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GEOLOGY OF THE KORA WELLS AREA

DEGREE SHEET 37, S.E. QUARTER
(With coloured geological map)

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ABSTRACT

The report describes an area of some 3,100 square kilometres (1,200 square miles) bounded by the Equator and latitude 0°30′N, and longitudes 38°30′E and 39°00′E.

The area is near the western limit of the eastern Kenya plains, and has been affected by the Tana river dissection. There is a faulted and sediment-floored trough in the west, and sediments also cover the eastern half of the map area, resting on the tilted and dissected end-Tertiary peneplain which was cut across the gneisses.

The gneisses are mainly a monotonous series of banded metamorphosed semi-pelitic sediments, with intercalated psammitic, calcareous and amphibolitic bands, and a few basic intrusive lenses. These have been mainly folded about north-south axes, but concomitant east-west folding is also present. There was low angle eastward thrusting in the south-east probably contemporaneous with the folding and metamorphism. Some Tertiary dykes cut the folded sequence.

The sediments are mainly soft red and green pebbly sands and clays of probable fluviatile origin, and considered to be Upper Pliocene in age.

No rock or mineral deposits were seen likely to be of economic interest.

Water supplies in the area are discussed.

GEOLOGY OF THE KORA WELLS AREA

I—INTRODUCTION

The area described in this report is bounded by the Equator and latitude 0°30′N and by longitudes 38°30′E and 39°00′E. The Tana river flows from west to east a few miles south of the southern boundary. The eastern half of the area lies in the Garissa District of North-Eastern Province, and the western half in the Isiolo District of Eastern Province, the administration boundary coinciding with the Benane-Kora Wells road.

The area is inhabited by nomadic tribes, of Somali stock in the east and Boran in the west; they are herdsmen of sheep, goats, cattle and camels, from which milk and meat form the bulk of their diet. The only permanent settlements in the vicinity are at Garba Tula and Benane, just outside the area to the north-west and north, Balambala, near the south-east corner, and Skot on the western boundary, which became a trading post during the time of survey.

The road linking Garba Tula with Garissa crosses the area diagonally, much of it following the main Tana-Uaso Ngiro watershed. There is a branch road to Kora Wells, linking with Skot on the west (and thence Garba Tula, Kinna, and Melka Rupia) and Balambala on the east. The Skot circuit, which had not been much used for an appreciable period, is now maintained by the Isiolo administration, but the Balambala section continues to be neglected. Most of these minor roads were built during the war, with the exception of the Kora Wells road, which was in use before the war. An additional motor track was cut during the war, from the Ndivi crossing on the Kora road to Balambala; much of it was on alluvial flats of the Ndivi, and since its abandonment these stretches have virtually disappeared. The track was partly re-opened at its western end during the survey, but was motorable only with great difficulty. A number of the larger cattle and game tracks are motorable after some attention, and most of the larger sand rivers (locally known as *lagas*) are suitable for four-wheel-drive vehicles, particularly the Rahole, which has a hard surface over much of its length, appreciably harder than that of any other river in the area. It is thought that this is due to the higher proportion of admixed silt in the sand, derived from the sediments through which the river mainly flows. It appears that the surface hardness of a given sand river can vary from year to year depending on the rainfall, which controls the amount of finer grade material washed down into the river.

Most of the area is covered with dense thorn bush, growing on the low humic red sandy soils, typical of these flat arid regions, which are underlain by metamorphic rocks or sandy and marly sediments. In the north-east quarter there are wide expanses of grey and black plains soils, on which the characteristic vegetation is thinner and more stunted thorn bush, with some grass and frequent small clumps of wild sisal (*sansevieria*). The larger river channels are lined with thorn acacias, and doum palms occur on the extensive alluvial flats of the Rahole and Bisanadi Rivers.

Game is fairly plentiful, particularly in the south near the Tana River. Of the larger types giraffe are extremely common, and elephant abound; signs of rhino and lion were also seen.

Rock exposures in the area are generally poor, being best in the smaller tributary channels. In the larger sand rivers outcrops are confined to the bends, the straighter stretches being lined by narrow strips of alluvial deposits. Elsewhere soil and vegetation tend to obscure the geology.

Rain falls during two seasons, from March to May, and from October to December, the wettest months being April and November. June and July are the coolest months, the skies being often cloudy, and a little drizzle may be experienced. No rainfall records are kept within the map area, but Garba Tula, a few miles to the north-west, averages 368 mm. (14.5 in.) per year, and Balambala to the south-east averages 275 mm. (10.8 in.).

Maps

The only map of the area available at the time of survey, the 1:500,000 Garba Tula sheet published by the Army, proved to be quite accurate in the north-eastern part, but less reliable in the south and west. The map accompanying this report was drawn from reduced Kodatrace strips traced from complete 1:50,000 scale air photo cover, flown by Spartan Air Services. The strips were controlled with a few fixed points on the Kenya trigonometrical network, two astro-stations (one in the east, the other near Balambala just outside the south-eastern boundary) and the western boundary, as determined for the adjacent Kinna area by Rix (1967). Approximate contour lines on the map were drawn stereoscopically, using data obtained with aneroid, Indian clinometer and Army spot heights (on the 1:500,000 map) as control; the latter were also used to calibrate the aneroid.

II—PREVIOUS GEOLOGICAL WORK

Many of the earlier explorers working along the Tana river must have passed close to the area, but there are only two who actually entered it, according to available records. J. R. W. Piggott (1890, p. 132)* probably crossed the Bisanadi on his journey up the Tana. The river he described had an estimated width of 60 yards and a trickle of clear and slightly salt water flowing in it; it was the first permanent tributary to the Tana. At present this trickle only extends a mile or so up from the confluence with the Tana, but at the end of the last century there might have been more water in the river, as the climate is generally considered to have been wetter then.

C. W. Hobley journeyed up the Tana River in 1891, and noted (1894, p. 107) that the name of the first permanent tributary was Salt River, from its tendency to dwindle and become brackish in dry seasons; this again was probably the Bisanadi. He estimated the width of the storm bed as 100 yards, rather more than Piggott's estimate, and noted that it was thickly fringed by *hyphaene* palms.

Count Wickenburg (1903, p. 199) crossed the south-east corner of the area at the end of a 40-hour waterless march from the Lorian Swamp to the Tana, during his expedition from Djibuti to Lamu.

J. Parkinson entered the area during his extensive pre-war travels in the Northern Province, and mentioned (1939, p. 164) the Benane-Kora Wells road in his description of the calcareous deposits there (*see* Matheson, 1971, p. 21). He was much concerned at the over-grazing problem, which was serious even then.

F. Dixey (1944) was also concerned with this situation, and recommended many improvements after his hydrographic survey of northern Kenya. He suggested that many natural pans could be deepened to form tanks, and numerous boreholes sunk, in order to improve water supplies in areas away from presently over-grazed areas. Although he crossed the Kora Wells area, along the Garissa road to Benane, he did not specifically mention any locality in it. Engineers from Howard Humphries & Sons (1958) investigated the water supplies of the Northern Frontier District during the period 1950-58. They noted some of the existing supplies in adjacent areas, but none in the Kora Wells area, except Benane Wells on the northern boundary. On their recommendation Lafageri pan was excavated to form a tank of one million gallons capacity. The engineers' report also recommended improvements to other existing pans and waterholes, but emphasized that these should if possible be more than thirty miles from the Tana and Uaso Ngiro rivers, because of the already serious over-grazing in those regions. Included in the report is a useful account of water-retaining properties of the different soil types encountered in these areas, with reference to their suitability as linings for excavated pans and tanks.

* References are quoted on page 43.

III—PHYSIOGRAPHY

The dominant drainage trend is eastwards down the regional slope of the area, with a strong southerly component due to the influence of the Tana River, which flows eastwards a few miles outside the southern boundary. There is also a small northerly component due to the weaker Golana Gof River just north of the area.

Although up to perhaps even historical times many of the rivers may have been permanent, drainage throughout the Kora Wells area is today only of seasonal type. Almost all the larger sand rivers however carry permanent sub-surface water, which is tapped in wells up to 20 feet deep. There are occasional springs where rocks near the surface force up the water tables, and also where stream gradients cut them near the Tana Valley. A few small seasonal pockets of water in the narrow sand channels draining the north-eastern plains are tapped by wells for short periods after rain.

The larger valleys are all floored by alluvial flats, into which the seasonal floods have cut channels to an average depth of some six feet, though this may vary between about two and fifteen feet. In some of the larger channels the alluvium is banked against steep rock faces. A good example of such a rock face, cut in gneisses, can be seen in the Ndivi River about three and a half miles east-south-east of the crossing on the Kora Wells road. Another such wall is carved in sediments on the easternmost bank of the braided Rahole, just upstream of its confluence with the Kaeri Tabaken. In the stream west of Maddo Diko a steep-sided valley cut in gneisses has been partly filled with alluvium, which has in turn been cut by a narrow vertical-sided channel six feet or more in depth. As a final example there is a small abandoned and alluvium-filled meander in the Iris Namdera, just north-west of the Kora Wells track crossing.

Such features are characteristic of drainage systems in the more arid parts of Kenya. The steep banks in the bedrock were perhaps cut during a former generally dry, torrential climatic phase, and the alluvium was then deposited in a succeeding wetter period, with more regular rainfall—possibly the last pluvial in Kenya. With the progressive dessication of the country since those times seasonal torrential rains have again become the characteristic form of precipitation and have led to the cutting of narrow steep-sided channels in the alluvial deposits.

In sediment-covered country, where the softer rocks have enabled rivers to cut rapidly down to base level, the valleys contrast strongly with those in gneisses, having wide alluvial flats transected by many tapering and braided channels. The Rahole has a fairly open sand channel throughout its length, but other lagas in the sediments are often choked by stretches of tree-covered alluvial deposits, with narrow, ill-defined channels winding through them. These may be due to local slight easing of the gradient so that the flood waters lose some of their force and a certain amount of alluvial deposition can occur. The Skot channel is an excellent example of this phenomenon. On aerial photographs the contrast between the alluvial flats of drainage on the sediments and the steep channels in the gneisses is very striking, and the abrupt changes in regime across the boundaries help to delineate them.

Water fills the stream channels to considerable depths at flood times, even if only for short periods: flotsam can often be found several feet above the floor of the channel and sometimes even higher than the sides, and indicates the height reached by the torrents. Large wave marks, a foot or so in amplitude and up to 20 feet in length, are also often developed in the sand. Eddy cavities, frequently reaching 20 feet or more in depth, at corners and behind rock walls hold water for short periods after rain.

The area is divisible into three physiographic units:

(1) The dissected gneisses of the low south-central spur and the north-west corner.

(2) The partly dissected sediment plain, in the east.

(3) The sediment-floored Skot trough, in the west.

(1) *The dissected metamorphic terrain*—in the south-central part of the area disappears northwards under sediments, near the main watershed separating the Tana from the Uaso Ngiro and Lorian Swamp river systems (Fig. 1). Two other important watersheds separate the

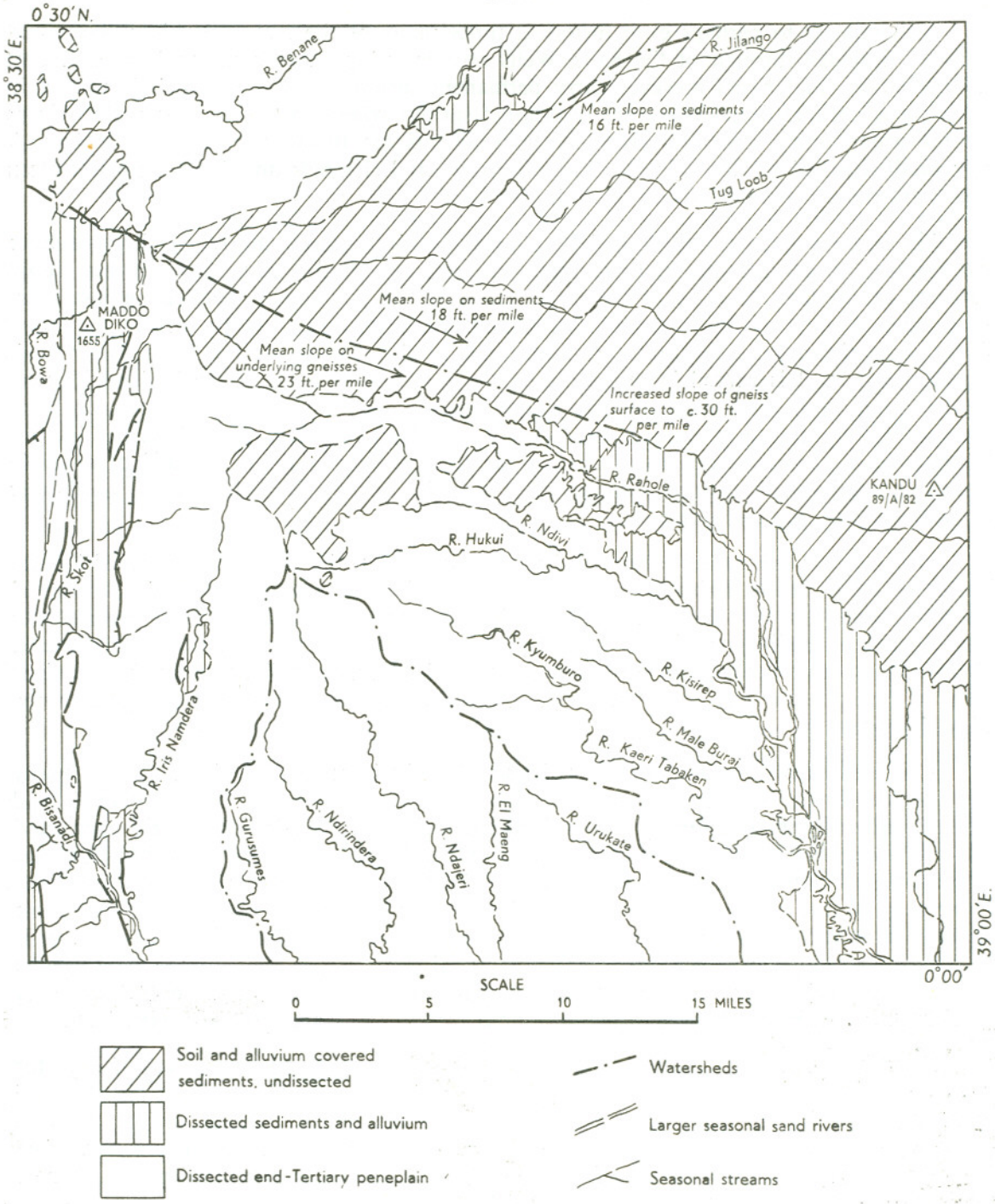


Fig. 1. Physiographic map of the Kora Wells area.

Bisanadi and Rahole systems from the rest of the Tana drainage. The metamorphic rocks are mantled with superficial deposits, especially towards the main watershed where dissection is at a minimum. There the drainage is poor, dark soils are developed, and the stream channels are poorly defined. Farther south they become well-marked sandy channels, often with steep rocky sides, particularly near the Tana. On the other side of the main watershed the pattern in the north-west corner is similar but less marked, because at these longitudes the Uaso Ngiro is a smaller river than the Tana, and has therefore achieved a smaller degree of dissection. Along meridian 38°45′E the erosional gradient is 700 feet in about 25 miles south of the watershed, as against 700 feet in nearly 50 miles on its north side. The drainage exhibits characteristics of a superimposed pattern, the larger sand channels cutting obliquely across the strike of metamorphic rocks. Only locally, in the lower reaches of the Gurusumes, Ndirindera and Urukate rivers, is there any correspondence between stream courses and structural grain.

The gneiss terrain is believed to form part of the end-Tertiary peneplain of Kenya, now heavily dissected. The surface approximating most closely to the original bevel can be traced beneath the sediments near the main watershed. A few small residual hills and ridges of gneiss, seldom exceeding 50 feet in height, rise from interfluves on the dissected peneplain.

(2) *The eastern plain*—is soil-covered and underlain by mainly red and green pebbly sands and clays, which are now undergoing dissection in the northern and south-eastern parts of the area. They connect along the main watershed with similar sediments in the Skot trough, and are part of the series covering most of eastern Kenya, which is generally believed to have been deposited on the end-Tertiary peneplain after it had been tilted slightly to the east. Post-sedimentation movements have brought the plain to its present altitude and further tilted it, so that the gneiss surface has an average east-south-east slope along the watershed of 23 feet per mile, whereas the sediment surface slopes at 18 feet per mile in the same direction. In the north however the surface of the sediments slopes just north of east with a slightly lower gradient of 16 feet per mile, because there is another watershed there, which separates the easterly plains drainage from the Golana Gof system in the Garba Tula area to the north, and which appears to be slightly higher than the main Tana-Uaso Ngiro watershed (Matheson, 1971).

It will be seen in fig. 1 that in this eastern region the main watershed is also the limit of Tana dissection into the soil-covered eastern plains, and the watershed must therefore be shifting gradually northwards. As it does so the channels now draining eastwards to the Lorian Swamp will be captured to become part of the Tana system, and it is considered that the easterly flowing upper reaches of the present-day Rahole, Ndivi and Hukui lagas were captured in this way.

Some degree of erosion of the end-Tertiary bevel took place before sediment deposition, with the development of some relief. Thus, over a small area near the Garissa road there are four gneiss exposures in shallow stream channels, surrounded by pebbles derived from the sediments banked round them. Minor irregularities of the sub-sediment surface were also detected at a few places in the north and south-east of the area.

The most striking irregularity in the sub-sediment surface however is the comparatively steep eastward slope against which the sediments are banked. It is well displayed in the upper Rahole Valley, where just south of the SKT4 tellurometer station the east-south-eastward slope of the gneiss surface increases from some 20 feet per mile to about 30 feet per mile, until it disappears beneath the sediments five miles downstream. Still farther downstream, in many places gneisses form the right bank of both the Rahole and Ndivi valleys, and can occasionally be seen in the actual sand channels, but they are never exposed to the east of them. The eastward slope of the gneiss-sediment boundary in those parts appears to be of the order of 100 feet per mile. The boundary is generally followed by the Rahole and Ndivi valleys and then continues practically straight across the Tana River

south of the area, with hardly any sign of a downstream "V"—this is a further indication that it is relatively steep.* Where the Tana crosses the boundary its regime changes from a valley with rocky sides cut in gneisses to alluvial flats and meandering channels on the sediments, due to attainment of a shallower profile on the more easily eroded sediments.

Gneisses also slope eastwards to disappear beneath the sediments in the north of the area, but the gradient there appears to be shallower. Unusually steep gneiss-sediment junctions have also been mapped by Rix and Dodson in the Kauro-Merille and Barchuma-Kom areas (both reports awaiting publication) north-west of the Kora Wells sheet. In those areas the boundary also trends generally north-west, and north-east of it no gneisses are seen.

(3) *The Skot trough* in the west, floored by sediments, extends west and south into the adjacent Kinna and Kora-Kalimangilu areas (Rix, 1967, and Jennings, awaiting publication). This feature is more fully described in a paper by the present author and Rix (Wright and Rix, 1966). It forms a noticeable depression in this region of generally low relief, and there are a number of low elongate north-south trending gneiss ridges within it. The sediments in the trough are virtually identical to those of the eastern regions and connect with the latter along the Tana-Uaso Ngiro watershed. There are two smaller elongate basins, also floored by sediments, just east of the Skot trough, along the Iris Namdera and Bisanadi rivers.

Many of the boundaries between gneiss and sediment are clearly visible on aerial photographs as long, unbroken, gently curving lines, sharply demarcating the medium grey tones of relatively upstanding gneisses from the paler grey and white of lower-lying sediments. Such boundaries are interpreted as fault planes, because not only do they frequently cut across the metamorphic grain at high angles but they are also steeply inclined, as can be judged from the absence of downstream "V" patterns where they are crossed by stream channels.

In some places, notably the small elongated basin in which the lower Bisanadi flows, the gneiss surface steepens downwards towards the gently inclined sediment surface, so that there is a marked change of slope along the boundary. Such a feature could not develop unless the sub-sediment surface were steep.

Across the western boundary fault of the Skot trough (Rix, 1967) the change of slope is gradual in most places, but is more abrupt where erosion seems to have been greater, particularly where the Bisanadi flows down on to the sediments in the trough. This is considered to be further evidence for a steep sub-sediment surface.

Breccias were found on the inferred fault lines in a few places: two along the eastern side of the Maddogoni hills, another on the continuation of the line passing south through Melka Magado, and a fourth on the side of a gneiss ridge about half a mile south-west of Marigi.

In some places there is a negligible altitude difference between gneiss and sediment along mutual boundaries, and these are shown simply as unconformities, although there may be concealed faults beneath. This type of junction is well developed at the northern end of the Skot trough where there has been less erosion and sediments have not yet been scoured out of the trough. The interfluve between the Skot and Bowa lagas there is formed on sediments.

Along the eastern boundary of the Skot trough east of the Skot laga the ground also rises from low-lying sediments to gneisses, but there the sediments are banked up level with the gneisses at interfluves between tributary channels. Furthermore, residual pebbly and sandy sediments actually rest on the interfluves due east of Marigi Wells and about four miles farther north. The gradient appears from measurements made on air photographs

*The Hargazo Falls in the Tana River may be connected with this feature.

to be as much as 15° in places, but is usually less. The shallowest slopes are those where sediments actually rest on gneiss interfluves, but even these are of the order of 5°, or nearly 500 feet per mile.

The small sedimentary basin in the Iris Namdera Valley appears to be bordered on the west by a fault, but its eastern slope too is remarkably shallow. Again, in the lower Bisanadi there is a small patch of sediments resting on gneisses in the left bank. This may indicate a shallow sub-sediment surface sloping down into the basin, but the occurrence is too small and ill-exposed for its field relations to be clearly appreciated.

The sediment-floored basins have had some influence on the drainage in the western part of the area, with the development of the southerly flowing Skot and Bowa lagas, and the south-south-westerly Iris Namdera. Some of the drainage however appears to be independent of these features and exhibits characteristics of a superimposed pattern. For example the Bisanadi, which is the largest river in this region, rises in the Nyambeni Range (Rix, 1967), descends into the trough along a steep rocky channel, and crosses it on sediments, cutting *en route* through a gneiss ridge in the Kinna area. The river leaves the Skot trough by a channel cut through one of the eastern boundary faults, although thereafter it is confined to the adjacent smaller trough until it leaves the area.

Two large tributaries of the Bisanadi rise in the Kinna area on low-lying sediments, and then flow through higher ground forming the northern end of the Maddogoni hills to join the Bisanadi. Another good example of superimposed drainage is in the north of the area, where westward flowing streams, which rise on the sediments forming the Maddo Diko interfluve, cut through a partly buried ridge of gneisses before joining the Bowa laga.

Inferred physiographic evolution.—Following maturation the end-Tertiary peneplain was gently tilted eastwards about an axis whose position is unknown but which is generally believed to have lain some distance to the east. The movement was probably associated with a phase of major faulting in the Gregory Rift Valley. The present area, lying west of the axis, must then have formed part of the rejuvenated zone and been subjected to erosion, which probably enlarged an earlier Tana Valley, and developed the irregularities in the sub-sediment surface described earlier. Base level was raised east of the tilt axis, encouraging deposition of the debris washed down from the rejuvenated regions, probably under semi-arid fluviatile flood-plain conditions.

The sedimentation belt, initially east of the tilt axis, is considered to have moved gradually westwards as denudation proceeded in the west, possibly assisted by some regional subsidence, until eventually the whole of that region, including the present area, was covered by sediments. The evidence for this lies in the uniformity of the sediments wherever they are seen, and the small patches of residual pebbles found on gneiss interfluves in the central and southern regions. Furthermore the flat north-eastern plains are yearly being cut back by erosion and must clearly have been formerly much more extensive.

Sedimentation was probably terminated by further tilting and uplift which together subsequently brought the area to its present attitude and elevation. As soon as this occurred the sediments must have become subject to rapid incision, particularly by the Tana River, which has a large catchment lying far to the west, and which therefore dominated the drainage trend from the start. Because the drainage was initiated on the sediments, stream courses, which were superimposed on the gneisses as they became exposed, in general bear no relation to the structures in gneisses, a feature already emphasized.

This general picture is complicated however by two important additional features, the relatively steep gneiss-sediment boundary in the east of the area, and the fault-bounded sediment-floored troughs in the west. The eastern gneiss-sediment boundary can be traced in a generally north-westerly direction across the Garba Tula, Barchuma-Kom and Kauro-Merille areas (Matheson 1971, Dodson (in the press), Rix 1973) respectively and no metamorphic rocks are seen beyond it until the north-eastern corner of the country is reached. In the

Kora Wells area it can be shown to steepen eastwards quite sharply until in places its slope is as much as four times that of the present-day slope of the end-Tertiary peneplain. Rix and Dodson (*op. cit.*) found similar and even larger increases in slope along the continuation of this junction to the north-west. The evidence from the Garba Tula area is less good, owing to poor exposure. The chances are remote that erosion alone could be the cause of such relatively abrupt steepening along a narrow but remarkably elongate belt, and it is concluded that the primary cause is regional warping along this line before the sediments were deposited.

Where sediments overlap the steepened slope, as they do in the present area along the main watershed, there is no change in the gradient of their upper surface, and this is considered to be evidence that warping occurred prior to deposition. Warping along this line would be consistent with the concept of a major sedimentary trough which is considered to have developed farther east beneath the Lorian Swamp and lower Tana basin, and whose presence tends to be confirmed by the results of recent borehole exploration.

There is some evidence to show that the troughs in the west, which extend beyond the present area, were in existence before sedimentation occurred, but that some faulting also occurred later.

1. In the region north of Maddo Diko sediments fill the trough up to the level of the surrounding gneisses, and there is no depression along the Tana-Uaso Ngiro watershed. If there had been faulting after sediment deposition such a depression would exist; its absence is evidence for a pre-existing trough.

2. Most of the drainage appears to have been initiated and established on an overall sedimentary mantle, so that when it reached the underlying faulted features it was able to cut more or less impartially through harder gneisses and softer sediments, producing only small differences of relief. Had trough faulting been initiated after sedimentation the superimposed patterns would still have been there, but the differences of relief between gneisses and sediments would probably have been greater. Nevertheless not all the drainage is superimposed, for a few stream channels show some measure of fault control, and this could be interpreted as evidence of post-sedimentary faulting. This is particularly true of the lower Bisanadi, and the presence of two river terraces there may have significance in this connection, though it is not at present understood. By and large, however, it is believed that trough formation was mainly completed prior to sedimentation. Between four and five miles north of the Bisanadi-Iris Namdera confluence there is a sediment-filled embayment into the faulted sediment-gneiss boundary. It could be explained as the filled-in valley of a river which drained into the trough while erosion was still active and before the sedimentation belt had encroached as far as this.

The troughs are on the whole asymmetric in form, with the strongest faults on the western side, chief of these being the major boundary fault in the Kinna area (Rix, 1967). Eastern boundaries in general have gentler slopes, particularly those east of the Skot laga, along part of the Iris Namdera valley, and in the lower Bisanadi. There is less evidence for the two smaller basins, but the eastern boundary slope of the main trough is too steep to be merely a pre-sedimentary erosion gradient. The most reasonable explanation is that eastern boundaries between gneiss and sediment, both marginally and along the gneiss ridges in the floor, are in the main downwarps into the troughs, which have fractured in some places to produce faults. The only two dips seen in sediments in the troughs are south-westerly, which is consistent with the inferred asymmetry of the trough.

Since the base of the sediments in the troughs is not seen, their thickness there is unknown. Nothing is known either about the degree of peneplain erosion between its maturation and the time of faulting and sedimentation. It is therefore not possible to make other than minimum estimates of the throw of the faulting in terms of scarp heights: the maximum scarp height anywhere in their region is about 200 feet, along the western boundary fault in the Kinna area. Elsewhere heights do not in general exceed 100 feet and are often much less.

The sediments originally extended some distance farther west, for they are preserved in other small faulted valleys which cross the Tana River in the North Kitui area (Dodson 1955, p.5) where they were recognized on aerial photographs. Where the Tana River crosses from gneisses on to sediments there it spreads out from its rocky channel to wide alluvial flats, as it does in the Skot trough and again farther east. Dodson attributed these changes to eastward tilting. but subsequent work has shown that they are due to change of gradient in the river on passing from hard gneisses to soft sediments, and although there has been eastward tilting the axis is probably considerably farther east (*see* also Rix, 1967, p. 6).

IV—SUMMARY OF GEOLOGY

The metamorphic rocks of the area comprise a monotonously banded series of metasediments of the Basement System, of Precambrian age. The rock types include biotite and biotite-hornblende gneisses with intercalated quartz-felspar gneisses, impure crystalline limestones, calc-silicate granulites and amphibolites. A small lens of biotite-sillimanite gneiss was seen, as well as signs of more extensive sillimanite formation in occurrences of "pseudo-sillimanite" bearing rocks. Two bands of semi-calcareous diopside-biotite gneiss and the presence of a thrust marked by a belt of brecciated rocks provide the only other interest among the metamorphic rocks.

Intrusive rocks include (*a*) pegmatites and quartz veins, some of them of large size, (*b*) small lenses of basic and ultra-basic rocks, part of a suite intruded along an irregular north-south belt across eastern Kenya during the later stages of Basement System metamorphism which has affected them, and (*c*) dolerite dykes of probable Tertiary age, similar in composition to the lavas and minor intrusives of the Nyambeni range, just to the west of the present area, but believed to pre-date them.

Sediments floor the Skot trough in the west and underlie the north-eastern plains which are undergoing dissection in the south-east. They are a uniformly poorly bedded and poorly consolidated pile of mainly red and green pebbly sands and clays, and have the same characters and appearance wherever they are seen. They are believed to have been laid down under fluviatile flood plain conditions, and to be of Upper Pliocene age, since they rest on the dissected end-Tertiary peneplain. They contain scarcely any igneous pebbles, and those few cannot be matched with Mount Kenya or Nyambeni lavas.

Among the otherwise unremarkable superficial deposits of younger age may be noted the interesting river terrace sandstones found in the lower Bisanadi Valley.

V—DETAILS OF GEOLOGY

1. Basement System

(1) Calcareous Rocks

(*a*) *Crystalline limestones.*—Crystalline limestones are rare in the area, and occur only as thin lenses whose true extent is rarely determinable owing to their poor exposures. The purest limestone found is a nearly white rock (specimen 37/572*) forming the steep eastern wall of a gneiss ridge overlooking the Skot laga. In the calcite mosaic there are scattered small rounded crystals of colourless diopside and garnet, small irregular quartz grains often aggregated together, and apatite. A small exposure of grey finely vesicular limestone with irregular lenses of coarse white calcite with crystals up to 25 mm. across was found protruding through sediments in a stream channel about two miles south of Lafageri tank. In thin section (specimen 37/447a) the calcite mosaic is seen to contain numerous rounded bodies, sometimes in aggregates, bordered by brown iron oxide and composed of finer-grained calcite mosaic, frequently with quartz which may be yellow-brown and spherulitic or cryptocrystalline. These inclusions are themselves also veined by brown iron oxide. Specimen 37/447b from the same locality has been more intensively silicified and contains more of these bodies, both bordered and reticulated by the brown oxide.

* Numbers 37/572 etc. refer to specimens in the regional collection of the Mines and Geological Department, Nairobi.

The other crystalline limestones seen all have pink calcite forming a base to varying amounts of dark green ferromagnesian minerals and deep red garnets. The best exposed limestone band, averaging more than 30 feet in thickness, was seen just east of the El Maeng laga in the south of the area. Near the centre it was seen to consist of pink calcite, while at the northern extremity garnet and epidote are developed in crystals up to several centimetres across, and as short lenses and massive segregations, almost to the exclusion of calcite; granular actinolite was also seen. Near the southern end also large garnets are developed as well as some actinolite, in more regular bands, and an apparently concordant garnet-bearing pegmatite lens was found within the band. Specimen 37/522, a saccharoidal pale green rock from this locality consists of epidote and diopside.

Of other rocks collected, specimen 37/440 from about two and a half miles west-north-west of Lafageri tank contains less calcite than usual, considerable amounts of pale green pleochroic diopside often altering to hornblende pleochroic from blue-green to olive, scapolite, and rounded grains of idocrase. The lens from which this was collected is locally coarse, with calcite crystals more than 25 mm. across, and a small iron ore segregation was seen nearby. Hard hornblende gneiss and a quartzite vein were also recorded from this locality. Specimen 37/443, from three and a half miles north-north-east of Lafageri tank, is much richer in pink calcite and carries, in addition to the minerals listed above, irregular grains of quartz and a little epidote associated with turbid alteration patches of unidentified material. Probably the best example of calc-silicate in close association with limestone was seen near the head of the Male Burai laga where there is a 50-yard exposure across the strike of pink crystalline limestone and associated pegmatite, overlain by a thin band in which calc-silicate minerals predominate (*see* below).

Thinner bands of crystalline limestones exposed in the banks of sand channels tend to weather easily. For example, one and a half miles up the Kisirep River from its confluence with the Ndivi, a limestone band about 15 feet thick was seen to have become very friable owing to its being riddled with secondary calcareous veining.

(*b*) *Calc-silicate granulites.*—Lenses of calc-silicate granulite are more numerous than the limestones, but are also of restricted size. They are hard rocks, sometimes banded, and generally coloured in varying dark shades of red and green. The banding may be somewhat contorted, as for example in the lens exposed as disjointed bouldery outcrops among quartz-felspar gneisses about five miles south-east of Marigi wells. As already noted, the thick limestone near the head of the Male Burai laga passes up to a thinner band of dominantly calc-silicate material forming knots, lenses and bands in the limestone. The knots contain appreciable amounts of quartzo-felspathic material and are associated with pegmatites, while the centre of each knot is formed of coarsely crystalline actinolite. Two such knots, joined together and forming part of a larger calc-silicate band, are illustrated in Plate IIa. Specimen 37/486, from the right hand end of the pair illustrated, is a green rock cut by narrow bands of coarse pink calcite paralleling the regional foliation. The mineral assemblage apart from these bands is seen in thin section to include scapolite, calcic plagioclase altering to sericite, pale green diopside altering to blue-green to yellow-brown hornblende, sphene, and appreciable amounts of quartz. Traces of microcline were also seen.

A curious feature of this particular locality is that immediately adjacent to the rocks just described there is a poorly exposed mass of brown limestone with white mottling, which appears to cut across the strike. It is composed (specimen 37/486a) almost exclusively of iron-stained calcite, the iron-staining forming a Liesegang-ring effect along the cleavage directions of the calcite. Other calcareous bands were seen further upstream from there among friable chloritized biotite gneisses, but they are also weathered and poorly exposed. The rock just described is free of garnet, as are two other thin calc-silicate bands found in this general region. Specimen 37/503 is from a thin band near the narrow shatter zone in the Kaeri Tabaken about four and a half miles west-north-west of its confluence with the Rahole, and is composed of quartz, felspar, pink calcite and actinolite, the latter two typically forming attractive large crystals. In a tributary stream two miles west-south-west of Bora

springs, a similar band forms the core of a small anticline (together with a coarse tourmaline-bearing pegmatite, described later) and is formed (specimen 37/510) of granular pale diopside altering in irregular lensoid patches to actinolite, which as in the specimen described above also forms attractive large crystals together with pink calcite and quartz.

Almost all the other calc-silicates collected carry garnet of varying shades of pink, as well as variable combinations of the other minerals already listed, although of these the clinopyroxene is often a deeper green hedenbergitic variety and the hornblende colours often have a predominance of brown rather than blue overtones to the dominant green. Where there is abundant plagioclase the garnet is almost invariably intergrown with it, to give the strikingly vermicular appearance well known in such rocks, and it is then frequently in close association with iron ore and green hedenbergite or the hornblende which replaces it. These features are common to the majority of calc-silicates in the area, and are well displayed in specimens 37/413 and 37/414 from a bouldery outcrop near the curving quartz-felspar gneiss ridge in the north-west corner of the area. These rocks also exhibit small amounts of zoisite or clinozoisite in reaction rims between plagioclase and epidote, which also contain sericite, calcite, and possibly a little apatite. In addition there are signs that plagioclase is being made over to scapolite in places, for it has locally higher interference colours, and at least one plagioclase crystal was seen to have a positive 2V of the order of 10° to 20°, whereas the bulk of the plagioclase is optically negative with the usual large 2V. Vermicular intergrowth between garnet and plagioclase is also well displayed in a series of specimens 37/555 (*a*), (*b*), (*c*), from a band associated with amphibolite about five and a half miles south-east of Marigi Wells, but there the plagioclase is partly sericitised. Where scapolite takes the place of plagioclase in these rocks, there is no intergrowth with garnet and the texture becomes intergranular throughout. Specimen 37/541a, from strongly but irregularly banded calc-silicates among quartzo-felspathic gneisses about five miles south-east of Marigi wells, is similar to the rocks described, but contains a green hornblende whose optic angle is unusually small.

A number of calc-silicates collected are free of garnet and have a heavily sericitised base. Probably the best exposed is in an amphibolite band forming part of the southern end of the ridge already mentioned just west of the Skot laga. The contact between calc-silicate and amphibolite is irregular as can be seen from the lensoid mass of hornblende in the hand specimen. In thin section there is a part of the main amphibolite consisting of crudely aligned blue-green to yellow-brown hornblende in a base of sericite, while the rest of the section shows relics of epidote and diopside, both colourless, again in a sericite base. Specimen 37/559 from three miles farther north is similar but contains more and yellower epidote, some relic scapolite and calcic plagioclase, while diopside was not positively identified. Specimen 37/492, collected from among amphibolites about half a mile south of the white quartzite inselberg east of the Kora Wells road, is finely banded with layers alternately richer and poorer in green hedenbergite locally altering to green hornblende, other minerals present being plagioclase, pale yellow epidote and a little apatite. The sericite base is poorly developed or absent in those bands where the pyroxene and hedenbergite form a granular mosaic.

Although calcareous rocks do not appear to be confined to any one part of the area. they seem to be fewer in the east, where none of them was recorded as carrying garnet, although garnet occurs in other rock types in their vicinity.

(2) Semi-calcareous Rocks

(*a*) *Biotite-Diopside Gneisses.*—Biotite-diopside gneisses form two prominent north-south trending bands, a long one in the east extending from three miles south of the Kaeri Tabaken River as far north as the Ndivi (with an adjacent short lens forming a short ridge in the Male Burai Valley) and a much shorter band exposed as an inselberg ridge near the northern boundary. The rocks of the massive rounded bouldery outcrop in the north are homogeneous across the lens, except for a fine banding, but the much wider belt in the east is made up of

leucocratic biotite-poor rocks and darker biotite-rich varieties in alternating bands of varying thickness, the alternations probably representing original sedimentary compositional differences. There are signs that there was fairly intense folding at both places where these rocks are developed, the rocks of the eastern belt being steeply dipping and strongly contorted about approximately north-south axes, particularly between the Kisirep and Male Burai lagas, while the ridge in the north is immediately adjacent to a tight fold closure outlined in quartz-felspar gneisses.

The best example of these rocks was collected in the Kisirep Valley about two and a half miles west-north-west of the Ndivi confluence, where the rocks are very tightly folded, and parallel-sided quartzo-felspathic veins were seen to be filling joints (*see* Plate Ic). The rock, specimen 37/469, is greenish grey and finely banded, and in thin section is seen to be composed mainly of microcline with a little oligoclase and quartz, sometimes myrmekitically intergrown, appreciable quantities of yellow-green diopside in irregular grains which are sometimes in aggregates, a good deal of accessory sphene, often associated with the diopside, a little iron ore and a few flakes of bleached biotite. In one part of the slide the diopside appears to be derived from a central core of hypersthene, now associated with some iron ore, the junction between the two pyroxenes being gradational. A thin band of relatively coarse calc-silicate rock at this locality, specimen 37/470, contains tabular ilmenite, diopside, yellow garnet, pale brown ragged biotite, microcline, and plentiful oligoclase with small amounts of myrmekite, but apparently no separately crystallized quartz.

Specimen 37/481 from the Kisirep Valley is a grey rock with green speckling, composed of microcline, quartz, and a little oligoclase, with appreciable amounts of uralitic blue-green to very pale yellow-brown amphibole, probably derived from diopside and now extensively altered to calcite and pale brown fibrous chloritic(?) material. Accessories include abundant sphene and iron ore, associated both with each other and with the amphibole, and a little biotite was also seen. Specimen 37/482 is a pegmatitic vein from this locality, containing quartz, iron-stained felspar and highly altered ferromagnesian material. The felspar appears to be entirely oligoclase, which is unusual in view of the preponderance of microcline in the host rock.

The brown rock, specimen 37/432, forming the ridge in the north of the area exhibits features transitional between those of the rocks just described, being composed mainly of microcline, quartz and oligoclase, in part myrmekitic. There is also a vermicular intergrowth of quartz and felspar along some of the boundaries between adjacent microcline grains. Pale green diopside is abundant, partly altered to the uralitic amphibole just described, which in turn is associated with calcite. Dark brown biotite is associated with both the ferromagnesians and with iron ore, and sphene is again present in quantity.

(3) Metamorphosed Pelitic Sediments

(*a*) *Biotite-Sillimanite Gneisses.*—Only a single narrow band of gneisses carrying sillimanite was found during the survey, in the El Maeng laga about two and a half miles north-north-east of Kora Wells. The rock is a flaggy biotite gneiss with sillimanite-rich knots or *faserkiesel* over 25mm. across and in thin section (specimen 37/525) appears to be a normal biotite gneiss, except that a vermicular intergrowth between muscovite and plagioclase was seen. Some of the muscovite in the rock is derived by leaching of biotite, as in specimen 37/525a, which contains only quartz and sillimanite as additional minerals, the latter pervading all the other minerals as random needles, often aggregated in sheaves.

Pseudo-sillimanite gneisses form a small ridge outcrop in the Kaeri Tabaken River some five and a half miles west-north-west of Bora springs, where the rocks have been involved in tight anticlinal folding with virtual obliteration of the foliation, leaving only the axial direction prominent in the rocks. Abundant fibrous muscovite is developed in the rocks (specimens 37/489 and 489a) but in thin section they are seen to be normal biotite gneisses with the addition of muscovite derived in part by bleaching of biotite, but mainly derived from original sillimanite.

(4) Metamorphosed Semi-Pelitic Sediments

Gneisses of this description form a monotonous banded series which constitutes the bulk of the rocks in this area. The usually thin bands are alternations of quartzo-felspathic with more basic material, most often biotite with or without hornblende.

(*a*) *Biotite Gneisses.*—Biotite gneisses form a series of prominent rocky ridges in the south of the area, about six miles east-north-east of Kora Wells. The rocks are flaggy finely banded rocks, with concordant pegmatitic auto-segregation veining. In thin section, specimen 37/507, the rock shows a simple irregular mosaic of quartz, microcline, oligoclase-andesine, brown to almost colourless biotite in large sub-parallel flakes, and a little reddish amorphous matter. Mutual inclusion of minerals is common and albitisation rims of plagioclase against microcline are present, although not conspicuous. Practically identical rocks (specimen 37/521c) are well exposed in the El Maeng laga, where the banding, well displayed on the waterworn rock surface, is very fine, seldom exceeding 25mm. in thickness. Accessories seen in the thin sections include iron ore, sphene, apatite and a little zircon.

In the Male Burai laga four and a half miles west-north-west of its confluence with the Rahole, a float block of green banded biotite gneiss, specimen 37/480, was seen to contain some copper mineralization, this being concentrated in the biotite-rich bands as the hydrated silicate chrysocolla.

In places the banding in the gneisses is irregular and lensoid, and undulates about an axis parallel to the dip direction, this feature being well seen on a small rocky outcrop close to the road about one and a half miles north of Kora Wells. The central part of this interfluve ridge is formed of somewhat irregularly banded biotite gneisses, which are well displayed in the Ndajeri section round Kora Wells. Signs of more intense stresses are visible in the apparently haphazard arrangement of leucocratic quartz-felspar streaks in the biotite gneisses at many exposures, which give the impression that the original banding has been torn apart by random movements, possibly when the rock was in a plastic condition.

Porphyroblastic biotite gneisses are occasionally seen, one locality where they are well developed being in the Kisirep laga some three and a half miles west-north-west of the Ndivi confluence, where the rocks form intercalations between dominantly amphibolitic bands, the whole forming an interruption of perhaps 20 yards within the normal banded gneiss sequence. The rock is very friable but appears to be a normal biotite gneiss with pink microcline porphyroblasts up to 25mm. in length.

Garnetiferous biotite gneisses are fairly common but have not been differentiated by colour on the map. Strongly garnetiferous biotite gneisses were mapped along a tributary to the Skot laga east-north-east of Marigi Wells, in which the sands contain a high proportion of garnet. Garnets forming porphyroblasts up to 20mm. across were found in felsparphyric biotite gneisses in the Maddogoni hills. In thin section these rocks, specimens 37/543 and 37/528a, can be seen to be composed of plagioclase, quartz, pale brown to olive biotite, pink garnet and apatite. The plagioclase tends towards andesine in composition. A small outcrop of gneiss very rich in garnet was found near the Benane laga about three miles west-south-west of Benane wells. The garnet is concentrated in numerous irregular bands in the very hard rock (specimen 37/438) which is generally similar to those described, apart from the presence of iron ore and epidote and some alteration of biotite and felspar.

(*b*) *Banded Biotite-Hornblende Gneisses.*—Banded biotite-hornblende gneisses are shown on the map as occupying large portions of the area. Not all the rocks mapped under this head contain both biotite and hornblende, and they are mainly alternations, often on a scale measurable only in tens of millimetres, of quartzo-felspathic material with bands containing biotite or hornblende or both. A good example of this type is specimen 37/476, from the Kisirep laga four miles west-north-west of the Ndivi confluence, which is made up of 10mm. bands all dominantly quartzo-felspathic containing respectively biotite; no ferromagnesian minerals; and hornblende (lineation is developed on the latter band). Often the banding is on a larger scale and the rocks more basic in character, with intercalated amphibolites too narrow to be differentiated on the map.

A good example of a gneiss containing both biotite and hornblende is specimen 37/549, from the Ndirindera just north of the southern boundary. It is a banded granular rock, with irregular pink bands mainly composed of quartz, microcline and a little plagioclase, while the main body of the rock contains microcline, somewhat sericitised oligoclase, quartz, green hornblende, and biotite altered to strongly pleochroic green chlorite with purplish interference colours. Another dark granular rock from banded gneisses in the Ndajeri about three miles north-north-west of Kora Wells (specimen 37/537) is similar except that it contains no microcline. Since the Ndajeri has a well-developed channel which cuts in general obliquely across the strike of the rocks, and is sometimes perpendicular to it, the section downstream of this locality is one of the best exposed in the area. The rocks in general are similar to the sample just described, with occasional intercalations of harder and more leucocratic quartz-felspar gneisses. The most striking feature of the section is the quartzo-felspathic banding of the gneisses. The banding is of widely variable thickness, and also varies in orientation, although mainly it is steeply inclined. The banding may be concordant, oblique or acutely cross-cutting, and the veins are usually parallel-sided and their margins often sharp (Plate IIb). Where such leucocratic bands cross one another the material is homogeneous with no signs of one vein cutting another, and it must be inferred that they were all emplaced penecontemporaneously. Locally the veins contain porphyroblastic felspars up to 100mm. across, and the banding is often contorted, apparently haphazard when viewed along the strike, but remaining irregularly sub-parallel on level surfaces. Three bands were sampled at a spot about two and a half miles north-north-west of Kora Wells, from a one metre concordant band, a 100mm. oblique band, and a 70mm. concordant band (specimens 37/545, 545a, 545b respectively), in what appear to be locally dominant biotite gneisses. The veins are all very similar, despite their differing trends and thicknesses, slightly coarser than the host rocks, white in colour, and composed of partly sericitised oligoclase, quartz, and chloritised biotite, with accessory zircon. As in the gneiss just described from a short distance upstream, there is no microcline. Farther downstream the rocks were recorded as grading to more leucocratic biotite gneisses, and about a mile north-north-west of Kora Wells these pass into a region of random and highly irregular pegmatitic digestion of the host biotite gneiss, of which only small vestiges are still visible. This belt, some 500 yards across, then passes back into more normal banded gneisses, and these in turn to the more leucocratic biotite gneisses forming the interfluve between the Ndajeri and El Maeng lagas. The intense invasion by pegmatitic material just described and the opposing dips on either side of it suggest that there may be an almost isoclinal anticlinal structure in this vicinity.

Five and a half miles south-east of Marigi wells there is a pavement exposure about 100 square yards in area, of biotite-hornblende gneisses with swirling and contortion of the banding. In this are porphyroblastic knots of mafic minerals up to 15 cm. long and ellipsoidal in shape, which contain (specimen 37/555) green hornblende apparently grown round brown biotite, with interstitial andesine, and alteration to chlorite and calcite at hornblende-plagioclase boundaries. A granular aggregate of apatite was also seen. Similar mafic segregations in biotite-hornbende gneisses were also well displayed on a small inselberg near the south end of the Maddogoni hills, where the foliation banding is irregular and undulose about an axis along the dip direction.

A section where the gneisses vary appreciably over a very short distance, and from which a number of specimens were collected, is in the Kaeri Tabaken laga just upstream from Bora springs, where there are some good wall exposures. The first of these is just west of the spring and displays variably but on the whole evenly banded rocks with minor irregularities, due to sometimes oblique injection of leucocratic pegmatite material (Plate IIc) and small-scale movements and adjustments, with consequent frequent boudinage effects, particularly well seen in the leucocratic veins (Plate IId). Signs of crushing and shattering were also recorded there. Samples were taken from practically adjacent pelitic and leucocratic bands. Specimen 37/501 is a grey flaggy quartz-felspar rock with thin biotite-rich layers, and is simply a leucocratic biotite gneiss with green-brown biotite, and highly irregular textures, in which the plagioclase is sericitised. Specimen 37/501a is more massive and

biotite-rich; no potash felspar was seen and the plagioclase is fresh. The biotite is mostly green, occasionally brown, and there are numerous areas of very finely granular quartz, felspar and biotite among the highly irregular textures, possibly connected with the shatter effects noted above.

A sequence of specimens was collected at the next bend upstream, south of the one described, where there is again an excellent wall exposure, this time perpendicular to the strike. Specimen 37/501b is a fine grey rock with sparse large calcite crystals, which appears to be a highly sericitised and calcified biotite gneiss with irregular shreds of greenish altered biotite and some quartz. It may originally have been similar to the last sample described. Specimen 37/501c, an intermittently and irregularly banded dark rock, is a plagioclase amphibolite with partly sericitised felspar and accessory sphene. Specimen 37/501b is closely similar but less homogeneous being finely banded and flaggy, and it contains some microcline. Specimen 37/501e is a coarse green friable rock with random plates of mica and locally large crystals of somewhat platy pale green actinolite. The platiness is probably due to incipient chloritization. In this section it is seen to contain irregular pale brown biotite and pale green pleochroic pyroxene and amphibole (diopside and actinolite) crowded with small iron ore inclusions. This band is some two metres thick, and immediately above it there is a normal amphibolite, specimen 37/501f, which appears to be composed entirely of green-brown hornblende with a little biotite. These two specimens were taken from the band marked as amphibolite on the map.

(5) Metamorphosed Psammitic Sediments

(*a*) *Quartz-Felspar Gneisses.*—Outside river sections leucocratic quartz-felspar gneisses are the most frequently exposed rocks, by virtue of their hardness and resistance to weathering. They are well-jointed, and usually weather to pink and buff rounded bouldery outcrops. Where the bands are steeply dipping, wall features are developed especially across stream channels, and sub-horizontal as well as vertical jointing produces tor-like ridges. Excellent examples of blocky jointed gneiss forming walls of this type were seen in the Kaeri Tabaken and in the Urukate near the southern boundary.

Although generally granular rocks, they may be almost pegmatitic throughout the entire length of a band, as in the curving ridge exposure eight miles north of Maddo Diko, where the felspar crystals are frequently porphyroblastic and as much as 75mm. across; there is much disseminated iron ore also, sometimes concentrated in thin impersistent bands. The coarse rock, specimen 37/410 is a highly irregular mosaic of microcline and albite with subordinate quartz, and the larger porphyroblastic crystals are antiperthite with albite acting as host to turbid microcline (37/412). This is an unusual composition for such rocks, and may account for the coarsely crystalline nature of those forming the ridge here.

Lineations are often very well developed in these rocks, either as grooves or in elongation of minerals, this property being perhaps also connected with their hardness. Foliation is generally undulose and not readily detectable, however, being often defined only by thin irregular auto-segregation veins, up to 10 cm. thick, of coarser quartzo-felspathic material and occasional thin layers slightly enriched in ferromagnesian minerals; there is frequently also a parting parallel to the foliation plane. Where such features are absent however, the foliation is almost impossible to determine, as at the most northerly exposure of these rocks, on the northern boundary. In addition to the concordant segregation veins, less regular veins pockets and lenses of leucocratic material, often nearly pure grey or white quartz, are often seen. Thus in the Rahole River, due south of reference point SG 138 on the Garissa road, there are hard leucocratic gneisses displaying irregular and impersistent but concordant quartz-felspar veins, with well-defined quartz selvedges, contorted and boudinaged in the plane of foliation. In addition there are ragged coarse pegmatitic veins with blurred junctions against the host rock, having an apparently haphazard distribution and orientation. More regular magnetite-bearing white pegmatites were also seen, both concordant and slightly oblique to the foliation. Boudinage effects are also often seen in the concordant bands richer in ferromagnesian minerals, and are in general to be ascribed to plastic flow movements within the rock.

These rocks are typically simple irregular mosaics of microcline, quartz and subordinate sodic plagioclase with myrmekite and albitization rims against the microcline, together with a little iron ore. Small zircons, sphene and apatite form very minor accessories. No biotite was seen, but locally hornblende is present, as in a lineated gneiss, specimen 37/523, from the Urukate laga near the southern boundary. In the north, jointing at Bamba close to a fault line has been accompanied by sericitisation of the plagioclase (specimen 37/433), which is not usually seen in these rocks.

The quartz-felspar gneisses can be richly garnetiferous, as for example in the Hukui valley two and a half miles west of the Kora Wells track, where garnet occurs both as disseminated crystals and locally enriched in narrow lenses. The rock is very like those just described, but contains in addition pink sieve-structured garnets bearing many inclusions of quartz, felspar, and bright red material. Garnetiferous quartz-felspar bands alternate with garnetiferous biotite gneisses (already described) at the northern end of the Maddogoni hills, where they are concentrated in the pegmatitic auto-segregation veins. Thinner leucocratic garnet-bearing bands also occur among biotite gneisses, also in part garnetiferous, in the Skot tributary east-north-east of Marigi wells. Coarse blocky-jointed garnetiferous quartzo-felspathic gneiss was also seen in a small outcrop close to the Ndivi-Kora Wells track crossing, the garnets reaching 5mm. in diameter.

(*b*) *Quartzites.*—Quartzites are not common in the metamorphosed sedimentary succession, but two varieties were distinguished. Dark grey quartzite forms two small lenses in the north-west, one near Bamba, the other at the northern end of the quartz-felspar gneiss ridge north of Maddo Diko, where it is associated with white quartz veining. The latter (specimen 37/416) is an irregular mosaic of quartz grains with iron ore both as inclusions in the quartz and as larger irregular masses between the grains, associated with a little apatite and some amorphous reddish brown matter.

There are a number of garnetiferous quartzite bands in the region south-east of Maddo Diko. The most important of these, six miles south-east of the survey point, is an elongate lens of flaggy banded rock, forming a low ridge feature at the head of a small valley. Biotite, muscovite, iron ore and some intercalated quartzo-felspathic material were recorded in the field at this locality. The specimen collected (37/564) is a dark grey and brown rock with small disseminated graphite flakes, and in thin section is seen to be composed of quartz, some microcline and sericitised plagioclase(?) with opaque black elongate flakes having serrate margins, presumably either graphite or iron ore. There is also some yellow material of high relief in irregular patches, and small round colourless garnets are scattered through the slide. Part of the slide of specimen 37/556, collected from the eastern end of this band, is similar to the above, but without felspar or apatite, the remainder being a mass of iron ore, with a great concentration of small colourless garnets and a little interstitial quartz. A few flakes of graphite were seen in the hand specimen.

A thin band of felspathic garnetiferous quartzite was seen in the extreme south-east in the Rahole Valley, pink garnets being present as scattered and well-shaped crystals a few millimetres across (specimen 37/517). Rocks of this type can be regarded as transitional to the garnetiferous quartz-felspar gneisses described above.

(*c*) *Muscovite Quartzites.*—Muscovite quartzites occur in bands forming low ridges only in the south-east of the area. Specimen 37/504, from the ridge about three miles south-west of Bora springs, is a silvery rock composed of quartz and muscovite, both colourless and pale yellow brown. An elongate knoll about a mile farther south-west is formed of similar rock, and narrow bands were mapped about two and a half miles north, and also among amphibolites in the El Maeng, about a mile north-east of Kora Wells.

(*d*) *Biotite-Muscovite Quartzites.*—A single band of this rock flanks the larger of the muscovite quartzite bands, being exposed in the adjacent valley on the west side. Specimen 37/508 contains much purplish brown to nearly colourless biotite, in part bleached to muscovite, quartz, ilmenite and small associated rutile grains. A little muscovite is also visible in the hand specimen.

(6) Metamorphosed Basic Rocks

(*a*) *Amphibolites and Plagioclase Amphibolites.*—Amphibolites are common as thin and often hard knots and lenses within the banded gneiss sequences described above, but locally become important constituents of them, and these stretches, as well as the more prominent lenses, are marked as amphibolites on the map. In places the individual amphibolite bands have suffered distortion and fracturing, as for example along the Ndirindera section between one and three miles north of the southern boundary, where they occur among dominantly biotite gneisses. Presumably this is due to their greater competence, so that they would be more prone to yield by fracture to the stresses accompanying fold movements. Irregular masses and veins of white pegmatite and quartz are in many places seen close to amphibolites, a good example occurring with a band near the Male Burai about seven miles west-north-west of the Rahole confluence. The rocks are most commonly simple hornblende-plagioclase mixtures, often with accessory sphene and a little quartz, in places coarse grained, with large porphyroblastic hornblende. The best exposure was seen in a tributary of the El Maeng, about a mile north-east of Kora Wells, where there is a banded dominantly amphibolitic succession, but thin biotite gneiss bands and a thin muscovite quartzite were also recorded. Some of the rocks are very coarse, with hornblende grains many centimetres across, though such rocks are not confined to this exposure. Specimen 37/521a, collected here, is a coarse even grained plagioclase amphibolite with green-brown hornblende, slightly sericitized andesine and a little iron ore associated with the hornblende. A nearby leucocratic band some 100mm. thick (specimen 37/521) consists simply of quartz and unaltered plagioclase in an irregular mosaic.

The plagioclase is sericitised in some amphibolites, in veins or patches which show up as greenish waxy areas on hand specimens, as in specimen 37/550 from a band two and a half miles east-south-east of Kuka, and the alteration is sometimes so complete that almost no signs of original plagioclase remain, as in specimen 37/571a from the southern end of the ridge just west of the Skot laga. Amphibolites alternate with biotite gneisses on the north bank of the Kaeri Tabaken just east of Bora spring, and there is a well-exposed section in banded plagioclase amphibolites, varying from nearly black rocks to leucocratic varieties, in the same river about a mile from the Rahole confluence. The rocks (specimens 37/499a, and b) contain blue-green hornblende, much accessory sphene and a little strained quartz, and the plagioclase has suffered sericitization which is more or less uniform, but insufficient to obliterate original crystal outlines. An irregularly banded amphibolite, specimen 37/515 from gently dipping mixed banded gneisses two and a half miles south-east of Bora spring, is similar. These rocks were collected from the vicinity of the thrust belt in this region.

It is possible that the patchy but complete sericitisation of plagioclase seen in some amphibolites is a retrograde metamorphic effect, while the less intense and more uniform effects seen in the samples from the east may be connected with the thrust disturbances discussed in a later chapter, which are believed to have occurred in relatively cool, hard rocks. The strained quartz can be attributed to the same cause, and in this connection it is perhaps pertinent to note that quartz is absent from those rocks in which the more intense type of sericitisation was recorded.

The plagioclase amphibolites also often carry diopside, as for example specimens 37/554 and 554a, dark granular rocks with white speckling collected from the Iris Namdera north of the Kora Wells track crossing, where amphibolites form an important part of the succession. The plagioclase in the former sample is sericitised, but there is quartz in the latter, and the plagioclase is fresh. Signs that the diopside contributes to formation of at least some of the hornblende in the amphibolites are seen in specimen 37/474, from the Kisirep three miles from the Ndivi confluence, where relics of diopside occur in larger hornblende crystals, often in optical continuity. The base in this rock is entirely sericite, formed of original plagioclase and possibly scapolite, which is also seen in this variety of amphibolite, notably in specimen 37/469 from two miles east of Marigi wells. A more

extreme example of such rocks is specimen 37/551, a black granular friable rock with reddish and yellowish discolouration patches, collected from a poorly exposed lens about four miles east-south-east of Kuka. It is practically monomineralic, consisting mainly of pale green diopside, veined by iron oxide, altered in patches to green-brown hornblende. There is a little interstitial quartz, and small patches of amorphous brown material with angular fragments of quartz and hornblende.

Some amphibolites also carry garnets, this variety being confined generally to the south-western part of the area, in which most of the other garnetiferous rocks have been found. Specimens 37/547 and 37/547a were collected from dominantly amphibolitic rocks in the Gurusumes laga between one and one and a half miles from the southern boundary, where there are garnetiferous varieties among the dominantly amphibolitic rocks. Specimen 37/547 is a dark faintly banded rock with sparse pale pink garnets, in which plagioclase ophitically encloses hornblende, the latter being often associated with iron ore which occurs as skeletal growths within some of the grains. Specimen 37/547a from farther downstream is much richer in hornblende and garnet, the former associated with iron ore and a little diopside, and the plagioclase wholly interstitial. An oblique leucocratic vein collected from the banded rocks there, specimen 37/547, is a simple quartz-plagioclase aggregate similar to those described from among banded gneisses in the Ndajeri section. The garnets in these rocks are free of inclusions but in specimen 37/546, from about half a mile east of the Ndirindera-Kora Wells track crossing, the garnets are filled with small felspar or quartz inclusions, and in specimen 37/561, from four miles south-south-east of Maddo Diko, they also carry iron ore inclusions. None of the plagioclase in garnetiferous amphibolites was seen to be sericitised.

(7) Breccias

Along a belt west of the Rahole, in the south-east of the area, there is a belt of brecciated rocks believed to have been formed by thrust movements. The exposures there are poor, but the general impression gained was one of shallow to moderate dips, mainly westerly, in shattered dominantly leucocratic and biotitic gneisses, with undulations about both north-south and east-west axes, mainly the former, in those places where foliation is still visible.

Specimens were collected from a number of localities within the belt. Specimen 37/496a is the most northerly of those from the Male Burai, three miles north-west of the Rahole confluence. It is a cream coloured gneiss with 20mm. porphyroblasts of felspar, mainly composed of microcline perthite stained pink by iron oxide, which also forms the larger crystals of the rock, with quartz and a little oligoclase. The thin section shows no sign of shattering, but in the hand specimen there are a number of sub-parallel cracks developed due to proximity to the thrust belt. Half a mile downstream there are intense contortions displayed in the foliation of the rocks, and a southerly plunging lineation is seen to steepen sharply. They are mainly dark-coloured fine grained rocks, although porphyroblastic gneisses were also recorded. Specimen 37/496, a fine grained dark grey irregularly-fracturing hard rock is in part almost a mylonite, with angular quartz and felspar fragments (mainly sericitised plagioclase and a little microcline) in a microcrystalline quartz base. There is also veining by greenish chloritic material, and a little iron ore was seen, while quartz and calcite form irregular later stage veining.

The porphyroblastic gneiss there, specimen 37/496b, is similar to that described above, but with less prominent porphyroblasts, and only faint signs of shattering in the hand specimen. In thin section however it is seen to be broken up into angular fragments of sericitised plagioclase, microcline in which twinning is partly obliterated, and strained quartz, which seems to have suffered translational stresses, having been re-crystallised in elongate strained crystals forming crude mosaic veins between the other crystal fragments. Specimen 37/496c is another fine grained dark grey rock, with irregular leucocratic banding of quartzo-felspathic material in which chloritized fragments of ferromagnesian minerals can be seen. Angular and rounded fragments of quartz, plagioclase and microcline are embedded in a finely crystalline quartz mosaic and range in size from a more or less uniform 0.5mm.

down to that of the base. There are faint signs of banding in the base which can in places be seen to flow round the larger fragments embedded in it. There are also elongate ragged flakes of iron oxide, and shredded biotite in irregular veins which are subparallel to the remarkably elongated mosaics of strained quartz and to the faint banding in the base. Sphene is abundant as rounded grains, and the rock is believed to have been originally a biotite gneiss.

A pink quartz-felspar gneiss, with little outward sign of shattering and with manganese dioxide fronds developed on the irregular fracture surfaces, was collected a further half mile downstream. There (specimen 37/496e) the quartz has suffered such a degree of translation and recrystallization that the elongate strained mosaics in places are diverted round the other fragments in the rock. The felspars have also yielded to the stresses, but to a lesser extent, and twinning in microcline is again patchily obliterated, possibly due to local elevation to the monoclinic orthoclase phase. From the same locality, specimen 37/496f is another pale pink quartz-felspar rock, again with few signs of shattering, but in the slide the pulverised base is prominent, with quartz in a fine grained mosaic often irregularly veining the groundmass between the other mineral fragments. The plagioclase is sericitised, and a good relic of myrmekite was seen in one part, while the potash felspar is fresh but again has partly-obliterated twinning. In such places the interference figure is negative, while elsewhere it appears to be positive, a most unusual phenomenon. It is possible that in such strained rocks patchy multiple microcline-type twinning may have developed in the plagioclase, and that it is potash felspar which has been sericitised.

A flaggy finely banded rock collected from the main belt of brecciation about one mile west-south-west of the Rahole-Kaeri Tabaken confluence (specimen 37/498) is a largely quartz-free microcline-bearing plagioclase amphibolite. The plagioclase is turbid, the hornblende crystals have ragged outlines and textures are in general irregular giving the impression of mutual corrosion at grain boundaries, but there is no brecciation. In the hand specimen of 37/519, an amphibolite inclusion in a minor fold core, there is quartz-felspar veining, which in thin section resembles the groundmass of the leucocratic breccias described previously, but the felspar in it is clear (although untwinned), in contrast to the turbid felspar of the host rock which seems otherwise to be a normal plagioclase amphibolite.

In general the amphibolites from the thrust belts do not differ, except in a slightly greater degree of cataclasis, from the amphibolites collected near these belts, and they have some type of sericitised felspar in which the crystal outlines are preserved, lending support to the hypothesis proposed earlier for the origin of this phenomenon. It would seem that the almost startlingly undisturbed aspect of the amphibolites among strongly shattered and brecciated rocks of other types can be attributed to two causes: (1) the amphibolites are for some reason able to resist the thrust effects and retain their identity, while in more leucocratic rocks the textures are completely destroyed, or (2) more probably the preserved amphibolites are merely fortuitously undisturbed members of an imbricate sequence of relatively normal rocks alternating with strips of completely brecciated rocks. In the small thrust area west of the main belt, the breccias which alternate with amphibolites are clearly derived from more basic rocks than those collected in the main belt, possibly in fact from the amphibolites with which they alternate. However, more detailed field examination would be required to test the validity of these suggestions.

2. Intrusives

(1) Pyroxenites

Hypersthene-bearing pyroxenites form rare small concordant lenses in a region extending about three miles north and south of Marigi wells, and also occur at the northern end of the Maddogoni hills. The rocks contain varying amounts of hypersthene, diopside, plagiocase and amphibole.

The best developed lens forms a black bouldery outcrop about two miles north-north-west of Marigi wells. Its true extent is not known because of the poor exposure, but it was estimated to be at least one hundred yards long and thirty wide. At one locality, in a good stream section, a knot of coarse pink and white quartz-felspar pegmatite was seen in the rock, apparently no different from that occurring among the gneisses. The eastern contact between the basic rock and the surrounding gneisses at that locality is poorly exposed but appears to be concordant and sharp. A number of specimens were collected there, all dark grey relatively fine and even grained rocks, some with small amygdale-like bodies which tend to stand out on the brown weathered surface. In thin section the rocks (specimens 37/560, a, b, and c) can be seen to be composed mainly of hypersthene with abundant small platy inclusions of pink oxide(?) (cf. O'Hara, 1961, p. 854), and sometimes showing the characteristic fine (100) exsolution of clinopyroxene. It is pleochroic in shades of pink, more usually tinged a faint brown, as is the otherwise colourless clinopyroxene. This colouration is due to marginal alteration to brown hornblende which also forms small granular aggregates and contains small opaque oxide inclusions. There is colourless garnet and sericitised calcic plagioclase. Where alteration of the plagioclase is complete, as in specimens 37/560 and 560c, the small amygdale-like bodies are found. They are simple cores of green spinel surrounded by sericite. The textures in these rocks are for the most part of simple intergranular type. Specimen 37/570, from a small outcrop of coarse rock about two miles farther south, is generally similar in appearance except that the plagioclase is much less regular, and is often intergrown with pyroxene. Although there is a little hypersthene, the pyroxene is mainly monoclinic, containing numerous irregular exsolution(?) blebs of orthopyroxene. There are small amounts of colourless garnet and a little green spinel. Some iron ore, possibly titaniferous, was seen in the hand specimen. This outcrop is not connected to the large lens described above, for the intervening ground was traversed, and no sign of basic rocks seen.

Near the end of a good tributary stream section three and a half miles south-south-east of Marigi wells, the pyroxenite locally grades to a coarse, almost pegmatitic facies. A granular mosaic of hypersthene, diopside and plagioclase, with the pyroxenes partly altered to greenish hornblende, can be seen in one part of the slide (specimen 37/541), but most of it is made up of granules of pyroxene, hornblende and plagioclase, the latter often forming aggregates of its own, while the pyroxene and hornblende are more intimately mixed. Occasional ragged larger crystals of hornblende are also seen.

Specimen 37/532, taken from a short lensoid exposure of bouldery hard dark rocks at the southern end of the Maddogoni hills, is a very striking rock in thin section, containing large irregular pink hypersthene crystals, partly dusted with opaque iron ore inclusions and partly altered to red-brown hornblende. There is green spinel in symplectic intergrowth with the hypersthene, and it also occurs in the hornblende. There are some relic olivines in the hypersthene, and the rock also contains irregular elongate crystals of plagioclase which are crowded with minute rods of spinel, usually in sub-parallel arrangement. At the northern end of the Maddogoni hills, almost on the strike continuation of this lens, there are two more, a few hundred yards apart. The more easterly one, specimen 37/528, is the thicker, and is seen to be a more gabbroic rock, being composed of labradorite and pink and green hypersthene with brown oxide veining. The hypersthene is locally altered to green hornblende which is often in granular aggregates and associated with opaque oxide.

The rocks described above are similar to the suites of hypersthene-bearing intrusives described from other parts of central Kenya, the most notable being those between Embu and Meru, described by Pulfrey (1946) and by Schoeman (1951), which grade to acid charnockites. In the present area they have sharp and apparently concordant contacts with country rocks, except possibly in the case of specimen 37/541 (described above) which occurs among dominantly amphibolitic rocks which were probably derived by metamorphism of the original intrusive. The granular appearance of this rock in thin section is evidence of metamorphic influences, as are the clouded felspars described in specimen 37/532.

PLATE I



(*a*)



(*b*)



(*c*)



(*d*)

Plate I (*a*)—Lineations and corrugations in irregularly banded biotite gneiss near Benane.
(*b*)—Lineations plunging north at 80° in biotite gneiss in the Skot laga.
(*c*)—Joints (*bc*) in strongly folded biotite-diopside gneiss, Kisirep valley.
(*d*)—Minor folds in biotite-hornblende gneisses in the Kaeri Tabaken laga.

PLATE II



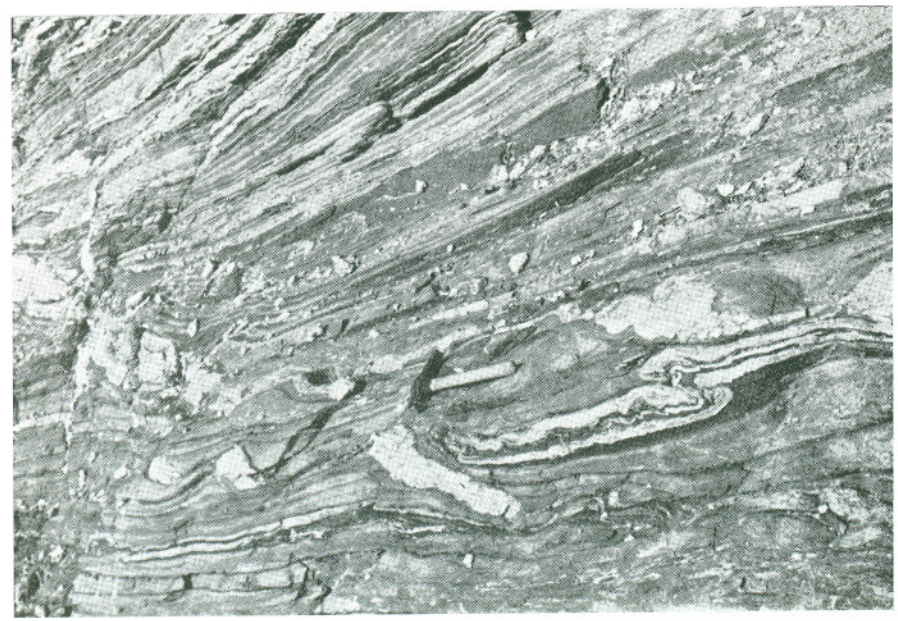
(*a*)



(*b*)



(*c*)



(*d*)

Plate II (*a*)—Calc-silicate knots and bands in crystalline limestone, Male Burai laga.
(*b*)—Quartzo-felspathic banding in biotite-hornblende gneisses, Ndajeri laga.
(*c*)—Banded biotite-hornblende gneisses in the Kaeri Tabaken laga west of Bora spring.
(*d*)—Close view of part of Plate II (*c*) showing oblique boudinaged pegmatitic material and minor structures.



(*a*)



(*b*)



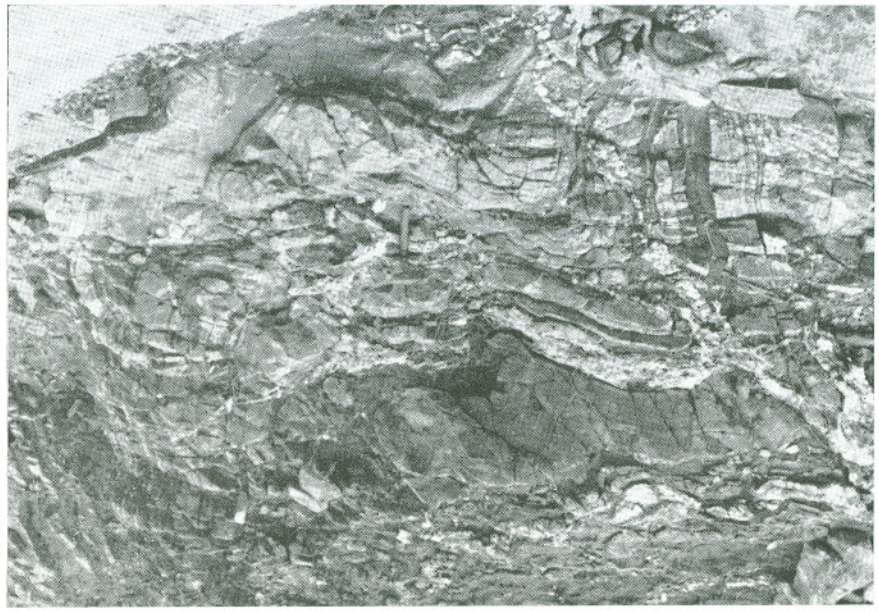
(*c*)



(*d*)

Plate III (*a*)—Sediments in the Rahole valley.
(*b*)—Erosion embayment in sediments, Rahole valley.
(*c*)—Residual pillar of cemented calcareous grits, lower Rahole valley.
(*d*)—Pebble-covered sediment terrain, showing gentle eastward dip of residual surface, south-east of Benane.

PLATE IV



(*a*)



(*b*)



(*c*)



(*d*)

Plate IV (*a*)—Minor fold, overturned to the East, in the Ndivi laga.
(*b*)—Curved lineations in leucocratic gneiss, Ndajeri laga.
(*c*)—Minor folds plunging westwards in banded gneiss, Kisirep valley.
(*d*)—Recumbent fold in banded biotite-hornblende gneisses near Bora spring.

The garnets in specimens 37/560a, b and c, and the ubiquitous development of hornblende, can also be considered as evidence of such influences.

These intrusives in places have sharp and usually concordant contacts against their host gneisses, and elsewhere have margins gradational through a zone of ortho-amphibolite. The development of hornblende in all the samples is regarded as due to metamorphic activity and some of the rocks (as noted above) show additional evidence of this. Furthermore, at least one of the lenses (the first to be described) is cut by a pegmatite indistinguishable from those found in the gneisses, and this phenomenon is widespread elsewhere (Pulfrey, 1946, p. 82). It is therefore likely that this suite was intruded during the later stages of regional metamorphism of the geosynclinal pile which now constitutes the gneisses of the Kenya Basement System.

(2) Olivine Dolerite and Dolerite Dykes

Basic dykes are confined to two relatively narrow strips of country, one trending just east of north in the west of the area, the other more or less centrally placed with a generally north-south trend. They are poorly exposed, outcrops taking the form of exfoliated rounded boulders and pebbles, and their width varies from three to thirty feet, the average being about four feet, and the length of outcrop is between six and 100 feet. Among the rocks sampled both olivine-bearing and olivine-free varieties occur in the western strip, while in the central strip only olivine-free rocks were found, but as not all the dykes seen were sampled it is not known if this is a true distribution.

Both centre and margin were sampled from a dyke about half a mile south-west of Bamba wells. The central part, specimen 37/434, has euhedral olivine microphenocrysts up to 1mm. across, showing alteration to calcite particularly round the margins, and veined with brown serpentinous material. The groundmass consists of plagioclase laths with intersertal purplish titanaugite, iron ore grains, calcite pseudomorphs of olivine with brown veining, and patches and amygdales of spherulitic green chlorite with central calcite mosaics. The margin of this dyke, specimen 37/435, is finer grained and more altered, containing only calcite pseudomorphs of olivine in an intersertal base of plagioclase laths and pyroxene, with iron ore granules and much green chlorite, often in small amygdaloidal patches. The only other olivine-bearing rock collected is specimen 37/567 from the Maddogoni hills, two miles from the southern boundary.

A small swarm of dykes is exposed near the Benane River some three miles south-west of Bamba wells. Specimen 37/437 from that swarm is olivine-free and felsparphyric, its elongate felspar phenocrysts being several millimetres long and often in interpenetrating aggregates. Otherwise it is similar to the rocks just described. The largest dyke seen in the area, some thirty feet wide, is a member of that swarm.

The other dyke rocks collected are generally similar in composition. Not all are felsparphyric but all are olivine-free, and differ from the rocks described above in grain size and in degree of alteration. Specimen 37/531, from the southern end of the Maddogoni hills, is interesting in that it contains fresh plagioclase laths, but the ferromagnesian minerals have been altered so that the interstices are packed with granules and fine lattices of iron ore. Small rounded calcite amygdales also occur. By contrast specimen 37/446, from about two miles south-west of the tellurometer point SKT4, has coarse fresh titanaugite, but the felspar has been heavily zeolitised and sericitised, and there are abundant patches of green chlorite in the groundmass.

The only dyke of this type with a west of north trend, specimen 37/526, collected in the Ndajeri six miles north-north-west of Kora Wells, is a normal felsparphyric basalt only slightly altered.

By analogy with similar dykes in other parts of Kenya, and from their relatively unaltered state, these dykes are thought to be not older than the Tertiary.

(3) Intermediate Dykes

In the south-east corner of the area, east of Bora, there is a dyke, with nearly east-west trend, of pale grey rock with yellow speckling. In thin section it is virtually unidentifiable being composed of calcite, amorphous brown material, and iron ore granules. Its anomalous trend and totally different appearance suggest it to be of different age to the rocks just described, and its leucocratic appearance in the hand specimen indicates that it may be related to the phase of minor intrusion which accompanied emplacement of the major Mesozoic syenites of the Endau area, far to the south (Baker, 1963).

(4) Pegmatites

Pegmatites were seen mainly in the south-west, particularly concentrated around Kora Wells. They take the form of bands and lenses up to a mile long and several hundreds of feet thick, and both concordant and cross-cutting types were seen. The largest are generally concordant, and typically form rounded ridges with superficial deposits and bush cover which tend to obscure the solid rock.

The rocks are pink or white in colour, being composed mainly of quartz and white or pink felspar or both, usually intergrown with the quartz, and the size of crystals may be measurable in feet, especially when the felspar is of the pink variety. The pink felspar seems to be invariably microcline, but the white is either microcline, as in specimen 37/510 from a small fold core about two miles west-south-west of Bora springs, or oligoclase, seen as the only felspar in well-developed graphic intergrowth with quartz forming a cross-cutting five foot thick band, with a central irregular quartz vein, four to five miles north-east of Lafageri tank (specimen 37/444). Ferromagnesian minerals are sparse but biotite, hornblende and iron ores (both ilmenite and magnetite in crystals up to 25mm. across) are usually seen, sometimes garnet, and tourmaline was found with biotite in specimen 37/510 from the fold core mentioned above. Coarse weathered biotite, incipiently vermiculitic, was seen with garnet at the northern end of a pegmatite ridge some three miles north of Kora Wells.

A pegmatite about 100 feet across is exposed in section in the Iris Namdera about a mile and a half south of the Kora Wells track crossing. It has sharp margins against the country rocks, and is typical of such bodies as seen in that area. The felspar and quartz are mainly intergrown, but there is a deep pink variety of felspar in simple crystals, which may be a result of late crystallization. There are elongate flakes of biotite developed on crystal surfaces, suggesting that this mineral also may be of late origin. The deep pink felspar is sometimes also seen together with quartz, but not intergrown, forming a coarse narrow centre to pegmatite intrusions, further evidence that this variety was the last to crystallise.

While pegmatites usually have quite sharp contacts against country rock, there are places where the margins are diffuse and irregular, and there has been digestion of country rocks by the pegmatite. One such locality has already been described, in an anticlinal fold core in the Ndajeri section, but similar relationships are visible at a number of other places, particularly where there are concentrations of large pegmatites, as north-east of Kora Wells and in the lower Iris Namdera Valley. In the Rahole Valley, about a mile downstream from the Kora Wells track crossing, there is a quartzo-felspathic pegmatite carrying a little magnetite, biotite, garnet and possibly hornblende. There are irregular bands of biotite gneiss, in part garnetiferous, presumably relics of country rock which have been digested by the pegmatite during its emplacement. There is also a well developed band of almost pure coarse amphibolite, with some crystals more than a centimetre across, which has been virtually unaltered by the pegmatite. A fine example of an amphibolite broken up within pegmatite was seen in the Male Burai about four miles west-north-west of the Rahole confluence, and nearby coarse biotite gneisses also have ragged amphibolite inclusions. Similar inclusion of amphibolite is illustrated among complex minor folds in the

Urukate near the southern map boundary. The relatively sharp margins of the amphibolite inclusions contrast with those of other rock types, presumably because the basic amphibolites are much more resistant to felspathisation and digestion than quartzo-felspathic gneisses of metasomatic origin.

Apart from the concordant and markedly cross-cutting pegmatites, a striking number are oriented slightly oblique to the gneissic foliation, irrespective of the attitude of the latter. They are mainly of the white variety and typically poor in ferromagnesian minerals. In some exposures they are themselves cut by markedly cross-cutting pegmatites, which are distinctive in being also slightly coarser, and at one place, about one and a half miles north-north-west of the point where the Ndirindera crosses the southern boundary, such a vein was seen to be actually folded within the foliation.

Close to Esmaili Gothir Wells a pegmatite trending approximately north-south was seen to have green marginal zones, which in thin section (specimen 37/468) are seen to consist of irregular strained quartz and very turbid plagioclase felspar. This marginal effect may be due to shearing movement along the emplacement plane, and it is interesting to note in this connection that the locality is on a continuation of the thrust belt in the Rahole Valley.

Two aplite veins were seen in the Male Burai about four miles west-north-west of the Rahole confluence, one six feet and the other one foot thick. In this section they are seen to be fine grained irregular quartz-microcline-plagioclase mosaics with biotite and iron ore.

(5) Quartz Veins

Veins of mainly white quartz can be seen everywhere in the area, cutting almost any rock type, including amphibolites. Fragments from these veins and small exposures of them are the most commonly seen of any rock type. Most are too small to be shown on the map, the best developed being the stumpily elongate lens of well-jointed white quartz about a mile east of the Kora Wells track south of the Kyumburo crossing. The rock (specimen 37/491) seems to be very pure for thin section examination shows only a sutured mosaic of irregular quartz grains with myriad minute inclusions, often in sub-parallel rows, of which many are iron ore.

3. Upper Pliocene Sediments

The sediments in this area are similar to the Northern Kenya sediments described by Dixey (1948) and are indeed part of them. Dixey, however, regarded the sediments as bevelled by the end-Tertiary peneplain, whereas in the present area they are seen to rest on the bevel, which was in places appreciably dissected prior to their deposition.

The sediments are best exposed in the south-east of the area along the Ndivi and Rahole lagas, which together with their tributaries are mainly responsible for the dissection of that area. The sediments display a characteristic tone pattern on aerial photographs: pale grey on interfluves and gentler slopes, where there is bush cover; white in exposures on steeper slopes of the ramifying gullies at the heads of stream valleys; dark grey where alluvium has been deposited in the lower parts of the larger valleys.

Although extensively dissected, the sediments are not well exposed, due to their unconsolidated nature, which encourages hill-wash and generally precludes the formation of well-defined sections, except in the sides of major sand rivers, where sections a few tens of feet high may be seen. Throughout the area they are seen to be a variable series of sands and clays, mainly red and green in colour, but sometimes grey, with occasional cream-coloured more calcareous facies. Rounded pebbles are scattered through the sediments, concentrated into small irregular bands and lenses. There is invariably a layer of gritty calcrete up to 10 feet thick at the top of each exposure, and at almost every locality visited this is overlain by a residual pebble sheet up to a foot thick, more than 90 per cent of the pebbles being of quartz, usually with brown surface discolouration. Small residual patches of rounded pebbles also occur on the gneiss terrain nearby. Layers of a secondary calcareous

cementation, usually showing carious weathering, can be found at any level in an exposure but appear to occur preferentially where the sediment is slightly coarser. This would account for the ubiquitous presence of an upper calcrete capping, due to the finer matrix being removed from the top of an exposure, leaving coarser gritty material. White quartz sands are ubiquitous, flooring the numerous small ramifying stream channels in the gullies dissecting the sediments. They are often of nearly pure quartz, washed white by abrasion which has removed the surface oxide pigmentation, but minor concentrates of heavier minerals frequently occur.

Fairly detailed examination of the sediments was made at a number of localities, mainly down the Rahole Valley, and these will be described in order of their occurrence downstream.

There are nearly one hundred feet of sediments exposed in the numerous steep-sided gullies which drain the plateau topped by well-developed red soils south of the upper Rahole, and one of these, south-west of survey point SG137, was traversed from top to bottom. The red soils forming the top of the dense bush-covered plateau there are underlain by a few inches of pebbles, which in turn rest on up to ten feet of gritty calcrete (specimens 37/458, 459) which is cream-coloured on fresh surfaces but contains appreciable amounts of iron, as shown by the reddish brown weathering surfaces. The grit fragments, angular to subrounded, range from about 1 to 10mm. in size, and are chiefly of quartz, though occasional cleavage fragments of felspar and grains of dark minerals occur. Beneath this the bulk of the sequence is composed of mottled and variegated reddish and greenish sediments varying from harder sandstone with a small amount of calcareous clayey matrix, the angular sand grains being mainly quartz but including appreciable amounts of fresh plagioclase and microcline (specimen 37/460), to calcareous clays with a small admixture of sand grains, in which the calcium carbonate is concentrated either in finely crystalline veins about 2mm. wide (specimen 37/461) or in irregular powdery nodules of varying size (specimen 37/462). At various levels down the gully there are bands of calcareous grit so similar to the bands at the top that it was not possible to be sure whether they were part of the sequence or merely the slumped upper calcrete capping. A specimen of calcareous grit collected near the bottom, however, (specimen 37/463) is cream coloured with intermittent thin reddish banding, and is finer grained than the usual gritty calcrete, and may be a secondarily cemented band within the actual sequence. In thin section it is seen to be composed of an irregular calcite mosaic in which are embedded angular quartz, plagioclase, iron ore and microcline grains. A single grain of epidote was also seen.

At a gullied semi-circular exposure on the north side of the Rahole River about three miles farther downstream, the gentler lower slopes of the exposure are formed of downwashed sands loosely cemented on the surface by lime to form a rough but unstable surface. Where the sediments are visible in sections they are red and green mottled sands with only a relatively small clay fraction in the matrix (specimen 37/465) and are practically free of calcium carbonate, which has probably mainly migrated into the calcareous bands occurring at various levels in the section. These bands protrude slightly from the sandy slopes and act as protective cappings to small vertical sections, the topmost layer forming the best sections. The bands of calcareous cementation, seldom more than a foot or two thick, give the impression of occurring at levels having a higher proportion of grit and pebbles, and can therefore be regarded as representing bedding. However, the variety of dips seen at this locality makes it unlikely that they are anything other than depositional and therefore meaningless on a regional scale. One gritty band seems to be dipping south at 40° (Plate IIIa) while on the western slopes of the exposure the calcareous layers dip gently westwards. On the north side an approximately north-south trending erosion embayment is visible in the topmost section (Plate IIIb). The residual pebble sheet is sometimes absent, as on an isolated 70-foot high ridge isolated by erosion on the opposite side of the river from the locality just described. A 10-feet calcrete layer forms the top there, debris from which mantles the lower slopes, and there may formerly have been an overlying pebble sheet, now removed by continued erosion of this isolated feature.

Gullies near the track leading from the Garissa road to Lubhalo wells expose sections near the upper limit of dissection. They are again very similar to those already described, comprising a one-foot layer of pebbles on six to ten feet of gritty and pebbly calcrete which in turn caps mainly soft red sands with greenish patches and occasional pebbles, irregular calcareous nodules, and sub-horizontal layers of calcareous cementation at levels of slightly grittier sediments.

A short distance north of the confluence of the Male Burai and the Rahole there is a 25-foot high bank forming the channel walls, which exposes three feet of gritty calcrete at the top, underlain by some 15 feet of sands with an irregular white limestone band at the base, which in turn rests on a few feet of marly sands with a calcareous concretion. This latter is connected with the overlying band and indicates that both limestone bodies are secondary in origin. The white band (specimen 37/485) is composed of impure calcite carrying sparse angular fragments of quartz and fresh felspar.

Just above its confluence with the Kaeri Tabaken, the Rahole ramifies into a number of sand channels, in the most easterly of which there is a good section about 30 feet high, exposing grey, greenish and pink sandy sediments, with one or two irregular cemented bands of slightly coarser grit, and the top ten feet is of gritty calcrete. Small irregularly elongate nodular concretions are well displayed at this exposure, generally sub-horizontal in attitude but of no uniform orientation. They average 10mm. in diameter and can be either of hard compact impure sandy limestone, or of quite coarsely crystalline calcite. A short traverse eastwards from here showed precisely similar sediments exposed in small sections, with the usual residual pebble sheet and layers of secondary cementation.

In the extreme south-east corner of the area green and red sandy sediments were seen in small exposures, again with pebbles and calcrete layers. The specimen collected there, 37/500, is precisely similar in appearance to the sands collected from the second Rahole section described above (specimen 37/465).

The sediments differ from the dominant red and green colouration only in very few places, the most striking of these being a V-shaped ridge about two and a half miles south of the Rahole-Kaeri Tabaken confluence. There the usual upper ten feet of gritty calcrete caps some 15 feet of pale grey slightly calcareous clay with kaolinized felspar and quite large quartz grains (specimen 37/514), which in turn rests on 30 to 40 feet of pale green to cream clayey sands, the junction being practically horizontal. The most interesting feature of this locality, however, is the occurrence of circular pillars of calcareous grit which stand about the base of the ridge, where the ground surface is also littered with calcrete debris (Plate IIIc).

A small exposure of darker grey clays with white mottling was found in the Rahole channel about a mile south of Lubhalo wells. It is chiefly interesting (specimen 37/484) for the occasional small aggregates of fine white silky selenite in it. The grey colour of these deposits is probably due to organic matter.

Junctions between sediments and gneisses are not often seen in the east of the area, but at two places close together about one and a half miles upstream from the Rahole-Male Burai confluence there are good exposures in successive river bends of sediments banked against gneisses, the sediment surfaces being inclined eastwards as much as 5°, and there are angular gneiss fragments at the base of the rather gritty greenish sediments with red oxidation patches 25 to 50mm. across. It is believed that these exposures rest on minor irregularities on a generally eastward sloping sub-sediment surface.

Reddish clays were recorded from only one locality in the south-east part of the area, the most westerly exposure examined there. However, this is also the best section seen, the others being largely obscured, as already noted, by hill-wash, and it is possible that such clays might occur farther down in the succession. The sediments exposed in the north-central part of the area seem to be more argillaceous however, and tend to be browner in colour. They are poorly exposed in low mounds, the ground being littered with pebbles.

A three-foot pit dug into the side of one mound about two and a half miles east-north-east of Lafageri tank exposed a 10cm. layer of pebbles, mainly quartz, 20cm. of calcrete, the rest being damp brownish, soapy, and slightly calcareous clay (37/445), with small white patches of impure calcite and small scattered gypsum crystals, as well as quartz grains. The sediments at that exposure are not more than 30 feet thick, for metamorphic rocks were seen in the floors of gullies, which also contain white sand like that described from the sediment terrain farther south. Brown sandy soils with rounded pebbles form the ground surface between exposures. A typical exposure of sediments in that region is shown in Plate IIId, with pebbles littering the ground and forming a gently eastward dipping residual layer. A calcrete layer underlies the pebbles.

Other minor irregularities in the sub-sediment surface are apparent at the small exposures of metamorphic rocks seen over a small region south of Lafageri tank. The gneisses are exposed in small stream gullies among pebbles and sand, which show up on aerial photographs as white gashes against the grey of the surrounding plains soils.

In the western fault-trough region exposures of sediment are not generally good, but a few small sections were seen, which will be described in order of their occurrence southwards.

The northern-most exposure is in a small stream channel crossing the Garba Tula-Skot track about four miles north-north-east of Maddo Diko, where there are pale pink and green quartzo-felspathic grits with angular to sub-rounded grains averaging 5mm. across, and occasional pebbles (specimen 37/423). They are overlain by thin calcrete, which is mantled by pebbles.

One and a half miles farther down the track there is a section about 50 feet high, poorly exposed because of hill-wash and the accompanying loose surface cementation. There are calcrete layers at various levels, at least one of which forms the top of a minor mound and is strewn with pebbles. The top-most layer is composed of angular quartz, microcline and plagioclase fragments in a calcite mosaic (specimen 37/421). The sediments are pink sands with a small proportion of admixed clay, and the stream gullies are floored by clean white sands.

Some four miles down the track from Maddo Diko a small stream channel exposes low mounds of white sand with calcareous bands both within and on them, which appear (specimen 37/420) to contain mainly quartz as detrital grains. From there northwards the interfluve which the track follows is thickly strewn with rounded brown quartz pebbles. The sediments at these three exposures give the impression of being slightly coarser than any others found in the area, and this may be due to their being closest to the top of the sedimentary pile, their present relatively lowered position being due to faulting of the Skot trough.

Four and a half miles south-south-east of Maddo Diko there is a small stream section showing pale green grits with an argillaceous matrix and brownish oxidation patches, as well as calcareous layers and pebble lenses, which together give the impression of a very shallow south-westerly dip. At the top of the section is a one-foot band of pebbly spherulitic calcrete.

At the Skot crossing of the Kora Wells track, just outside the western boundary of the map area, there are well-exposed mottled and variegated green and red sands and clays (specimen 37/536), with bands of cemented coarser grit, which also dip gently south-westwards.

Nearly three miles south-east of Skot there is a 20-foot bank of mainly green sandy and gritty clays with a few pebbles and irregular white calcareous concretions, as well as the usual cemented layers. There is very little oxidation discolouration of these sediments, and there is no top calcrete layer, the only place where this was seen to be absent.

Only two small exposures of sediment were seen along the Iris Namdera channel in the more northerly of the two subsidiary fault troughs. They are gritty and pebbly deposits with a sparse clay matrix, pale green with white and pink calcareous material, and in part grading to grey sand, possibly due to the admixture of organic matter.

Where the Iris Namdera meets the Bisanadi in the southern small trough, there is a wall exposure of mainly red sandy clays with pebbles and calcareous bands, at the western end of which green-mottled red clays (specimen 37/529) are banked against an approximately 60° slope of crumbly biotite gneisses, at the southern end of the fault line marked on the map there. The clays were not seen to show any signs of disturbance however. The only other place in that region where the sub-sediment surface was seen is in the left bank of the Bisanadi about a mile from the southern boundary, where pink sediments rest on a southerly sloping gneiss surface, and both formations have been overlain by the lower river terrace.

The only fault breccia actually seen to separate gneiss from sediment was collected from the fault line less than a mile south-west of Marigi Wells. It is also the only breccia to contain appreciable amounts of calcite. Breccias were seen close to sediment in places along the right bank of the lower Bisanadi, but the two were never seen in contact there.

Elsewhere in this region, as in the east, stream channels occasionally expose small cuttings of pink and green sandy sediments, but the major part of the terrain is covered with pink and brown sands, soils and alluvium, with the ubiquitous mantle of rounded pebbles, which is well seen on the Kora Wells track where it turns east from the Bisanadi. The mounds of sediment recorded on the interfluves east of Marigi and south of Maddo Diko are mainly quartz pebbles and white sand, with brown and grey soils, and are clearly largely residual deposits.

On the eastern boundary the height difference between the sediments on the main watershed and those in the Rahole Valley on the southern boundary is about 450 feet. The small difference in height between the minor watershed near the northern boundary and the main Tana-Uaso Ngiro watershed may be due to slight undulations in the original upper sediment surface, possibly reflecting variations of relief in the underlying topography. The surface of the sediments must originally have been nearly level, for otherwise the almost flat plains could presumably not have developed on them. Therefore, although the surface of the sediments may have been slightly depressed over the buried early Tana valley, the height differences between sediments on the main watershed and in the south of the area give the right order of magnitude for the thickness of exposed sediment. It must also be remembered that the soils rest on residual pebbles, which indicates some lowering of the original surface.

If the sub-sediment surface slope of some 50 feet per mile on the right bank of the Rahole in the south continues eastwards, there should be about 200 feet of concealed sediments in the south-east corner, making an overall original thickness of at least 650 feet. In the north-central part, the exposed sediment thickness was seen to be about 30 feet near the western limit, but the sub-sediment slope is impossible to gauge there, so that estimates of thickness farther east can at best be very tentative. However, if the gneiss surface slopes east at an average of 30 feet per mile, there would be about 300 feet of concealed sediments in the north-east corner. A downwarp of the sub-sediment surface was postulated more or less along this line, and if this increases eastwards, thicknesses are liable to be greater.

At the northern end of the main Skot trough 50 feet of sediments were recorded in one of the sections. The base was not seen, but from aerial photographs it is possible to estimate that the dissection in this vicinity east of Maddo Diko is of the order of 100 feet, all in sediments. From the fact that there is a tenuous connection, in the form of a thin residual pebble layer along the main watershed, with the sediments farther east, it can be inferred that there has been considerable lowering of the sediment since uplift terminated

sedimentation, at least of the order of 50 feet, since this thickness of sediment appears to be preserved in the trough near the northernmost exposure of grits described earlier. It is impossible to arrive at any figure for the thickness of sediments farther south, but the minimum is believed not to differ greatly from the figures quoted above.

The central southern part of the area can be regarded as a low spur extending south from the main watershed, for the height difference between the watershed and the centre of the southern boundary is only about 300 feet. A substantial proportion of this difference must be due to dissection in the Tana valley after sediment deposition, and it is unlikely that there can have been more than 200 feet of sediments deposited in the vicinity of what is now Kora Wells. The only remnants of the sediments which once covered this region are occasional small patches of rounded pebbles occurring on interfluves.

The sediments rest on the appreciably dissected end-Tertiary peneplain and must therefore post-date the mid-Pliocene maturation of the bevel. More precise evidence of their age can be deduced from a pebble sheet rich in lava pebbles found by Jennings (Report awaiting publication) just north of the Tana river in the Skot trough. Almost all the lava pebbles can be matched with Mount Kenya and Nyambeni lavas. In addition however, Jennings found that rounded pebbles are common in the bed of the Tana River, and more than half of a random collection, even well downstream east of Kora Wells, are lavas which strongly resemble Mount Kenya and Nyambeni types. The pebble sheet found by Jennings in the fault trough must have been deposited by the Tana some time after the rise of the Mount Kenya and Nyambeni volcanoes, which are considered to be late Upper Pliocene and Middle Pleistocene in age respectively (Baker, 1967; Rix, 1967). If the present Tana can carry lava pebbles in quantity so far downstream, then the earlier drainage supplying the sedimentation area would be expected to have carried lava pebbles into the sediments, had the volcanoes then been in existence. Since no trace of their lavas was found in the sediments it is concluded that the bulk of the latter pre-date them, and are Upper Pliocene in age.

It is pertinent to note here that the uniformity of sediments all over the area, including the Skot trough, and indeed over much of the rest of central Kenya, indicates that they accumulated during a single cycle of sedimentation. The colour and lithology of the sediments, and their poor degree of sorting and compaction, are consistent with deposition on the tilted peneplain as fluviatile flood-plain deposits, under semi-arid conditions.

Although no diagnostic fossils were seen, two fragments of silicified dicotyledonous wood were found in or near the sediments, one about a quarter mile beyond the feather edge of the sediments, just south of the Rahole-Kaeri Tabaken confluence (specimen 37/520f), the other among pebbles derived from sediments banked against gneisses five miles north of Kuka (specimen 37/540).

4. Pleistocene to Recent Superficial Deposits

(1) River Deposits

There are three ridges formed of poorly exposed deposits, thought to be of fluviatile origin, apparently underlain by gneisses, on the left bank of the Iris Namdera laga eight or nine miles north-north-east of the Bisanadi confluence. The southern and northern ridges where exposed are seen to be capped with a soft, pink, earthy and gritty calcrete, while the middle ridge has the more usual harder grey calcrete as capping. Loose fragments of quartz and felspar are the only other solid material among the grey and brown sandy soils mantling the slopes. The base of the deposits as well as the ridges formed of them make a V-pattern which is directed downstream along tributaries to the Iris Namdera, and shows that the underlying gneiss surface slopes gently westwards, perhaps as the result of warping.

That particular stretch of the Iris Namdera Valley is regarded as a faulted trough acting as a sedimentary basin, because not only are the deposits confined to it, but there are in addition two small outcrops of the normal sandy Upper Pliocene sediments, which do not occur anywhere else along the Iris Namdera. However, the appearance of the deposits which form the ridge is very different from that of the Upper Pliocene sediments, and together with their relative dispositions suggests that the former are younger, although it is impossible to say whether they were derived from the earlier sediments or not.

Indurated current-bedded calcareous sandstones and pebbly grits form river terraces in the lower Bisanadi Valley, the most important occurring just south of Melka Masa. The top of the deposits is some 50 feet above the present channel, but their thickness is indeterminate for fallen sandstone boulders mantle the lower slopes. The impression gained from the current bedding was that the source of the material lay upstream, as would be expected. Iron oxide and pink garnet were among the mineral grains visible in hand specimen, and thin section examination showed the rock (specimen 37/567a) to contain abundant green-brown hornblende and some microcline and plagioclase in fresh angular fragments, as well as the usual predominant quantity of angular quartz grains, all in a turbid calcareous base.

Similar rocks were seen at three other places in the lower Bisanadi, forming part of the channel wall between five and fifteen feet above the floor. At two places they overlap sediments on to gneiss or breccia, and are overlain by alluvium with a bouldery base. These deposits, specimen 37/534, very similar in appearance and composition to those at the higher level, are termed the 10-foot terrace. Terrace sandstones of this type were seen nowhere else in the area, and may possibly be connected with the fault movements of this trough.

Virtually unbedded and unsorted coarse calcareous bouldery deposits, sometimes pink in colour, were found in a few places, mainly in small exposures along stream valleys. Only one was seen in the east, in the Kaeri Tabaken about half a mile west of Bora spring; others were found in right bank tributaries to the lower Bisanadi where they are relatively extensive, and in the Iris Namdera just south of the Kora Wells track crossing. The boulder deposits were seen to overlie a 10-foot bank of pink and green sandy Pliocene sediments at an exposure in the Bisanadi channel where the Skot-Kora Wells track swings in towards it, but at other localities they rest on gneisses. Since the deposits all occur close to present-day channel floors they are presumed to have been laid down in quite recent times, when dissection was well advanced, possibly as the result of a torrential climatic phase.

Alluvial deposits of the area are usually structureless, pink or reddish brown in colour, and of silt grade, but locally current-bedded sands and gravels are visible in some channel wall sections, and there is in places a bouldery base, presumably of torrential origin. In some parts of the sediment terrain, for example along the Rahole Valley, channel walls appear to be formed of re-sorted Pliocene sediments and admixed alluvium, with scattered pebbles. Because streams reach base level more quickly in the soft sediments than in the hard gneisses, there is much more alluvium in the stream valleys of the sediment terrain, and it is generally pink in colour, while reddish-brown tints are commoner in the gneiss terrain.

The river sands may be both graded and current-bedded, and sections resemble unconsolidated versions of the terraces described above. The dominant quartz-felspar component of the sands is virtually colourless, the action of seasonal flood waters having worn off the colouring films of red-brown iron oxide from the quartz grains which make up most of the sediments and the red soils. The sands of small gullies cutting well-exposed sediments are almost dazzlingly white. Some river sand samples were examined by Dr. C. G. B. DuBois, with the following results:—

Specimen 37/422, from a small sand stream draining the sediment section two miles north-east of Maddo Diko, described earlier: clean white nearly pure quartz sand, containig 2 per cent felspar and less than 1 per cent ilmenite.

Specimen 37/436, garnetiferous quartz-felspar sands from Benane laga about five miles south-west of Bamba wells: heavy minerals comprise mainly garnet, with magnetite, ilmenite and hornblende.

Specimen 37/464, black sand "streak" concentrate from among clean white quartz sand of a small stream draining a typical sediment section on the north bank of the Rahole three miles north-north-west of Lubhalo: contains about 50 per cent ilmenite, the remainder being quartz and felspar, with a little garnet and epidote.

Specimen 37/479, dark quartz-felspar sands from Male Burai laga about four miles north-west of the Rahole confluence: heavy minerals comprise mainly titaniferous iron ore, with some hornblende and garnet, and significantly some quite large zircons.

Specimen 37/488, garnetiferous quartz-felspar sands from a small tributary to the Benane, about one mile east of El Gidut: heavy minerals comprise garnet and hornblende in roughly equal amounts, with a little iron ore, a trace of biotite, and possibly a little epidote.

It is interesting to note that despite the frequent occurrence of sphene and apatite in the more basic gneisses, neither mineral was recorded in any of the sands collected.

A thin layer of sun-cracked reddish brown silt is locally seen on the surface of sand lagas, and some of the depressions encountered along the channels, which tend to hold water after rain, are sometimes floored by a thin layer of chocolate-coloured semi-bentonitic clay.

The sand is also muddy at Bora springs, where there is a trickle of surface water, while the shallow sub-surface pockets of water encountered at Bilgis and other places along the lagas of the poorly drained north-eastern plains appear to have accumulated in locally clayey sands which prevent the water escaping.

Salts form an insignificant part of the river deposits. They can frequently be seen as a thin impersistent encrustation on rocks of stream beds where there is surface water close by, but also occur as impregnations in damp soft rotting gneisses, up to a few feet above the surface of the sand. Occurrences of the latter type, an excellent example being seen at Esmaili Gothir wells in the Ndivi, are utilized as salt licks by the Somali herds and by wild animals.

(2) Terrestrial Deposits

Calcrete is found almost everywhere in the area, particularly in the sediment terrain. It also develops on the gneisses, particularly round the Benane laga in the north-west, where exposures are poor and the terrain gently undulating. It was not found possible to delimit with any accuracy the areas covered by calcrete, and they are indicated on the map by the superimposed symbol Qc.

Lag concentrates of rounded pebbles, mainly of quartz, have also been described previously as ubiquitous in the sediment terrain. Small patches of such pebbles are also fairly common among the gneisses, particularly on interfluves, where they indicate that the sediment cover was once considerably more widespread. The calcrete capping of the sediments is almost everywhere overlain by pebble sheets but this relationship is rarely seen with the calcrete formed on gneisses. The best example of it was found on the north side of the Kyumburo lugga, at the Kora Wells track crossing, where a steep six-foot bank of calcrete is capped by a thin layer of rounded quartz pebbles. A pit dug into the calcrete revealed fragments of biotite gneiss at shallow depth, but the pebbles are almost certainly a residual sheet derived from sediments now largely eroded away.

Poorly sorted angular pebbles are common among superficial deposits on the gneisses, particularly in less well exposed regions, and those are clearly derived from the underlying rocks, their unrounded form testifying that they have not travelled far. It is interesting to note that these, like the pebbles derived from sediments, are mainly composed of quartz.

Low humic red sandy soils (Qr on the map) are widespread on the gneisses, locally giving way to browner varieties. It was originally thought that the colour difference was a function of slight differences in quality of the drainage, brown soils occurring where the drainage was less good. Brown soils were frequently found mantling the better-drained slopes of interfluve ridges, while red soils covered their apparently less well drained crests. It is therefore likely that compositional differences are involved, the brown soils being slightly more calcareous, an hypothesis borne out by the more frequent occurrence of such soils in the regions of calcrete formation.

Well-developed red sandy soils with thick thorn bush vegetation and scattered seasonal waterholes are the typical cover of the end-Tertiary peneplain away from the main rivers, which there forms a practically featureless plain. In the Kora Wells area the terrain is too broken for such soil cover to develop well, except along the major interfluves, but there are two larger areas of flat typical bush country, both situated near the gneiss-sediment boundary in the central western part of the area.

Soils (Qr on the map) developed among the dissected sediments in both the eastern and western parts of the area are red and brown in colour, the brown colouration being in part due to slightly inferior drainage conditions, in part to a slightly higher lime content. Similar soils also occur patchily on top of the shallow interfluves on the sediment plains.

Grey soils (Qg) are locally and insignificantly developed on a few interfluves among the gneisses, but form a widespread cover to most of the featureless undissected sediment terrain in the north and east, where the stunted vegetation includes hook thorn, wild sisal (*sansevieria*), coarse grass, and other plains varieties. The soils vary between sun-cracked dark grey sandy and silty clays which become glutinous when wet, and locally near-white sands in places where the wind has removed much of the finer material from the surface. Scattered residual pebbles derived from the sediments may also be seen anywhere on the plains.

Close scrutiny of the aerial photographs covering this part reveals a series of fine, close-set striations across the virtually uniform grey of the plains. They have a dominant east-west orientation, and clearly reflect the influence of the prevailing easterly winds on the vegetation.

The most interesting feature of the grey plains soils, however, is the spotted pattern developed round and sometimes on the shallow interfluves, hardly detectable on the ground, but clearly discernible on aerial photographs as a honeycomb arrangement of pale circular spots, standing out against the darker background of the grey soils. The spots are circular, virtually bare sandy "islands", depressed six inches to a foot below the surrounding terrain. They may be a remnant flood pattern, since on aerial photographs they can be seen in places to coalesce and pass into a network of minor watercourses.

This phenomenon resembles in photographs the *gilgai* pattern developed in tropical black clays in Kenya and elsewhere (Stephen *et al.*, 1956), but which is almost exactly its reverse: circular mounds with good vegetation cover rise scarcely a foot above more sparsely vegetated surroundings, and also produce a honeycomb effect on aerial photographs. Stephen *et al* offered no explanation for the phenomenon and recorded only that the soil of the mounds is less clayey but has a higher loam and lime content than that of lower lying ground.

VI—METAMORPHISM

Rocks of the Kenya Basement System have long been recognized as comprising a metamorphosed and granitised geosynclinal sedimentary sequence, with intercalated volcanics. In the Kora Wells area the gneisses do not differ from those found elsewhere in the country. Their most obvious feature is the practically ubiquitous banding, typically on a scale measurable in inches, which has been generally regarded by previous workers as being of migmatitic origin, since it comprises rapid alternations of semi-pelitic and pelitic with quartzo-felspathic bands.

In a synthesis of studies in this field Dietrich (1960) listed the criteria for classifying metamorphic processes which lead to the formation of banded gneisses. An attempt is made here to apply it to the rocks under discussion. Banding of regional extent in gneisses is almost always based on original sedimentary banding, the Relict Supracrustal Banding of Dietrich (*ibid.*, p. 105). Large scale relict supracrustal banding is represented in the thicker bands of fairly homogeneous composition, for example the psammitic quartzo-felspathic gneisses and calcareous bands. The much commoner fine-scale banding, being parallel to the thicker relatively homogeneous bands, is also to be regarded as of relict supracrustal origin, accentuated by metamorphic processes.

The banding is generally regular and follows quite faithfully the often intense minor contortions and folds seen in many outcrops. If actual fusion of material had been prominent in the development of these gneisses it is unlikely that such regular banding would have been preserved, particularly where the contortions occur. It is therefore concluded that the main mechanism involved in the development of banded gneisses from the original sediments, apart of course from reconstitution and recrystallization of minerals under heat and pressure, was movement of alkalis into leucocratic bands by permeation processes, including any or all of ionic diffusion, pneumatolysis and hydrothermal activity (Dietrich, *op. cit.*, p. 110). Alkalis are particularly cited, for it has been generally agreed that there was introduction of these elements, particularly potash, during metamorphism of the Basement System rocks. Certainly it would seem that the large amounts of microcline seen in the quartz-felspar components of the finely banded gneisses and the thicker psammitic bands cannot all be due simply to redistribution of potash available in the original sediments. It is probable that soda metasomatism preceded the more important phase of potash invasion. The smaller and more mobile Na+ion, having entered the calcium-rich rocks, is considered to have formed more or less stable Na/Ca assemblages—ionic radii of Na+ and Ca++ are closely similar—which were largely impervious to the later invasion of larger potassium ions.

Migmatisation has also most probably played a part in the development of these gneisses, especially where the banding is less regular, for migmatisation by definition involves fusion of at least part of the rocks affected. Dietrich (*op. cit.*, p. 107), recognized two categories, differential anatexis and *lit-par-lit* injection, of which the former is believed to have been more prominent: adjacent bands have merely been alternately enriched and impoverished in the lower-melting quartz-felspar constituents derived by differential fusion and ionic exchange processes more or less *in situ*. To invoke an origin for the banding by *lit-par-lit* injection alone necessitates postulating the ability of quartzo-felspathic fluids, presumably derived by differential fusion of rocks in depth, to inject themselves as sheets of great area to thickness ratio along the bedding planes of a tightly compressed geosynclinal pile. The possibility of a small degree of *lit-par-lit* movement and injection of differentially fused quartzo-felspathic material cannot be ruled out however, but it would be only local in extent. Where permeation and migmatization processes were locally accentuated, extremes of metasomatic activity and soaking resulted, with development of felspar-rich rocks, digestion of host material, and distortion and obliteration of structural features. Such is considered to be the origin of the irregular pegmatite masses with indistinct margins already described. It is in the vicinity of such intensified activity that some movement of fused material might be expected with possibly some *lit-par-lit* injection, and an example of such injection could well be the Ndajeri section earlier described. At that place there is dominantly concordant quartzo-felspathic banding of widely variable thickness, sometimes reaching almost pegmatitic proportions. The concordant and discordant veins and bands are of the same age since there is no change in rock textures where they cross one another, and as the discordant veins are manifestly of injection type, the concordant ones may be so regarded also. It is, however, of interest to note that material forming these bands must be local in origin, for like the host rock it contains no microcline. For this reason, it appears that in that region at least the otherwise generally dominant potash metasomatism was absent.

Distinct from the banded semi-pelitic and pelitic gneisses are the more or less homogeneous leucocratic quartz-felspar-rich gneisses with their auto-segregation veins and pockets of similar material. The latter, though generally concordant, differ from the banding of more basic gneisses in being more widely spaced and having substantially the same composition as the host rock, as well as being more coarsely crystalline. Such recrystallization of host rock material in veins and pockets within it is difficult to explain, but it can be noted here that at least one of the quartz-felspar gneiss ribs in the area (in the north-west corner) is itself coarsely crystalline almost throughout its length. The quartz selvedges developed for example along the boudinaged veins described in quartz-felspar gneiss from the upper Rahole, are also difficult to explain. They may have developed as a result of late plastic movements which disrupted the banding and squeezed out the lowest melting constituent to recrystallise round the margins of the lenses.

Amphibolites.—These are generally regarded as metamorphosed igneous rocks, probably lavas or tuffs, which formed part of the geosynclinal sequence, since they are nowhere in the present area seen to be discordant. Dietrich, under the heading "Relict: igneous" (*op. cit.*, p. 102) lists a number of criteria for recognizing gneissic rocks of igneous origin, but only those involving chemical changes or lack of them could be applied here, for the rocks have been so thoroughly recrystallized as to obliterate original igneous features such as chilled margins, characteristic textures, etc.

Amphibolites in Connemara, Eire, have been made the subject of a detailed mineralogical and chemical study by Evans & Leake (1960), who have demonstrated with reasonable certainty an igneous origin for the rocks, which they believe to have been originally lavas, tuffs or minor intrusives. Their work is mentioned here because many of the features they described can be seen in the amphibolites of the Kora Wells area, and no doubt elsewhere in Kenya also. Points they make are:—

1. Boundaries between amphibolite and other metamorphic rocks are always sharp.

2. The rocks are frequently banded or striped with alternations of hornblende and plagioclase-rich material, although the banding may be poorly developed or absent. In the present area, the incidence of banding could not be termed frequent, but it is locally well-developed, as for example in the section west of the El Maeng laga, described earlier.

3. Concordant pegmatitic quartz-plagioclase veins sometimes occur. Such veins were not recorded in the present area, but it may be noted that the hornblende-rich bands are locally of very coarse grain.

4. Occasional small pale green lenses of epidotised amphibolite were recorded among the Connemara rocks. A similar but larger occurrence was found at the southern end of the ridge marked as calc-silicate just east of the El Maeng, where it seems to be formed of granular epidote-rich rock.

The presence of microcline in some of the amphibolites of the Kora Wells area is presumed due to introduction of metasomatic potash during metamorphism; Evans & Leake (*op. cit.*, p. 354) also attribute the sericitization of plagioclase to a similar cause.

Formation of banded amphibolites from original virtually homogeneous sheets of igneous rock is a criterion for regarding them as having been derived by processes which come under Dietrich's (*op. cit.*, p. 112) heading of Metamorphic Differentiation (cf. Evans & Leake, *op. cit.*, p. 359) with local introduction of potash to form microcline, and perhaps sericite, by permeation processes. It is worth mentioning here that banding in calc-silicates (where present) and the occasional presence of microcline can be attributed to the same causes. It would seem that when the lime content falls below a certain value, potash can invade readily, as in the semi-calcareous diopside-biotite gneisses which are rich in microcline, while this mineral is exceptional in calc-silicate and amphibolite rocks, and not found in limestones. The presence of sericite derived from plagioclase is not so indicative of potash enrichment as is microcline, as can be gathered from a study of the modal and chemical analysis tables provided by Evans & Leake.

The many features which the Basement System amphibolites have in common with the striped rocks of Connemara provide strong evidence for regarding the former, like the latter, as metamorphosed volcanic or minor intrusive rock sheets. In support of this view may be cited recent work by O'Hara (1961) on the Scourie dyke in Sutherland, which has shown that a continuous variation can be traced from dolerite to garnet-plagioclase amphibolite.

Pegmatites.—The pegmatites can be divided into two main groups:—

(1) Irregular bodies with indistinct margins, containing blocks of country rock, whose origins by metasomatic processes have been discussed earlier, and which are regarded as being formed more or less penecontemporaneously with the main phase of metamorphism.

(2) The generally much coarser more or less parallel-sided and regular veins and lenses of dominantly quartzo-felspathic composition, representing the late crystallised remnants of the fluids derived by differential fusion and permeation during metamorphism of the rocks. The presence of pegmatite cutting one of the hypersthene-bearing intrusives, which are regarded as having been emplaced towards the close of the metamorphism, is evidence that pegmatite injection was probably the last event in the metamorphic history of these rocks. As usual in these gneisses the majority of pegmatites occupy either the foliation plane or recognizable joint planes. Insufficient measurements were taken to confirm whether the most prominent joint directions also contain the most pegmatites, but it seems probably that they do. However, many of the pegmatites are orientated oblique to the foliation plane, independent of its attitude and sometimes folded with it. It is clear that these veins must have been emplaced well before the majority of pegmatites, probably along an extensive plane of weakness at a low angle to the foliation, which has since been obliterated.

The presence of tourmaline in one of the pegmatites is presumably due to the redistribution of a little boron in the original sediments. Because of its uniquely small ionic radius boron cannot follow aluminium into trivalent lattice positions, and must therefore concentrate in the late pneumatolytic or hydrothermal stages of metamorphism.

The veins and stringers of white quartz which are so common in the area are considered to be the crystallization products of the final residuum of the pegmatite-forming fluids, while the crystalline epidote seen on fracture surfaces of semi-pelitic gneisses in many places is presumed to have developed hydrothermally during the closing stages of metamorphism.

Metamorphic facies.—The recorded mineral assemblages in the rocks of the Kora Wells area, particularly the calcareous bands, and the presence of sillimanite and pseudo-sillimanite, indicate that the majority belong to the sillimanite-almandine-orthoclase subfacies of the almandine-amphibolite facies (Turner & Verhoogen, 1960, p. 549). Traces of hypersthene were however recorded from a diopside-biotite gneiss band, and it is possible that locally the grade of metamorphism may have extended up to the granulite facies.

Pseudo-sillimanite rocks were also found in the vicinity of the hypersthene-bearing rocks, and Sanders (1954, p. 148) has established that pseudo-sillimanite rocks form along belts of intensive alkali metasomatism—it may therefore not be coincidental that the development of pseudo-sillimanite should occur in rocks where microcline is the dominant felspar, and where fold forces seem to have been especially powerful. The possibility must not be ruled out, however, that the pseudo-sillimanite may have been derived by retrograde metamorphism rather than by metasomatic action, and the presence of some uralitic green amphibole seen in the diopside-biotite rocks lends some support to this alternative.

VII—STRUCTURE

Structures in the area are extremely difficult to determine owing to the poor exposures, so that the structural pattern (Fig. 4, at end) can be deduced only in general terms from the observed minor folding and by statistical analysis.

As in similar rocks elsewhere in Kenya, foliation is developed parallel to lithological boundaries in the gneisses and thus marks bedding planes in the original sedimentary series. It is defined by a preferred orientation of platy minerals, especially micas, and also by metamorphic quartzo-felspathic banding, which is more striking in basic than in leucocratic gneisses.

In some places irregularly reticulated quartzo-felspathic veining is prominent. Flat surfaces at such localities display the quartzo-felspathic veining at least sub-parallel to the undulose and usually steeply inclined foliation. On vertical surfaces perpendicular to the regional strike however, the veining is often random and appears to bear no relation to the foliation. However, minor plications in the veining always show axial trends parallel to the statistically determined regional axes. The section best displaying such features is in the Ndajeri laga, and in Plate IIb can be seen the sequence of successively more complex contortions of the rocks. As described earlier, over most of this section the bands are fairly thin and straight, although often randomly oriented. However, about a mile above Kora Wells the rocks grade rapidly into a zone of profuse and random quartzo-felspathic veining, often thick, coarse, and irregular, where foliation has been virtually obliterated. The zone extends over a few hundred yards and then passes back into more regularly banded and foliated rocks.

Lineations were almost all found on foliation planes, usually in the form of surface grooving (Plate Ia), often accompanied by elongation of prismatic minerals, particularly hornblende and quartz. Lineations also take the form of felspathic or quartzo-felspathic rodding (Plate Ib), of which the end-product is mullioning in rocks with virtually no foliation, as seen at El Gidut, in the lower El Maeng, and in the Male Burai about five miles upstream from the Rahole confluence. There are other instances of lineation obliterating foliation, the best example being displayed in the elongate quartzo-felspathic gneiss exposures south of El Gidut, where the rocks have a strong grooved lineation plunging steeply north throughout the entire mile long outcrop, with only faint traces of northerly to north-easterly dipping foliation visible in a few places. Just north-west of Bamba, in a tight anticlinal fold closure, foliation disappears and only the lineation can be seen. This phenomenon was also seen elsewhere, for example in the Ndajeri section (*see* Plate IVb), but is generally more local in extent.

The dominant lineation trend is east of north, but there are a few lineations which trend more nearly east-west. One of these was found on the surface of an obliquely cross-cutting pegmatite intruding gently dipping rocks in the Iris Namdera laga about half a mile downstream from the Kora Wells track crossing. The plunge of lineations is variable over the area, but is usually not much greater than 45°. The most striking exception occurs in a tributary of the Skot laga about four miles in from the eastern boundary of the area along parallel 0°10′N, where a strong lineation plunges north at 80° (Plate Ib). Along this exposure vertical and steeply dipping beds have a nearly east-west strike, in contrast to the regional north-north-easterly trend, and the orientation locally varies by up to 60° over only a few yards.

Along a narrow east-north-east trending belt in the south of the area between the Gurusumes and El Maeng lagas there are lineations which appreciably change their plunge within the confines of a single outcrop. The best developed of these was found in the Ndajeri section and is illustrated in Plate IVb, which shows the lineation plunge decreasing from near 30° to 5° north, and locally reversing to southwards. Another such occurrence is in the Gurusumes where the lineations not only steepen along the direction of plunge but the magnitude of plunge varies considerably over only a few inches along an easterly axis of curvature, steepening from 32° to 37° in one place and from 9° to around 30° only a few inches away.

Because lineations were often found parallel to minor fold axes or the strike of vertical beds, and because they plot close to them on the stereograms (Fig. 4) they are taken to be in all cases *b* or fold-axes lineations (Weiss, 1959, p. 26).

The majority of minor folds in the area have axes trending east of north, like the lineations, but a subordinate number trend more or less perpendicular to this direction. There are a few localities at which minor folds with dominant east of north trend are accompanied by sub-perpendicular folds or lineations.

Folds with a regional east of north trend vary in style from open to isoclinal, and in attitude from upright to overturned (Plates IVa and IVd), but there does not seem to be any marked spatial distribution of the different styles or attitudes. The subordinate minor folding about near east-west axes is usually open in style, but occasionally is asymmetric. The only place where such folding appeared to be fairly tight was in the Ndajeri section about three and a half miles upstream from Kora Wells, where south-easterly trending small folds occur in quartzo-felspathic veining of apparently random orientation, close to a northerly plunging lineation. In places where the regional foliation strike is more or less regular, as in the Maddogoni Hills, east-west folding is seen simply as mild corrugations of a few inches in amplitude, axes being parallel to the dip. In areas of greater complexity the folds are larger, with amplitudes measurable in feet, but they do not appear to be much tighter.

In some places minor folding with the dominant east of north trend is unusually strongly developed, so that whole sections expose nothing but plicated and corrugated rocks. Such stretches are mainly confined to the east of the area, and are best displayed along the Kaeri Tabaken about three miles upstream from Bora springs (Plate Id), and along the diopside-biotite gneiss belt farther east.

The majority of minor folds are of normal flexural slip type (Weiss, 1959, p. 9), although many of them are isoclinal. Near Bora, and in the southern part of the El Maeng section however, folds were recorded which appear to have resulted mainly from slip in the direction of dip and of strike respectively. There may also have been a predominance of slip in the formation of the small fold at El Gidut and in the minor folding of quartzo-felspathic banding in the upper Rahole.

Major fold closures were clearly seen at only two places in the area, just north of Bamba and three and a half miles north-north-west of Maddo Diko. Both folds are overturned anticlines, and the former seems to be the isoclinal extremity of a more open irregular anticlinal structure. Its outcrop pattern is similar to the shape of the minor fold photographed in the Kaeri Tabaken River upstream of Bora, and lineation has blotted out the foliation in the nose of the fold.

Axes of a few major open folds, tentatively inferred from opposing dips and to some extent from stratigraphical considerations, have been tentatively sketched in for the better exposed southern parts of the area. They cannot give a very reliable picture, however, because there is probably overturned as well as open folding there, and many major structures are obscured by poor exposures. Anticlinal axes have been drawn along the diopside-biotite gneiss band, which is a belt of intense minor folding, and through the intense migmatization zone in the Ndajeri just upstream from Kora Wells.

Statistical Analysis.—The area was subdivided for the purpose of statistical analysis, in an attempt to delimit regions of more complex from less complex folding. The sub-areas are delineated on the map and the data from them plotted on Schmidt net stereograms in Fig. 4. They are largely self-explanatory, but their salient features are summarized below:—

Sub-Area 1.—On the whole this is a region of fairly open folding, with notable exceptions in the tight fold closures seen round El Gidut. The regional axis plunges at moderate to steep angles a few degrees east of north, and this is the only sub-area where neither cross-features nor southerly plunging axes were recorded.

Sub-Area 2.—The foliation poles tend to concentrate in the eastern part of the stereogram, indicating easterly overfolding consistent with the eastwards directed thrust plane there. The cross structures and lineations plunge mainly to the west, by implication down the limbs of the overturned folds. There is considerable undulation in

the regional axis, which trends just east of north, as indicated by the lineations and minor fold axes plunging north and south with almost the same order of frequency, usually at angles not exceeding 10°.

Sub-Area 3.—The foliation poles in this sub-area are concentrated mainly in the west and the minor cross-structures and lineations plunge east, indicating a pattern opposite to that in sub-area 2. There is more variation in the plunge and direction of the regional axis, and it is in this sub-area that curving lineations were found. There is an additional tendency for foliation poles to concentrate south of the stereogram centre, but this may not be significant.

Sub-Area 4.—This is a subsidiary portion of sub-area 3, and its stereogram also indicates a degree of westerly overfolding with cross-structures and associated lineations plunging mainly eastwards. It is the most complex sub-area of all. A dominant north-north-east axial trend is discernible, but the plunge of lineations and minor structures along this direction is widely variable, being often very steep. Poles to vertical foliation planes plot practically all round the stereogram and could be indicative of steep or vertical fold axes. Although there are probably strong undulations in the regional axis for this sub-area, it is unlikely that they even approach the vertical and the steep axes indicated by minor structures and the stereogram are more probably the product of subsidiary folding developed on the limbs of tight upright major folds.

Joints.—Jointing is well-developed, and a large number of readings of joint plane directions was taken. The few joints that are not vertical or sub-vertical are too insignificant statistically to be recorded on the contoured stereogram of poles to joint planes in Fig. 4. It will be noted that the pattern displayed in this stereogram fits most satisfactorily with the dominant axial trends determined from the structural analysis discussed above. The dominant joint direction is the normal *ac* plane, which is the plane most commonly found in regionally metamorphosed and folded rocks (Weiss, 1959) with the subsidiary *bc* and *hkO* joints grouped symmetrically around it. It is possible that *bc* joints develop preferentially in regions of tight folding, for they are well displayed in places along the belt of diopside-biotite gneisses in the east of the area (Plate Ic).

The north-easterly dipping pegmatites in the south-west of the area seem to fill inclined planes with one of the *hkO* orientations, but the majority of pegmatites fill the much commoner steep or vertical joint fractures.

Thrusts.—The poorly exposed thrust in the south-east of the area, west of the Rahole, is characterized by gentle to moderate west to south-westerly dips and minor folds overturned to the east. It was suggested earlier that the movement occurred close to the end of the orogenic episode, for the rocks are shattered and were obviously cool and relatively hard when thrust. Alternatively the thrusting may have occurred at a comparatively high level, away from active centres of orogenesis and metamorphism.

Two small and unimportant displacements of low inclination were seen in the Gurusumes laga near the southern boundary, and others probably occur elsewhere in the area.

Shatter belts have already been mentioned; the most important one is in the east, along a north-south line two and a half miles north-west of Bora spring, where there is also a small well-exposed recumbent anticline overturned to the west (Plate IVd).

It is considered that the area underwent only a single orogenic phase of folding, for the following reasons:—

1. Neither the rocks nor their metamorphic grade differ noticeably from one part of the area to another.

2. Cross structures are not confined to any one portion of the area, and are statistically almost perpendicular to the regional axial trend.

3. The joint pattern, as plotted in Fig. 4, is symmetrical and such a pattern would be unlikely to result from two independent orogenies.

Faults.—Faults in the metamorphic terrain are rarely seen, and since those recorded are almost all strike faults it is not possible to estimate their displacement. The faults that were seen all have a generally west of north trend, which is the same as that of the thrust belt. One of the faults, accompanied by slight alteration of leucocratic gneiss, is well exposed at Bamba.

Features of Tertiary structural developments have already been described in Chapter III, and need no further comment here.

VIII—ECONOMIC GEOLOGY

1. Minerals

Clay lenses are common in the sediments, but are generally calcareous and ferruginous and contain too much sand and silt to be considered as more than the crudest of building materials. The few grey clay occurrences might be more promising, but they also contain quartz grains.

Felspar is abundant in the many large pegmatites which form hills from which it could easily be extracted. Much of it is impure, however, being in graphic intergrowth with quartz. *Garnet, ilmenite* and *magnetite* are abundant in gneisses and are locally concentrated in river sands, but the concentrations are too small and scattered for economic working.

Quartz is common and is nearly pure in the abundant white veins of the area. Impure quartz sands occur in quantity in all sand channels, but are noticeably cleaner in the small gullies dissecting sediments.

Sillimanite occurs as knots in a thin band of biotite-sillimanite gneiss in the El Maeng laga and small amounts of pseudo-sillimanite were found in the east of the area, but no economic concentrations were found.

Gold.—Five samples from thrust and fault breccias were assayed by J. Furst, Mines and Geological Department, Nairobi, for possible gold enrichment, but none was found to contain more than 0.2 pennyweights of gold per ton.

Radioactive Minerals.—In 1960 D. Hobden, Government Prospector, made a car-borne scintillometer traverse along the Garba Tula-Garissa road. From Garba Tula to half-way between Benane and Lafageri, i.e. over metamorphic rocks, the instrument recorded variable low to moderate intensities, but beyond that point, where the road traverses sediments, uniformly low intensities were recorded. A Redbox ratemeter was carried over much of the metamorphic terrain during the present survey, but gave no readings significantly above background level.

2. Water Supplies

As the area is close to the Tana River it has abundant water in the dissected southern and western parts, where the larger sand lagas all have a perennial supply of sub-surface water, tapped by wells varying in depth from 1 to 30 feet or more, although at most places the water is not more that five feet down. It is probable that the position of the wells does not change much from year to year, since many of them have names. There are more wells in the area than have been shown on the map, especially along the Skot laga, where they occur at frequent intervals as far upstream as Maddo Diko.

The underlying rocks frequently force the water table to the surface as springs, examples being displayed in the Kaeri Tabaken (Bora spring), in the lower Rahole, and in the Ndajeri just upstream from Kora Wells. Downstream of such localities the water table again drops below the surface; at Kora Wells, for example, it has just started to do so, and the water level is only a foot or so down.

In the two largest sand rivers, the Bisanadi and Rahole, the water tables are close to the surface, as is indicated by the forests of doum palms which line their banks. The accumulated volume of water in the lower reaches of the Bisanadi, combined with the slightly increased gradient of its profile as it approaches the Tana River, is sufficient to raise the table to the surface, so that even in the dry season a trickle of water flows down the Bisanadi over the last mile or two of its course. During wet weather, the larger lagas carry much more water, so that there is surface flow over considerable stretches, and the Bisanadi becomes a continuous stream.

The source of the sub-surface water in the southern and western parts of the Kora Wells area is a matter of some interest, for apart from the Bisanadi none of the channels can be supplied by the Nyambeni catchment, because of the intervening Skot fault trough. It must therefore all be ground water which has soaked in during rainy seasons and is continually percolating through cracks and fissures in the gneisses, and into the sand channels. It is likely that the water generally reaches the lagas below the level of the sand surface, but springs are sometimes seen in the rock walls of lagas a foot or two above the sand, being particularly well displayed along the Kaeri Tabaken, at and above Bora spring, where as already noted there is also a surface flow due to rocks forcing the water table to the surface. The salt-impregnation of damp, soft, altered gneisses at the salt licks described earlier is probably due to the slowly percolating ground water being evaporated as it reaches the porous rock, leaving the salts behind.

In the virtually undissected north-eastern plains the water supply position is different, however. Water there is confined to small seasonal pockets in the sand lagas, where it is tapped in wells as long as it lasts, generally not more than three or four months after rain. There again the position of the wells does not change much from year to year, as they too have names. As already noted, the sand at these localities has an appreciable amount of admixed clay, and it is considered that the water is held in these local pockets either by capillarity within a body of clay-rich sand or by a semi-pervious or impervious lining of clay.

The only remaining sources of water in the area are the seasonal pans which however are only of reasonable size in the area of well-developed red soils supporting thick thorn bush. The red soils are presumably the "red clayey sand known as *Waiama*" which, according to the engineers of Howard Humphries & Sons (1958, p. 21), is found over large areas of the Wajir and North Garissa Districts.

On the recommendation of the Howard Humphries engineers, Lafageri tank was excavated in May 1957, and lined with the treated red soil. It is re-excavated annually when dry, to remove accumulated silt and cattle effluvia, and in the year of survey, 1960, this was done in late July, the tank having just dried out after holding water since the April rains.

The greatest benefit to the grazing of the area might well derive from developing the seasonal wells in the north-eastern plains as perennial sources of water, although it is admittedly difficult to see precisely how this could be brought about, for the problems of increasing the size of clayey water-bearing pockets to provide more water must be formidable.

At all events, as has been pointed out by many previous workers in this part of Kenya (*see* Chapter II), it is imperative to provide water sources as far away as possible from the seriously overgrazed belts along the Tana and Uaso Ngiro, and this obviously means that they should be as close as possible to the main watershed separating the two systems. In the final analysis, however, it is useless to increase water supplies without a vigorous de-stocking policy, otherwise stock increases as improved water supplies open up new pasturage, and the whole overgrazing cycle is repeated.

Ions (p.p.m.)	Group I				Group II		Group III	
	Kora Wells (D.J.J.)	El Maeng (J.B.W.)	Komunyu (D.J.J.)	Kalimangilu (D.J.J.)	Rahole (D.J.J.)	Ridge camp (D.J.J.)	Thangatha (P.R.)	Ura (P.R.)
Cl'	204	742	3,900	770	12	20	2	2
SO_4''	72	255	965	319	6	8	4	4
HCO_3' (calc.)	395	892	805	1,354	503	128	49	43
CO_3'' (calc.)	—	—	156	228	—	—	—	6
F'	1·5	2·2	3·8	0·8	0·5	0·2	0·2	0·7
NO_3' (as N)	—	—	—	1·7	—	0·05	—	tr.
NO_2' (as N)	—	—	—	—	—	0·06	—	—
Ca''	31	35	27	40	106	23	7	6
Mg''	12	40	121	26	28	8	3	3
Na' (Calc.)	260	826	3,153	1,246	26	23	8	11
(Fe)	>0·1	—	—	—	>0·1	>0·1	0·1	0·1
SiO_2	25	20	25	35	25	25	35	25
(NH_3 as N)	n.d.	n.d.	0·71	0·15	n.d.	n.d.	0·03	0·04
Possible salts (p.p.m.)								
$Ca(HCO_3)_2$	125	142	109	162	429	93	28	24
$Mg(HCO_3)_2$	73	243	736	158	170	49	18	18
$NaHCO_3$	330	801	147	1,515	51	23	18	14
Na_2CO_3	—	—	276	403	—	—	—	11
Na_2SO_4	107	377	1,428	472	9	12	6	6
NaCl	336	1,224	6,430	1,270	20	33	3	3
NaF	3	5	8	2	1	0·4	0·4	1·5
$NaNO_3$	—	—	—	10	—	—	—	tr.
pH	8·5	8·3	8·9	8·5	7·5	8·1	7·9	7·3
Conductivity (micromhos/cm_3)	1,300	3,500	11,600	4,750	730	250	n.d.	n.d.
% Total Ions	0·097	0·279	0·913	0·399	0·068	0·021	0·007	0·008

Table I—Chemical Composition of Water Samples.

All the analyses have two features in common; an almost total absence of iron, and virtually identical silica contents. It is likely that the silica is in the form of hydrated colloidal suspension rather than in the ionic state, and that the near-constant analysis figures approximate to the limiting amount of silica which will go into suspension in these waters.

Otherwise, however, the analyses show certain features which can be related roughly to the distribution of sample sites, and enable a subdivision of the samples into three groups (*see* table) to be made.

Group I.—These are all situated along a relatively narrow north-south belt among gneisses and basic rocks, well away from large areas of sediments. These samples are all more saline than the rest (*see* table) and tend to plot away from the carbonate end of Fig. 2 (*a*), and near the sodium end of Fig. 2 (*b*). The relative deficiency in carbonate and enrichment in sodium are probably real characteristics of the water in these central regions, for the gneisses through which they percolate are low in CO_2 and high in alkalis. The greater salinities, however, can in part be attributed to local conditions: the Komunyu, Kalimangilu and El Maeng samples were collected from sites conducive to concentration of salts, and it is significant that the least saline sample of this group was taken from practically flowing water of Kora Wells, during a rainy period.

Group II.—These two samples were collected on either side of the gneiss-sediment boundary, and as would be expected are relatively enriched in the calcium and carbonate ions, particularly the Rahole water, in which the salts must have been derived largely from sediments. The composition of the Ridge Camp sample is transitional towards those of Group I (Fig. 2), which appears to indicate that its salts were derived both from gneisses and sediments. The lower salinities in Group II are attributable to absence of rock barriers permitting greater freedom of movement of sub-surface water and thus lessening evaporation.

On Fig. 2 smooth curves join the points representing the samples of Groups I and II, which occur among gneisses and sediments. The curves may be of general significance, since these waters must derive their salts either from gneisses or sediments, or both.

Group III.—The Ura and Thangatha are rapidly flowing rivers draining the well-watered Nyambeni range (Rix, 1967), where they have little chance either of leaching out notable quantities of salts, or of being subjected to significant evaporation, and for this reason their salinities are extremely low. The points for group III plot away from the curves joining the other two, which would be expected, since the origin of the few salts in these samples is quite different.

Water at surface and in perennial deep and long-established wells is likely to be polluted both by animals and humans (as can be seen from available ammonia figures in the analysis table) and should at least be sterilized before drinking. When water is obtained by digging a few feet into sand channels it is less suspect and likely to be safer, but it is nevertheless advisable to boil it. The fluorine content is not much above the recommended safe limit of one part per million in any of the waters except those at Komunyu and El Maeng, but the waters at those localities, as well as at Kalimangilu, are relatively saline due to evaporation, except shortly after the biannual dilution by rain.

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