist of red-brown glass with numerous vesicles with opaque oxidized rims and filled with colourless spherulitic and flamboyant growths of chalcedony. Orthoclase microphenocrysts are rather common, showing Calsbad twinning and slightly resorbed margins.

The summit ridge is curved and concave to the east and from the ridge the descent eastwards rapidly steepens into a deep amphitheatre cut off on the east by the cliffs descending to the Koora plain. The amphitheatre presumably represents the crater of the volcano, and the summit ridge the last lava, which failed to flow very far down the hillside.

At the base of the north-west slopes there is a total of seven small ash-vents. None of these small ash-cones is more than 100 feet high and those on the west slope are situated on the fault-plane. The cones, which are steep-sided and have no depressions at their summits, are extremely fresh—no soil has developed on them and only a little grassy vegetation. The ashes consist of yellow-brown highly scoriaceous fragments up to half an inch in size in a fine brown volcanic dust. There is only a trace of bedding and the rocks are uncompacted. Ash beds extend from these cones to the west and cover the flat ground up to a mile to the south-west of the hill.

A satellite vent, some 200 yards in diameter at the base and approximately 150 feet high is found at the foot of the southern slope of the hill. It is composed of vesicular dark grey fine-grained lava with a few felspar phenocrysts approximately half an inch in length. This vent probably formed before the faulting and appears to be older than the ash vents. Its lavas did not flow further than the slopes of the vent itself.

A section in a stream-bed about one mile south-west of Ol Doinyo Nyegi is shown in Fig. 5. Here ashes overlie the uppermost of the alkali plateau trachytes and are overlain by and interbedded with green, black and brown glassy lavas similar to those found on Ol Doinyo Nyegi. The section includes a fault upthrowing the plateau trachyte to the east. The ashes, which in this section clearly belong to the main eruptive phase of the volcano, are older than the faulting.

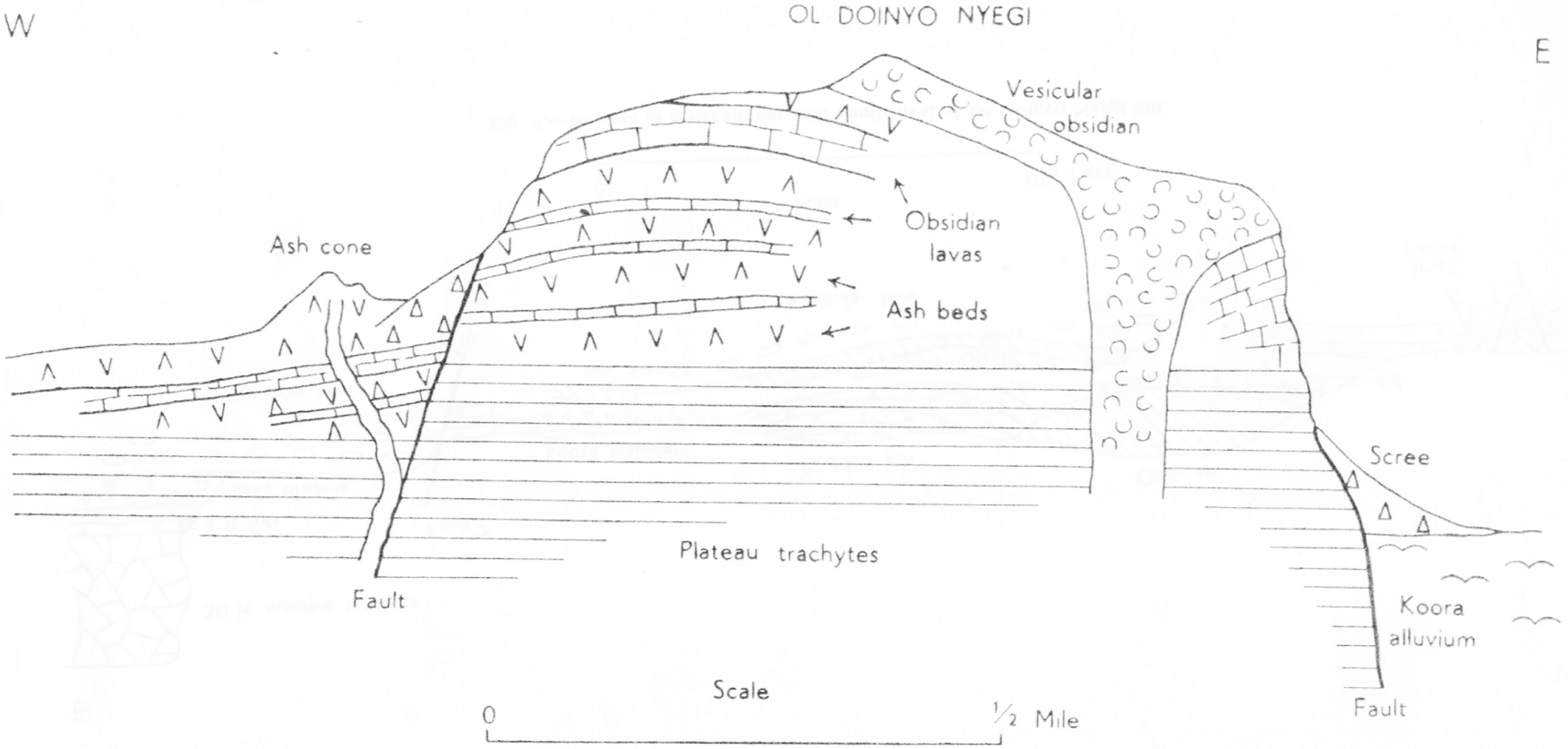


Fig. 4.—Diagrammatic section through Ol Doinyo Nyegi hill.

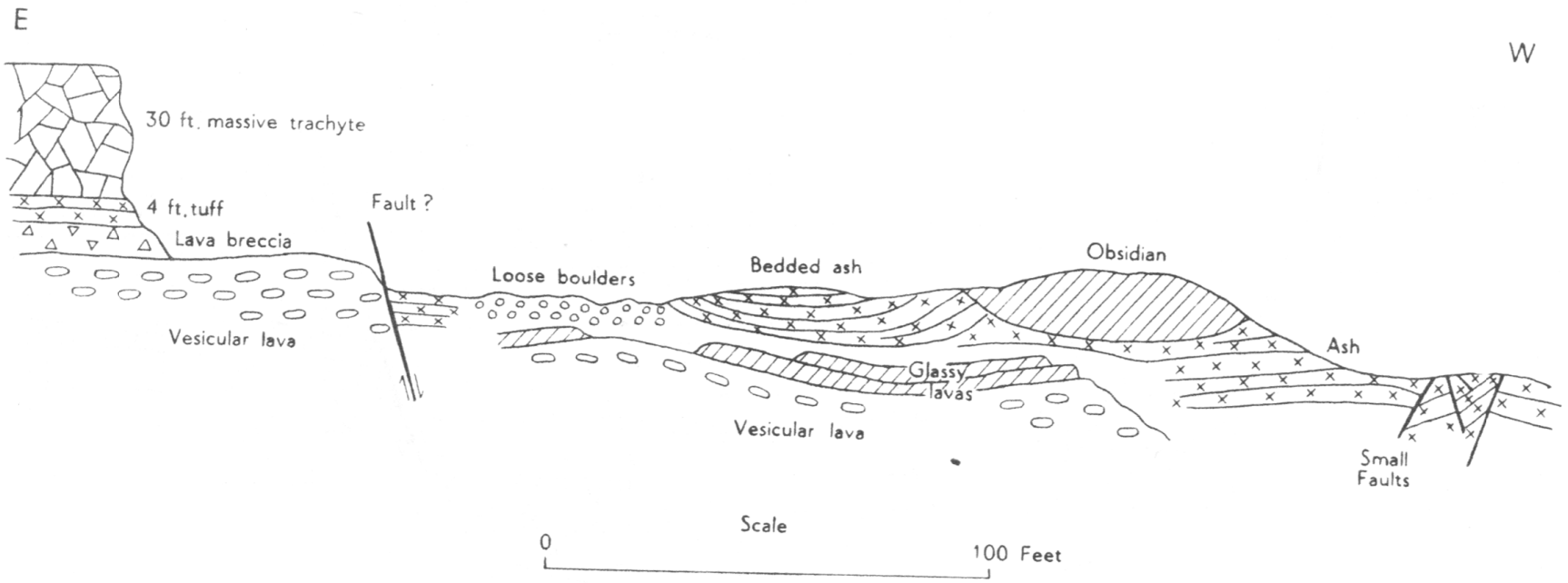


Fig. 5.—Section in a stream one mile south-west of Ol Doinyo Nyegi hill.

About three-quarters of a mile north-west of the hill a section exhibits reddish brown and black microcrystalline to glassy lavas overlying plateau trachyte lavas. The junction is not visible and the glasses, which total about 32 feet in thickness, dip at 41° to the north-east. The reason for the anomalous high dip is not apparent.

The fault-scarp truncating the eastern part of Ol Doinyo Nyegi was visited to see if part of the neck of the volcano was exposed in the cliff. The cliff on this side reaches some 800 feet in height and its lower part is obscured by scree while the upper part is inaccessibly steep. So far as can be observed from below, the neck of the volcano is not cut by the fault and the cliff seems to consist of plateau trachyte in the lower part, followed upwards by more or less conformable sheets of obsidian without interbedded ashes.

The volcano was therefore built on a platform of alkali trachytes and its extrusions consisted of glassy lavas alternating with ashes, some of which travelled at least one mile from the centre. Two faults then cut through the volcano, one downthrowing the eastern third of the hill to the east, by at least 800 feet, the other downthrowing a small part of the western flank to the west by at least 300 feet. A number of small ash cones then formed, mainly on the western fault-plane, and brought the vulcanicity to a close.

(7) Ash and Scoriaceous Lava Vents

Several small vents composed of ash or scoriaceous lava are found overlying the plateau trachytes. Since some of these have been cut by grid-faults, and since they are all petrologically related to the plateau trachytes, it is supposed that they represent the closing phase of alkali trachyte vulcanicity.

The largest vent of this type is Kisamis, an almost undissected hill with the typical outline of a volcano and a central crater depression. The hill was not examined in detail but exposures at the base suggest that it is composed almost entirely of fine-grained highly vesicular porphyritic lava, similar to that forming the summit ridge of Ol Doinyo Nyegi. Some exposures consist of fragmental and brecciated rocks while others are of agglomerate composed of small fragments of lava similar to that forming the bulk of the hill.

A small hill situated about five miles south of Ol Doinyo Nyegi, near the edge of a fault escarpment, is about 300 yards in diameter at the base, rounded in outline, and composed of a finely vesicular, almost pumiceous, lava of fine grain carrying sparse clear felspar phenocrysts. The rocks are highly weathered to a red-brown colour. On the western slope of the hill and at its base bedded brown porous ash is found dipping steeply away from the vent. The ash is confined to a zone about 50 yards wide on the west margin of the hill and the ash beds rest on a weathered surface of plateau trachyte.

Situated some two miles west of the Legemunge plain, on the edge of the main fault escarpment forming the east wall of the central Magadi trough, is a rounded hill rising some 300 feet above the surrounding plateau trachyte surface. It is composed of laminated brown and black cryptocrystalline lava (specimen 51/370) which, in thin section, is seen to be composed of small partly resorbed microphenocrysts of orthoclase in a reddish brown glass groundmass. In the sides of small stream-channels on the eastern margin of the hill the lava is seen to overlie thin impersistent beds of agglomerate containing lava fragments up to one inch in size. The hill is bisected by a narrow fault-trough, the western part of the hill now being several hundred feet below the eastern part; the central part in the trough has been partly covered by alluvium.

Koriamát, a small hill a few miles east of Kisamis, was not visited by the writer but some float fragments found in a stream-bed nearby were of pumiceous fine-grained lava probably derived from this hill. Its appearance suggests that it is a small vent similar to those described previously. It is bisected by a small fault downthrowing to the west.

En Doinyo Nyiro, a small hill on which a trigonometrical survey point is established, is about one mile west of the fault escarpment bounding the west side of the Kordjya plain. The summit and slopes show scattered exposures of a dark grey to black partly devitrified glassy lava crowded with small felspar laths about one millimetre in length. In thin section the rock of the summit (specimen 51/386) is seen to consist of dark red-brown, almost opaque, glass containing numerous partly resorbed potash felspar microphenocrysts.

The principal features of these small glassy lava vents are their similarity in shape and size, their relation to the plateau trachytes, and the likelihood that they are all of the same age, that is, later than the plateau trachytes and earlier than the grid-faulting. They are therefore probably of the same age as Ol Doinyo Nyegi. The small ash cones associated with Ol Doinyo Nyegi are, however, much younger than the vents described above, since they are unaffected by the grid-fault on which they rest, and since the unconsolidated ashes of which they are composed are almost untouched by erosion.

3. Lacustrine and Fluviatile Sediments

Lake beds are widely distributed throughout the area and bear witness to the fact that at times large lakes existed on the floor of the Rift Valley. Unfortunately the numerous fault escarpments make correlation between different series of lake beds difficult, and erosion has affected these almost unconsolidated rocks much more than the lavas.

Almost without exception lake beds occur only in the bottoms of fault-troughs where they have been protected from erosion. Thus it is very common that all depressions and fault-troughs are partly filled and floored by sedimentary rocks, while the neighbouring raised fault-blocks are of bare lava. Unfortunately in almost all the troughs alluvial silts, clays and boulder beds cover and obscure the lake beds and it is in only a few places that any useful sections in them can be found. Apart from the Magadi trough, where exposures of lake beds are fair, there are only two places where evidence concerning the relationship of the lake beds to the underlying rocks can be obtained: one is on the Oloronga plateau and the other is at the southern edge of the Legemunge plain.

The Oloronga plateau slopes gently westwards and eventually passes under the alluvial plain of the Uaso Nyiro. Resting conformably on plateau trachyte lava is a thin sequence of lake beds with gentle dip to the west, covered by kunkar limestone. The exposures indicate that the lake beds were laid down on a more or less smooth level surface of plateau trachyte and that both lavas and the lake beds overlying them were subsequently faulted and slightly tilted. Faulting has also affected the Olorgesailie lake beds north of Olorgesailie mountain. The faults are not large and the lake beds were deposited in the Legemunge fault-trough and did not extend far, except possibly down the Koora and Kwenia valleys.

In connexion with the deposition of the lake beds Parkinson (1914, p. 42) states: ". . . I conclude that the Nguruman scarp on the west and the great scarp near Mile 62 on the east are older than those which lie between; the faulting took place during the deposition of the lacustrine beds, and the lateral parts of the lake were thereby drained and deposition continued in the central area". Parkinson therefore suggests that all the lake beds can be attributed to one lake, though this lake was split into minor lakes by faulting and persisted till the present day only in the Magadi trough. In the Magadi trough, however, there is evidence for at least two distinct series of lake beds whose deposition was separated by a period of faulting, and it is considered probable that similar series exist in the larger basins of deposition such as the lower Uaso Nyiro basin and the Kordjya and Koora troughs, although this cannot be demonstrated.

The lacustrine sediments have therefore been divided into series, occurring in different places and between which correlation is to some extent speculative. A general correlation table for the groups of sediments discussed below follows:—

Magadi trough	Legemunge-Koora trough	Uaso Nyiro basin
Evaporite Series High Magadi Beds kunkar limestone	boulder trains and sands kunkar limestone	high terrace kunkar limestone
minor faulting Chert Series*	Olorgesailie Lake Beds	Ngare Nyiro Beds
grid faulting		kunkar limestone Oloronga Beds
Plateau Trachytes (in part Olorgesailie lavas)		

*Subsequent work has shown that the Chert Series occurs lower in the succession. *See* Appendix, p. 81.

(1) The Oloronga Beds

As previously mentioned the Oloronga beds overlie plateau trachyte lava and dip gently to the west. The area of outcrop is not large since superficial hill-wash and soil cover the beds at many places, and towards the west they dip below the Uaso Nyiro alluvium. The surface of the beds is covered with two kinds of kunkar limestone—a pale greyish white platy variety and a brownish white nodular variety containing large oolitic bodies. Only the upper few feet of the beds are exposed in stream channels on the higher, eastern edge of the plateau, where they consist of yellowish brown calcareous silts with irregular bedding. Lower down the slope, near the point where the beds pass under the Uaso Nyiro alluvium, a number of small sections show the following sequence:—

	ft.	*in.*
3. Nodular kunkar limestone	1	6
2. Yellow-buff fine silt	4	–
1. Light brown porous ash	4	–

Northwards from the Oloronga plateau the country is broken into fault-blocks and superficial gravels and light brown structureless loess-like silt fills the troughs. These circumstances, where troughs are partly filled with fine-grained unbedded silts, are very common throughout the area, and make it difficult to determine whether lake beds that have been faulted and tilted like the Oloronga beds occur in other areas. It is clear in the case of the Kordjya basin, which is connected to the Oloronga plateau, that the trough is filled with several hundred feet of sediments of some sort, but exposures only show superficial material, soil and fluviatile deposits. The fact that in many of the longer troughs which decline gently to the south the surface of superficial deposits declines southward also, suggests that the troughs are floored with lake beds older than the faulting and which were tilted in sympathy with the lavas on which they rest.

Of the few exposures indicating the existence of beds similar in age to the Oloronga beds, one is by the roadside where the Magadi-Uaso Nyiro road crosses the narrow fault-trough linking the Kordjya plain to the Oloronga plateau. The beds at this spot rest on an irregular surface of alkali trachyte and dip at some 2° northwards. They show the following sequence:—

	ft.	*in.*
4. platy kunkar limestone	–	4
3. brown silt	7	–
2. honeycomb rock	3	–
1. light brown bedded silt	10	–

The honeycomb rock is most unusual; it is light brown in colour and consists of irregular septa enclosing angular cavities about 0·5 to 1 centimetre in diameter. The cavities are rarely filled with brown earthy material which effervesces slightly with acid. The cavities may be due to the solution of crystalline salts, but, being irregular and dissimilar in shape to most crystals of sodium salts this is considered unlikely.

About a mile to the south of the above occurrence, by the water pipe-line in the same trough, a small section in lake beds with a dip of 1° to the north-west is seen:—

	ft.
2. current-bedded yellow-brown silts	8
1. fine-grained buff-brown clay (unbedded)	10

A pillar of travertine limestone about 35 feet high and 12 feet across the base occurs by the side of the Magadi-Uaso Nyiro road near the descent down the last escarpment on the way to the Uaso Nyiro. The pillar is composed of brownish white and porous travertine in the form of vertical pipe-like structures with horizontal septa. Under the microscope it is seen to be composed (specimen 51/382) of fine-grained calcite. Temperley (1951, p. 22), describing this pillar, concludes that it may have originated by calcification of lake beds, possibly at the intersection of vertical joint-planes, and that the calcified rock remained standing after the removal by erosion of the surrounding unconsolidated lake beds. The

writer, however, failed to see any trace of bedding or of lake beds included in the travertine and although it is possible that a thin layer of lake beds rested on the lava surface in this area and has since been removed by erosion, it is considered that the travertine pillar was built by a feeble calcareous spring after the lake beds had been eroded away.

In the Magadi trough, between three and four miles north-north-west of Shanamu, at the northern end of a plain consisting of unconsolidated silts, there are exposures of lake beds beside the track shown on the map. The succession at this point is:—

	ft.	*in.*
5. yellow brown silt (superficial)	8	–
4. brick red ashes	15	–
3. green ashes	2–3	–
2. green fine-grained silty clays	4	6
1. yellowish porcellaneous clays..	2	–

The rocks dip gently to the south and it is uncertain whether they are part of a widespread series of lake beds or were laid down in the trough after it had formed by faulting.

About a quarter of a mile north of the north-eastern lagoon of lake Magadi in the west side of a narrow steep-sided fault-valley a sequence of about 40 feet of green silty clays is exposed dipping gently southwards and resting on a lava surface. The upper surface of the clay beds is approximately 100 feet above lake-level and the exposures indicate the clays were laid down after the formation of the valley. They may possibly be equivalent to the basal part of the Chert Series.

The sections described suggest that lacustrine sediments were deposited fairly widely on the plateau trachytes previous to the grid-faulting. Such lake beds may be more widespread than has been indicated and may be present as the lowermost lacustrine series in nearly all the larger basins where they have been protected from erosion. It is clear, however, that even if lake beds were deposited on the lavas before grid-faulting began, the series could not have been very thick, no thicker perhaps than 50 feet, or some relics would be preserved on the fault-blocks at the present day.

(2) Ngare Nyiro Beds

As indicated in the tabulation of the sequence the Ngare Nyiro beds are considered to be equivalent in age to the Olorgesailie Lake Beds and possibly the Chert Series. These groups of sediments are confined to the troughs in which they occur and were laid down subsequently to the major grid-faulting episode which gave the Rift Valley floor more or less its present shape. The lake beds are considered to have been deposited more or less contemporaneously in the three tectonic depressions—the Uaso Nyiro depression, the Magadi trough and the Legemunge-Koora-Kwenia interconnected troughs. The lakes in which these sediments were deposited were probably of different levels due to their effective separation from one another by up-standing fault-blocks.

The Ngare Nyiro beds are only exposed in the immediate vicinity of the upper Uaso Nyiro to the north of the point where the track from Camp IV reaches the river bank. They are not shown by colour on the map as they outcrop in steep banks and are covered by younger deposits so that their exposed horizontal extent is negligible. Their position is, however, indicated on the map. In a number of exposures some 20 feet above the river bank where the river has degraded its high alluvial terrace, slightly dipping beds are exposed overlain by platy kunkar limestones and calcareous tufa which were deposited on a smooth horizontal plane. On the kunkar and tufa rests the horizontally-bedded remnants of the highest alluvial terrace of the Uaso Nyiro.

The Ngare Nyiro beds consist of somewhat variable pale reddish brown and dusty white clays with thin gravel lenses, which rest on a westward-sloping rubbly lava surface. The beds dip at approximately one degree to the west. The area of outcrop is limited to the slopes of hills capped by the high terrace alluvium. In the lower parts of the valley the high terraces pass below the recent alluvium, a fact which suggests that the Uaso Nyiro basin has been tilted southwards in Recent times. Down river the Uaso Nyiro flows in a deep channel cut in its own alluvium.

(3) Chert Series

Parkinson (1914, p. 39) first drew attention to the existence of siliceous beds and rocks in the Magadi trough. He regarded the chert as coating the lavas along fault-planes which carried siliceous springs and thought that silica from the springs caused silicification of lake beds.

Temperley (1951, pp. 11-13), described some exposures in greater detail, and gave the series its name. He recognized the main features of the series—that it rests unconformably on lavas and has been faulted and tilted since its deposition. From the fact that the series is faulted Temperley (*op. cit.*, p. 12) concluded that the beds are older than the Magadi trough and were down-faulted into it during the grid-faulting. The beds are, however, confined to the Magadi trough, and certain sections described below suggest that the principal boundary faults of the Magadi trough were already in existence when the series was laid down. The writer therefore believes that the greater part of the grid faulting preceded the deposition of the Chert Series and that the series, like the Olorgesailie lake beds, suffered only minor faulting after its deposition (but *see* Appendix, p. 81).

The most extensive exposures of Chert Series rocks occur on both sides of the south-western lagoon and in the floor of the southern part of the Nengeba trough. The finger-shaped fault-ridge to the east of the south-western lagoon is composed entirely of cherty rocks. The ridge rises to approximately 30 feet above lake-level and is margined by a shingle of chert plates, while the greater part of the top of the ridge is covered by kunkar limestone filled with angular chert fragments. A good section on the western slope of the ridge shows horizontal massive laminated greenish cherts interbedded with thin horizons of green clay with thin stripes of greenish grey platy chert. The bedding planes of the cherts are often slightly undulating on a small scale and have a porcellaneous appearance with white or dirty buff colour. This section ends some six feet above lake-level. A section a little lower down the slope, the top being about eight feet above lake-level, is as follows:—

	ft.	*in.*
3. superficial limestone (kunkar)	–	12–18
2. irregular grey chert	2–3	–
1. coarse dark ash cemented with calcite	3	–

The ridge in question declines to the south and the chert passes below fine-grained brown silt resting unconformably on the chert-kunkar surface—the silts probably belong to the High Magadi Beds. The level plain to the south of the ridge is covered with flakes and accumulations of chert fragments derived by the erosion of Chert Series rocks.

The ridge further east, which appears to be a fault-block tilted to the west, projects northwards into the lake and is also composed of Chert Series rocks. It is covered principally by chert rubble but on the crest of the ridge where it is crossed by the motor track, exposures of platy chert occur interbedded with brown and yellowish brown clays dipping to the east at shallow angles. On the crest of the ridge further north and as isolated outcrops a few feet high round its edge are hard massive cherts of variable colours, with many small angular cavities and cracks, some parts being white, others green and brown. The exposures are structureless but are often arranged in lines and, on the crest of the ridge, a discontinuous line of outcrops of massive chert up to a foot wide suggests that the rocks may have formed in small faults or fractures. On this ridge and a short distance to the south of the area the Chert Series rocks are seen to rest on lavas, the plane of the junction dipping northwards.

The "Bird Rock" fault-block is similar to those already described but the exposures of cherty rocks are limited to the margins of the ridge, where there are three or four outcrops some two or three feet high at the western side near the motor track, and others at its north-western and north-eastern extremities. There rocks are all massive chert and are assumed to be on fault fractures.

West of the south-western lagoon a stream descends the low scarp bordering the lake and affords an excellent section through Chert Series rocks. This section and others in the same area are illustrated in Fig. 6.

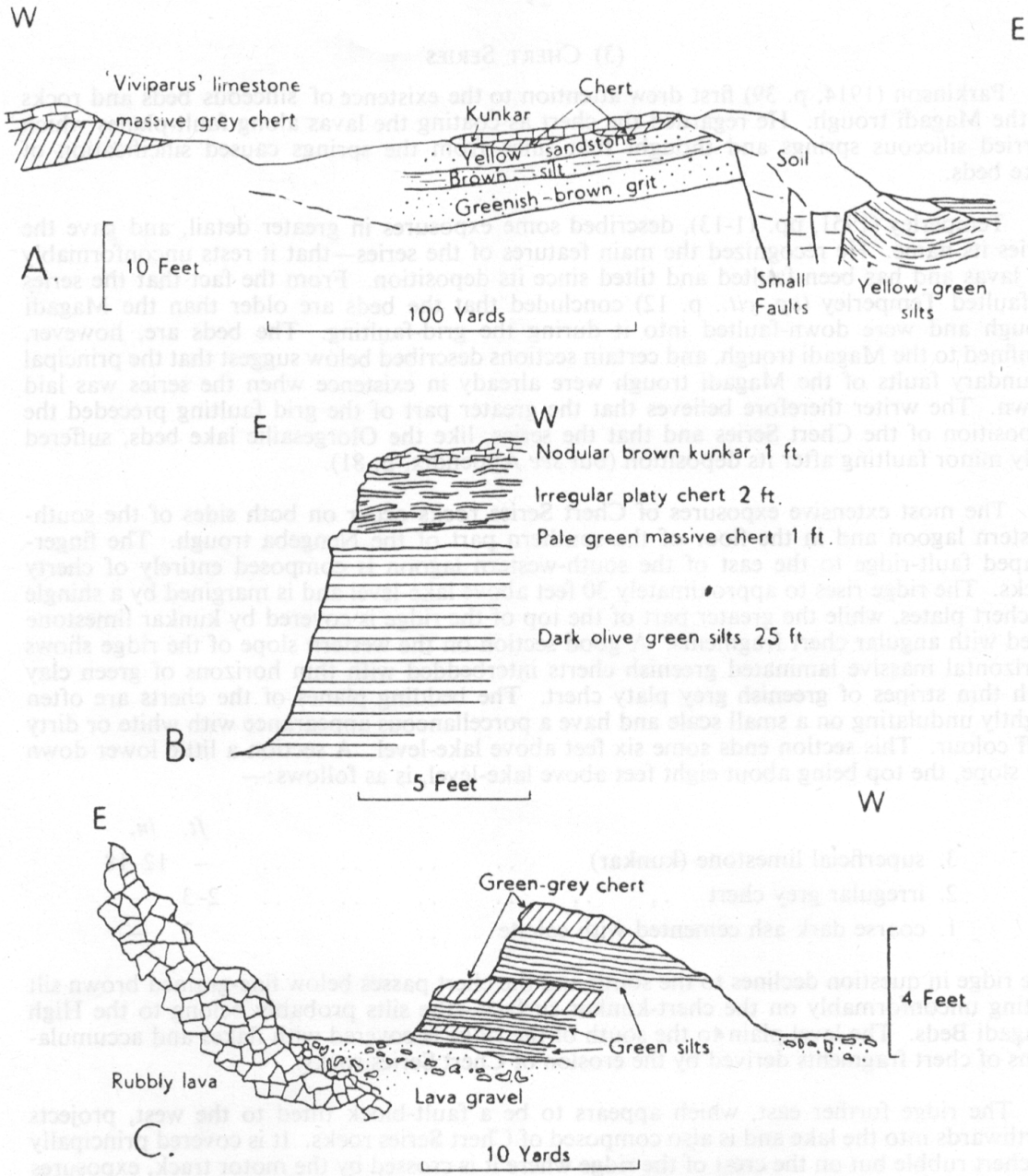


Fig 6.—Sections in Chert Series Rocks, Magadi.
A.—In the valley half a mile north-west of the south-western hot springs.
B.—At cliff, 60 yards south of section A.
C.—In cove, three-quarters of a mile north of Section A.

The stream section shows recent lake beds (probably high Magadi beds) at present lake-level overlying Chert Series rocks with unconformity. At the junction there is locally a bed of shingle composed entirely of lava, chert and kunkar fragments less than half an inch in size, the bed itself only reaching one inch in thickness. West of the junction olive green very faintly bedded silts dip at varying angles east and west in a shallow synclinal fold. The small faults shown further west in the diagram are all small with crush-zones one to two inches wide. The western end of the section contains a thin bed of chert followed above by a more massive bed overlain by fossiliferous partly silicified limestone. This is certainly the limestone referred to by Parkinson (1914, p. 41) in the following words: " . . . occurs a thin bed of limestone, for the larger part silicified and crowded with fossils, associated above and below with green and buff coloured silts. Mr. Bullen Newton, of the British Museum of

Natural History, has kindly had sections cut of these rocks. He describes the specimens as—'A silico-calcareous limestone made up entirely of gasteropodous shell remains belonging to *Melania* resembling *tuberculata*, the common and well known species of Africa and other countries, and a small form of *Viviparus*, besides the scale of a Teleostean fish. The rock was deposited under fresh-water conditions, and would represent part of an ancient lake region. Its geological age might be younger Pliocene or ancient post-Pliocene' ".

The limestone oversteps the underlying chert beds and at its western margin rests directly on lava. The limestone is estimated to be about twelve feet in thickness, and its lower part is almost completely silicified, when it is hard and massive and contains silicified *Viviparus* casts. It is yellowish buff in colour and is traversed by thin veins of greenish chert. Locally the limestone is only partly silicified and in one specimen the casts of the *Viviparus* shells alone are silicified, so that they protrude on weathered surfaces. The unsilicified limestone is also rather massive and devoid of bedding; it is composed almost entirely of shell fragments containing moulds of *Viviparus* in large numbers. The rock is medium grey when fresh, but within three inches of the surface it is weathered to a pale brown colour. Solution holes and cavities are common.

The section described and figured is the only one showing folded lake beds. The folds are very gentle and, it is believed, due to faulting and tilting rather than compression above.

Along the western margin of the south-west lagoon, half a mile north-east of the stream-section, low cliffs facing eastwards show platy chert overlying hard dark green silts, dipping at 7° to the south-south-west. Other exposures in the vicinity indicate that these rocks are repeated a number of times by small faults trending north-westwards.

Further north along the shore of the lagoon, near the point where the Chert Series beds taper out on the lava surface, a small cove surrounded by low cliffs yields the section illustrated in Fig. 6C.

The cliff facing south in the cove shows the following sequence:—

	ft.	*in.*
5. brown nodular kunkar limestone	*c.* 1	–
4. yellow-brown bedded silt	0–8	–
3. silicified *Viviparus* limestone with lava pebbles in its lower part	–	6–9
2. lava pebble conglomerate	–	0–10
1. pale olive-green silt with shell fragments	–	6–12
lava (alkali trachyte type)		

The cliff facing east is higher and shows the following beds dipping south-west at 12°.

	ft.	*in.*
6. variable light to dark brown kunkar	2	9
5. light brown false-bedded silts	7	–
4. laminated brown and dark brown silts	3	–
3. massive dark brown silt	2ft. 6 in. to 3 ft.	
2. pale olive-green silt with shell fragments	–	4
1. light brown massive silt	3	–

It will be seen that the middle part of this section is similar to that of the south-facing cliff with the exception that the conglomerate and *Viviparus* limestone are not present.

At the northern end of the fault-block on which the Magadi works and buildings stand is a fairly extensive area of Chert Series rocks. The whole works area, which is on the low-lying ground near lake-level is covered with mixed lava and chert rubble. At the western margin of the block there are numerous rocky exposures of massive chert, weathering brown and fawn. The exposures are small, rising to three or four feet above the ground, and are aligned roughly along the presumed site of the fault-plane on the west side of the Magadi fault-block. The rocks show no structure, the chert being similar in every way to the massive chert previously described, with the exception that some of the larger exposures between the garage and the heavy workshops have curiously smoothed upper surfaces. These surfaces are often convex upwards and oval in plan giving the exposure the appearance of representing the crest of a small fold. There is no suggestion of folding, however, in the rocks themselves and it may be that the rounding of the outcrops is due to erosion, possibly by wind action.

On the flats at lake-level east of the factory area are numerous massive chert outcrops in the form of rocky hillocks separated by chert rubble. The chert is similar to that already described, being patchy in colour, white, green and pale brown, with cracks, small cavities and local traces of colour lamination. The outcrops are aligned parallel to the lines of faulting and may represent silica deposited in the vicinity of a buried fault. These chert outcrops are frequently overlain by silts of the High Magadi series and by patches of superficial limestone.

Further outcrops of Chert Series rocks occur in the valley floor south of Nengeba and these extend to the edge of Lake Magadi south-east of "Needle Rock". The valley floor is partly obscured by alluvium and brown dusty soils. There are, however, scattered low *mesas* a few feet high capped by kunkar limestone which give the following sequence:—

	ft.	*in.*
4. grey-brown kunkar limestone with chert fragments	*c.* 1	–
3. laminated white and brown platy chert	1	6
2. clayey brown silt with rootlets	2	–
1. green or grey silts and clays in which are thin brown chert beds	4–5	–

Some of the weathered surfaces of the chert flags exhibit a variety of unusual structures. The specimens collected (51/345) are composed of chert with two types of surface, one with coarse reticulations and the other being finely reticulated. The surface of one plate of greenish brown chert about one inch thick showed small upstanding roughly spherical bodies from a half to one and a half centimetres in diameter. The bodies have very small-scale reticulated patterns on their surfaces, but are composed of homogeneous chert showing no organic structure. Other cherty bodies are more irregular, consisting of a central rounded undulating portion with numerous lobate extensions of all shapes. It seems as if these lobate chert plates were formed by the flow of plastic colloidal silica over an irregular body of already solidified chert. The reticular patterns may well have been formed during drying. Among the variety of forms of chert a rather rare structure is one consisting of rounded flat thin discs. These are about three centimetres in diameter, about one and a half millimetres thick, and have a reticular pattern on their surfaces. Again no organic structures are apparent. The reticulate patterns in all these cherty rocks are confined to a thin weathered porcellaneous surface layer which is approximately one millimetre thick.

Four bore-holes were drilled in August, 1953, along the centre line of the Magadi trona deposit and were continued through the trona beds to the Chert Series below. The positions of the bore-holes are indicated on Fig. 9. The holes were not bored through much of the Chert Series since the prime object of the drilling was to discover evaporite deposits. Moreover the core recovery in the cherty rocks was extremely poor due to the alternation of hard and soft beds, only the hardest parts of the rocks drilled being satisfactorily recovered. The intervening soft layers appeared to be green, judging from the appearance of the drilling mud.

In bore-hole A approximately 75½ feet of Chert Series rocks were drilled from 70½ feet to 146 feet below the surface of the lake. The cores were fragmentary and consisted of rather porous massive black chert with many angular cavities. Some parts of the core were streaky with black and white chert. At 145 feet a few fragments were of the whitish green platy type of chert.

The chert in bore-hole B is similar to that described above but the core also included fragments of light grey clay. The chert was cored from 156 feet to 201 feet below lake-level. The chert in bore-hole C, cored from 102 to 121 feet, is similar to that described. The cores from bore-hole D were poor and the fragments were of grey-black rather gritty chert composed of small grains about one millimetre in size cemented by silica. The Chert Series was penetrated from 158 to 164 feet.

A fifth bore-hole, E, was sited at the south-west end of a fault-scarp on the east side of the flats on which the salt plant is situated. Chert Series rocks were encountered somewhat earlier than was expected and the hole was abandoned at 32 feet. Chert was struck at 8½ feet and was found to consist of white and green platy chert interbedded with green clays.

The evidence of the bore-holes supports the conclusion that the Chert Series underlies the High Magadi beds and covers the lavas over the greater part of the floor of the Magadi trough. The nature of the rocks encountered in the bore-holes is, however, somewhat different from the members of the Chert Series at surface. Almost all the cherts in the cores are dark-coloured and massive whereas, although massive cherts occur at surface, they are light in colour and not nearly so full of cavities as those encountered in the bore-holes.

The small elongated island north of the Magadi factory area was not visited, but can be seen from the Magadi ridge to consist of massive chert. The island represents the northward extension of the line of chert outcrops at the western margin of the Magadi fault-block and the fault, which follows the same line, outcrops again in the centre of the Nengeba plain, south-east of "Needle Rock". The area of thin trona crust and mud flats east of this fault is underlain at a depth of only a few feet by bedded cherts, and is comparable to the dry south-east arm of the lake. The only reason for the existence of a thin trona and mud layer north-east of the Magadi factory area is the action of the springs in this area. West of the fault-line mentioned the upper surface of the Chert beds is down-faulted to a depth of 100 to 200 feet below present lake surface.

It is assumed, there being no evidence to the contrary, that in the deepest parts of the lake, the Chert Series directly overlies the plateau lavas, as is the case in sections at the lake margin. The thickness of the Series is unknown, but 76 feet were proved by the drilling and it may be that it reaches several hundred feet in thickness.

(4) Olorgesailie Lake Beds

This series of lake beds occurs on the Legemunge plain north of Olorgesailie mountain and covers a large area. Not only is the series well exposed but it has also been mapped in detail by Dr. R. M. Shackleton.

The Legemunge plain occupies the floor of a fault trough that has two southerly extensions: one passing west and the other east of Olorgesailie mountain. The western trough contains the Koora plain and continues southwards outside the present area, the other, the Kwenia plain passes out of the area east of Olorgesailie and ends in a seasonal swamp some eight miles north of Singaraini station.

Good sections in the Olorgesailie lake beds are exposed at the northern margin of Olorgesailie mountain where the Ol Keju Nero has cut a shallow gorge through them exposing, in part of its length, the lava bed-rock. Gregory and Hobley (Gregory, 1921, p. 221) discovered Paleolithic artifacts here in 1919 lying "on a bank of white diatomaceous earth" at a locality described as "near our camp at the Ol Keju Nyiro, at the northern foot of Mount Ol Gasolik". It was on the eroded slopes above and to the north of the Ol Keju Nero that Mrs. M. D. Leakey discovered in April, 1942, a large number of artifacts belonging to the Acheulian culture. As a result of this re-discovery extensive excavations were made and more artifacts, living floors and vertebrate fossils were discovered.

Dr. Shackleton, while an officer of the Mines and Geological Department, undertook during 1944 a detailed survey of the lake beds in the area that is now the "Olorgesailie Prehistoric Site". Since the maps and sections he prepared illustrate the greater part of the lake bed sequence found at the south end of the Legemunge plain, his descriptions will be quoted in detail and his map of the beds in the enclosed area of the Prehistoric site is included (at end).

Almost all the information given here on the lake beds in the enclosed area is taken from Shackleton's report (1944). He states: "The deposits in which the artifacts and fossils occur are largely diatomites with varying proportions of clay, marl and volcanic ash. In most cases the artifacts lie on surfaces which are sharply defined by lithological changes and evidence of erosion. These surfaces are therefore interpreted as land surfaces due to temporary recessions of the lake margin. The resultant non-sequences would be the natural horizons at which to subdivide the series, but for the purpose of mapping this was less convenient than the subdivision adopted, which is based on easily recognizable marker beds. The area now enclosed, known as the main area, is taken as the type area for the part of the succession (L_1–L_{10}) which is exposed there, since it is there that several artifact-bearing horizons are best seen close together. Some higher beds (L_{11}–L_{14}) are best exposed a mile and more west of the main area".

The succession, condensed from Shackleton's report (pp. 3–9) is as follows:—

		Approx. thickness ft.
L14.	Diatomite	13
L13.	Diatomaceous clays	17
	Flaky diatomite with a few grey ash stripes	22
L12.	White diatomite underlain by tuffaceous grey diatomite and with strong reddening at the top	11½
	—local irregular erosion surface—	
L11.	Impure diatomites with ash bands	19–27
L10.	Gravels, volcanic sands and pumice tuffs	3½–8
	—erosion surface—	
L9.	Grey bedded tuffs grading into white diatomite	18–21
L8.	Dirty buff diatomaceous clays—with manganese oxide films in cracks Crumbly clays with the upper part locally reddened Reddened zone	3½–5
L7.	Diatomaceous clays with erosion surfaces	5–10
L6.	Green sand —erosion surface— Yellowish white bed Greenish sands	0–1
	—erosion surface—	
L5.	Dirty cream clays and marls	4–8
L4.	Grey pumice sands and gravels	3½–7
	—erosion surface (in part)—	
L3.	Greyish-weathering bedded tuffaceous diatomite	4½–13
	Thin purple or greyish purple band	a few inches
L2.	L_2''' Crumbly impure diatomite L_2'' Brownish laminated clay Pure white diatomite Brownish laminated clay L_2' Pale brownish buff clay	11–14
	—erosion surface—	
L1.	Laminated cream-coloured diatomite with a bluish grey stripe a foot from the top Purplish buff clays (in part)	8½–23

The lowest beds of the L1 group occur outside the enclosed area a few hundred yards to the south-west and in some parts consist of purplish buff clays. The erosion surface separating L1 and L2 contains artifacts and fossils. Shackleton in his sections shows the thin purple or greyish purple band or stripe separating groups L2 and L3, but does not refer to it in his text.

The pumice sand and gravel of group L4 are seen in some sections to be current-bedded and resting on an eroded surface. At other localities L4 appears to grade downwards into the L3 bed. The clays and marls of L5 are well stratified and contain a zone about one and a half inches thick crowded with spherical concretions two or three centimetres in diameter. Both the erosion surfaces in group L6 yield artifacts. The upper sands of the L6 group pass upwards into the almost unbedded diatomaceous clay of the L7 group. This bed contains two erosion surfaces, one marked by desiccation cracks and lava stones; artifacts are locally found on the erosion surfaces. Overlying the fissured surface is a brownish buff concretionary bentonitic clay cut off by a further erosion surface which is overlain by small lenses of greenish sand and white diatomite. The highest bed is a massive marly clay with sporadic irregular concretions.

Group L9 consists of several beds of soft powdery grey tuff, each grading into whitish diatomite. All or part of these beds have been eroded locally before the deposition of the succeeding sands and gravels (L10) which rest on a strongly eroded surface. They are a variable series of lenticular gravels, volcanic sands and black pumice gravel.

Only part of the L11 beds is exposed in the enclosed area and is composed of impure diatomites with several ash bands as shown on the map (at end) of the enclosed area. Some distance to the west of the enclosed area the L11 beds are chiefly pinkish or beige clays with layers of calcareous concretions in the middle of the sequence.

The L12 beds consists of a bed of pure white powdery diatomite 3½ to 4 feet thick, with strong reddening at the top, underlain by tuffaceous grey diatomite. The upper part of this bed has in the past been sampled and used by the Magadi Soda Company.

The L14 bed, the highest in the Olorgesailie lake beds as mapped by Shackleton, consists of hard white diatomite and forms the upper part of a scarp crossed by the Magadi road near the south-western limit of the series.

The thickness of Olorgesailie lake beds as determined by Shackleton along the north bank of the Ol Keju Nero river amounts to some 175 feet.

At a few places in the scarp of lake beds north of the Ol Keju river and about one and a half miles west of the Prehistoric Site, the writer saw the contact of the lake beds with the lava floor; the section at this locality is as follows:—

	ft.	*in.*
whitish diatomaceous clays (Olorgesailie Lake Beds)		
black clay soil locally	0–3	–
brown soil with rootlets	2	–
brown soil with angular lava fragments	4	6
—erosion surface—		
lava rubble cemented by kunkar limestone	–	6–18
—erosion surface—		
Ol Keju Nero basalt		

At the south-western end of the Legemunge plain, immediately to the west of the Magadi road, impure rather massive diatomites are overlain by travertine limestone in the form of four distinct hillocks some twenty yards apart. The travertine rests on a level surface of diatomite and reaches 25 feet in thickness. It is massive and consists (specimen 51/432) of faintly laminated pale brown fine-grained calcium carbonate, some layers of which are fibrous with the fibres perpendicular to the bedding. Parts of the lowest travertine bed are traversed by many curved tubes about one third of an inch in diameter which are interpreted as worm-borings. The diatomite surface between the travertine mounds is locally hard, greyish and calcified to a depth of a few inches, while locally small plates of greyish-white kunkar limestone litter the surface. There is a strong parallel between these travertine occurrences and those found on the surface of the Ngare Nyiro beds (*see* p. 28).

Shackleton (*op. cit.*, p. 12) appears to consider that the Olorgesailie lake beds extended somewhat further to the east and west than they do at the present time and that the greater part of the grid faulting of the area was later than the deposition of the lake beds. The fault escarpment bounding the lake beds to the west was, however, already in existence at the time of their deposition for the lake beds can be seen overlying the scree at the base of the escarpment. Several small faults do cut the lake beds but they are not comparable either in age or size to the grid faults which must have existed before the deposition of the lake beds began. The fault downthrowing eastwards which runs to the north from the eastern side of the Prehistoric Site is post-lake beds, but on the whole the faulting younger than the lake beds was minor in extent and probably confined to intra-formational episodes and small movements along some of the pre-existing grid faults.

The lake beds described dip very gently to the west or south-west along the north bank of the Ol Keju Nero and, where this river turns southward into the upper Koora valley, they pass below superficial deposits. The Ol Keju Nero section in this valley exposes about 15 feet of chocolate-brown bedded earths and clays overlying seven to eight feet of laminated brown and yellow clays with gravel lenses, but no lake beds. From this point southwards along the Koora valley to a point some 9 miles south-east of Koora station only superficial deposits and soils of "black alkali" type are seen.

Parkinson (1914, p. 42) described a shaft he put down to nearly 100 feet on the Koora plain some 10 miles north of the railway. The shaft must have been somewhere in the upper Koora valley approximately on a line between the south summit of Olorgesailie and Shanamu.

The beds encountered in the shaft were mainly finely laminated silts and clays, except for a few pebbles and boulders of lava at 73 feet below surface. The uppermost part of the shaft passed through 14 feet of red surface clay and the underlying silts contained much volcanic material, including pumice in unconsolidated bands. Parkinson also mentioned yellow tuffs and a four foot bed of grey kaolin which may, in fact, have been impure diatomite since kaolin in such circumstances is unlikely. At 53 feet below surface Parkinson discovered a silt crowded with fossils identified by R. B. Newton as *Planorbis pfeifferi* (Krauss)* and *Planorbis gibbonsi* (Nelson)†. Associated with these fossils, but commoner in the underlying bed were *Melania tuberculata* (Muller) and *Isodora contorta* (Michand)‡.

Whether the beds penetrated by Parkinson's shaft are equivalent to any part of the Olorgesailie lake beds is impossible to say. The lithology is somewhat different and no invertebrate fossils are known from the lake beds. Since, however, the Koora trough was probably in existence at the time of deposition of the Olorgesailie lake beds further north, it is likely that contemporaneous beds were laid down in the Koora trough but that considerable thicknesses of fluviatile deposits brought down from Olorgesailie mountain and by the Ol Keju Nero river now cover the lake beds.

A bore-hole (C.1662) drilled in the upper Koora valley near mile 16 from Magadi showed the following succession:—

depth (*feet*)	
0–40	clay
40–95	gravel
95–311	sand mixed with lava (gravel)
311–370	lava
370–410	clay
410–600	red soil

The log, presumably recorded by the driller, is not easy to interpret and may be inaccurate. Water was struck at 350 and 410 feet, coming to a rest-level at 298 feet, but the yield was only 30 gallons per hour. The water was, in any case, highly alkaline having a content of dissolved solids of about 0·6 per cent.

Some nine miles south of Koora station the Koora trough narrows and there are large expanses of diatomaceous soil. In the soil from bush-pig holes well-rounded vesicular lava pebbles are sometimes found. Apart from these there is no exposure of rock in the valley floor.

In the Legemunge area lake beds comparable to those described by Shackleton are found south of the Ol Keju river. They overlie the northern and north-eastern lower slopes of Olorgesailie mountain and dip gently to the north. The broad valley east of the Legemunge plain is somewhat lower than the latter and is covered by brown dusty soil containing isolated lava boulders. The Magadi road is a little below ground-level at some points on this plain and a flat surface of homogeneous brown clay silt is exposed. In the shallow gorge of the Ol Keju Nero where it crosses this lower plain exposures are of brown or grey laminated clays overlain by unconsolidated reddish brown and buff silty clays. In places the lava floor is exposed and is seen to consist of plateau trachyte. The deposits of the trough east of Legemunge are therefore rather different in character from the Olorgesailie lake beds. Since the two troughs were originally one area of deposition it is assumed that rocks of the Olorgesailie lake beds are present locally in the deeper parts of the trough, but that when the eastern part was downfaulted a further sequence of lacustrine beds were deposited on the Olorgesailie lake beds in the lower eastern trough. The uneroded character of the plain surface suggests that the later lake beds may be much younger than the Olorgesailie lake beds. The poor exposures, however, do not allow a certain conclusion to be found.

The upper Kwenia valley like the Koora valley is covered with soils and sheets of alluvial boulder beds derived from Olorgesailie mountain. Both the Koora and Kwenia extensions of the Legemunge plain slope gently southwards in harmony with the general tilt of the area and it is clear that this slope could not have existed while the Olorgesailie

*Now known as *Biamphalaria pfeifferi*.
†Now known as *Gyraulus gibbonsi*.
‡Now known as *Bulinus contortus* (Michand) and is probably synonymous with *B. allverdi* and *B. syngenes*.

lake was in being, otherwise the waters could have escaped southward. It is possible that some of the southward slope of this region was due to deepening of the troughs subsequent to the deposition of the Olorgesailie lake beds.

Vertebrate fossils have been found in the Olorgesailie lake beds, in excavations in or near the Prehistoric Site, some of the bones being found on the actual living sites of prehistoric man and associated with artifacts. The fossils recorded (Leakey, 1951, pp. 32-33) are:—

Simopethicus
Archidiskodon recki (Dietrich)
Hypsihipparion cf. *albertensis* (Hopwood)
Equus oldowayensis (Hopwood)
Equus quagga subspecies
Ceratotherium sinum germano-africanum (Hiltz)
Potamochoerus majus (Hopwood)
Notochoerus dietrichi (Hopwood)
Phacochoerus africanus (Cuvier)
Hippopotamus gorgops (Dietrich)
Sivatherium olduwensis (Hopwood)
Giraffa cf. *capsensis* (Geoffrey)
Taurotragus sp.

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The above fossils and the Acheulian artifacts found on the living sites are comparable with those of Bed IV at Oldoway in Tanganyika (Leakey, 1952) and are interpreted as being of upper Middle Pleistocene age (upper Kamasian or in Leakey's more recent terminology, Kanjeran—*see* Leakey, 1950, p. 63).

(5) High Magadi Beds

Temperley (1951, pp. 15-16) first described and named these beds, although Parkinson may have had them in mind when describing horizontally bedded brown silts in the south-eastern mud flats of the lake (Parkinson, 1914, p. 43). Temperley named the beds "High Magadi Beds" on account of the fact that they represent the remnants of the deposits of Lake Magadi when it stood at a level some 40 feet higher than the present lake surface. White (1953) has also described these beds, and believes that they are due to sudden repeated floodings of the lake. No extensive areas of the beds remain at the present day, most of the exposures being found on the steep sides of the west-facing escarpments on the east side of the lake. The beach-line of the former high Magadi lake is clearly discernible in the scarp bounding the eastern side of the lake, where it is seen to be horizontal and undisturbed by any faulting—features that are common to all the exposures of High Magadi Beds, and which show that no tilting or faulting has taken place in the Magadi trough since the formation of these beds.

The High Magadi Beds rest unconformably on Chert Series rocks and plateau trachyte lavas and frequently overlie a kunkar limestone horizon. They consist principally of brown silts and clays with occasional fossil horizons.

Where the High Magadi Beds are preserved at the base of fault escarpments they can often be traced downwards to the level of the lake and appear to be continuous with the brown silts that make up the floor of the mud flats in the south-eastern arm of the lake. Although much of the area of mud flats surrounding the lake is covered with superficial shingle, mud and thin efflorescences of salts, it seems as if the High Magadi Beds continue downwards below the level of the surface of the present lake and that part of the series of evaporites and their interbedded clays may be included in the High Magadi Beds. In any case there must be a stratigraphical break due to a period of erosion somewhere in the succession below the lake, but whether it is at the Evaporite Series—Chert Series junction or somewhere in the Evaporite Series is not known. The question whether any part of the High Magadi Beds contained evaporites is, at the moment, impossible to answer, nor is it known whether the whole or only a part of the High Magadi Beds under the lake were eroded away previous to the deposition of the Evaporite Series. It seems reasonable to suppose that originally the High Magadi Beds covered the entire trough and that the greater part of them have been removed by erosion. This erosion was probably effected initially by streams escaping from the south end of the lake and later by wind. The reduction in lake-level below the present level must have been due to evaporation and probably took place during a

relatively dry period when the supply of meteoric water was greatly reduced. It is not necessary to assume, however, that the lake dried up completely—it is possible that evaporation concentrated the lake waters to such an extent that the crystallization of trona beds began. Once trona crystallization begins and the trona reaches the lake surface the rate of evaporation drops considerably, for the area of brine exposed to the atmosphere is much reduced. In the case of lagoons skins of floating crystals of sodium carbonate monohydrate develop and the liquor below is protected from evaporation.

In the central part of the Magadi trough there may therefore be no stratigraphical break between the High Magadi Beds and the Evaporite Series. In any case it must be assumed that due either to rise in the water-table or to the activity of alkaline springs more alkaline water was supplied to the lake and that by alternate evaporite formation and clay deposition the Evaporite Series was deposited up to the present lake-level.

For descriptive purposes the High Magadi Beds are taken as those outcropping at and above present lake-level as will be described below, while the Evaporite Series are the beds cored during drilling on the lake and comprise evaporites and clays resting on Chert Series rocks.

The most instructive sections in High Magadi Beds are seen in the "dry lagoon", a small cove traversed by the motor track leading south from Magadi. Here yellowish brown fine-grained silts showing little bedding overlie lava, vertical sections exposing up to 15 feet of the silts. The basal bed consists of 16 to 28 inches of lava shingle cemented by kunkar limestone indicating that the lava surface was similar to that at the present day. Diagram A, Fig. 7, illustrates a section in the "dry lagoon". The floor of the lagoon consists of lava and kunkar shingle mixed with dark grey dusty hill-wash, and outcropping in the floor is a small exposure of green clays about two feet high dipping at 18° westwards. This exposure probably represents disturbed Chert Series rocks underlying the High Magadi Beds. The upper surface of the outliers of silts in the "dry lagoon" are more or less level and are about 30 feet higher than present lake-level.

By the side of the lake about half a mile north of the "dry lagoon" a facet of High Magadi Beds comparable in altitude and type to the "dry lagoon" sections, rests on a westward slope of lava in a small valley. The beds are unconsolidated fine yellow-brown silts without any bedding or characteristic basal bed. Scattered black fish scales are common in the silts.

At the south-eastern extremity of the south-eastern arm of the lake a stream has cut an unusually deep and precipitous gorge along a fault-plane in lavas. Facets of boulder beds and fluviatile silts occur in the lower part of this gorge at a level some 25 to 45 feet above present lake-level. It is probable that these beds are the marginal fluviatile equivalents of the High Magadi Beds that formerly filled the south-east arm of the lake. The section is as follows:—

	ft.
3. boulder bed (boulders from 3′ to 1″ diameter)	*c.* 6
2. thin bedded brown silts grading upwards into the overlying boulder bed	15
1. roughly graded conglomerate containing lava fragments from 24″ to ½″ size in a matrix of brown silt	10

The mud flats round the mouth of the gorge are covered by a shallow alluvial cone of lava boulders about 300 yards wide. The floor of the southern part of the south-east arm of the lake, immediately north of the gorge described, is quite flat and smooth and consists of yellow-brown dust, unconsolidated and traversed by sun-cracks and partly overgrown with reeds. At the northern end of this area of yellow-brown dust, in the narrow part of the trough between the Magadi and Rifle-range scarps the ground is of undulating brown and grey loess rising to some 25 feet above lake-level. The brown and grey dusty loess overlies an eroded surface of relatively compact High Magadi Beds consisting of homogeneous light brown silts.

In the Rifle-range scarp immediately east of the range High Magadi Beds occur as facets adhering to the scarp face. The lower part of the section consists of some 25 feet of homogeneous unbedded brown silts overlain by a zone of highly irregular arborescent white chert bodies in a matrix of silt. Above the chert zone are 15 feet of finely laminated brown and buff clays forming, at their upper limit, a narrow impersistent terrace on the side of the scarp which is itself composed of plateau trachyte lava. On the surface of this terrace there

are often many tubular kunkar limestone bodies, some bifurcating, others curved, which have clearly formed by the deposition of limestone on the outside of twigs and fragments of branches. The kunkar limestone is usually a quarter to half an inch thick and the tubes are from two thirds to one and a half inches in diameter. No organic material remains in the tubes but in some specimens the mould of the original outer surface of the bark can be discerned.

The flat floor of the trough in the vicinity of the rifle-range is composed of the homogeneous brown silt of the High Magadi Beds locally overlain by thin beds of shingle and dust. Where the silts are exposed, however, they frequently have an irregular surface composed of numerous rounded knobs from three to five inches in diameter projecting up to six inches above the smooth silt surface. The lower part of the knob is usually narrower than the upper part, giving the structures the appearance of being on small pedestals. The knobs are continuous with the silt floor and have been formed by wind erosion of the saturated silts. It is also interesting to note that the silts at and near present lake-level always appear massive and rather darker in colour than those occurring a few feet above lake-level. This is attributed to their being saturated with alkaline waters. The knobs and the smooth silt floor of the trough are locally covered in dry weather by thin crusts of varying colour consisting of efflorescences of salts containing silt particles.

Resting on the nodular chert outcrops about 600 yards north-west of the rifle-range are silts of the High Magadi Beds. Their relationship to the chert is shown in diagram C, Fig. 7. The beds rise from six to ten feet above the level of the surrounding shingle surface and consist of brown fine-grained friable silts, having locally a dip of $6\frac{1}{2}^{\circ}$ towards the south-west. They rest on an eroded massive chert surface and have patches of kunkar limestone at their base. In this section the small outliers of High Magadi silts resting on chert are dry, friable and visibly bedded whereas the adjacent silts which pass below the shingle are damp, saturated and massive in appearance.

At the base of the scarp below and to the east of the golf-course a section exposing a grey-brown loess overlying an eroded surface of High Magadi Beds similar to those previously described is seen. The section is illustrated by diagram B, Fig. 7. About half-way down the section a thin horizon of white slightly plastic powder about one and a half inches thick was found interbedded in the brown silts. A similar bed was seen at lake-level on the flats about 200 yards north-east of the section. At this point, however, the bed was plastic like putty and about three inches thick. Specimens (51/427 and 51/428) of this material proved to be extremely finely divided silica devoid of organic structure which, on the drying out of some specimens, became hard and porcellaneous. It is concluded that the bed represents a chemical precipitate of colloidal silica which has not yet been converted to chert by recrystallization. This occurrence and the zone of arborescent chert found near the rifle-range represent the only two known occurrences of silica as discrete bodies in the High Magadi Beds.

Other exposures of the High Magadi Beds occur as relic outliers at the base of the high eastern boundary scarp of the lake. One of these is found at the point where the road and railway converge about one mile east of the factory. Here, as in the other exposures, the beds are horizontally bedded silts.

The scarp bounding the lake north-east of the Magadi factory has a well-marked terrace at the upper limit of the High Magadi Beds. It is best developed some distance to the north of the factory area, on the south-east side of the Nengeba valley. Here a well-defined terrace with cliff exposures below it shows the section illustrated by diagram E, Fig. 7. The fish bed referred to is a narrow zone of laminated brown clays crowded with black fish skeletons. The fish have been identified by H. Copley, Fish Warden of Kenya, as *Tilapia nilotica*, a fresh-water type common in existing African faunas.

A section almost identical with that described above occurs in two small outliers of High Magadi Beds below the "needle", at the base of the "Needle Rock" scarp. The section is illustrated in diagram D, Fig. 7. The silts and clays at this locality rest on a slightly sloping surface of cherty kunkar limestone which overlies the Chert Series. The outliers are well rounded and covered by a thin efflorescence of salts. Their squat, rounded and flat-topped character may have caused Gregory, who probably saw them from the top of the escarpment to the east, to misinterpret them as mud-volcanoes, for he says (Gregory, 1921, p. 178) "A group of mud-volcanoes on the eastern shore, a few miles north of the Hospital, indicates the ascent of hot water under pressure". In fact no mud-volcanoes were seen in this area.

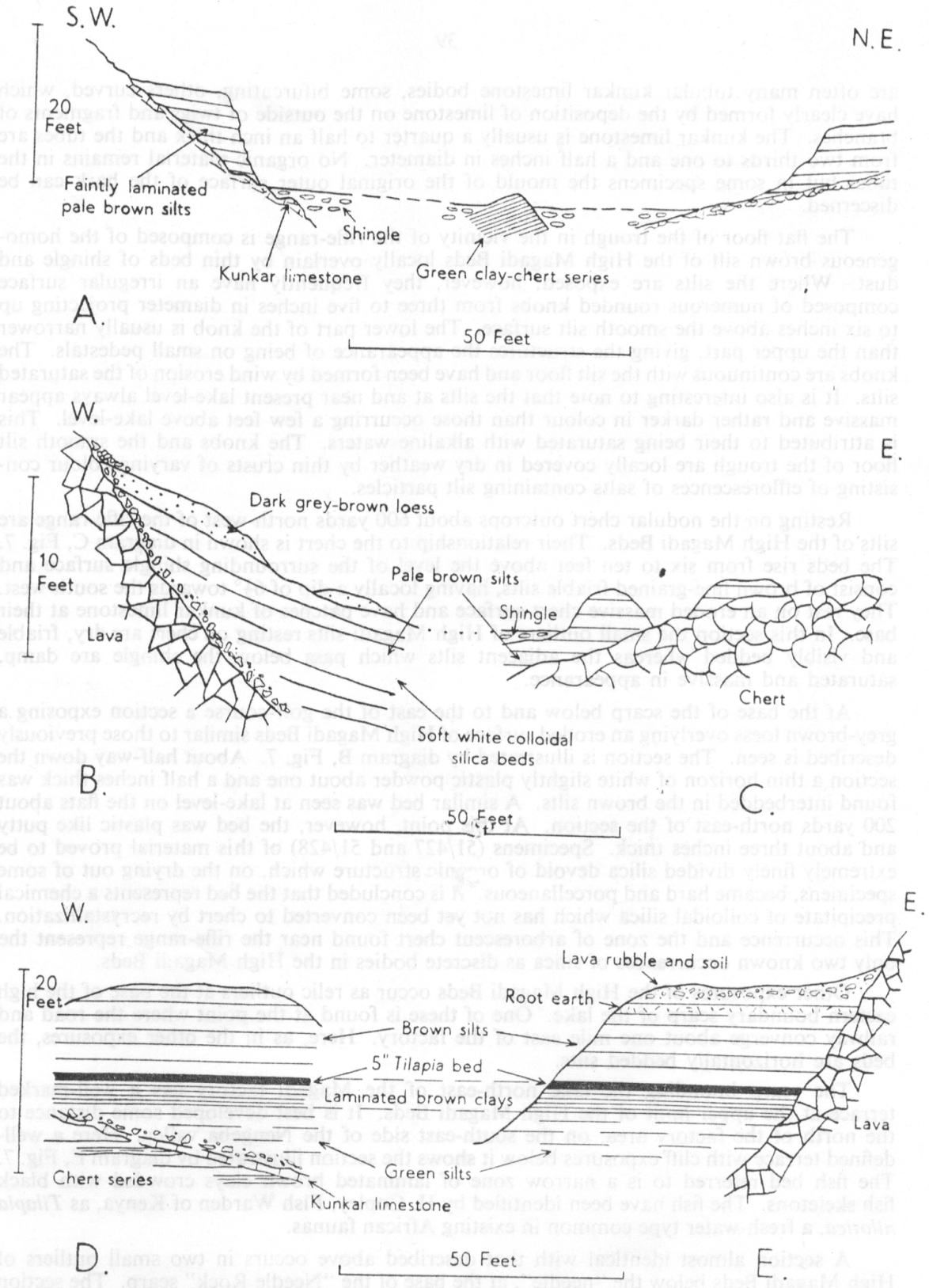


Fig. 7.—Diagrammatic sections in the High Magadi Beds.

A.—In the "Dry Lagoon", 5 miles south of Magadi

B.—At the base of the scarp east of Magadi Golf Club

C.—500 yards east of B

D.—Outlier, 200 yards east of "Needle Rock"

E.—Base of scarp, three quarters of a mile south-east of D

(6) The Evaporite Series

Until recently nothing was known of the rocks underlying the uppermost trona bed of Lake Magadi, though the Magadi Soda Company has for many years carried out routine tests on the lake and made numerous analyses of the upper 8 to 12 feet of the Evaporite Series. In general it was found that at about 8 to 10 feet below lake-level an increasing amount of black mud was included in the trona and, in places, a bed of almost pure black mud was found at approximately 11 to 12 feet. It was assumed that this mud continued downwards without interbedded evaporites.

During August, 1953, core drilling was undertaken by the Company at the writer's suggestion and five bore-holes, of which four were on the central part of the lake, were put down, each penetrating to Chert Series rocks. The principal object of this drilling was to discover whether sodium chloride evaporites or brines existed in depth, but a secondary object was to discover the geological sequence of lake beds. The drilling was carried out by the Mowlem Construction Company with a "Sullivan" diamond rotary drill-rig mounted on a truck. Drilling water was obtained from a well dug in the trona alongside the rig and consisted of lake liquor (*ca.* 35 per cent solids in solution). The sites of the bore-holes are marked on Fig. 9 and the log of the cores is illustrated diagrammatically in Fig. 8. The bore-holes penetrated considerable thicknesses of trona beds and showed that over an extensive area of the lake the trona occurs as a series of evaporites interbedded with clays. Crystalline sodium bicarbonate (nahcolite) occurs with the trona (*see* p. 44). On later pages, however, the evaporite beds are referred to in general terms as trona. The cores are logged and described below and an indication of the core recovery is given in parenthesis.

Bore-hole A

0 to 7 feet	.. medium-grained crystalline trona—core buff to greenish-white, crushed (28%).
7 to 12 feet	.. medium-grained crystalline trona (40%).
12 to 15 feet	.. about 18 inches of pure trona at 12 feet, grading downwards into pale green clay with scattered trona crystals (66%).
15 to 21 feet	.. two inch bed of coarse grey trona—no other core (3%).
21 to 31 feet	.. pale olive-green clay with thin bands containing trona crystals—two small half-inch trona beds at about 25 feet, five inch massive bed at 29 feet grading upwards into green clay and trona needles (50%).
31 to 38 feet	.. pale olive-green clay spotted with grey trona needles grading into pure olive clay at 32 feet and continuing to 35 feet where the clay lightens to a light yellow-brown colour; trona crystals are present in the clay at 35 and 38 feet (100%).
38 to 41 feet	.. pale green clay with large acicular trona crystals (100%).
41 to 48½ feet	.. pale green clay with large acicular trona crystals (7%).
48½ to 65 feet	.. pale greenish brown clay without trona crystals, grading at 64½ feet into yellow brown clayey silt (37%).
65 to 70½ feet	.. pale brown clayey silt (50%).
70½ to 91 feet	.. at 70½ feet a few inches of pale brown silt containing a fish scale, followed by fragmentary black chert (2%).
91 to 146 feet	.. fragmentary patchily black and buff chert, some fragments up to three inches long. The drilling record indicates alternating soft and hard drilling and the drilling muds indicate that green clay is interbedded with the chert (4%).

It will be seen that core recovery in the chert was extremely poor and the recovery of the rest of the core was rarely satisfactory.

Bore-hole B

0 to 3 feet	.. crushed pure trona (33%).
3 to 10 feet	.. white and pale grey pure crystalline trona (4%).
10 to 16 feet	.. white pure fine-grained to medium crystalline trona (33%).
16 to 20 feet	.. white crushed trona (50%).
20 to 36 feet	.. fragmentary crystalline trona grading downwards into massive fine-grained yellowish white trona (6%).
36 to 50 feet	.. coarsely crystalline massive dark grey trona in beds 1½ inches thick—some beds are up to 5 inches thick (39%).

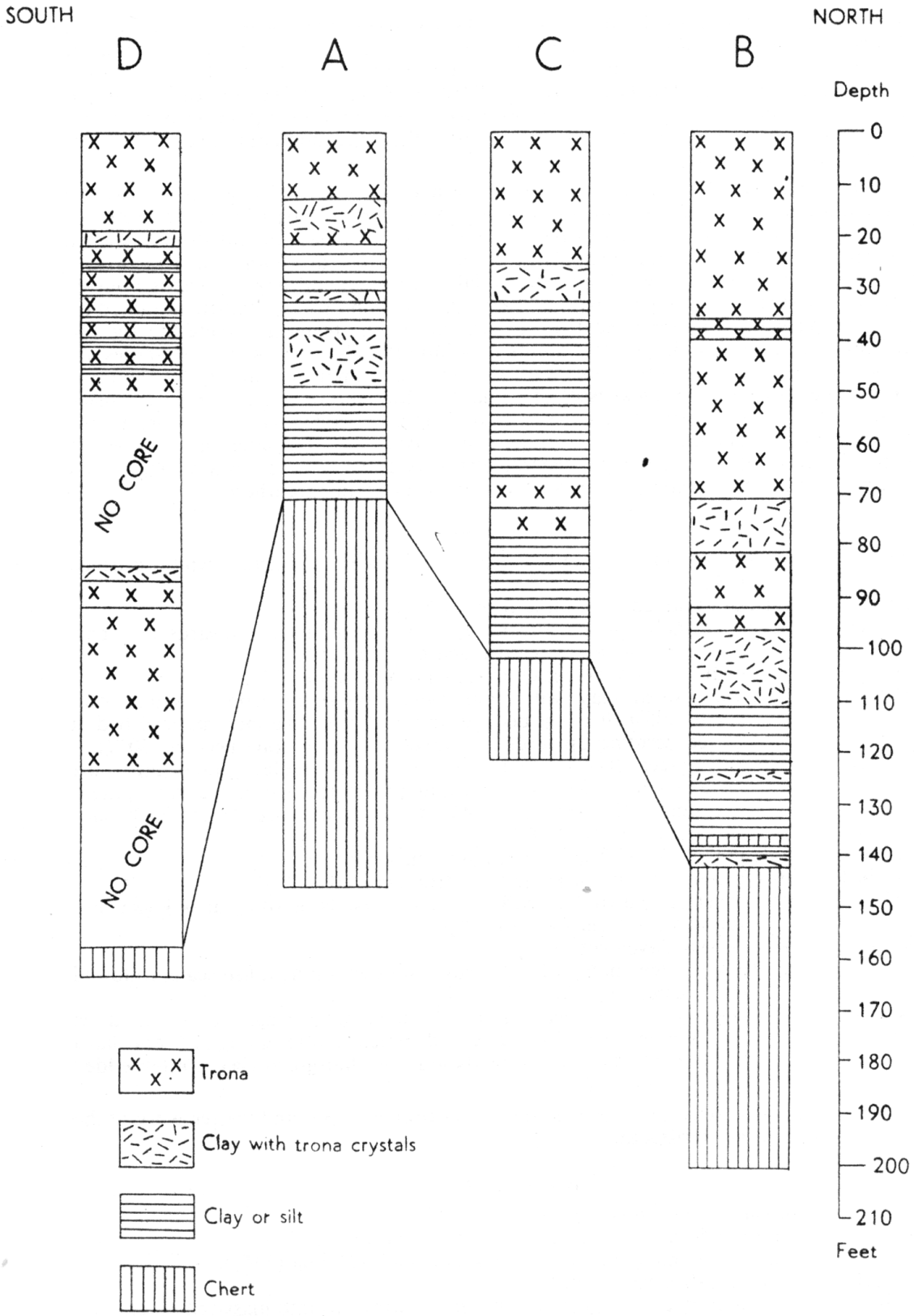


Fig. 8.—Diagrammatic logs of bore-holes drilled in the Evaporite Series at Lake Magadi.

50 to 72 feet .. massive coarse trona in beds up to 6 and 9 inches thick (43%).
72 to 82 feet .. acicular trona crystals in pale greenish brown clay, the trona predominating over the clay; nahcolite detected at 81 feet (30%).
82 to 92½ feet .. massive coarse dark grey trona; nahcolite detected at 92 feet—in beds several feet thick (100%).
92½ to 96 feet .. massive coarse dark grey trona; olive-green silt with trona crystals 9 inches thick near 96 feet (100%).
96 to 112 feet .. Three inches of coarse trona at 96 feet; trona crystals in dirty green silt to 111 feet; last foot is of pale greenish buff clay with brown spots (83%).
112 to 125 feet .. pale greenish brown unbedded silts with acicular trona in 3 inch bed at 125 feet (80%).
125 to 138 feet .. pale olive-green silty clays; the lower part of the core is of dark grey chert, some platy, some massive with irregular colour lamination, whitish to green-grey in colour; the exact depth of the chert/silt contact is not known (4%).
138 to 141 feet .. cream and dark grey chert with cavities, possibly pseudomorphous after trona (30%).
141 to 153 feet .. pale olive-green silt with trona needles; the lower part of core is fragmentary black and white chert (5%).
153 to 158 feet .. fragmentary chert above, some coarse trona (nahcolite detected) in lower part of core (20%).
158 to 201 feet .. fragmentary chert with adhering olive-green clay (8%).

Bore-hole C

0 to 10 feet .. crushed pure trona (25%).
10 to 20 feet .. —no core—
20 to 33 feet .. coarse massive trona, yellowish in colour, occurring as three inch thick beds—grading at 25 feet into trona-bearing green clay (43%).
33 to 52 feet .. pale green silty clay with rare one-inch trona beds (10%).
52 to 62 feet .. pale green clay with several 2-inch trona beds (55%).
62 to 72 feet .. One inch whitish green trona grading into 1 ft. 9 in. pale green spotted clay, then 2-inch transition through clay with trona to a 1 ft. 2 in. massive coarse grey trona bed, followed by 4½ in. of green clay with trona crystals and 6 ft. 6 in. of massive white and grey trona (100%).
72 to 75 feet .. massive coarse grey trona (35%).
75 to 81½ feet .. 75 to 78 feet massive trona, underlain by one foot of brown spotted clay followed by pale green spotted clays (50%).
81½ to 91 feet .. pale brown clay grading downwards into pale greenish brown clays at the base (75%).
91 to 102 feet .. light brown clays grading downwards into dark brown silt (90%).
102 to 121 feet .. fragmentary chert, coloured green, white and grey (5%).

Bore-hole D

0 to 6 feet .. white clean trona (17%).
6 to 21 feet .. white clean trona grading into pale green silt with trona crystals at 20 feet (15%).
21 to 51 feet .. massive clean coarse trona beds 4 to 6 inches thick (20%).
51 to 84 feet .. —no core—
84 to 87 feet .. pale greenish buff clay containing trona crystals (20%).
87 to 91½ feet .. fine-grained trona (90%).
91½ to 95½ feet .. approximately 2 feet of very pure large trona crystals with massive coarse trona below (50%).
95½ to 124 feet .. fine-grained white and brownish grey trona in massive beds (43%).
124 to 158 feet .. —no core—
158 to 164 feet .. fragments of pale green clay and nodular dark grey chert (5%).

From the logs and the figure (Fig. 8, p. 42) it can be seen that it is not possible to make obvious correlations between the trona beds cored in the different bore-holes. The bore-holes do show, however, that the Evaporite Series beds rest on an irregular chert surface and that considerable bodies of trona occur below the surface.

The underground trona beds are similar in appearance to those found on the surface with the exception of colour and degree of compaction. The underground trona is often dark grey or brownish due to the inclusion in the crystals of black mud. Within ten to twenty feet of the surface, however, the trona is often white or yellowish, and in some beds muddy. The near surface trona is also very porous, there being many cavities between crystals. Individual beds vary in porosity but in general the trona beds 20 feet below the surface and lower are massive and with few if any cavities.

At the time of drilling, all the cores, with the exception of the near surface trona, were black and smelled of hydrogen sulphide. Some parts of the core turned brown and green within 24 hours of being drawn, other parts took several weeks to oxidize fully. The colour of the clays when first drilled and the presence of hydrogen sulphide gas suggests that the deposition of the clays was under anaerobic conditions and that these conditions persist to the present day. The evolution of hydrogen sulphide may be due to the action of anaerobic bacteria on sulphates, reducing them to sulphides and generating hydrogen sulphide. The hydrogen sulphide may in turn attack the iron salts in the clays with the formation of black amorphous iron sulphide. The reactions suggested are as follows (Pettijohn, 1948, p. 458):—

$$RSO_4 + 2C \rightarrow 2CO_2 + RS$$
$$RS + CO_2 + H_2O \rightarrow H_2S + RCO_3$$

The change in colour noticed in the cores is therefore probably due to the oxidation of metallic sulphides in the clays.

Deposition of the Evaporite Series may be considered as continuing at the present time. The material being deposited now is composed almost wholly of sodium sesquicarbonate and this is being added to by the introduction of salts from the springs. Small amounts of dust are contributed during dust storms and probably account for the small amount (*ca.* 1 per cent) of clay fraction in the surface trona.

The surface of the lake, when seen from a distance, is slightly off-white in colour, some parts near the margins being pinkish due to the presence of algae. The surface is mostly flat, but locally is slightly hummocky or traversed by cracks and small thrusts where plates of trona have overidden each other due to expansion of the surface. The thrusts often result in the formation of ridges of trona plates leaning together like the two sides of a roof and in other cases the trona simply overthrusts a neighbouring slab and rises up to one foot in height. The ridges produced by expansion enclose perfectly level areas of trona which vary greatly in size. In general, where the interstitial liquor is a few feet below the surface the ridges are either absent or few. Where it is near the surface, however, the ridges are close together and enclose plates of trona a few feet in diameter. Most commonly, however, the ridges enclose roughly circular areas of trona some ten yards in diameter. The trona surface itself consists of upstanding bladed crystals with sharp points that sometimes reach two and a half inches in length. On breaking a piece of the surface trona it is seen that the crystals grow upwards as stellate groups penetrating each other and forming a firm mesh of crystals. Frequently successive growths of crystals give a section in the upper part of the trona a layered appearance, the nuclei of the stellate crystal growths being in the same plane. The crystals radiate upwards and terminate against the overlying layer, which consists of the nuclei of the succeeding generation of crystals. It is assumed that these layers, which are approximately one inch in thickness, represent seasonal growths. On the trona surface thin flat plates of small interfelted trona needles are found, varying in size up to several inches in diameter. They represent the thin skin of floating trona crystals that forms on the liquor surface when it rises above the trona after the rains. The thin plates only form after the flood waters have been concentrated and often occur in depressions in the trona surface where surface water collects and remains longer than in other places.

In wells dug near the causeway over the lake the upper six feet of trona are exposed. The trona is massive, porous and coarsely crystalline, there being no obvious stratification. In general the lower layers are light grey to grey in colour due to mud included in the crystals.

The interstitial liquor of the lake is usually between a few inches and two feet below the trona surface in dry seasons and is turbid and reddish brown, blood red, or greenish brown in colour. Where the liquor is near the surface of the trona the trona is sometimes tinged with the colour of the liquor.

The composition of the trona is straightforward—it consists of trona crystals (sodium sesquicarbonate—$Na_2CO_3.NaHCO_3.2H_2O$), sodium fluoride (NaF), and rarely of small amounts of common salt (halite, NaCl) which sometimes crystallizes on the surface of the trona due to complete evaporation of shallow pools of liquor. It seems that the existence of fluoride in the lake was unsuspected until 1923. In 1943, J. A. Stevens, in an unpublished report to the Magadi Soda Company, suggested that the mineral had not been previously reported in a natural occurrence and proposed to name it magadite. Naturally-occurring sodium fluoride had, however, been discovered in a rock collection made by Villiaume of the alkaline igneous rocks on the islands of Los, French Guinea, where it fills small miarolitic cavities in nepheline syenite. The mineral was described by Lacroix in 1908 (*see* Dana, 1951, p. 10), and named villiaumite. Since then villiaumite has been reported from alkaline rocks in the Lovozero and Khibina tundras of the Kola peninsula, U.S.S.R.

The writer made efforts to separate sodium fluoride from crushed crude trona by means of heavy liquids, without success. Recrystallized sodium fluoride obtained from the Magadi Soda Company was examined and was seen to have the optical properties of artificial villiaumite. It consisted of rounded greyish white crystals giving translucent cubic cleavage fragments when crushed; the specific gravity was determined as 2·80, and the refractive index as less than 1·3323. Villiaumite was observed as well-formed cubic crystals occurring as inclusions in the larger trona crystals, and also occurs as clots of crystals adhering to the margins of the trona crystals. The villiaumite is present as crystals of remarkably uniform size which are easily released by crushing, and which have been separated from the trona by panning and washing. The washed concentrates show an abundance of clear cubic crystals which are isotropic, and have the optical properties given above. It is of interest to note that villiaumite in igneous rocks is red and anomalously anisotropic until heated to 300° C, when it becomes isotropic.

The occurrence of villiaumite at Magadi is particularly interesting in view of the fact that previously it has only been reported in igneous rocks. The crystallization of villiaumite from cold aqueous solutions, as has taken place at Magadi, is probably not unique but does not seem to have been reported before.

A typical analysis of the surface trona is quoted below:—

	per cent
Na_2CO_3	45·2
$NaHCO_3$	35·7
NaF	0·9
NaCl	1·7
Na_2SO_4	0·06
Combined H_2O	15·3
Insoluble..	0·9
	99·76

Anal.—Magadi Chemical Laboratory.

Analyses of lake liquor taken on 19th August, 1951, from the dredge paddock are given below:—

	I	II	III
Na_2CO_3 ..	15·9	15·9	18·1
$NaHCO_3$ ..	1·4	1·6	1·0
NaCl	6·9	7·1	5·9
NaF	0·272	0·304	0·336
Total Alkali ..	16·8	16·9	18·8

All figures are in grams per 100 grams liquor.

I Paddock liquor at surface.
II Paddock liquor at 4 feet below surface.
III Paddock liquor at 8 feet below surface.

A number of analyses were carried out on liquors and cores from various depths during the drilling of the bore-holes on the lake. Since it was impossible to pump the bore-holes dry before taking each sample and since surface liquor was used as drilling water, the analyses of the liquors at various depths represent mixtures of surface and underground liquors. As the composition of the surface liquor is known it is possible, however, to obtain a rough impression of the nature of the sub-surface liquors. All figures in the analyses of the liquors are expressed as grams per 100 grams solution unless otherwise stated. The analyses were carried out by Dr. W. Goldsand of the Magadi Soda Company unless otherwise stated.

Liquors from Bore-hole A

Feet below trona surface	41	65	120
$NaHCO_3$	0·5	1·8	2·0
Na_2CO_3	17·3	8·8	15·3
NaCl	9·6	4·2	6·3
NaF	0·29	0·26	0·42
Specific gravity	1·25	1·13	1·22

Core from Bore-hole A
(clay with trona crystals, calcined)

Feet below trona surface	38
	per cent
Na_2CO_3	53·2
NaCl	4·4
NaF	0·5
SiO_2	25·1
Insoluble (other than SiO_2) ..	16·8

NOTE.—Analysis recalculated to 100%.

Anal.—J. Furst, 15–12–53.

Liquors from Bore-hole B

Feet below trona surface	20	50	72	112	125	170
$NaHCO_3$	0·12	0·19	0·8	0·18	0·12	0·92
Na_2CO_3	20·4	18·7	12·0	19·5	20·3	12·5
NaCl	10·9	11·8	11·9	11·3	10·6	7·25
NaF	0·32	0·30	0·29	0·27	0·28	0·17
Specific gravity	1·30	1·28	1·24	1·31	1·30	1·20

Cores from Bore-hole B (calcined trona)

Feet below trona surface	15	20	60
	per cent	*per cent*	*pre cent*
Na_2CO_3	97·4	89·6	96·6
NaCl	1·63	2·55	0·63
NaF	0·85	1·2	0·30
Insoluble	0·22	6·5*	2·50
	100·10	99·85	100·03

*Including two per cent of gaylussite ($Na_2CO_3 . CaCO_3 . 5H_2O$)

(Uncalcined evaporite)

Feet below trona surface	81	92	158
	per cent	*per cent*	*per cent*
$Na_2CO_3.NaHCO_3.2H_20$ ..	50·7	66·6	40·3
$NaHCO_3$	44·4	29·0	56·3
Free moisture	0·93	0·42	0·67
NaCl	1·00	0·3	0·1
NaF	0·12	0·05	0·17
$CaCO_3$ (acid soluble)	0·25	0·28	0·11
SiO_2 (acid insoluble)	2·24	3·00	2·00
Organic matter	0·20	0·28	0·20
	99·84	99·93	99·85

Liquors from Bore-hole C

Feet below trona surface	20	52	62	75	121
$NaHCO_3$	0·12	0·12	0·24	0·25	0·24
Na_2CO_3	19·9	19·8	20·0	20·1	18·7
NaCl	10·6	10·7	10·4	9·8	11·5
NaF	0·25	0·34	0·28	0·31	0·25
Specific gravity	1·29	1·29	1·30	1·28	1·29

Core from Bore-hole C

(trona, calcined)

Feet below trona surface	78
	per cent
Na_2CO_3	95·6
NaCl	0·4
NaF	0·2
SiO_2	2·6
Insoluble (other than SiO_2) ..	1·2

NOTE.—Analysis recalculated to 100%

Anal.—J. Furst, 15–12–53.

Liquors from Bore-hole D

Feet below trona surface	21	87	91	104	128
$NaHCO_3$	0·12	0·25	0·31	0·50	0·31
Na_2CO_3	17·8	15·8	14·4	15·1	16·3
NaCl	10·7	12·0	13·7	11·3	11·3
NaF	0·23	0·28	0·25	0·22	0·30
Specific gravity	1·3	1·27	1·27	1·27	1·28

Core from Bore-hole D

(*trona, calcined*)

Feet below trona surface	120
	per cent
Na_2CO_3	89·5
NaCl	1·3
NaF	0·2
SiO_2	8·1
Insoluble (other than SiO_2) ..	0·9

NOTE.—Analysis recalculated to 100%

Anal.—J. Furst, 15–12–53.

The above analyses indicate that the sub-surface evaporites consist primarily of sodium carbonates, and a cursory examination of the cores shows the abundance of trona. The analyses of the lower part of the core from bore-hole B, however, indicate the presence of substantial amounts of sodium bicarbonate (nahcolite; *see* W.F. Foshag, *Amer. Min.*, vol. 25, 1940, pp. 769–778), and the occurrence of nahcolite as small needles in the clay matrix between trona prisms in this core was confirmed microscopically. Owing to the fact that most of the core samples were calcined before analysis the bicarbonate content in general was not determined. It is possible that much bicarbonate occurs with trona in the sub-surface evaporites. It will also be noted that, in the case of bore-hole B, the fluoride content at depth is considerably less than at surface.

It is evident from the nature of the succession of the Evaporite Series that the beds were deposited under conditions similar to those obtaining at the present day. The trona beds are probably impersistent laterally and are almost certainly lenticular. During the deposition of the lower part of the series the lake was probably a more or less level area of mud flats with shallow depressions containing concentrated alkaline liquor similar to but probably much less rich in sodium chloride than the present-day lake liquor. In these depressions trona would crystallize as well as in the liquor-saturated muds. Climatic fluctuations bringing wetter weather would allow the dilution of the surface liquors and prevent the crystallization of trona, and at the same time lead to the deposition of more mud.

To account for the continual supply of sodium carbonate in solution, a supply which must have been more or less regular during the deposition of the series, it is necessary to postulate either alkaline spring activity or the supply of alkaline ground-water. The question of the origin of the salts is fully discussed in a later section (p. 55).

Parts of the trona bed that were dredged by Magadi Soda Company to a depth of 5–7 feet twenty or twenty-five years ago have now been refilled by "reformed" trona. This trona is similar to the rest of the upper part of the trona bed but is slightly purer since it contains less mud and probably slightly less fluoride. The rate of crystallization of reformed trona is approximately three inches *per annum*.

Since solutes are being added to the lake faster than salts are removed by the Magadi Soda Company, the trona deposit will continue to grow in size until either climatic or tectonic changes alter the present conditions.

(7) FLUVIATILE DEPOSITS

The main area of fluviatile deposits is in the south-western part of the area where there is a wide flat plain of alluvium deposited by the Uaso Nyiro. Earlier than this expanse of alluvium surrounding the lower reaches of the river are the high alluvial terraces, remains of which are found as outliers at the northern extremity of the area of Uaso Nyiro alluvium. These high terraces are at a level of some 60 feet above the bed of the Uaso Nyiro and consist of small outliers of fine dusty unbedded clayey silts with their light and darker brown colour-laminations. The outliers rest partly on lava and partly on gently dipping clays of the Ngare Nyiro beds. At the contact with the Ngare Nyiro beds there is a kunkar limestone horizon.

some parts of which contain nodular travertine casts of twigs and, in one case, of a tree trunk about nine feet long. Where the alluvial terrace has been removed by erosion the kunkar surface is locally preserved as a pavement of slabby dirty-white or brownish limestone on which two low mounds of travertine were found. The alluvium resting on kunkar limestone which in turn rests on dipping lake beds recalls the relationship of the High Magadi Beds to the Chert Series and it may well be that the High Uaso Nyiro terrace can be correlated with the High Magadi Beds.

The High Uaso Nyiro terrace is not seen at the latitude of the Oloibortoto gorge and is probably overlain by the more recent alluvium which covers the whole of the lower Uaso Nyiro depression. This alluvium is quite homogeneous and structureless and contains no gravel or boulder horizons where it is seen in section in the 40-foot gorge cut by the Uaso Nyiro. It is composed of yellow-brown dusty clays and silts stretching to the base of the Nguruman escarpment in the west and to the Oloronga plateau in the east. Two partial analyses have been made of the silts near the bridge over the Uaso Nyiro and are given below:—

	Per cent	Per cent
SiO_2	54·72	55·40
Fe_2O_3	22·84	24·26
Al_2O_3		
TiO_2		
CaO	trace	trace
Loss on ignition ..	14·58	11·20

Anal.—Magadi Chemical Laboratory.

Two areas of river alluvium occur at the northern extremities of the western and northern arms of lake Magadi. This alluvium has been brought down by seasonal streams descending the slope of fault-blocks, which have the usual southward tilt. The alluvium at the north end of lake Magadi is fine-grained brown silt without bedding or coarser beds. The alluvium is in the form of low dunes and wind-eroded hummocks and has been partly redeposited as loess in the same area.

The alluvium or hill-wash that floors the numerous fault-troughs is generally speaking a red-brown or light brown dusty silt with a high proportion of clay minerals. It is usually quite structureless and although some of the material was originally deposited by streams much of it is local hill-wash derived from neighbouring fault-plateaux and should be considered as soil.

The alluvial boulder fans at the base of the Nguruman escarpment and those surrounding Olorgesailie are the only coarse fluviatile deposits in the area. This is due to the fact that the streams descending the Nguruman escarpment and, to a lesser extent, Olorgesailie mountain, have steep gradients and more rainwater discharge than the others. Also they have been in existence longer than the streams on the younger rocks. The outwash fan or alluvial cone of the Oloibortoto river is typical of those occurring at the base of the Nguruman escarpment. The fan is approximately 400 feet in thickness at its maximum and is several miles wide and consists of quartz sands and gravel beds in the lower parts and boulder beds with interbedded sands in the higher parts. The boulders are well rounded and consist principally of Basement System quartzites with rarer boulders of Kirikiti basalts. Near the entrance of the Oloibortoto gorge some boulders are several feet in diameter, but over most of the alluvial fan the boulders do not exceed one foot in diameter.

Small areas of boulder beds are common where seasonal streams descend the escarpments and are particularly noticeable on the flat ground round the margin of lake Magadi. These boulder beds, in common with those described above, are too large to be in process of formation at the present time and their present extent must be due to the fact that the streams were more active in the recent past than they are at present.

(8) Superficial Deposits

On the raised lava-blocks soils are frequently absent or confined to small depressions. In the fault-troughs, however, the surface almost invariably consists of light brown dusty soils which are derived partly by hill wash and partly by wind erosion of the neighbouring plateaux. In the centres of the larger alluvium- and soil-filled basins, such as the Kordjya and Koora valleys, the soil darkens and becomes similar to black cotton soil, with contraction cracks when dry and a rough surface. This dark soil is probably allied to the "black alkali" soils referred to by Robinson (1949, pp. 383-384) which are considered to be formed by the accumulation of alkaline humic matter. The dark soils in the Magadi area bear a much thicker vegetation than elsewhere.

Kunkar limestone is widespread as a superficial deposit. It is met with more often on lava surfaces and in small seasonal stream-beds where it forms a matrix for lava rubble. As is normal in semi-arid areas the kunkar, when in the soil, lies near to the surface. The limestone is precipitated in the soils by the loss of carbon dioxide from bicarbonate of calcium which is formed during the weathering of numerous silicates (*see* pp. 57-61). Since calcium is precipitated at an early stage in the weathering of the lavas, which are the source-rocks for all the soils in the area, the remaining transported soils are relatively calcium-free and kunkar limestone forms on them only rarely. The part played by calcium carbonate in base exchange in the Magadi soils is outlined in a later section (pp.57-61).

Some partial chemical analyses of kunkar limestones have been carried out by the Magadi Soda Company:—

	I	II	III	IV
	per cent	*per cent*	*per cent*	*per cent*
SiO_2	17·84	18·06	18·74	17·34
TiO_2	0·25	0·26	} 6·26	6·51
Al_2O_3	0·75	5·46		
Fe_2O_3	5·91	2·02		
CaO	39·78	39·50	39·99	40·54
$CaCO_3$ (calculated)	72·6	70·51	71·4	72·39

I. Average of nine samples taken in one square mile, three miles south of Magadi golf-course.

II. Average of nine samples taken from small area at south end of Oloronga plateau (south of area mapped).

III. One sample from western edge of Oloronga plateau.

IV. One sample from low plateau near bridge over the Uaso Nyiro.

The principal feature of the analyses is their remarkable similarity.

The character of the soils of the Magadi area generally appears to be the result of leaching following base exchange, resulting in soils with marked superficial concentrations of relatively insoluble carbonates and the absence of soluble carbonates. Such clay minerals as have formed in them are predominantly bentonitic. The alkaline solutions released during base exchange carried with them silica in solution and when the silica-rich alkaline waters entered lake basins such as occurred during the Pleistocene history of the area, the growth of diatoms was favoured, giving rise to extensive diatomaceous deposits as are found in several places near Magadi.

A complete study of the nature and development of the soils in the Magadi area is beyond the scope of this report. Such a study would, however, yield interesting information and would have an important bearing on the possibility of the origin of some of the Magadi trona by surface leaching.

4. The Alkaline Springs and Lagoons

J. A. Stevens, formerly of the Magadi Soda Company, in one of the Company's technical reports entitled "Lake Magadi and its Alkaline Springs" (1932), gave a full account of the various springs near the lake and quoted numerous analyses of the spring and lagoon waters. Almost all the information in this section is taken from his report. The distribution of springs and lagoons is shown on the drawing presented in Fig. 9 in which the numbers used for the various groups of springs are the same as those employed by Stevens.

The number of individual springs near the lake is large since a group of springs often consists of a large number of small seepages rising in the mud and shingle at the lake shore. Others, such as the main springs feeding "little Magadi" lagoon are larger, and with a much greater flow. Although certain sections of the lake shore have no springs at all, there are many stretches along which there are innumerable springs, rising usually within three feet of lake-level and running down to form a strip of alkaline liquor which separates the trona from the shore.

It has not been possible to measure directly the flow of individual springs but Stevens (*op. cit.*, p. 30) described a method whereby the inflow of the groups of springs feeding isolated lagoons can be measured. The method is described later (p. 54). The temperature of the springs varies considerably, from 33° C. to 86° C., but there appears to be no relationship between temperature and rate of flow. In any group of springs the temperature may vary by 5° C. in individual springs. The temperature and composition of the various springs are given in the following table (Stevens, 1932, p. 16):—

SPRING LIQUORS, MAGADI

(*Analyses expressed as grams/100 grams liquor*)

Spring No.	Temperature °C.	Na_2CO_3	$NaHCO_3$	NaCl	Na_2SO_4	NaF	Total Solids	Sp. Gr.
1	35·5	0·878	1·037	0·768	0·013	0·022	2·349	1·017
2	37	0·476	0·862	0·513	0·013	0·015	1·561	1·014
3	39	0·336	1·302	0·610	0·022	0·014	1·824	1·016
4	45·5	0·265	1·673	0·708	0·029	0·015	2·092	1·019
5	*c.* 44	0·255	1·690	0·699	0·029	0·016	2·082	1·0185
6	*c.* 48	0·338	1·661	0·728	0·031	0·017	2·176	1·0195
7	38	0·780	0·699	0·566	0·021	0·022	1·844	1·0155
8	39	1·181	1·272	1·042	0·027	0·022	3·093	1·0275
9	37	0·203	0·522	0·247	0·019	0·007	0·820	1·006
10	37·5	0·560	0·705	0·476	0·028	0·016	1·537	1·013
11	38·5	0·539	0·655	0·462	0·027	0·016	1·470	1·0125
12	38·5	0·817	0·890	0·714	0·034	0·019	2·160	1·019
13	42·8	1·067	1·203	0·969	0·032	0·023	2·864	1·026
14	44·2	1·173	1·250	1·035	0·033	0·025	3·068	1·0275
15	40	1·538	0·630	1·025	0·029	0·024	3·021	1·0265
16	40	1·548	0·630	1·025	0·028	0·024	3·035	1·0265
17	35	0·111	0·381	0·217	0·028	0·004	0·617	1·004
18	85	0·345	2·076	0·838	0·026	0·027	2·564	1·024
19	81·5	0·595	1·695	0·842	0·024	0·028	2·569	1·0235
20	81	0·590	2·055	0·955	0·025	0·033	2·913	1·026
21	67	0·487	2·065	0·912	0·022	0·028	2·763	1·025
22	33	0·492	0·438	0·378	0·010	0·009	1·174	1·010
23	34	0·419	0·442	0·338	0·009	0·009	1·063	1·009
24	36	0·822	0·581	0·597	0·009	0·012	1·817	1·015

All the spring waters observed are clear and colourless at their points of issue but in the small pools and seepages near the springs the liquors are frequently found to contain dark green, bright red, light brown and dark brown algae. The algae seem able to tolerate temperatures up to 68° C. but in the very hot springs at the north end of Little Magadi lake

there are no algae. These hot springs are unusual since the group rises along the bed of a dry valley at the base of the tall escarpment which forms the western edge of Little Magadi lake. The various springs combine into a rapidly-flowing steaming stream of hot water in which are lava boulders fallen from the escarpment above. The boulders are corroded and coloured grey on their lower parts where they have been exposed to the action of the hot spring water, while the upper parts are weathered dark brown and black similar to the other lavas in the area.

The actual sites of the springs vary considerably in character. Most commonly the springs issue at the bases of the fault escarpments bounding the lake and in these cases, if not all, the liquors must rise in the fault-zones and then trickle through the scree at the base of the escarpments or find their way through small channels in the lake sediments abutting against the escarpments. The numerous small springs rising on the lake shore south of "Bird Rock" are seepages nine to eighteen inches wide through shingle and mud. The seepages are surrounded by small green, brown and red plants. Those rising at the north end of Little Magadi lake trickle from the base of the lava rubble at the lake shore while others issue from small cauldron-like depressions one to two feet in diameter.

South of the south-western lagoon one of the larger springs issues in the middle of a shallow valley filled with lava and chert shingle. The water issues from small holes and cracks in the centre of a shallow mound of lake sediments (probably High Magadi Beds) whence it flows northwards in a shallow stream four to eight feet wide and two to three inches deep to the south-western lagoon. None of the springs have sufficient pressure to throw water into the air and no gas was seen to bubble up with the liquor.

Nearly all the spring liquors eventually find their way into the stagnant lagoons that margin the main trona bed at lake-level. Most of the lagoons are known to be shallow and near the points of inflow of spring liquors their bottoms consists of lava or chert shingle or black clays; further out into the lagoons, where the liquor is more concentrated by evaporation, the bottoms are formed of a thin layer of trona crystals. Further away from the springs and towards the margin of the exposed trona bed the trona at the bottoms of the lagoons becomes thicker and slopes upwards until dry trona emerges at the lagoon edges.

The lagoon liquors are always cloudy and vary in colour from pale green to yellow and brown. The colouration is probably due to micro-organisms which feed the dwarf *Tilapia grahami* that inhabit the more dilute parts of the lagoons.

There are some ten lagoons, all of which are shown on Fig. 9; they are as follows:—

South-western lagoon—the largest with the exception of that at "Little Magadi", which is really a lake. It is fed mainly by a small but relatively powerful group of springs—numbers 13 and 14—and occupies a fault-trough, but also spreads out on to the trona surface and is linked by a narrow channel to the *Western scarp lagoon* and the *North-west lagoons*. The North-west lagoons are fed by relatively dilute springs, numbers 1, 2, 3, 4, 5 and 6. The smaller lagoons include the *Bird Rock lagoon* at the south end of the lake, which is connected to *Graham's lagoon* by a narrow channel; both are the homes of numerous water-birds—flamingo, waders, duck, etc. Graham's lagoon narrows northwards and finally forms a narrow discontinuous channel near the base of the escarpment of the ridge on which the Magadi Soda Company's plant is built. This is called the *Factory scarp lagoon*. The *Fish springs lagoon* is an oval pool on the soda-encrusted mud flats north-east of the factory—it receives its liquor from the springs numbers 22, 23 and 24. A little to the north of the *Fish springs lagoon* is one circular lagoon neighboured by two very small lagoons. These are not fed by any springs at the lake's edge and it must be assumed that they are supplied by springs issuing through the lake sediments. The *North-eastern lagoon*, like that in the south-west arm of the lake, occupies a fault-trough and is fed by a group of hot steaming springs (No. 21) in the northern extremity of the trough. The liquor from this lagoon overflows by a winding stream to the *Northern lagoon* which separates the trona bed from the alluvium brought down by rivers flowing into the lake from the north.

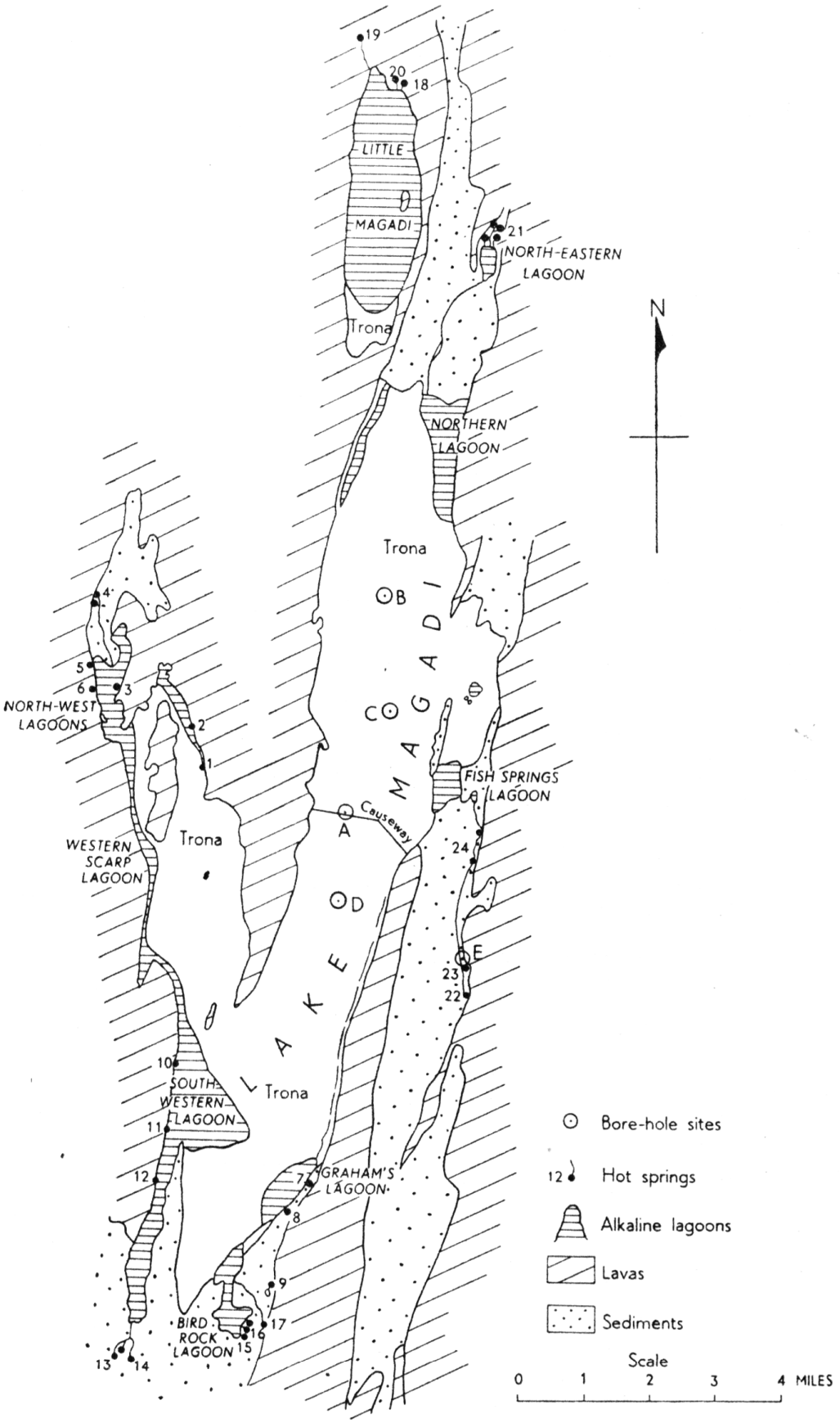


Fig 9.—The alkaline springs and lagoons of Lake Magadi.

Little Magadi lake, though not strictly a lagoon is, like the true lagoons, maintained by the inflow of spring water. It is bounded east and west by fault escarpments, to the north by lavas and to the south by river alluvium and a shallow trona bed. It is probable that a certain amount of liquor from Little Magadi lake, which is some 50 feet higher than the main lake, finds its way through the narrow lava horst separating the two lakes, to replenish the western arm of the northern lagoon.

Such analyses of lagoon liquors as are available are quoted below:—

	I	II	III	IV	V	VI	VII	VIII
Na_2CO_3 ..	6·7	1·31	2·1	9·57	10·20	4·68	9·3	11·4
$NaHCO_3$ ..	2·1	0·46	0·48	2·17	2·16	1·11	3·2	3·1
NaCl ..	3·6	0·76	1·87	6·53	6·15	1·94	6·2	7·7
NaF ..	0·01	0·075	0·020	n.d.	n.d.	0·062	0·21	0·27

NOTE.—Figures are grams/100 grams liquor.
n.d.—not determined.

Anal.—Magadi Chemical Laboratory.

I, II, III } Factory scarp lagoon.

IV South end of Western scarp lagoon
V Centre of south-west lagoon } Stevens 1932, p. 18.
VI Bird rock lagoon.

VII Little Magadi lake, 1,100 yards north of the south-east corner of the lake, 3 feet from lake edge.

VIII Little Magadi lake, liquor in contact with trona 100 yards south of VII.

The above figures indicate the variability in concentration of the lagoon liquors from place to place and suggest that the solutions represent partially concentrated (evaporated) spring liquors.

From the table of analyses of spring liquors (p. 51) it can be seen that although the concentration of spring waters varies considerably, from 0·6 to 3 per cent of dissolved solids, there is a remarkable constancy in the ratio of the principal acid radicles—carbonate and chloride. Thus the Na_2CO_3/NaCl ratio for almost all the spring waters is 1·9 to 2·0. The proportion of sodium sulphate is the most variable of the constituents, while the amount of sodium fluoride is comparatively constant.

Stevens (1932, pp. 31-32), showed that according to available evidence the composition and temperature of individual hot springs had not appreciably changed in the 20 years during which chemical work had been done at Magadi. To calculate the amount of salts they add to the basin he assumed that the rate of flow remains constant and, since direct measurements are impossible in all cases, that the rate of flow of groups of springs could be estimated by measuring the total area of each lagoon and the average rate of evaporation of its liquor in dry weather, on the further assumption that during dry weather the rate of inflow is balanced by the rate of evaporation. He measured the rate of evaporation of tap water in a pan at the Magadi laboratory over a period of 122 days in 1930 and found the average rate was 1·06 centimetres per day (*op. cit.* p. 26). Taking into account the fact that 1930 was an unusually wet year, Stevens calculated that the average rate of evaporation from the lake when covered by water is approximately 0·63 centimetres per day, and assumed that the lagoons evaporate at a similar average rate. Having measured the areas of the lagoons from the map he then calculated the maximum rate of inflow of spring liquor into each of them and, by using the average analyses for the group of springs feeding each lagoon, computed

the amounts of sodium carbonate and chloride introduced. The results obtained (Stevens, *op. cit.*, pp. 27-28) are as follows:—

Lagoon	Total inflow Cubic feet/day	Input Na_2CO_3, tons/day
Fish Springs	380,000	106
Factory Scarp	270,000	90
Graham's	555,000	278
Bird Rock	315,000	166
South-western	2,490,000	1,175
Western Scarp	390,000	141
North-western	1,560,000	564
Northern	720,000	360
North-eastern	180,000	90
"Little Magadi"	2,820,000	1,330
TOTALS	9,680,000	4,300

The validity of the figures also depends on the assumption that there are no springs underneath the lake or the lagoons and that there is no recirculation of carbonates. The most interesting feature they reveal is that the amount of soda in the lake is increasing much faster than the Magadi Soda Company remove it. On this estimate, therefore, the soda deposit has an infinitely long life.

(1) Origin of the Springs and Spring Solutes

The question of the origin of the solutes in the hot spring liquors has been treated by almost every investigator who has worked at Magadi. The problem is interesting from the scientific as well as from the economic point of view and since a considerable mass of evidence has been accumulated due to the Magadi Soda Company's chemical work and the initiative of J. A. Stevens, while working as chemist for the Company, it is possible to assess the relative merits of such theories as have been put forward. Theories that have been developed in the past can be broadly classified as Parkinson's Theory, Stevens' Hypothesis, and the Re-circulation Theory. These are considered in detail below, and followed by a statement on the writer's ideas, which are collated as "The Surface Leaching Hypothesis".

Before considering the various theories it will be useful to define terms to be used, as the phrases "hot springs" and "alkaline springs", have not been defined by previous workers on the Magadi area. Barth (1950, p. 16) quotes Allen and Day's definition of hot springs as used by them in their monograph on thermal activity in the Yellowstone National Park (1935). The definition is: "Hot springs are circulating ground water of surface origin heated and augmented by steam originally in a superheated state rising from an underlying magma through deep cracks in the earth's crust". Barth supports this definition as a result of his comprehensive work on the Icelandic hot springs. "Alkaline springs" or "alkaline waters" are defined for the purpose of this report as waters whose principal cations are sodium or potassium and which have a concentration of dissolved solids exceeding 2,000 parts per million (i.e. the salinity is greater than 0·2 per cent).

Parkinson's Theory.—Parkinson (1914, p. 45) states: "These hot springs . . . appear to me to be clearly of plutonic origin . . . the term 'plutonic' signifies a deep-seated origin, implying that the water was an original constituent of the rock magma, as distinct from being 'meteoric' or 'vadose'." It is clear that his statement does not fit Allen and Day's definition, as he believed all the spring water to be juvenile. This is unlikely since juvenile water or steam is almost certain at some stage to come in contact with ground-water and give up its energy to it and become mixed with it. Parkinson suggested that the juvenile hot water, charged with magmatic carbon dioxide, reacted with the sodium silicates in the lavas through which it passed and formed sodium carbonate and silica. In support of this reaction he quoted Gautier (*Ann. des Mines*, Memoires 9, 1906, 10e Ser., p. 358) who gave the reaction:—

$$Na_2SiO_3 + 2CO_2 + H_2O \rightarrow SiO_2 + 2NaHCO_3$$

That breakdown of sodium silicates does occur by the action of carbonated waters is known (Kelly, 1950, p. 67), but whether significant quantities could be dissolved by spring water in its relatively rapid rise to the surface is, in the writer's opinion, doubtful.

Parkinson's suggestion that the spring waters are juvenile is not borne out by a consideration of the salts dissolved in them. Many springs due to volcanic action are known and the principal compounds carried in such springs or released as fumarole gases and deposited as primary magmatic sublimates are ammonium chloride, sulphur, gypsum, silica and sulphates in minor amounts (Barth, 1950, pp. 46-47). Shand (1947, pp. 39-40) gives analyses of primary volcanic gases and sublimates and concludes that water vapour is the main constituent of volcanic gases followed by variable amounts of carbon dioxide and monoxide, sulphur dioxide and trioxide, nitrogen, hydrogen and chlorine. As would be expected therefore primary magmatic salts in juvenile springs and gases give them a strongly acid reaction (Barth, 1950, p. 43). The Magadi springs are altogether different in character to known juvenile hot springs and it is concluded that they carry little if any juvenile water or salts.

Gregory (1921, p. 79) followed Parkinson's theory in outline but suggested that the plutonic (juvenile) waters attacked and leached sodium from nepheline crystals in the nepheline tephrite and nepheline augitite lavas that he believed underlay the lake. Willis (1930, pp. 239-240) held similar views. This theory is essentially the same as that of Parkinson and the same difficulties, outlined above, apply to it. Gregory also mentioned the possibility "that the lake is a great evaporating pan in which is deposited soda leached out of the adjacent lavas by percolating water". Gregory, however, inclined to Parkinson's hypothesis because he saw the other Rift Valley lakes during years of good rains, when there were no encrustations of salts round the edges of those that are saline, and when the possibility of Lake Nakuru drying out until it was an almost waterless salt-pan, as has happened in recent years, could not be imagined. The possibilities of the "leaching" hypothesis are discussed at greater length on a later page.

Stevens' Hypothesis.—Stevens (1932, p. 39) discussed both Parkinson's and Gregory's suggestions and pointed out that were nepheline the source of the soda in the springs potassium should also be found, since natural nepheline usually contains some potassium as well as its predominant sodium. He also drew attention to the fact that no explanation had been given of the chloride, sulphate and fluoride of sodium found in the spring waters. A further difficulty recognized by Stevens rested on the relative proportions of carbonate to chloride in the lake as a whole and in the spring liquors. If the lake salts were supplied entirely by the springs one would expect the ratio to be the same for the lake (trona and interstitial liquor), and the springs. Stevens showed that this is not the case. He also objected to the surface leaching process followed by evaporation put forward by Gregory. He mentioned lake Kabongo, a seasonal lake fed by the Turoka river, which when it dries up does not leave any efflorescence of salts, and regarded it as evidence that leaching by surface water could not bring about any concentration of salts. He, therefore, concluded that the greater part of the lake salts of Magadi must be derived from the spring liquors, in spite of the contrary suggestion offered by consideration of the ratios of salts in the waters. Continuing, Stevens concluded that the constancy of the carbonate/chloride ratio in the springs implied a common source for them all, a source which he believed to be "an enormous body of concentrated mother liquor miles below the earth's surface". As pointed out by Temperley (1951, p. 7) the existence of such a body of liquor is quite incompatible with the pressure and temperature conditions known to exist at those depths.

It seems that Stevens in his 1932 paper made little advance on the hypotheses of Parkinson and Gregory. Later, however, he proposed an entirely new theory, the re-circulation theory, in conjunction with N. J. Guest (Guest and Stevens, 1951, p. 7).

The Re-circulation Theory.—The re-circulation theory was put forward by Stevens (Guest and Stevens, 1951, p. 1) to account for the apparent high rate of inflow of salts into Lake Natron, a rate of inflow which suggests that the Natron springs could have supplied all the saline material in the lake in 100 to 150 years. Stevens (1932, p. 28) had made similar calculations for Lake Magadi, and concluded that the evaporite could have accumulated in 115 to 460 years. In these calculations the rate of flow of the springs was estimated by calculation of the area of lagoons and the rate of evaporation of water from them, and it was assumed that no lake or lagoon liquor disappears underground. It is impossible for the evaporites and interbedded clays at Magadi, which are known to be over one hundred feet thick, to have accumulated in so short a time and to resolve this difficulty Guest and Stevens put forward the re-circulation theory.

The theory maintains that since the specific gravity of lake liquor (in the case of Lake Magadi) is 1·3, and is greater than that of spring water or fresh water, there is a downward movement of liquor from the lake and that this liquor becomes mixed with ascending hot spring water, thus rendering the spring water alkaline. According to this view a part of the salts contained in solution are in continuous cyclic movement, and it can be deduced that the spring solutes are not contributing additional salts to the lake but only replacing the salts removed by downward seepage of lagoon or lake liquor and by the crystallization of trona. The theory is supported by the similarity in chemical composition between spring water and the lake and lagoon liquors (*see* Fig. 10, p. 60). The carbonate/chloride ratio of the lagoon waters does vary, but the ratio in the spring waters is remarkably constant throughout all the springs and this lack of similarity in the ratios is one of the difficulties of the theory. A further disability is that with the continuation of re-circulation over a prolonged period of time, during which the evaporites and clays were deposited, one would expect a progressive enrichment of the re-circulating waters in chloride, since no chloride has crystallized out of solution so far as is known. An explanation of this may be that the solutions from which the older evaporites crystallized were very poor in sodium chloride.

If the assumption were made that no original salts are being contributed to the lake by the springs, then re-circulation must diminish the rate of precipitation of salts in the lake. There is no evidence that the rate of crystallization of salts in the lake is diminishing and it would be necessary to postulate some way in which salts could be added to the cycle.

Guest and Stevens (1951, p. 16), as a corollary to their proposal of the re-circulation theory, suggest that the salts of the Natron springs are juvenile in origin and James (1953, p. 16) supports their view by a study of the composition of gases and spring waters in the north Tanganyika rift-zone. James (*op. cit.*) also mentions the evidence presented by J. J. Richard (1942), who studied the 1940-41 eruptions of the volcano Ol Doinyo Lengai near the south end of Lake Natron. On the ash beds laid down as a result of the eruption there was a thin white crust of soda and some soda was also seen in cavities. James (*op. cit.*, p. 22) believes that the soda crusts left after various eruptions have been leached by rain-water and that the solutions so provided have contributed to the accumulation of sodium carbonate in Lake Natron. The origin of the soda incrustations seems to be in doubt for Richard refers to them as a sublimate (*op. cit.*, p. 90) and later (p. 107) as derived from weathering of volcanic *ejectamenta*. Clarke (1924, p. 266) however, refers to sublimates of sodium chloride and sodium carbonate deposited around fumaroles on a flowing lava from Etna. The difficulties of the view that the salts are entirely juvenile are summarized on p. 56.

The writer considers it unlikely that re-circulation plays any important part in supplying salts to Lake Magadi, though some of the smaller springs, which are little more than seepages, may be re-circulated lagoon water in part. The greater part of the spring water is probably alkaline ground-water, heated by contact with igneous rocks and forced to the surface as a result of pressures generated by boiling of the water that is in contact with hot rocks deeper in the earth's crust.

Surface Leaching Hypothesis.—Orr and Grantham (1931, p. 12) considering the origin of the salts of the lakes in the northern Tanganyika rift-zone state " . . . these salts have formed . . . by the evaporation of surface waters in a basin of inland drainage over a considerable period of time. . . . The main source of alkali carbonates is probably the volcanic areas. . . ." The possibilities of this view, which is similar to that mentioned but discarded by Gregory (1921, p. 79), are discussed below.

Another view, that the Magadi salts were derived from ground-water rendered alkaline by leaching of felspathoid minerals from lavas, was put forward by the Imperial Institute (Anonymous, 1923, p. 441), and is in many respects similar to the process suggested in the following pages.

The leaching of surface rocks by meteoric water to account for the formation of alkaline waters has also been discussed by Stevens (1932, p. 41) and Temperley (1951, p. 6). These writers discounted leaching as being an insufficiently powerful process to give rise to large accumulations of salts, since, they argued, there are several lakes in East Africa with no outlet, whose water recharge comes from volcanic rocks, yet they have no deposits of salts. Lake Kabongo, mentioned by Stevens (*op. cit.*, p. 41), is considered by the writer as a special case in so far as the greater part of its catchment area is on gneisses and schists of the Basement

System, whose principal minerals are quartz and felspar. It is doubtful whether Lake Kabongo ever dries up through evaporation alone; although obviously much of the water evaporates, much also seeps downward and the concentration of salts probably never approaches saturation before the water disappears underground.

Other Kenya lakes such as Nakuru, Elmenteita and Naivasha are most probably "water-table lakes" or "hydrographic windows" (Barth 1951, p. 17), being lakes formed by outcropping ground-water. With the exception of Lake Naivasha the contributions of surface streams to their maintenance are small, and they are mainly kept in being by the inflow of ground-water, both underground and by means of marginal springs. The analyses of lake and spring waters quoted below show that some of the Rift Valey waters are alkaline and that their ratios of dissolved salts have considerable similarities (*see* also Fig. 10).

ANALYSES OF SOME RIFT VALLEY LAKE AND SPRING WATERS

(*in parts per million*)

(*Taken from Stevens*, 1946)

	1	2	3	4	5	6	7	8
Na	135	262	5,017	5,550	33,855	1,252	23,271	89
Ca	n.d.	42	n.d.	10	n.d.	n.d.	n.d.	15
Al, Fe ..	—	2	—	6	—	—	—	10
Mg ..	—	15	—	—	—	—	—	—
CO_3 ..	170	421	6,640	6,150	37,400	1,245	20,100	146
Cl	tr.	20	492	1,375	7,160	461	10,460	11
SO_4 ..	tr.	1	131	253	1,457	104	1,317	13
F	4	6·3	144	n.d.	1,400	95	1,627	5·3
SiO_2 ..	n.d.	69	n.d.	n.d.	n.d.	n.d.	n.d.	96
K	—	—	—	256	—	—	—	—
% Salinity..	0·031	0·083	1·24	1·36	8·12	0·31	5·67	0·038

	9	10	11	12	13	14	15	16
Na	81	1,619	29,671	14,360	5,100	1,584	1,228	191
Ca	26	14	27	26	n.d.	448	10	26
Al, Fe ..	9	2	21	tr.	—	—	8	2
Mg ..	—	—	—	tr.	—	—	6	49
CO_3 ..	153	1,720	31,906	17,650	5,125	1,312	1,495	174
Cl	6	319	5,930	3,450	1,460	424	452	134
SO_4 ..	13	58	270	204	—	—	143	120
F	5·2	73	1,170	n.d.	185	41	0·18	n.d.
SiO_2 ..	94	124	550	n.d.	1,210	150	134	85
K	—	—	—	304	—	—	—	—
% Salinity..	0·037	0·392	6·95	3·56	1·308	0·395	0·347	0·078

1. Lake Naivasha water.
2. Seepage into Lake Naivasha.
3. Water from the "Crater Lake" near Lake Naivasha.
4. Lake Nakuru water.
5. Lake Nakuru water.
6. Hot spring near Lake Elmenteita.
7. Lake Elmenteita water.
8. Hot spring three miles from Lake Hannington.
9. Hot spring near Lake Hannington.
10. Geyser S.W. of Lake Hannington.
11. Lake Hannington water.
12. Lake Hannington water.
13. Lake Hannington water.
14. Lake Baringo water.
15. Hot spring near Lake Rudolf.
16. Lake Rudolf water.

NOTE.—All analyses carried out in the Magadi Soda Company's chemical laboratory.

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The concentration of salts in the waters of Lakes Hannington, Elmenteita and Nakuru is even greater than the concentration of salts in the Magadi springs. Furthermore, Stevens (1946, p. 6) gives analyses of mixtures of crystalline trona and common salt found in small pools at the margins of the same lakes. This partly invalidates the objections of Gregory (1921) and Stevens (1932) that no alkali salts are found in Rift Valley lakes other than Magadi.

The salts in the Rift Valley ground-water are derived from the weathering of igneous silicates. The bicarbonates of the base elements sodium, potassium, calcium and magnesium are formed by the action of carbonated meteoric water and can convert to normal carbonates by the loss of carbon dioxide. The normal carbonates of calcium and magnesium are relatively insoluble and, under semi-arid climatic conditions, are precipitated in the B horizon (zone of accumulation) of the soil (Reiche, 1950, p. 65). Potassium is commonly strongly absorbed by the colloids of the soil, where it participates in the formation of clay minerals.

River waters are generally to be regarded as solutions of bicarbonates, with calcium predominating over other cations. In lakes, however, especially lakes in closed basins, evaporation leads to the break-down of bicarbonates and the precipitation of the greater part of the calcium (cf. Clarke, 1924, pp. 160, 162), and sodium is greatly enriched at the expense of the other bases. Where surface or lake waters have not dissolved connate salts or pre-existing evaporites from sedimentary rocks other than carbonates, as is the case in the Rift Valley, carbonate is the dominant anion (*see* Fig. 10).

Sodium carbonate may have accumulated in the Rift Valley lakes by the process described above. Sodium can also accumulate in soils by the process of adsorption and base exchange, and this sodium may be leached out by carbonated waters under suitable climatic conditions. Kelly (1950, p. 70) quotes an experiment by Mondesir which illustrates the capacity of some soils to adsorb sodium—"Mondesir exhibited before the French Academy of Science, in 1888, 100 grams of trona ($Na_2CO_3.NaHCO_3.2H_2O$) which he had prepared from one kilogram of calcareous soil by twenty repetitions of the treatment—leaching with sodium chloride solution, then with water and finally with carbonated water".

Evidence that several lakes existed in different parts of the Magadi area at different times since post-middle Pleistocene times has been presented in previous pages. There is also evidence that many localized lakes existed throughout the Rift Valley (Willis, 1930, pp. 279-280), and that there has been a long period of time during which evaporation and concentration of Rift Valley waters has taken place. Since the valley slopes southwards from the watershed along the line Eburru-Gilgil-Ol Joro Orok to the Magadi-Natron basin, residual ground-water will have found its way southwards towards Magadi. By repeated evaporation of lake waters and by repeated fixation and re-leaching of sodium in the soils of the numerous pans between fault escarpments, the greater part of the soluble salts leached from volcanic rocks in the southern part of the Rift Valley will have become concentrated in the ground-water of the Magadi-Natron basin.

Calcium, initially an important constituent of the waters, has been precipitated largely in the form of lacustrine limestones or occasionally as double salts such as gaylussite. Silica has also been deposited from lake waters in large amounts to form cherts and diatomaceous deposits. Gypsum and magnesite may also have been deposited comparatively early in the history of the concentration of the waters. It is to be expected that in some lake basins the waters remained comparatively fresh, while other basins may have been little more than swamps, but it is not likely that any significant amounts of salts, if any, were deposited in basins other than the Magadi-Natron basin, for the slope of the Rift Valley floor is such that the ground-water must have been constantly moving towards Magadi and this would limit the development of concentrated alkaline waters at higher altitudes.

In the Magadi area the first evidence of the existence of appreciably alkaline water is the efflorescences of salts on the outliers of High Magadi beds e.g. near "Needle Rock". The presence of stunted *Tilapia nilotica* fossils in the sediments also suggests that the waters may have been slightly alkaline. The deposition of tufa on twigs and roots on the upper surface of the High Magadi beds has a parallel in the contemporaneous deposition of tufa on tree trunks and branches on the shores of Lake Hannington, a lake which is distinctly alkaline (cf. Clarke, 1923, p. 160). The High Magadi beds represent the deposits formed in the Magadi basin during the most recent pluvial period. The recession of the High

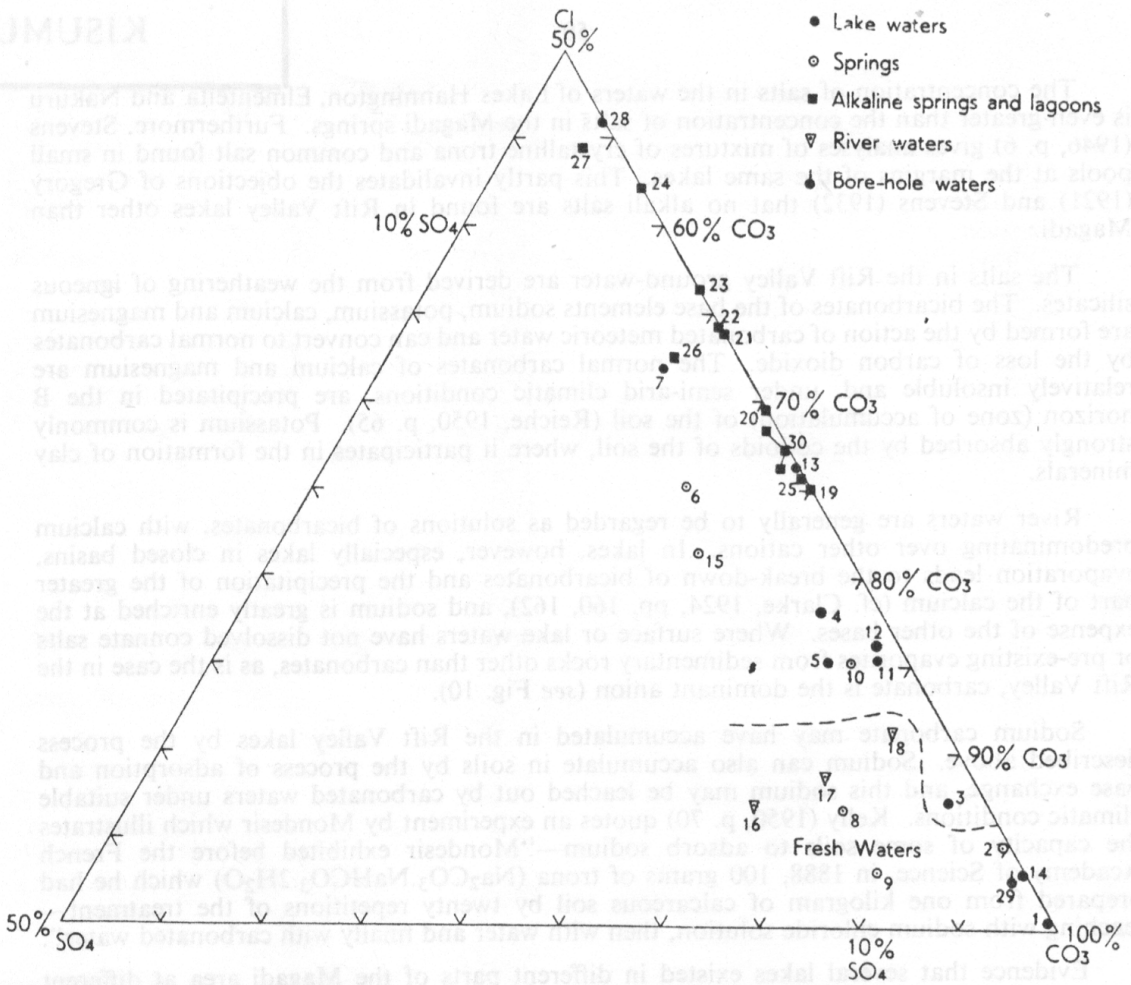


Fig. 10.—Triangular diagram representing the relative proportions of anions in Rift Valley waters.

1. Lake Naivasha water
2. Seepage into Lake Naivasha
3. Water from the "Crater Lake" near Naivasha
4. Lake Nakuru water
5. Lake Nakuru water
6. Hot spring near Lake Elmenteita
7. Lake Elmenteita water
8. Hot spring three miles from Lake Hannington
9. Hot spring near Lake Hannington
10. Geyser south-west of Lake Hannington
11. Lake Hannington water
12. Lake Hannington water
13. Lake Hannington water
14. Lake Baringo water
15. Hot spring near Lake Rudolf
16. Endosapia river water
17. Uaso Nyiro water
18. Oloibortoto water
19. Lake Magadi paddock liquor (at 8 feet depth)
20. Lake Magadi paddock liquor (at surface)
21. Magadi lagoon liquor (Factory scarp lagoon)
22. Magadi lagoon liquor (South-west lagoon)
23. Magadi lagoon liquor (Western scarp lagoon)
24. Magadi lagoon liquor (Factory scarp lagoon)
25. Magadi lagoon liquor ("Bird Rock" lagoon)
26. Average of Lake Natron hot springs
27. Average of Lake Natron brines
28. Bore-hole water, C.1662, upper Koora valley—mile 16 Magadi-Nairobi road
29. Bore-hole water, C.1559, near mile 30 on Magadi-Nairobi road
30. Magadi springs (average and range)

NOTE.—Complete analyses of waters Nos. 1-15 are given in the text, *see* p. 58. Analyses of Nos. 28 and 29 are given on p. 77.

Magadi lake and the erosion of its deposits mark the onset of drier conditions, and the subsequent Evaporite Series, with its interbedded clays and evaporites, represents alternating wetter and drier phases of climate, with a general tendency towards arid conditions. It is impossible that the comparatively small High Magadi lake, the waters of which had a salinity of perhaps 0·5 to 1·0 per cent, could have given rise to the extensive trona beds by evaporation. Were it not for the activity of the alkaline springs it is probable that the lake would have dried up altogether and that the present Evaporite Series would be represented by only a localized, thin trona bed, or no bed at all, and that the lake basin would subsequently have been filled by loesses and fluviatile clays. The onset of alkaline spring activity, however, served to maintain the lake in being and to allow the uninterrupted evaporation of the additional alkaline water so provided. In this view the spring waters are regarded as heated alkaline ground-water, and as supplying increments of salts to the lake over a considerable period of time. Other factors influencing the course of events at Magadi are that there is no outlet from the lake and that no significant amounts of fresh surface water reach it by rivers and streams.

The principal factors leading to the accumulation of the remarkably large trona deposit at Magadi are, therefore, believed to be:—

(1) the large area of recent volcanics over which leaching has taken place.

(2) the repeated concentration of the waters by evaporation in many lakes over a prolonged period,

(3) the accumulation of a body of alkaline ground-water beneath the Magadi basin due to its situation in the lowest part of the Rift Valley,

(4) the activity of springs in keeping the lake in being as a large evaporating pan and in supplying the alkaline waters for evaporation.

The foregoing hypothesis thus classifies the Magadi trona with numerous other occurrences of "salt pan" or "playa" type. The closest parallels are with the Lahontan basin of Nevada, and the Owens and Searles lakes of California (Clarke, 1923, pp. 159-162).

VI—STRUCTURE

The Magadi area is unusual in that the structural elements of the geology are clearly recognizable. This is due to the short geological history of most of the rocks, which, apart from the Basement System rocks range from late Tertiary to Recent in age. Erosion has not been sufficient to level off features of tectonic origin and, since faulting is the dominant factor in the structure it determines not only the geological lines but also the topography.

The most striking feature of the area, and one that is apparent even when viewing from a distance or from an aeroplane, is the number of fault escarpments traversing it from north to south. These escarpments are usually vertical cliffs in their upper parts, while the lower parts consist of steep scree slopes covering in almost every case the actual site of the fault. The ground between the escarpments is generally smooth and the whole of the central part of the area gives the impression of an originally smooth level surface of lava, cut into table- and step-like strips by the numerous sub-parallel faults. Details of the fault pattern are apparent from the map of the area (at end), while the main structural trends are indicated on Fig. 11.

The faults can be roughly grouped into three types—rift faults, grid faults and minor faults. Of the Rift faults those at the base of the Nguruman escarpment are the most important.

The structure of the Nguruman escarpment suggests that it was initially formed by faulting previous to the eruption of any Rift Valley lavas. The first fracture was a fault of some 3,000 feet throw, cutting through Basement System rocks, down-throwing eastwards and which can be traced along the base of the Nguruman escarpment in its southern part but passes below the Kirikiti basalts north-north-west of the Oloibortoto gorge. The fault is hidden from view by lavas and boulder beds except in the Oloibortoto river section. It is the oldest fault in the area and is probably of middle or early Tertiary age judging by the stage of dissection reached by the escarpment. It may perhaps be regarded as the fault initiating the Rift Valley subsidence in the area. From a study of its fracture-zone it appears that the fault hades slightly eastwards and that it is of normal tensional character.

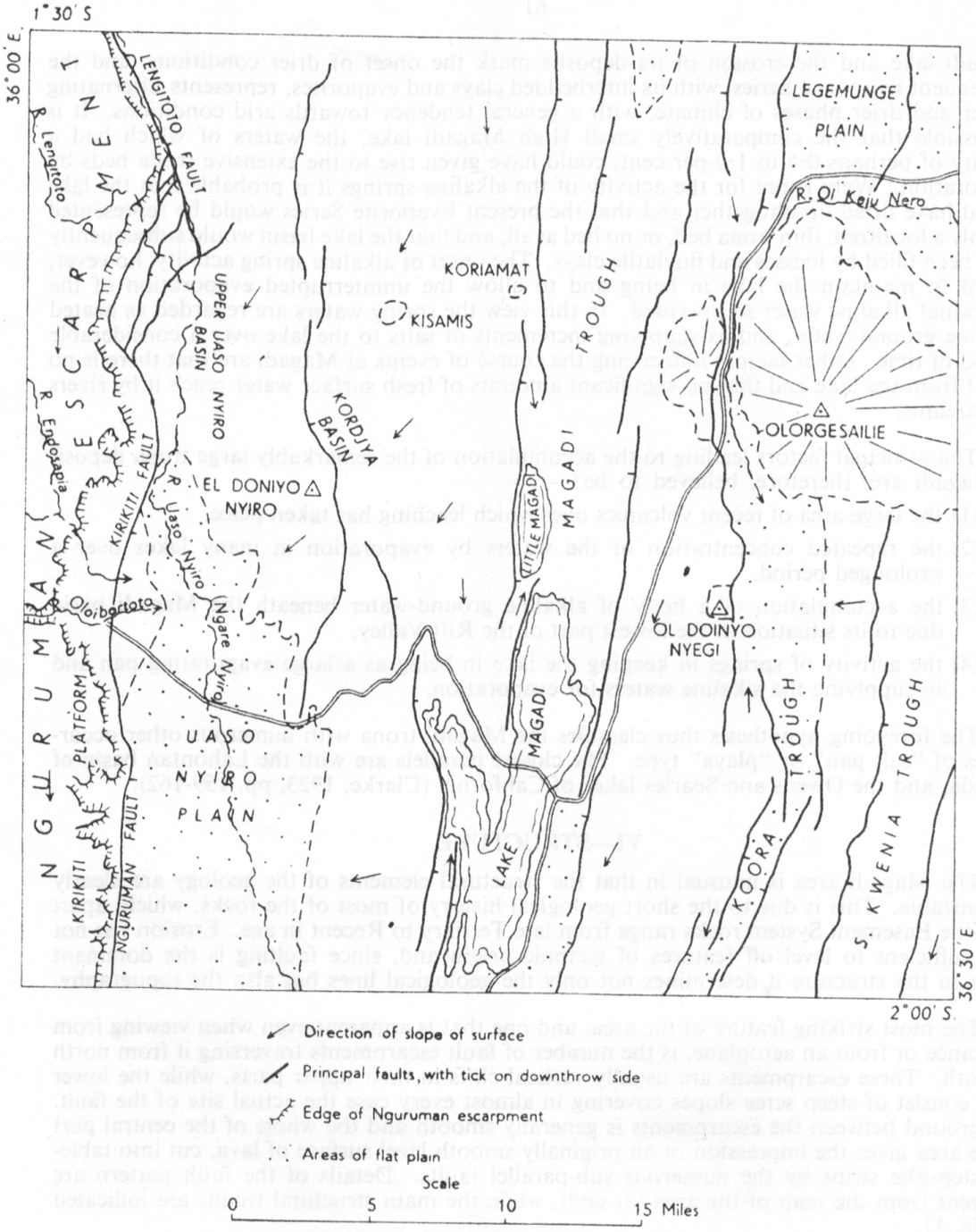


Fig. 11.—Major structures of the Magadi area.

A later movement along the southern part of the Nguruman fault, and the formation of new faults north of the Endosapia river after the eruption of the Kirikiti basalts, deepened the Rift Valley by another 1,000 feet at least and gave rise to the Kirikiti platform. The platform is composed of basalt lavas resting on the lower slopes of the Basement System rocks forming the foot of the first escarpment. The second, or Kirikiti fault, divides into two major and one or two minor faults east of the Naimithigiria plateau. These faults trend north-eastwards and join the Lengitoto fault, which is the offset continuation of the Kirikiti fault and is situated along the gorge of the upper Uaso Nyiro. The branches of the Kirikiti fault downfault lava blocks tilted to the east. The tilting may possibly be due to the slope of the Basement System surface on which the lavas rest.

The upper Uaso Nyiro depression is margined on the west by these step faults, but to the east there is no clear-cut boundary, the ground sloping gently to the river from the scarp north of En Doinyo Nyiro.

The age of the rejuvenation of the faulting along the Nguruman escarpment is not precisely known, but it must be considerably younger than the earlier fault, for the edge of the Kirikiti platform is comparatively uneroded. The fault may, therefore, be end-Tertiary or early Pleistocene in age.

Whether any faults in the floor of the Rift Valley are contemporaneous with the Kirikiti fault is unknown. The eastern edge of the Rift Valley, which is outside the present area, is not so precipitous as the west side, and the impression given is that the main Rift faults are in the west and that the Valley floor sloped westwards throughout most of its history.

The grid faults, which occur across the whole width of the Rift Valley, are entirely lower Middle Pleistocene in age, and cut the level surface formed by the plateau trachytes. The resulting step, table and trough structures have the general trend indicated in Fig. 11. The fault pattern in the grid-faulted area indicates that the general structure is that of quite extensive, raised and often tilted fault-blocks, traversed by marginal relatively shallow narrow fault-troughs. The Orkaramatien-Oloronga block is a good example of this: the surface of the block slopes westwards and south-westwards over a distance of 30 miles and the eastern edge of the block is marked by the *en échelon* faults east of En Doinyo Nyiro and those along the western margin of Lake Magadi. Such fault-blocks which retain their main tectonic characters throughout their length are common, and include the block south of Olorgesailie and the block west of the "Little Magadi" lake.

An interesting feature of the grid faulting is the effect of Olorgesailie mountain. The bulk of this pile of lavas has effectively stiffened the crust on which it rests and to the south of the mountain extends a strip of lavas that has been protected from faulting.

The throw of the faults is variable from a few feet to several hundreds of feet and the faults die out quite rapidly, the movement being continued on another fault *en échelon* nearby. Ramp structures often occupy the spaces between the ends of the *en échelon* faults. In the centre of the Magadi trough, lines of narrow hog-back ridges with steep slopes are common, and represent up-standing fault slices.

The general trend of the faulting is remarkably constant in a direction a few degrees east of north, though in the south-eastern corner of the area the direction swings a little more to the east. It would be difficult to find an area where parallel grid faulting is so extensively and clearly developed as at Magadi. It demonstrates clearly that fault-lines even in comparatively flat-lying and homogeneous rocks such as a bedded succession of lavas, can take quite violent turns and curves and that the patterns produced are often complex, facts which are often overlooked by those who have to map faults in areas where evidence of their existence is scant.

Minor faulting took place in the Upper Pleistocene period, and affected the Chert Series and the Olorgesailie beds, which are lacustrine sediments laid down in the troughs formed by the grid faulting. This latest faulting took place largely along pre-existing lines of weakness. The level and undisturbed nature of the High Magadi Beds shows that there have been no tectonic movements subsequent to their deposition.

There is thus evidence for four periods of faulting, the two earliest being large movements along one or two planes in the west of the area, the third being grid faulting, which is pre-Kamasian in age in this area, and the last movement the minor faulting along pre-existing lines.

VII—ECONOMIC GEOLOGY

1. The Magadi Soda Company

(1) General

The following two paragraphs are taken *verbatim* from "Magadi Calling", a brochure published by the Magadi Soda Company (1951). Other information given subsequently is correct at the time of writing (December, 1953) but may need modification in parts as time goes on, as the company is continuously carrying out research on the extraction of soda, and progress in the methods used may be expected.

"The lake was first surveyed in detail by Major F. Burnham in 1904 and later, in 1908, by J. S. Coates, a Colonial Office geologist [*see* Anonymous, 1923]. The expedition of 1904 included a chemist who had previously been with Chance and Hunt Ltd., and who subsequently became technical adviser to the promoters of the first Magadi Soda Company. The first concession was taken out by T. Deacon, a private prospector who sold his rights to the East African Syndicate, but nothing seems to have happened and the deposits were not worked by them. Then the firm of Marcus Samuel and Company of the City of London took a hand in the matter and sponsored the flotation, in 1911, of a Company called the Magadi Soda Co., Ltd. with a capital of £1,312,000."

"Work was started at once on a 91-mile branch railway linking the lake to the Kenya-Uganda Railway main line, on warehouses and a deep-water pier in Kilindini, and on a factory at Lake Magadi. Most of this work was completed by August 1914, but for a number of reasons, including the outbreak of war and failure of the Company to find a satisfactory solution to the technical problems of soda recovery, the enterprise ran into heavy weather almost from the start. Competition with Brunner, Mond and other rivals in the export field became increasingly severe, and in 1923 the Company went into liquidation. A number of reconstruction schemes were put forward, including one sponsored by Brunner, Mond and Co. Ltd. This was ultimately adopted, and it resulted in the formation of the present Company at the end of 1924. Brunner, Mond (soon to become I.C.I.) were appointed managers but held a relatively small minority of the shares. Since then, I.C.I. has acquired virtually a 100 per cent holding."

The Magadi Soda Company leases two areas of land, one covering the lake and part of the surrounding country, the other covering the part of Lake Natron on the Kenya side of the Kenya-Tanganyika border. The first agreement was signed on 20th March, 1928, and leased the two pieces of land to the Company for 99 years with effect from 1st November, 1924. A new lease was signed on 31st May, 1951, and replaces that drawn up in 1928.

The two portions of land leased are L.O. 1026, the greater, covering an area of 211,110 acres and bounded by latitudes 1° 40′ S. and 2° 05′ S., and longitudes 36° 10′ E. and 36° 20′ E., and L.O. 3867, the smaller, covering an area of 11,364 acres, bounded by latitude 2° 05′ S., and longitudes 36° 00′ E. and 36° 05′ E. and the Kenya-Tanganyika border. The boundary of L.O. 1026, the leased area covering Lake Magadi, is shown on the geological map.

A few of the more important terms of the lease are summarized below. The lease gives the Company the right to work, process and dispose of the deposits of sodium carbonate and other salts mixed with it, and also sodium chloride occurring in the leased areas. Rights to all minerals apart from the Magadi salts referred to above, precious stones, relics, antiquities, etc., discovered in the leased areas, are reserved to the Government of Kenya which also reserves the right to work such minerals, precious stones, etc., so long as the working does not prejudice the Company's activities or property. Local natives retain the right to remove salts from the lake for their own purposes.

The annual rent for the two leases is twenty shillings and royalties are payable on the Company's products at the rate of two shillings per ton of raw, untreated or unpurified soda or common salt. Purified and treated soda, presumably soda ash and derivatives of soda such as sodium bicarbonate, bath salts, etc., are liable to a royalty of three shillings per ton. No further royalty or duty is liable on any soda products when they are exported from the Colony.

By the terms of the lease the Company agrees to allow authorized Government officers to enter, inspect and examine the manner of working and managing the deposit with the reservation that Government officers are not entitled to inspect or obtain information concerning plant designed to improve the purity of the Company's products.

From the time of its reconstruction by Brunner, Mond, the structure of the Company and its production technique began to assume the outline of its present-day form. A dredge was built and methods of production were brought into line with modern practice. The world price of soda ash, always subject to fluctuations, was however not sufficiently high during the years 1927-1939 to allow the Company to operate with any consistent profit. In fact in several years the Company showed a considerable loss. Nevertheless during this period much experience was gained and efficiency improved as a result and, when the

opportunity for increased production came with increased demand and rising prices during the post-1939 period, the Company was able to expand its production capacity rapidly in spite of war-time difficulties. The Company has been able to effect considerable capital expenditure on new plant and on the replacement or modernization of existing equipment. Similarly construction and reconstruction schemes for European, Asian and African housing have been drawn up and are being implemented at the present time.

The Company employs approximately 30 Europeans, 116 Asians and others, and 1,450 Africans. These are all locally housed, and supplied with water, lighting and medical services. Clubs and welfare facilities are provided and a shop is available to all residents.

Broadly the Company can be divided into two functional groups the productive departments and the ancillary services departments. Of the former the ash plant, salt plant and dredges are the more important while the latter comprise stores, electrical power, housing, garage, heavy repair workshop, labour and welfare offices and hospital. Offices include the management offices and technical offices with a chemical laboratory attached.

Since the lake consists of a bed of almost pure trona, soda ash has always been the Company's main product. The raw trona is dug by a dredge of shallow draught which floats in a paddock of its own making. Since the lake-liquor level is never far below the trona surface the dredge remains more or less at ground-level and is designed to cut to at least eight feet below trona surface. The dredge now used has been recently built but it has general similarities in design to an older, smaller dredge that has been in use for many years. From the dredge buckets the raw trona passes down a shute to the first breakers which crush it to fragments not exceeding six inches in size (Fig. 12). The second breakers crush the fragments to two-inch size. From the breakers the trona goes under an electro-magnetic separator to extract tramp iron as it passes on to a Locker Titan vibrating screen. Oversize material is passed through crushing rolls and with the material passed through the screen goes directly into the sump on the dredge where it is mixed with lake liquor pumped in by an eight-inch centrifugal self-priming pump. From the sump the slurry is pumped by an Allen centrifugal pump through a pipe-line to the factory.

A flexible pipe-line, of ten inches diameter, floats on drums in the dredge paddock and can follow the movements of the dredge. From the edge of the paddock the slurry passes through a ten-inch fixed pipe-line with two booster pump stations to maintain the pressure, as the distance from the dredge to the ash plant may be up to one mile. On arrival at the ash plant the slurry is passed at once into dewatering and washing equipment. It is first passed into a dewatering trommel, oversize material being crushed and passed into a second trommel. In the second trommel it is washed with the relatively dilute liquor from the "fish springs" east of the factory. The fines from the first trommel are carried as a slurry to four settling cones arranged in parallel, the overflow going to waste in the lake, and the settled fines from the settling cones then being fed into a stirring tank and thence into two Broadbent V-shaft centrifuges. The liquor drained off goes to waste while the centrifuged fines are returned by conveyor belt into an elevator. The oversize fraction passes from the No. 2 trommel into a gravity chute where it is again washed with spring water and joins the centrifuged fines at the elevator. The trona crystal "mush", as it may be termed, is carried by screw conveyor to the soda stock floor where excess liquor is allowed to drain off.

From the storage floor the "dry side" of the process (Fig. 13) begins by the shovelling of the stocked trona on to portable conveyor belts which feed an elevator followed by a screw conveyor. From a hopper the soda is passed by a feed table to screw conveyors which supply the calciners. The calciners, of which there are two, are oil-fired rotary kilns, the average throughput of ash being in the region of 250 to 290 tons per twenty-four hours. The calciners are worked continuously on a shift basis.

The soda ash leaving the calciners is fed by screw conveyor and elevator to four Christy-Norris pulverizing mills and thence by conveyor and elevator to six Newaygo screens* arranged in parallel. The oversize fraction passes through two Christy-Norris return mills and is put back into the feed to the screens. The fraction passing the first screens is passed directly into a silo for storage. Three Avery semi-automatic weighing and sacking machines are fed from the silo and the bagged ash is loaded direct into railway trucks or is stacked in a warehouse, according to requirements.

*The Magadi Soda Co. state that now (1955) the place of the Newaygo screens has been taken by six Rotex screens.

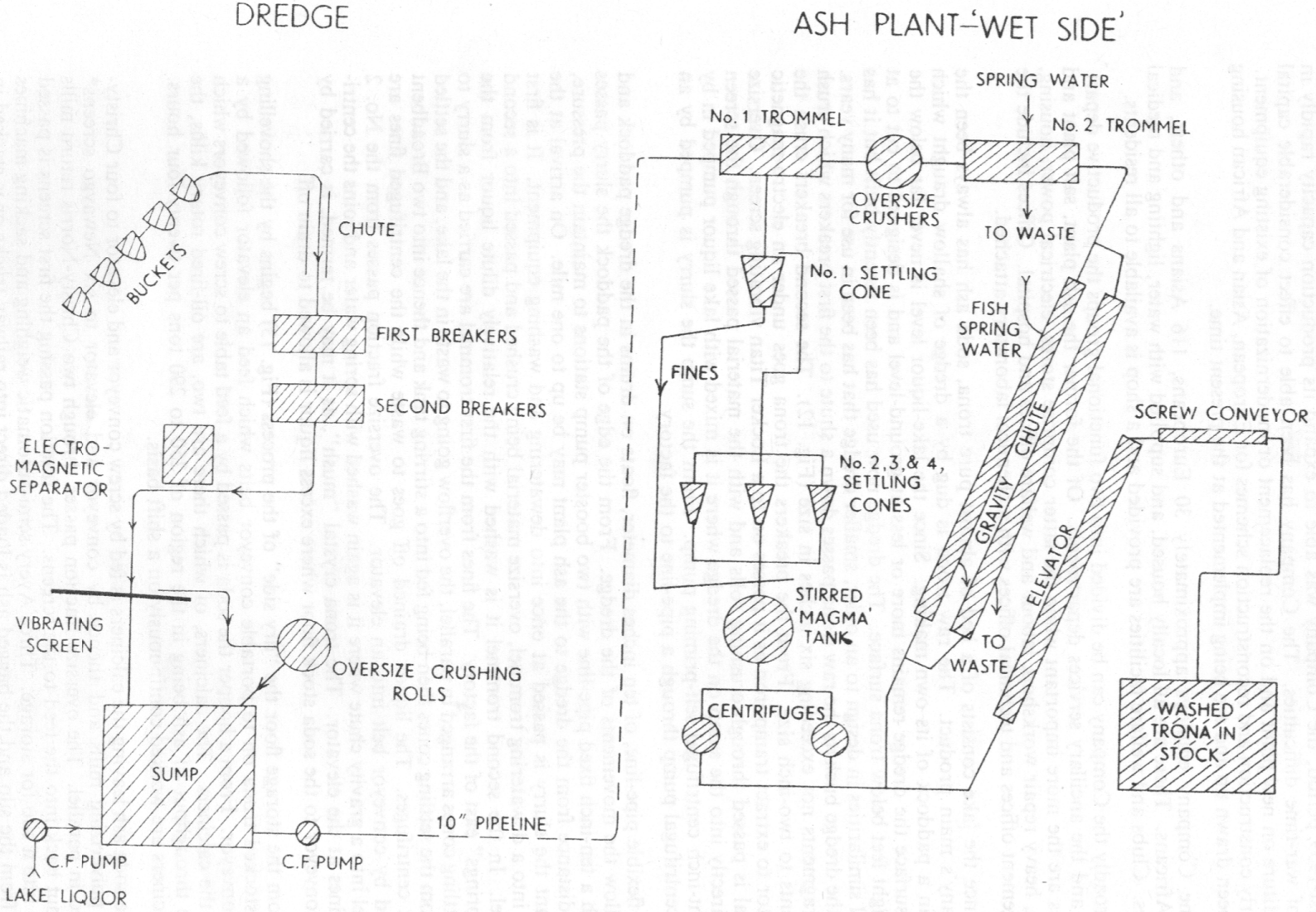


Fig. 12.—Flow diagram; Magadi dredge and ash plant—wet side.

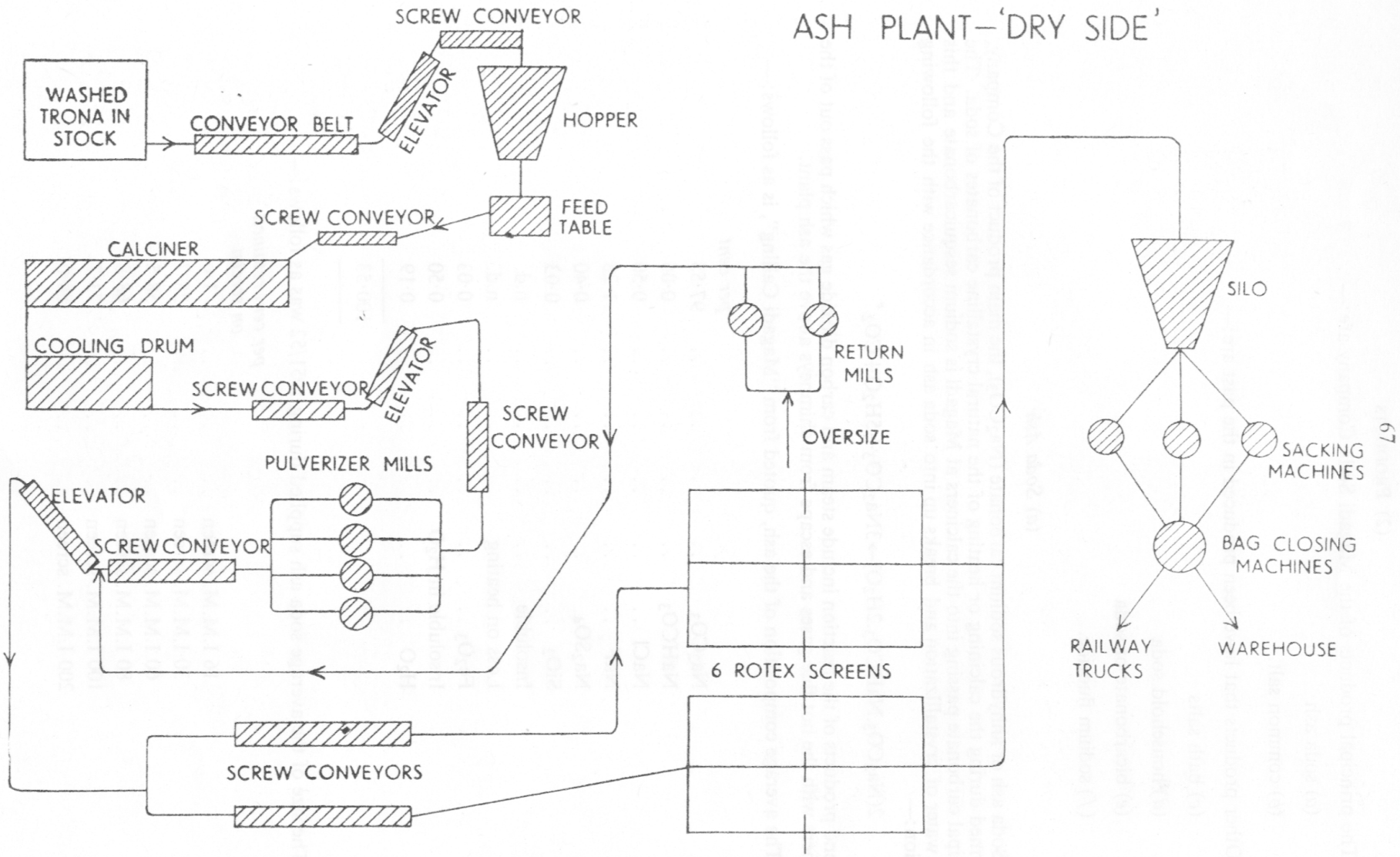


Fig. 13.—Flow diagram; Magadi ash plant—dry side.

(2) Products

The principal products of the Magadi Soda Company are:—

(*a*) soda ash

(*b*) common salt.

Other products that have been produced in the past are:—

(*c*) bath salts

(*d*) household soda

(*e*) bicarbonate of soda

(*f*) sodium fluoride.

(*a*) *Soda Ash*

Soda ash or anhydrous sodium carbonate (Na_2CO_3), the main product of the Company, is formed during the calcining or heating of the natural crystalline carbonates of soda. The principal carbonate passing into the calciners at Magadi is sodium sesquicarbonate and this loses water of crystallization and breaks up into soda ash in accordance with the following reaction:—

$$2(Na_2CO_3.NaHCO_3.2H_2O) \rightarrow 3Na_2CO_3 + 5H_2O + CO_2$$

The end products of the reaction include steam and carbon dioxide gas which pass out of the calciners with the hot flue gases and escape from chimneys above the ash plant.

The average composition of the ash, quoted from "Magadi Calling", is as follows:—

	per cent
Na_2CO_3	97·55
$NaHCO_3$	0·05
NaCl	0·50
NaF	1·28
Na_2SO_4	0·40
SiO_2	0·03
Insoluble	n.d.
Loss on heating	n.d.
Fe_2O_3	0·03
Insoluble in H_2O	0·50
H_2O	0·19
	100·53

The size of the average soda ash supplied during 1951/52 was as follows:—

	per cent retained on screen
16 I.M.M. screen	1·6
30 I.M.M. screen	28·7
60 I.M.M. screen	58·5
80 I.M.M. screen	68·8
100 I.M.M. screen	73·7
200 I.M.M. screen	88·0

Production figures provided by the Magadi Soda Company for 1921 onwards are given in the following table, together with export figures for 1916 to 1920, taken from an earlier report (Anonymous, 1923, p. 444).

	Production (tons—2,240 lb.)	Gross realization on sales—£
1916–1917	2,163	not known
1917–1918	4,688	,,
1918–1919	12,007	,,
1919–1920	10,544	,,
1920–1921	12,892	,,
1921	38,898	,,
1922	46,751	,,
1923	23,846	,,
1924	44,321	,,
1925	46,610	,,
1926 (4 months) ..	15,221	,,
1927	56,857	,,
1928	72,738	,,
1929	61,303	,,
1930	43,172	,,
1931	43,072	249,553
1932	43,642	213,612
1933	37,143	215,686
1934	29,160	151,798
1935	43,122	155,527
1936	42,733	205,791
1937	41,700	212,048
1938	27,666	178,370
1939	41,150	243,877
1940	24,310	185,511
1941	57,130	428,448
1942	70,960	541,500
1943	65,680	668,141
1944	65,100	641,668
1945	66,110	797,552
1946 (9 months) ..	61,900	647,524
1946/47*	89,665	898,492
1947/48	117,115	1,678,891
1948/49	82,760	997,605
1949/50	87,100	995,352
1950/51	118,000	1,423,072
1951/52	125,110	1,802,487
1952/53	81,259	1,135,221

*Change-over of Financial Year from January/December to October/September.

The production figures show a remarkable increase of output during and particularly subsequent to the recent war.

The value of soda ash exported in 1952 was approximately 61 per cent of the total mineral production of the Colony for that year, and amounted to approximately 5 per cent of the total value of domestic exports from Kenya for the year 1951.

Among the consumers of Magadi soda ash the largest are the glass industries, next soap and other cleansers, then the chemical industry, where it is converted into refined bicarbonate, caustic soda, sodium silicate, drugs, dyestuffs and chemicals for the cotton, rayon and paper industries, etc. It also finds a large use in water softening, refining oils and in metallurgical processes such as desulphurizing steel. The principal countries importing soda ash from Magadi are South Africa, India, Australia and some countries in South America and the Far East.

(b) Common Salt

The Company has manufactured several grades of common salt (NaCl) for different uses. The grades being produced at the present time are:—

coarse salt
crushed and screened salt
red cattle salt.

The following grades were produced but are now discontinued:—

finely ground salt
fine salt
dairy salt
cattle blocks.

The initial steps in the process of salt production are the same for all grades—lake liquor is pumped from a series of wells alongside the causeway over the lake. The wells are constructed with a circular trench dug six or seven feet into the trona, in which a well-tamped clay wall is built. The wall is approximately 15 feet in diameter, about two feet thick, and projects some three feet above the trona surface. The well itself is dug inside the clay wall to a depth of 10 to 12 feet. The raised circular wall of clay prevents the inflow of dilute surface liquors into the well when the lake liquor rises up to eighteen inches above the trona surface for a short time during the rains. The only liquor entering the wells comes from a depth of eight to ten feet and is considerably richer in sodium chloride than the surface liquor. It was discovered when using a single well that a high rate of pumping resulted in the drawing into the well of some weak near-surface liquor and several wells, now totalling six or seven, had to be dug in order to keep the rate of pumping from each well to a reasonable figure. The liquor is pumped from each well by diesel-driven centrifugal pumps and fed into the most easterly well, where a large electrically-driven centrifugal pump feeds the pipe-line carrying the liquor to the evaporation ponds almost a mile distant. The rate of flow in the pipe-line is 300 to 400 gallons per minute.

From the pipe-line the liquor discharges into the first-stage evaporation ponds. These are simply constructed on the flats east of the factory; each pond is some 200 to 300 yards square and is margined by a low wall of mud and shingle. The liquor in the pond is allowed to evaporate till it reaches a concentration of 18 per cent Na_2CO_3 and 14 per cent NaCl, by which time all the sodium sesquicarbonate ($Na_2CO_3.NaHCO_3.2H_2O$) has crystallized out and the monocarbonate has begun to separate. The concentrated liquor is then pumped to the "salt-making ponds", where the liquor is kept one or two inches deep. Further evaporation takes place, when monocarbonate crystallizes during the day and sinks to the bottom of the pond, while sodium chloride crystallizes during the night. The salt is brushed up into little heaps in the pond to drain and is then removed to the purification plant.

The salt raked off the ponds is called "crude salt" and is not sold in this form. A typical analysis of crude salt is as follows:—

	per cent
NaCl	94·1
Na_2CO_3	4·3
$NaHCO_3$	0·4
NaF	0·11
	98·91

Anal.—Magadi Chemical Laboratory.

The refining process consists of washing impurities off the coarse salt, which involves stirring the crude salt into a filtered brine solution which is saturated with chloride and contains less than 3 per cent sodium carbonate and bicarbonate. The resulting brine is made slightly caustic to destroy the bicarbonate and finally the pure salt is separated from the sodium carbonate and fluoride in solution by screening. It is understood that the salt will

ABSTRACT

This report describes an area of some 1,200 square miles in the southern part of the Gregory Rift Valley in Kenya; the area is bounded by latitudes 1° 30′ and 2° 00′ S. and longitudes 36° 00′ and 36° 30′ E.

The rocks exposed consist of gneisses and quartzites of the Basement System (Archæan) which are exposed only in the western part of the area, the rest being built of considerable thicknesses of trachytic, basaltic and alkaline lavas of Pleistocene and presumed Pliocene age. Several series of Pleistocene lacustrine sediments and the trona deposits and springs occurring at Lake Magadi are described. All the volcanic rocks and some of the lake sediments are shown to have undergone extensive grid-faulting.

Various hypotheses relating to the origin and accumulation of the trona in Lake Magadi are discussed. A short account of the Magadi Soda Company's works is given and the economic possibilities of the area are discussed.

shortly be extracted by centrifuging rather than screening. The salt thus obtained is referred to as "coarse salt". A typical analysis of the "coarse salt" (from "Magadi Calling", p. 25) is as follows:—

	per cent
NaCl	99·50
$NaCO_3$	0·40
NaF	0·019
Insoluble	0·07
	99·989

Anal.—Magadi Chemical Laboratory

"Boiled Salt", the material which formed the basis of the fine salt and dairy salt, was made by dissolving coarse salt and precipitating out carbonates by the addition of calcium chloride ($CaCl_2$). The solution was then filtered and evaporated. The final product was suitable for dairy and domestic purposes. An analysis of fine salt (taken from "Magadi Calling", p. 25) is as follows:—

	per cent
NaCl	99·88
Na_2CO_3	0·08
NaF	0·007
Insoluble	0·05
Mg	trace
	100·017

Anal.—Magadi Chemical Laboratory

As can be seen the fine salt was exceptionally pure and was said to be purer than all varieties of imported salt.

Total production figures for salt are given in the following table:—

	Production (tons—2,240 lb.)	Gross realization on sales—£
1933	57	not known
1934	1,362	,,
1935	1,364	,,
1936	1,761	,,
1937	2,663	,,
1938	4,570	,,
1939	3,918	,,
1940	9,211	,,
1941	13,946	,,
1942	13,473	,,
1943	15,076	,,
1944	14,034	55,167
1945	15,216	58,945
1946 9 months	11,165	42,465
1946/47*	14,757	57,951
1947/48	15,186	59,491
1948/49	18,210	81,498
1949/50	19,022	98,266
1950/51	18,114	103,537
1951/52	15,422	110,216
1952/53	15,619	121,804

*Change-over of Financial Year from January/December to October/September.

(*c*) *Bath Salts*

These consist of crystals of sodium sesquicarbonate which are tinted and scented and sold in one pound cellophane packages or in bottles. No figures for the production of this commodity are available but it is probably limited to one or two tons per annum.

(*d*) *Household Soda*

Household soda was made of centrifuged, sun-dried and screened "washery fines". The material passing the screen was ground in a mill and packed in five pound lots in paper bags.

The household soda consisted of small crystals of sodium sesquicarbonate. Its alkalinity was approximately equal to that of soap so that its main use was for partly softening water in which silks and woollens were to be washed.

No exact figures of production are available but between 300 and 400 tons of household soda were produced annually.

(*e*) *Bicarbonate of Soda*

Sodium bicarbonate was a further minor product until recently. It was produced and sold mainly as a source of carbon dioxide gas for local mineral-water manufacturers. A typical analysis (from "Magadi Presents", p. 13) is as follows:—

	per cent
$NaHCO_3$	99·15
Na_2CO_3	0·58
NaCl	trace
NaF	0·019
Insoluble	0·062
H_2O	0·19
	100·001

(*f*) *Sodium Fluoride*

Sodium fluoride (villiaumite—NaF) has been separated from the coarse fraction of the slurry as pumped from the dredge. In one process the coarse fraction was washed in spring water when the average content of NaF, as determined on several samples taken from 150 tons of the washed trona, was found to be 5·4 per cent. After washing, the trona rich in fluoride was completely dissolved in water and salted out with sodium chloride (NaCl) when the fluoride separated as a very fine white powder of the following composition:—

	per cent
NaF	97·0
Na_2CO_3	0·6
Insoluble	1·4
Loss on heating	0·2
	99·2

Anal.—Magadi Soda Company Ltd.

NOTE.—Analysis taken from "Magadi Presents", 1948, p. 15.

An earlier process involving the treatment of the coarse fractions of calcined soda ash by "rolling" on an inclined table, yielded concentrates varying from 9 to 23 per cent NaF the average being 15·4 per cent.

A certain amount of sodium fluoride was produced during the recent war for the use of the air forces in Africa and India but since then there has been no regular production. The annual rate of production of recent years was of the order of 4 to 9 tons.

It is clear from the analyses of the soda ash (*see* p. 68) that sodium fluoride is the principal impurity. Dredging operations are therefore limited to areas low in fluoride and this imposes a limitation to dredging efficiency if frequent moves of the dredge have to be made. Also

the lower layers of the surface trona are, in places, somewhat richer in fluoride than the upper layers and this fact often limits the depth to which the trona can be dredged. Other factors influencing the amount of fluoride present in the ash are seasonal. During and shortly after wet weather, when the lake may be partly or completely flooded, the lake liquor in the dredge paddock becomes under-saturated with respect to fluoride and a certain amount of fluoride is dissolved in the slurry pipe-line. During such periods areas of relatively low-test trona (high NaF) can be worked.

As the discovery of a method of removing the fluoride from the trona would be of value the writer suggested that the problem should be investigated by A. L. Stewart, Metallurgist in the Mines and Geological Department. It was known that most of the fluoride is present in the +4 mm. and —60 mesh B.S.S. fractions of the crushed trona, and experiments showed that on crushing the coarser fraction the fluoride passed into the fine product. The process, therefore, reduces to the treatment of the —60 mesh portion of adequately crushed material. Other experiments proved that the fluoride can be concentrated from the —60 mesh fraction either by flotation with fatty acids or by gravity concentration on tables.

The process recommended as a result of these tests involved screening on 4 mm. vibrating screens, the oversize being passed through a rodmill, and the total—4 mm. product through a rake or spiral classifier to yield —60 mesh and +60 mesh fractions. The coarser material with low fluoride content would be passed to the trona plant, while the —60 mesh material would be treated by flotation to yield a high fluoride fraction, suitable for further refining. It was pointed out that further work was required, particularly on flotation.

2. Other Economic Minerals

(1) Cinnabar

A small piece of cinnabar (sulphide of mercury—HgS) discovered in most unusual circumstances, was found in the area some years ago. J. A. Stevens (1948) describes the discovery as follows: "Two African laboratory assistants were making a bonfire to burn rubbish on 16th May, 1945, and cut some fuel from a nearby tree of the species *Calotropis procera*. They stated that when breaking one of the branches a small dark red stone fell from the pith hole in the centre of the wood, and not knowing what this material was, they brought it to me. The piece weighed nearly 50 grammes and had an overall specific gravity of 8·0. It was friable and had one large smooth flat surface perpendicular to the grain of the crystal which resembled Edinburgh rock in appearance. On the side of the lump opposite to the large flat surface was a small flat surface approximately parallel to the large one. Dr. Pulfrey of the Kenya Mines Department suggested that the lump was cinnabar or mercuric sulphide, the chief ore of mercury, and a variety of tests amply confirmed this diagnosis."

How the cinnabar got into the branch remains a mystery, but its presence in the Magadi area may perhaps be explained by the fact that the tribes around the base of Mt. Kilimanjaro are said to prize cinnabar, and a piece may have found its way to Magadi in the hands of Africans. In any case, no evidence of any natural deposit of cinnabar was found in the Magadi area.

(2) Sodium Nitrate

While doing geophysical work in the Magadi area in 1950 A. O. Thompson discovered a small deposit of sodium nitrate at the base of a cliff on the western side of the Magadi-Uaso Nyiro road, some ten miles from Magadi (*see* Anonymous, 1951). Thompson found that the nitrate occurs at the contact of two lava flows and on the old land surface separating the two flows, as well as in joints in the upper of the two lavas. In some places the nitrate occurs as massive crystals while at others it is present as small powdery crystals. Thompson considered that the nitrate has formed by infiltration from higher ground along open joints and cracks, and by dissemination through the open structure of the old land surface.

Much baboon and bat excrement are visible about the cliffs but Thompson considered that this is not the source of the deposit on account of its fairly extensive nature, though a contrary opinion was expressed in the published note, which was not written by Thompson. Nitrates are generally considered to be formed by the decomposition of organic waste through the agency of nitrifying bacteria. The deposits so formed are usually small, as is the case in this deposit, which is not of economic interest.

(3) Diatomite

Diatomite and diatomaceous beds are widespread throughout the Olorgesailie lake beds exposed north of Olorgesailie mountain. Small areas of diatomaceous earth are also known from the southern end of the Koora valley. The beds at the south-western end of the Legemunge plain are, however, the only ones which may be sufficiently pure and extensive to be of economic interest.

For some years the Magadi Soda Company used diatomite from the Olorgesailie lake beds for filtration in its sodium bicarbonate plant. The diatomite was taken in small quantities from the L12 bed, which outcrops at the base of a conspicuous scarp that is crossed by the Magadi road west of the Olorgesailie Prehistoric site. The diatomite was dug from the uppermost part of the bed, which is a pure white powdery diatomite with rare pumice pebbles. The bed is easily recognized by the local strong reddening of its upper surface. The diatomite is very light in weight and free from clay and sandy impurities. Under the microscope (x 400) it is seen to be composed mainly of *Epithemia* frustules (Kent, 1947) and elongate rod-like bodies akin to *Synedra*. The purity and low apparent density of the diatomite suggest that it would be an economically useful material were it not for the thinness of the bed (it is only four feet thick), and its distance from rail.

The value of other diatomaceous beds in the Olorgesailie lake beds succession is reduced by the presence of impurities such as tuff, gravel, grit and calcareous nodules. Although it is possible to remove some or all of these impurities by screening and air classification it is probable that the necessity to beneficiate these diatomaceous beds would render them uneconomic under present circumstances (but *see* footnote on p. 79).

Some figures and analyses taken from the technical records of the Magadi Soda Company concerning the Legemunge diatomite are given below:—

bulk density 25–32·2 lb./cu. ft. *in situ.*
15·5 lb./cu. ft. powdered

Partial analysis:—

	per cent
Al_2O_3	2·203
Fe_2O_3	2·821
MgO	0·393
CaO	0·595

Anal.—Magadi Chemical Laboratory.

(4) Limestone

Limestone occurrences in the area are:—

(*a*) travertine mounds on the east bank of the Uaso Nyiro

(*b*) four travertine mounds half a mile west of the Legemunge diatomite and immediately west of the Magadi road

(*c*) *Viviparus* limestone west of the south-west lagoon

(*d*) pillar-rock limestone at mile 11 on the Magadi-Uaso Nyiro road.

None of the above occurrences are large enough to be of interest except perhaps for small-scale lime production. An analysis of the travertine by the roadside at the south-west extremity of the Legemunge plain is as follows:—

	per cent
SiO_2	2·5
R_2O_3	0·8
$CaCO_3$	90·0
$MgCO_3$	0·2
P_2O_5	tr.
SO_2	—
Na_2CO_3	3·75
	97·25

Anal.—Magadi Chemical Laboratory, 4th March, 1949.

3. Water-supply

As the Magadi district has a semi-arid climate water-supply problems have assumed a considerable importance both for the settlement at Magadi and for the indigenous Masai.

There is no perennial potable water-supply within a 15 mile radius of lake Magadi and the development of the community there has been dependent on a supply of piped water from the Ngong hills. This piped supply has of recent years become insufficient to provide adequately for the community at Magadi and the demands of the works because of the increase in the number of people at Magadi and the drawing off of water by the railway and the township of Kajiado, which are also supplied from the same pipe-line.

The nomadic Masai tribesmen, who are almost entirely dependent on their cattle for food, are also severely limited by the availability of water, although the situation has been improved for them by the provision on the Magadi pipe-line of one or two watering troughs.

Some water seepages on the east shore of the lake immediately north and south of the entrance to the dry lagoon have been dug by the Masai to form small water-holes. The waters are near to lake-level, are turbid, and have a composition similar to that of the most dilute springs nearby. The water was probably used for watering Masai stock in times of drought, before the provision of water points elsewhere. A similar water-hole which is still used by Masai occurs on the east shore of the lake two miles north-west of "Needle Rock". A well 20 feet deep also has been dug by Masai in alluvial silts just beneath a low lava scarp one mile east-south-east of the north end of "Little Magadi" lake. The composition of these waters is as follows:—

	I	II
	grm./100 *grm.*	*grm.*/100 *grm.*
Na_2CO_3	0·005	0·08
$NaHCO_3$	0·268	0·78
NaCl	0·174	0·33
NaF	0·003	0·008

Anal.—Magadi Soda Company, 11th November, 1953.

I. Water from water-hole 2 miles north-west of "Needle Rock".

II. Water from well 1 mile east-south-east of north end of "Little Magadi" lake.

A drinking trough for cattle is situated on the water pipe-line at the "Black Tank" on the scarp overlooking the east side of Lake Magadi and a bore-hole at mile 30 on the road, on the plain immediately east of Legemunge, was also provided for the Masai. The available watering places during the dry season are limited and the Masai have to drive their cattle over great distances to obtain water. They obtain supplies during the dry season from the Uaso Nyiro in the western part of the area, where there is perennial flow. Other perennial rivers flow down the Nguruman escarpment and comprise the Oloibortoto, Endosapia and Lengitoto rivers. These, however, descend into the *tsetse*-infested areas west of the Uaso Nyiro, which are avoided by the Masai. The Ol Keju Nero river carries seasonal water and supplies Masai for about two months after a normal rainy season, and water-holes also contain water for short periods after the rains. The areas surrounding troughs, bore-holes and water-holes are liable to severe over-grazing.

Potable water for the settlement at Magadi is obtained from headworks on the south-eastern slopes of the Ngong hills. The headworks consist of springs, reservoirs, wells and a bore-hole the total yield being of the order of 75,000 to 95,000 gallons per day. A pipe-line carries this water to Kajiado township where the Railways quarters, locomotives and some other domestic users are supplied with water. The total consumption at Kajiado is approximately 20,000 gallons per day. From Kajiado the pipe-line follows the Kajiado-Magadi railway-line as far as mile 65 (measured from Konza junction). The pipe-line supplies the locomotive high service tanks at Turoka and Singaraini railway stations. The piped water may be augmented by the addition of ground-water from three bore-holes situated near Turoka station when the consumption at Kajiado is so great as to limit the amount of water available further down the pipe-line. The Turoka bore-holes are together capable of yielding up to 30,000 gallons per day.

From mile 65 on the railway the pipe-line travels across country to Koora station where there is a locomotive high-service tank. From Koora the pipe-line continues across country to the "black tank", a break-pressure tank, on the scarp overlooking the eastern part of Lake Magadi. The average flow into the "black tank" is of the order of 37,000 to 40,000 gallons per day. The Masai and their cattle consume about 1,300 gallons per day at the drinking trough at the black tank and this leaves some 38,000 gallons per day for the Magadi Soda Company and railway requirements at Magadi. At times of drought, or when the Railway consumption is abnormally large during heavy railing schedules, the total available at Magadi may drop to a little above 30,000 gallons of water per day. The company has found that this amount is often insufficient for its needs and at times a stringent system of water rationing has had to be introduced. As a result of these recurrent water shortages at Magadi the Company has been forced to adopt measures to augment its water-supply. The first of these measures to be implemented was the drilling of the bore-holes at Turoka. Since the pipe-line is only three inches diameter over much of its length the amount of water obtainable from it is strictly limited. It was eventually decided during 1948 that an independent water-supply for the Company would have to be found.

The only bore-hole put down for water near Magadi was drilled on the Koora plain near mile 16 on the Magadi-Nairobi road. This was unsuccessful since the yield was only 30 gallons per hour and the water contained 3,706 parts per million of dissolved salts and was thus unfit for continuous human consumption. It was, therefore, considered that a reliable supply of potable waters from bore-holes was difficult, if not impossible, to obtain on account of the highly mineralized nature of the ground-water in the Magadi part of the Rift Valley. Attention was then turned to the use of the perennial rivers descending the Nguruman escarpment as sources of water.

During 1948 the Company sought the advice of Messrs. Balfour and Sons, Consulting Engineers of London, who after a study of available sources of water proposed a scheme to make use of the Oloibortoto river. The Uaso Nyiro water, though chemically suitable is turbid throughout the year and in any case the river is too low to deliver water to Magadi by gravitation. The Endosapia river is also chemically suitable and the water is clear but since part of its flow is diverted into irrigation channels to water the fields of Kalemma village, it was considered better to employ the Oloibortoto river water.

The Oloibortoto river has a large catchment area in the Looita hills which are over 7,000 feet high. It descends to the floor of the Rift Valley by a series of precipitous gorges and is not used by Masai. The flow at a "V notch" erected near the point where the river leaves the lower gorge was estimated at 6 cusecs (3 million gallons per day). At the point of exit from the gorge the altitude of the Oloibortoto river is some 623 feet above the surface of Lake Magadi and 463 feet above the level of the reservoir tank at Magadi. The water can therefore be fed to Magadi by gravity through a pipe-line 23·6 miles long. The first part of the pipe-line is of seven inches diameter and the part nearer Magadi is of six inches diameter. Its route is indicated on the geological map (at end) and is situated on as direct a line to Magadi as the terrain permits. The pipe is already laid over the greater part of its length and the reservoir and treatment plant, which is situated near the Golf Club, is erected and almost complete. It is expected that the new water-supply will be in operation early in 1954.*

It was originally intended to construct a small dam at the mouth of the Oloibortoto river but the actual intake works have been built on the alluvial fan some three hundred yards east of the proposed dam site.

The headworks are simple and consist of an unroofed concrete chamber some six feet wide sunk three or four feet into the side of the river-bed. The entrance is protected by heavy iron bars in the form of a grill to prevent the entry of boulders. From this chamber a pipe carries the water to a sedimentation chamber a short distance away. From the sedimentation chamber the pipe-line (7 inch diameter) carries the water to Magadi. To prevent damage by cattle and game the pipe-line is sunk two feet into the ground throughout its length, except for the crossings of the western and central portions of Lake Magadi. At these crossings the pipe-line is carried some three feet above lake level on angle-iron struts driven into the lake. The crossing over the Uaso Nyiro will probably be alongside the steel bridge carrying the road.

*The work was completed in June, 1954.

It is estimated that the pipe-line will be capable of supplying some 200,000 gallons of water a day to the treatment plant and reservoir at Magadi. The reservoir has a capacity of 500,000 gallons, a capacity large enough to maintain a good supply for two or three days in event of failure of the pipe-line or the necessity to flush out sediment. It is understood also that one or two watering troughs for Masai cattle will be built on the section of the pipe-line west of Lake Magadi. These should extend the area of grazing available to Masai cattle during the dry season.

The new scheme will supply Magadi's water needs for many years to come and will reduce or eliminate the need for water rationing. The old pipe-line will presumably continue to supply the needs of the railway and possibly the factory at Magadi and should be adequate for this limited purpose.

Bore-holes.—Two bore-holes have been drilled for water in the Magadi area by the Public Works Department on behalf of the Administration of the District, which has its headquarters at Kajiado. The first of these, near mile 16 on the Magadi-Nairobi road, in the upper Koora valley, was unsuccessful. It was sunk to a depth of 600 feet and struck water at 350 and 410 feet, the rest-level of the water being at 298 feet depth. The yield of water was, however, only 720 gallons per day and was highly mineralized as is indicated by the following analysis:—

ANALYSIS OF WATER FROM BORE-HOLE C.1662—MILE 16, MAGADI ROAD

	per cent
total alkalinity	0·24
Na_2CO_3	0·045
$NaHCO_3$	0·30
NaCl	0·066
F	32 parts per million
total solids at 240° C.	3,706 parts per million
pH	8·5

A second bore-hole was drilled in the centre of the flat plain east of Legemunge and about half a mile north of mile 30 on the Magadi-Nairobi road. The total depth of the hole is 391 feet and water was struck at 310 feet, with the rest-level at 275 feet. This bore-hole was very successful and yielded a good flow (68,160 gallons per day) of potable* water as the figures below suggest:—

ANALYSIS OF WATER FROM BORE-HOLE C.1559—MILE 30, MAGADI ROAD

	per cent
total alkalinity	0·04
Na_2CO_3	0·01
$NaHCO_3$	0·05
NaCl	0·0025
total solids at 240° C.	520 parts per million
F	8 parts per million
pH	8·2

The yield and quality of water from this bore-hole is remarkable considering the results of the bore-hole drilled in the Koora valley. It is probable that the water of the successful bore-hole (C.1559) is derived from the Lasagut hills which rise to approximately 6,900 feet a few miles to the north-east of the site. This may explain the ample supply of fresh water at this spot.

Generally speaking, it is considered unlikely that fresh water could be obtained by boring in the area, particularly in its central parts. At the base of the Nguruman escarpment, however, particularly in the ill-sorted alluvial cones, an ample supply of underground water is available and potable water could probably be obtained by drilling almost anywhere in the Uaso Nyiro depression north of Lake Natron. Surface water is plentiful in this part of the area and, since the Magadi Soda Company has made provision for its water-supply for some considerable time to come, no further bore-holes are likely to be drilled in the area for

*The fluorine content (8 p.p.m.) is, however, too high for human consumption over an extended period

some years. Should the question of improving the water-supply for the Masai be raised, it would in any case be more economical to make arrangements whereby a part of the Magadi piped supply is drawn off to watering troughs, rather than to undertake drilling which would probably result in a high proportion of dry holes.

In the next few years the water-supply position for Masai cattle will be most severe in the area north of Lake Magadi. Here there is a large area stretching northwards to the slopes of Mt. Suswa and north-eastwards to the Uaso Kedong basin which is devoid of water in dry seasons. Underground water in this area is likely to be too highly mineralized to be potable and it seems that the only way to provide water would be the construction of simple earth dams on some of the larger seasonal streams.

4. Economic Possibilities in the Area

The Magadi Soda Company is the sole producer of minerals in the area and the only materials which are found in potentially economic quantities, and which are not yet being exploited fully, are sodium fluoride and possibly diatomite. *Sodium fluoride*, being found in the Magadi Soda Company's lease area, and being under the terms of the lease a mineral which the Company is entitled to work, is therefore not open as a proposition to individuals and concerns other than the Company.

As previously described the Company has at various times in recent years produced small quantities of sodium fluoride and has also conducted experiments on various means of separating the fluoride from the trona prepared for the calcining kilns. Recently, however, the principal incentive behind the separation of the fluoride has been not so much to establish it as a product but to remove it so as to produce still better quality in soda ash. Up to the present, however, no economic method of separating the fluoride has been discovered.

The fluoride occurs naturally in the trona of the lake and is present in variable amounts ranging up to two per cent. The fluoride content of the soda ash varies from 0·95 to 1·57 per cent. Since the percentage of sodium carbonate in the ash is not allowed to fall below 97 per cent, considerable difficulties are encountered when dredging areas of the lake relatively rich in fluoride. The depth of cut of the dredge has frequently to be reduced since the fluoride appears to be enriched in the lower layers (7 to 8 feet below lake surface) and when the amount of fluoride in the slurry rises above the permissible amount, the plant has to be shut down and the dredge moved to a less fluoride-rich area. There are, therefore, several advantages to be gained from the separation of at least part of the fluoride. Investigations undertaken in the Mineral Research laboratory of the Mines and Geological Department, Nairobi. suggest that tabling or flotation may prove acceptable as methods of separation. Should it be possible to concentrate it to a purity of approximately 95 per cent, it may have a value between £60 and £80 per ton.

During recent years there has been an increasing demand for *common salt* among the African people of East Africa. The principal grades of salt used by Africans are Coarse and Crushed Salt and the entire Magadi production of these grades is sold in East Africa and the demand cannot be fully satisfied. The Magadi Company has, therefore, been anxious to find means of increasing coarse salt production. The principal limiting factors are the supply of salt-rich liquor and the area of evaporation ponds. Since salt garnering is done manually by African labour increases in the area of evaporation ponds would involve an increase in the labour force employed and, at the moment, there is no accommodation for more labour at Magadi.

A supply of liquor rich in common salt and with relatively minor quantities of other dissolved salts would, of course, be ideal as a source material for salt manufacture. It has been assumed, on the basis of Stevens's calculations (Stevens, 1932, pp. 28) that since the amount of sodium chloride in the lake is considerably less than would be expected had the springs supplied all the salts to the lake, that there must be an underground leakage of chloride-rich liquor from the lake. The Department was requested to assist in detecting the cause of the supposed leaks, and A. O. Thompson carried out geophysical tests in the area south of the lake in an endeavour to locate a fault or other fissure that might be draining saline liquor from the lake. The geophysical work was, however, inconclusive and the writer believes that no such fissure exists.

Among the analyses of liquors sampled in the bore-holes drilled into the lake surface (quoted on p. 46) there are some which appear to contain almost as much sodium chloride as carbonate. The liquors tested, however, were mixtures of underground and surface liquor used in drilling and give only a general indication of the nature of the underground liquors. The writer considers that the question of the composition and amount of underground liquor should be investigated further since there is a possibility that a liquor rich in common salt might be found. Nevertheless, the relatively thin and impervious nature of the deeper trona beds and the way in which they are interbedded with clay beds makes it probable that individual bore-holes would yield only small quantities of liquor.

It seems, therefore, that there are no obvious sources of suitable saline liquor other than those in use at the moment. In any case lake liquor appears to offer the best prospects and an examination of the composition of the deeper liquors in the lake will show whether a richer source of salt can be discovered.

The writer considers that there are no beds of pure *diatomite* in the area that are sufficiently thick to warrant exploitation at present. Suitable material does exist at the south-west end of the Legemunge plain in bed L12 and other material capable of beneficiation occurs in bed L14, and these may be worthy of reassessment in the event of an increase in demand for diatomite in the future.

The deposits at Legemunge are, however, a considerable distance from rail—25 miles from Magadi and 43 from Nairobi. It would be difficult to arrange to rail the material from Magadi in view of the fact that the railway is fully occupied in transporting soda ash. Transporting the diatomite to Nairobi would involve the long haul by road, which climbs from approximately 3,500 feet at Legemunge and over the southern spur of the Ngong hills at approximately 7,000 feet. Moreover, steep hills on the Legemunge-Nairobi road would limit the carrying capacity and economical operation of trucks. It is, therefore improbable that the diatomite deposits at Legemunge could compete satisfactorily with other better situated deposits.†

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†Since the report was written diatomite has been produced from Legemunge. It is believed that the production in 1956 was 386 tons and in 1957, 506 tons.

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APPENDIX

Subsequent work in the area south of Magadi, where the relationships of the Oloronga Beds, the Chert Series and the Plateau Trachytes are well seen in numerous sections, necessitates revision of the tabulation of lake sediments (p. 26). In a later report—"Geology of the Area South of Magadi", which is in preparation, it is shown that the Chert Series rests directly on the Plateau Trachytes, and that the Oloronga Beds overlie them with unconformity. Both these groups of lake beds are older than the 'grid' faulting, and it follows that the Chert Series is unlikely to be the time equivalent of the Olorgesailie Lake Beds, but is probably older. The revised correlation and tabulation is as follows:—

Magadi trough	Legemunge-Koora trough	Uaso Nyiro basin
Evaporite Series High Magadi Beds Kunkar limestone	Boulder trains and sands Kunkar limestone	High terrace Kunkar limestone
Minor faulting	Olorgesailie Lake Beds	Ngare Nyiro Beds
Grid faulting Oloronga Beds *Erosion* Chert Series		Oloronga Beds
Plateau Trachytes (in part Olorgesailie lavas)		

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