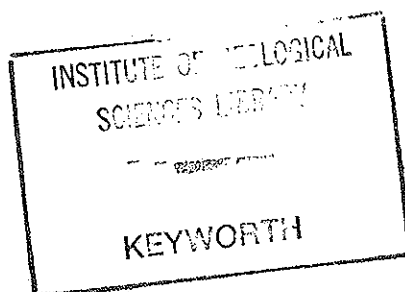


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MALAWI
MINISTRY OF NATURAL RESOURCES

GEOLOGICAL SURVEY DEPARTMENT

THE GEOLOGY OF THE MLANJE AREA

by

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I. INTRODUCTION

The Mlanje area lies in the south-east of the Southern Region of Malawi. It is bounded to the east and south by the Mozambique border and to the west and north by longitude $35^{\circ} 30'$ East and latitude $15^{\circ} 30'$ South respectively (*see* Fig. 1). The area mapped is about 900 square miles, 35 square miles of which are in Zomba District in the extreme north-west, the remainder comprising most of the Mlanje District. Although largely underlain by high grade gneisses of the Basement Complex the area also contains a wide range of Lower Cretaceous sub-volcanic and plutonic rocks of the Chilwa Alkaline Province. The largest group of intrusions forms the Mlanje Massif, the dominant topographic feature in the area, which rises to nearly 10,000 feet above sea level.

Topographic 1 : 50,000 map sheets 1535D and 1635D were used as a base in compiling the accompanying coloured geological map (in the back pocket).

(a) Communications

In the south-east, the district headquarters at Mlanje is situated on a main tarred road between Blantyre, 42 miles to the west, and Portuguese Milange, 21 miles to the east on the Mozambique border. The railway from Limbe to the port of Beira crosses this road at Luchenza Station 15 miles from Mlanje. Numerous subsidiary dirt roads with fairly good surfaces lead off from the main road to the tea estates on the southern slopes of Mlanje, and to many villages near the Ruo River to the south.

An all-weather gravel road connects Mlanje with the administrative sub-headquarters of Palombe 30 miles to the north. From Palombe several district roads, which are normally open during the dry season only, branch towards Zomba (47 miles), to Nambazu in the north-east (25 miles), through the Fort Lister gap between Michese Mountain and the Mlanje Massif, and to various villages on the Palombe Plain. Much of the area immediately to the south of Lake Chilwa is accessible by dirt road during the dry season only. A poor seasonal road from Fort Lister around the eastern foothills of the Mlanje Massif joins with the main tarred road near the border at Milange.

On the Mlanje Massif there are several paths connecting the various forestry plantations on the main plateaux and basins, while on Chambe and part of Tuchila Plateau there are networks of earth roads used by vehicles transporting timber. Access to the plateaux is by a few steep paths and at Likabula there is a cableway for transportation of timber and heavy equipment between the forestry depot and the south-eastern rim of Chambe Plateau.

(b) Climate and water supply

(i) Climate

Much of the area, apart from the Mlanje Massif and a few large isolated hills, is low-lying; the altitude varies between 1,900 feet and 2,400 feet above sea level and the climate is warm to hot and humid throughout most of the year. Annual temperatures average around 70° F. to 75° F. with maximum temperatures around 90° to 95° during November and December. In the dry season during June to mid-August, the climate on the Palombe Plain and on the plain south of Mlanje is much cooler, especially at night. On the Mlanje Massif during this period temperatures drop at times to freezing point and there are very occasional falls of snow on the highest peaks.

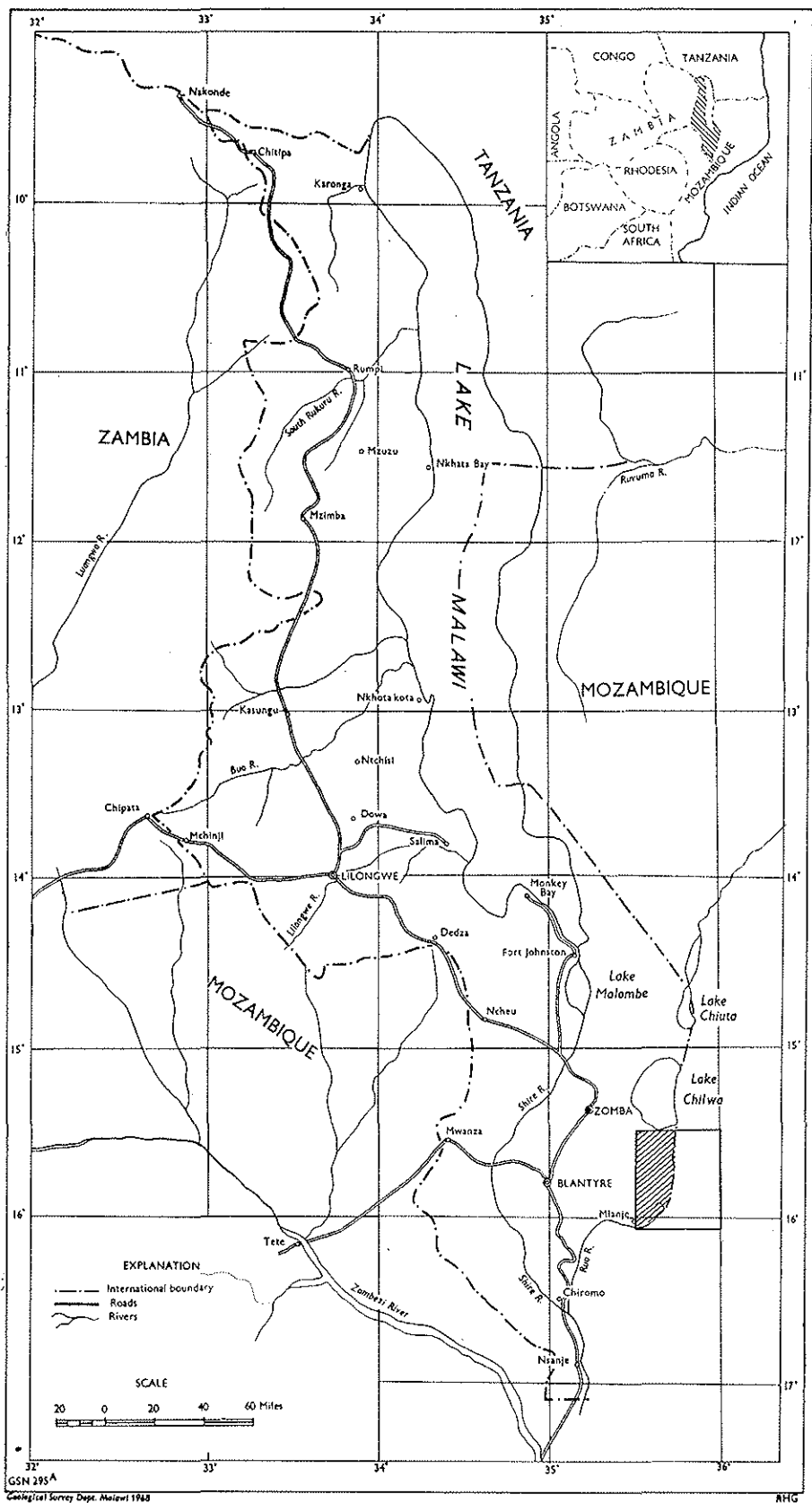


FIG. 1. Location map.

The rainfall on the Palombe Plain is about 40 inches and is mainly confined to the wet season between December and March. In the tea-growing belt along the lower slopes on the southern and southwestern part of the Mlanje Massif the rainfall varies between 50 and 80 inches while on the mountain itself rainfall figures of over 130 inches have been recorded. Within the tea-belt and on the massif there is often intermittent light rain and mist known locally as *chiperoni*.

(ii) *Water supply*

The Mlanje area is well served by normally perennial streams with consistently good flows throughout the year. In the northern parts the Palombe and Sombani rivers drain into the swampy ground around Lake Chilwa, and several tributaries of the Sombani River from the northern slopes of Michese Mountain carry water for the greater part of the year. Major drainage systems on the northern slopes of Mlanje comprise the Palombe, Sombani and Tuchila rivers; other major rivers flowing from the remaining portion of the massif include the Likabula, Malosa, Ruo, Lichenya, Lujeri and Nanchidwa.

River flow information on the major rivers is given in Table I below. The minimum and maximum flows shown are the lowest and highest recorded flows since records commenced.

TABLE I
RIVER FLOW DATA

River	Locality	Minimum flow* (cusecs)	Maximum flow**† (cusecs)	No. of years recorded	Average of 10 years	
					Minimum monthly mean flow (cusecs)	Maximum monthly mean flow (cusecs)
Ruo	Mlanje Road	7.5	30,000 (estimated)	8	58	779
Ruo	Ruo Estate	25.0	33,000 (estimated)	6	—	—
Tuchila	Chionde	Nil	25,000 (estimated)	9	—	—
Tuchila	Kambenje	2	—	10	7	189
Lichenya	Mlanje Road	3.0	14,000 (estimated)	8	13	347
Sombani	Paloni Hill	Nil	2,600	9	0.2	249
Palombe	Rigola Village	Nil	11,360	12	—	—

* Information from *Annu. Rep. Water Development*, 1961, p. 32.

† Maximum flow figures represent sudden and spectacular floods from the Mlanje catchment area.

Owing to the seasonal rain there are very large differences between the maximum and minimum flows of the rivers and several rivers become dry downstream towards the end of the year. However, in these cases adequate water supplies are generally available from pools, or shallow wells sunk in the sandy beds of the streams. Other sources of water are springs at Mauze Mountain, Machemba Mountain, Michese Mountain and the lower slopes of the Mlanje Massif. A small hot spring occurs on the northern bank of the Malosa River at Salima Village.

Water shortages in low-lying areas remote from the lakeshore and other perennial sources of water, mainly in the north and north-west, have been countered by the sinking of numerous boreholes (see Table II).

TABLE II
WATER BOREHOLES SUNK IN THE MLANJE AREA BETWEEN 1931 AND 1964

No.	Village	Year drilled	Completed depth (in feet)	Yield (g.p.h.)	Rest water-level (feet)	Geology
3/31 (Z28)	Mwenye	1931	134	450	25	Gneiss and dolerite
4/31 (Z29)	Ngaluwe	1931	146½	180	26	Gneiss
12/31	Chilumpa (Zomba District)	1931	76½	100	42	Gneiss
5/32	Njaia	1932	148	960	32	Gneiss
6/32	Ngaluwe (1 mile south of 4/31)	1932	158	13	120	Gneiss
13/32	Chintalo (Kawiriza-Zomba District)	1932	123	400	58	Drift on gneiss at 112 feet
K8	Mimosa Tea Research Station 1	1953	120	1,000	20	Red clayey alluvium
K9	Mimosa Tea Research Station 2	1953	130	1,000	30	Red clayey alluvium
M41	Mkumba's Court	1953	81	800	10	Alluvium on syenite
M44	Waruma	1953	73	700	12	Alluvium
M49	Laston Njema	1953	115	350	13	Alluvium on biotite-gneiss
K25	Chisupe (Chaweza)	1954	130	560	45	Sandy drift
L306	Filisa	1956	124	725	58	Sandy clay and gravel
L307	Thumbula	1956	116	450	59	Sandy clay and gravel
L308	Chinani	1956	185	675	120	Sandy clay and gravel
L309	Mpindi (Pindani)	1956	190	210	112	Sandy clay and gravel
L310	Chimbalanga	1956	125	600	62	Gneiss
L311	Mtemanyama	1956	103	530	42	Gneiss
L312	Chiwalo	1956	156	75	73	Gneiss
L325	Chimenya (Pangani)	1956	98	550	37	Gneiss
L326	Nampinga	1956	110	900	47	Sandy clay and gravel
L327	Thunga	1956	129	350	57	Sandy clay and gravel
L352	Likangaria	1956	132	460	72	Sandy clay and gravel
L353	Namalima	1956	103	720	12	Nepheline-syenite
L354	Kaliyati	1956	84	400	6	Gneiss
L357A	Nkoko	1956	106	120	76	Gneiss
L367	Mpasa	1956	106	600	33	Sandy clay and gravel
L368	Mgogodera	1956	94	750	74	Gneiss
L369	Nyezerera	1956	110	650	34	Sandy clay and gravel
L370	Matekenya	1956	130	420	74	Syenite-gneiss
L371	Njobvu	1956	100	600	20	Sandy clay and gravel
L373	Chimombo	1956	118	500	19	Sandy clay and gravel
L374	Chabwera	1956	96	360	18	Sandy clay and gravel
L376	Gunda	1956	95	300	19	Sandy clay and gravel
E30	Chitekeza	1957	102	720	30	Thick drift
E36	Malosa Customs Post	1957	75	720	14	Syenite
E39	Chilima	1957	90	1,200	10	Thick drift
E40	Mbona	1957	90	720	19	Thick drift
E41	Ligola (Chaweza)	1957	90	900	18	Thick drift
E43	Tamani	1957	80	450	16	Migmatite
E81	Nampwalala	1957	100	720	22	Migmatite
L372	Maliro	1957	97	720	10	Thick drift
L390	Nasiyaya	1957	79	420	6	Thick drift
E7	Chimwaza	1957	110	600	14	Gneiss
E175	Ndungunya	1958	64	438	32	Gneiss
E207	Mkezalamba	1958	110	960	14	Drift on gneiss
E208B	Makina	1958	100	110	48	Gneiss and dolerite
E209	Thondolo	1958	102	624	12	Clay on gravel
E210	Nambela	1958	165	500	114	Drift
E211	Kolowika	1958	150	480	108	Drift
E212B	Maone/Maloya	1958	155	180	120	Drift
E213	Maone/Maloya	1958	122	720	29	Drift

TABLE II—*continued*
WATER BOREHOLES SUNK IN THE MLANJE AREA BETWEEN 1931 AND 1964

No.	Village	Year drilled	Completed depth (in feet)	Yield (g.p.h.)	Rest water-level (feet)	Geology
E214	Phodogoma	1958	95	480	8	Gneiss
E215	Chiringa (N.A. Nazombe)	1958	102	438	34	Gneiss
E216	Ntepa	1958	113	720	15	Gneiss
E217	Yuwa	1958	101	500	24	Gneiss
E218	Kasongo	1958	136	800	111	Gneiss
W54	Chete	1959	102	1,080	18	Sand, clay on gneiss
J29	Kalinde Dispensary	1959	121	800	24	Alluvium on gravel
W181	Palombe Police Post	1960	130	250	5	Gneiss
W247	Palombe Asian Sch.	1961	75	970	10	Sand and boulders
A10	Namasokho	1961	132	150	55	Sand on gneiss
A94	Saidi	1961	160	1,200	75	Sand, gravel on gneiss
A106	Limbuli Market	1962	180	1,200	31	—
A107	Malosa Court	1962	80	840	25	Gravel on Basement gneiss
A152	Mundawala	1962	160	960	65	—
A153	Muwa	1962	148	720	—	Thick alluvium
A154	Chinani Court	1962	204	1,030	152	Thick drift
A155	Chimbalanga	1962	110	1,200	40	Thick drift
A157	Mikate/Chimombo	1962	30	—	15	Thick drift
A207	Gideon	1962	105	720	54	Gneiss
W318	Nazombe School	1964	103	440	12	Thick alluvium
W319	Mumbo	1964	180	880	96	Thick alluvium

Boreholes from 1953 onwards have been sited by the geophysical resistivity method developed by Cooper (1965). This method and a fuller account of the location of underground water supplies are described by Holt (1955). On the Palombe Plain aquifers comprise either sandy and gravelly beds in thick deposits of sandy clay or decomposed gneiss immediately below clayey drift. In the latter cases, the water supply is sometimes semi-artesian. In the other parts of Mlanje District water is contained in fault and shear-zones, and in stretches of deeply weathered gneiss, in general at depths of less than 100 feet.

In view of the possible development of bauxite deposits on the Mlanje Massif a brief survey was made of the water and hydro-electric resources of the Lichenya area. A preliminary note on this by J. G. Pike (1963) of the Department of Water Development is given in full below.

1. *Water Supply*

An estimated 3 million gallons per day (6 cusecs approximately) are required for certain development proposals on Lichenya Plateau. Regular flow measurements have been undertaken on certain streams in the area. These are:

1. Chapaluka (Chambe) March 1954 to date (1963).
2. Likabula January 1954 to date (1963).
3. Linji April 1958 to October 1961.
4. Nakatete March 1958 to January 1962.

Measurements of flow in the Lichenya have been maintained at the foot of the mountain for nine years, but an occasional measurement was made in the gorge of this river on the plateau in May 1958. With regard to the Linji and Nakatete, these are the only two streams draining the western buttress that have their sources on the plateau. The flows measured at the foot of the mountain are considered to represent the approximate flow at the tip of the plateau.

1. *Chapaluka Stream*

The minimum flow of this stream during the years 1954–1962, measured at its outlet from the Chambe Plateau, has been found to have been 3.70 cusecs (2 million gallons per day approximately). This site was considered as a possible intake for the Blantyre/Limbe water supply scheme, and with storage on the plateau, the consultants

estimated that in an extremely dry year 2.8 million gallons per day could be assured, and 3.08 million g.p.d. during a "normal" dry season. The nature of the foundations at the proposed dam site were however found to be unsuitable for a concrete dam, although the possibilities of a rock-fill dam just upstream of the lip of the plateau remain to be investigated.

2. *Likabula River*

Flow has been measured in this river, near the Forestry Depot at the foot of the narrow valley that divides Chambe from Lichenya plateau, since 1954. Over this period the minimum flow measured was 3 cusecs. It is apparent that the main dry season source of water for this river is the Chapaluka and there is some loss of flow in the Likabula Valley.

3. *Linji Stream*

This stream has its headwaters on the north-western section of the Lichenya plateau. A number of small dam sites near the lip of the plateau have been noted. The minimum flow measured during the years 1958-1961 at the foot of the mountain was one cusec.

4. *Nakatete Stream*

A similar catchment to the Linji but with a much lower yield. Minimum flow measured at the foot of the mountain was $\frac{1}{2}$ cusec during the years 1958-1961. Storage sites on the plateau are limited.

5. *Lichenya Stream*

The minimum flow measured at the base of the mountain over the years 1952-62 has been 4 cusecs. In two years out of ten the flow has dropped to below five cusecs. In May 1958 a flow of 16 cusecs was measured in the gorge where the river has cut down into the plateau, as this was at the beginning of the dry season, however, the measurement is of limited value in assessing minimum flow.

From depletion analogies with other Mlanje streams it is thought however that the major proportion of the dry season flow of the Lichenya is derived from this part of the catchment and the minimum flow at this point would be of the order of 3 cusecs ($1\frac{1}{2}$ m.g.p.d.).

Summary

Although there appears to be no one site from which a firm 6 million g.p.d. can be drawn, a combination of schemes on the Chapaluka, Linji and Lichenya would appear to be feasible. Storage on the Chapaluka and Linji are possibilities but would be difficult on the Lichenya owing to the incised nature of the river. It should be stressed however that these observations are suggestive only and a considerable amount of field work would have to be done before a firm opinion could be given.

II. *Power Possibilities*

There are four possible hydro-power sites within the Mlanje area that would provide 3,000 kW. or more, although the estimates are based on reconnaissance surveys and are of a tentative nature only.

1. *Ruo River above Lujeri*

A storage site at an elevation of 6,050 feet storing 1,150 acre feet exists in the upper Ruu Valley. From this site a total head of 2,790 feet would be developed to produce some 5,000 kW, with an average regulated output of 17 m. kW.h.

2. *Chapaluka River at Chambe*

If the Chapaluka is not utilized for water supply on the plateau, a run-of-the-river scheme could be developed with a minimum output of 1,000 kW. This could be increased to 3,000 kW. with storage on the plateau.

3. *Ruo River at Likabula confluence*

This site is situated some 10 miles south of Mlanje and would be a low head/high storage scheme. A dam 120 feet high to store some 285,000 acre feet with an average net head of 94 feet would provide 10,000 kW. with an average regulated output of 50 m. kW.h.

4. *Zoa Falls, Ruu River*

Although situated some 30 miles south-west of Mlanje, power possibilities at Zoa Falls are considerable. As the result of an investigation made by consultants some years ago, it was estimated that some 15,000 kW. could be developed here providing an average regulated output of 80 m. kW.h.

(c) Agriculture and vegetation

There is fairly widespread cultivation throughout the Mlanje area apart from on the mountainous slopes of the Mlanje Massif. Small patches of rice are cultivated along the swampy and somewhat saline margins of Lake Chilwa and the Sombani Marsh. An attempt to produce paddy rice on a larger scale in irrigated plots near the swampy shores of Lake Chilwa at the north-western foot of Nkalonje Hill failed because of the poor water supply from the Sombani River towards the end of several fairly dry years.

Throughout most of the Palombe Plain the main crops are maize, cassava, beans, groundnuts, sugar cane and millet. A little tobacco is also grown. Bananas, paw-paws, pineapples and guavas are the main fruit crops.

The tea industry in Malawi first became established when tea seed was successfully grown by the Livingstonia Mission in the high rainfall area on the lower slopes of the Mlanje Massif. The total acreage is now nearly 15,000 acres of mature tea, and annual exports over the last five years from the Mlanje tea-belt, and the adjacent Cholo tea-belt of the same size, have been between 16 million and 24 million pounds with a total value of about 3 million pounds sterling per annum.

There is a heavy cattle population in the northern parts of the Palombe Plain near Lake Chilwa. Elsewhere small stock including goats and pigs are of local importance.

The biggest area of major timber-producing indigenous forest in Malawi is the Mlanje Massif cedar forest which has been worked for over 65 years. The cedar (*Widdringtonia whytei*) grows in small scattered patches of total extent probably about 10 square miles. The whole of Chambe which originally carried much cedar has now been afforested with *Pinus patula*. There has also been some experimental planting of apple trees. Plantations of *Eucalyptus saligna* are fairly common in the tea-belt and around several villages in the Michese area.

The lower slopes of the Mlanje Massif, Michese Mountain, Machemba Mountain and Mauze Mountain are occupied by *Brachystegia* woodland with scattered clumps of bamboo. Surviving fragments of original natural vegetation indicate that prior to tea-planting the whole of the wet belt along the southern foot of the Massif was occupied by a type of wood unusual in Malawi (Chapman, 1962). Remnants now include *Brachystegia spiciformis* up to 60 feet high together with various savannah species including *Newtonia buchananii* and *Khaya nyasica*. On the mountain there are secondary plateau grasslands and a rich and varied community of shrubs, heath, herbs and species of ferns.

In the swamp regions of the northern part of the Palombe Plain there is abundant *Vossia* and *Phragmites* reed (*bango*). The flat lacustrine areas carry local patches of *Acacia seyal* and *Acacia spirocapa*, and vestiges of original *Brachystegia* woodland occur on the numerous small hills on the plain and along the banks of the main streams.

III. PHYSIOGRAPHY

Some of the most spectacular scenery in southern Malawi occurs within the Mlanje area. The dominant features are the Mlanje Massif and adjacent Michese Mountain which rise precipitously several thousands of feet above the surrounding plains. In the northern half of the area these plains form a monotonously flat surface broken only by steep-sided inselbergs, and to the east there is a uniform expanse of level country extending into Mozambique.

The Mlanje area can be sub-divided into three main physiographic units (see Figure 2): (a) the Palombe Plain (b) the area south of the Mlanje Massif and (c) the Mlanje Massif* and Michese Mountain.

The evolution of the present form of the Mlanje Massif has proceeded by four major stages involving intermittent uplift and peneplanation commencing in Cretaceous times. According to Dixey (1956, p. 5), the Palombe Plain and the plain south of the massif comprise parts of a well-developed mid-Tertiary surface, corresponding to the African surface of King (1962, p. 277) and Lister (1967). The Lichenya and Tuchila plateaux probably belong to the post-Gondwana (early to mid-Cretaceous erosion cycle) and the actual summits of the Mlanje Massif may reflect the initial surface of the newly emplaced rock. An account of the erosion levels in the Mlanje area and their morphological development is given in chapter XVII.

(a) The Palombe Plain

The Palombe Plain is about 2,100 to 2,450 feet in altitude and stretches to the north and north-east of the Mlanje Massif. It slopes gradually to the north to merge with the Lake Chilwa depression (Garson, 1960, p. 16). A few hills and groups of hills rise abruptly like islands to heights of up to a few thousand feet but generally much less. The low country consists largely of *dambo* and lacustrine flats which are either treeless or occupied by sparse thorn-bush. Around the isolated inselbergs there are wooded colluvial pediments forming good agricultural land ranging from one to several miles in width.

On first sight the Palombe Plain appears flat but closer inspection reveals that there are several terrace levels indicating successive drops in the level of Lake Chilwa. The best defined fossil lakeshores occur in the north-west and north-east at 10 feet and 40 feet above present lake level. Other lakeshores are found at 55 feet, 80 feet and 115 feet above lake level. On the old raised lacustrine platforms there are various low fossil spits the most conspicuous of which are found at the north-western foot of Nkalonje Hill, east of Nkalonje Wa'ngono Island, and north-east of the Tundulu complex. The above lacustrine deposits are described in more detail in chapter XVI.

Several inselbergs on the plain consist of resistant quartzo-feldspathic granulite and granitic gneiss but more elongated, ridge-like features owe their resistance to erosion to the presence of central cores of dykes of microgranite, sölvbergite, phonolite or dolerite. Weathering along joints in some of the microgranite dykes has resulted in a battlemented appearance. The agglomerate and carbonatite vents at Tundulu, Nkalonje and Songwe form craggy steep-sided ridges and conical hills; similar erosional forms occur on the flanks of the Namangali

*The term Mlanje Massif is used to denote the main part of the mountain range excluding Michese, it is shown on the accompanying coloured map as Mlanje Mountains.

Vent where a crater-like hollow has been carved out of feldspathic and phonolitic agglomerate. The nepheline-syenite at Mauze exhibits smooth, rounded surfaces rising abruptly from low foothills consisting of fenitized gneisses. The steep elongated ridge at Machemba Mountain is made up of a resistant intrusion of quartz-syenite which towers above the more easily eroded syenitic gneisses enclosing it.

(b) The area south of the Mlanje Massif

The plain south of the Mlanje Massif is largely covered by colluvium and varies in elevation from about 1,900 feet to 2,300 feet above sea level. Numerous rivers and streams rising in the mountains to the north have carved out small gorges in the foothills and further south have produced a gently rolling landscape. The Ruo-Malosa drainage system forming the boundary with Mozambique occupies a wide mature valley with river meanders in places carved down through alluvium to solid rock.

Minor hill features consist of meta-basic rocks at the Chingozi-Nachironga Hills, syenitic gneisses forming the Mpakha Ridge, and resistant garnetiferous gneisses between the Ruo and Lichenya rivers.

(c) The Mlanje Massif and Michese Mountain

The following paragraphs are based mainly on the very full account of the physiography of the area published by Dixey in 1927.

The Mlanje Massif consists essentially of a cluster of coalescing plutonic intrusions of syenite, quartz-syenite, and granite rising in a most spectacular manner from the Palombe Plain to a maximum height of 9,847 feet above sea level. It is not a volcanic pile as believed by early travellers and, despite the elevation, there is no evidence of glaciation. The massif is about eighteen by fourteen miles and so shaped that, broadly speaking, the four sides face the cardinal points of a compass. The bounding slopes are bold and precipitous, a very distinctive feature especially when viewed from the plains to the north and west. Surmounting these steep outer cliffs are a series of discontinuous marginal plateaux at a markedly uniform height of about 5,000 to 6,000 feet. These plateaux or bevels of rolling grassland, intersected by deep wooded ravines and gullies, are up to a mile wide and separate the outer slopes from a rugged central area which includes several ancient upland valleys of great size with floors approximately the same level as the marginal bevels. The largest of the upland valleys is occupied by the Ruo River which divides the main part of the massif into unequal eastern and western lobes. Practically all the upland valleys and many of the rivers draining the marginal plateaux are abruptly truncated upon reaching the sides of the massif to descend in fine waterfalls that are so conspicuous a feature of Mlanje scenery, particularly towards the end of the rainy season. Huge boulders are prominent on the piedmont slopes and in the river gorges, particularly on the north-west and north between the Likabula Valley and the Fort Lister Gap; they have originated from the cliffs above.

The highlands of the central area are deeply fissured and boulder-strewn and are surmounted by numerous peaks and ridges most of which rise to between 8,000 and 9,000 feet. In many places the ridges and slopes have been split into innumerable large rectangular boulders, usually rounded at the angles and edges, separated from one another by fissures which may be ten feet across at the top and 30 feet deep.

To the north Michese Mountain is separated from the main mass of the Mlanje Massif by a broad saddle about a mile wide called the Fort Lister Gap. Michese is remarkable for its sheer conical peak rising to 7,510 feet and the occurrence all

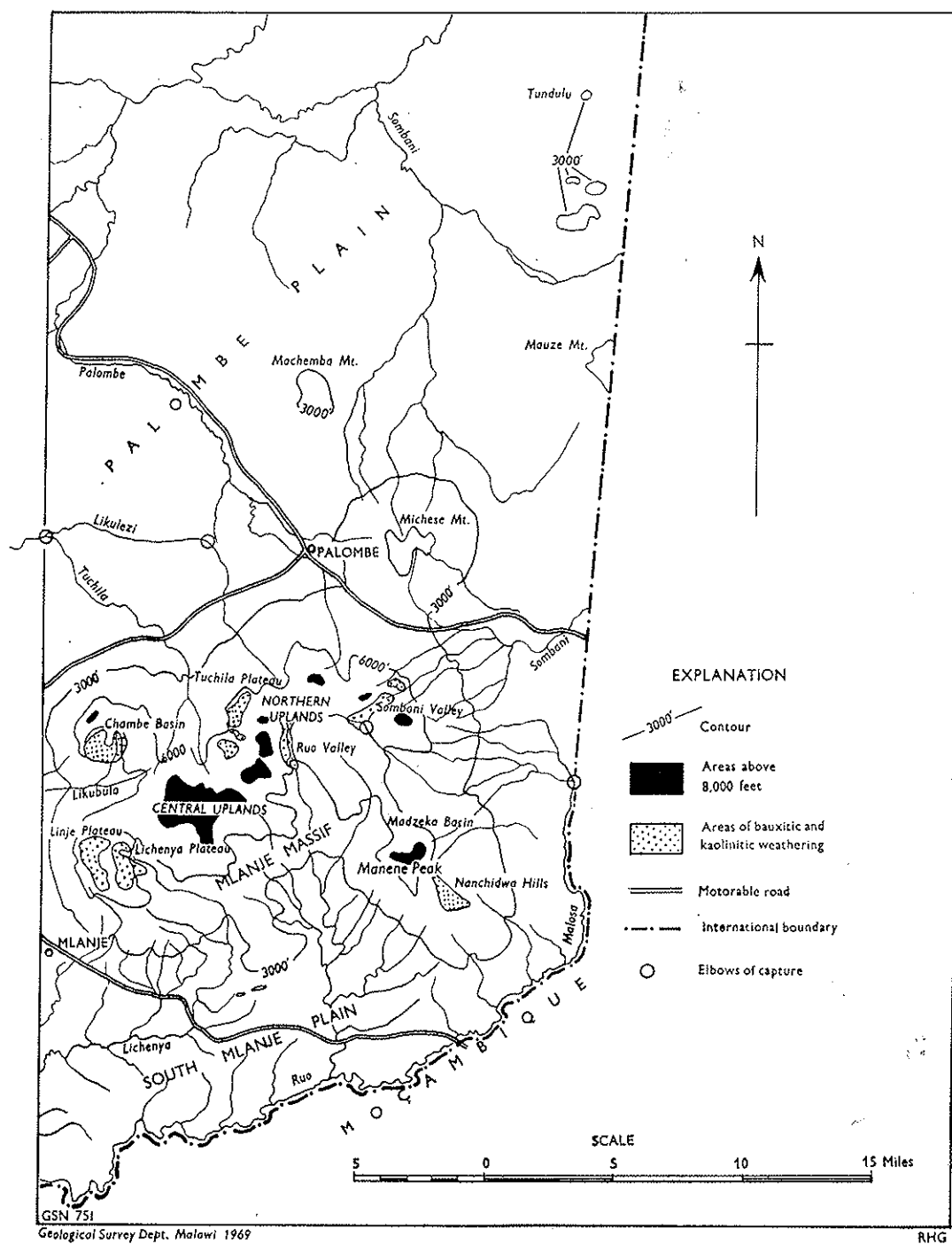


FIG. 2. Physiography of the Mlanje area.

round the mountain of narrow, well-nigh inaccessible gorges, often little more than deep clefts separated by narrow precipitous spurs.

In general there has been pronounced structural control of the drainage and erosion is assisted by exfoliation and by a complex system of vertical joints and faults. A major fault cutting diagonally across the whole massif from the northern slopes of Chambe to the south-eastern slopes of Nanchidwa has controlled parts of the courses of three major river systems: the Nanchidwa, Little Ruo and Tuchila. This same fault is probably also responsible for the presence of the Ruo Falls which lie approximately on its line. On the flanks of the mountain, headward erosion along joints has given rise to deep narrow clefts running back into the mountain sides. When a cleft of this type meets another line of weakness running transversely to it, there is a tendency to the development of deep cauldron-like hollows. An excellent example of this is the densely forested "crater" behind Lauderdale Estate, the walls of which rise vertically for about 300 feet (*see* Frontispiece). When headward erosion of this type proceeds along parallel lines, it sometimes gives rise to enormous buttresses that project boldly from the adjacent mass, for example, the peaks at the entrance to the "crater".

XVII. POST-KARROO TECTONIC AND MORPHOLOGICAL HISTORY*

The tectonic evolution of the Mlanje area, including the development of the magmatism of the Chilwa Alkaline Province, the emplacement of plutons and the origin and age of erosion surfaces, must be considered in relation to the whole of southern Malawi which has undergone cyclic uplift, warping and rifting generally with continent-wide effects. For this reason the following account extends outside the present area to embrace most of southern Malawi, in particular the Lower Shire River and Shire Highlands areas.

The dominant structural feature since Karroo times has been the Cholo Fault, the escarpment of which separates the Shire Highlands from the Lower Shire Valley some 40 miles south-west of the Mlanje Mountains. Since Stormberg times, at least, three major periods of movement along the fault have had profound effects on the morphology of southern Malawi. The fault was also probably in existence before Karroo times (Habgood and Walshaw, in preparation) but the absence of faulted pre-Karroo sediments and the lack of direct evidence in the Basement makes this difficult to demonstrate. Plate XIII shows a series of greatly simplified sections across the Cholo Fault from Doa in the Zambezi Valley to Sapitwa, the highest point on Mlanje. All subsidiary faults, particularly numerous in the Karroo rocks, have been omitted.

It is convenient to consider first the retreat of the Dwyka ice-sheet. Although direct evidence is lacking in Malawi, glacial and fluvio-glacial deposits in the Middle Zambezi and Ruhuhu basins suggest that the ice was of widespread occurrence (Tavener-Smith, 1962). As the ice retreated, differential isostatic recovery gave rise to a shallow downwarp, coincident with the present day Lower Shire/Zambezi area, in which began to collect Upper Ecca coal shales and lacustrine sands. Further subsidence of the basin and relative uplift of the flanks then caused a marked change in the sediments which became dominantly arenaceous and deltaic, the result of rapid sheet erosion of the adjacent basement. Seven thousand feet of coarse, cross-bedded sediments were swept in from the north-east followed by argillaceous red beds deposited under desert conditions in lower Beaufort times. After the period of intra-Karroo erosion lasting until Upper Beaufort times, further subsidence caused a resumption of basement erosion and the deposition of 2,000 feet of Stormberg grits and arkoses. These once more filled the basin and desert conditions reappeared in Upper Stormberg times (Habgood and Walshaw, *op. cit.*).

A total of at least 12,000 feet of sediments, mainly continental and deltaic sandstones and arkoses, collected in the Karroo basin apparently as a direct result of intermittent crustal warping. Warping eventually led to widespread fracturing and the first major movement along the Cholo Fault. The exact position of the fault relative to the margins of the Karroo depression is not known and neither is the magnitude of the latter movement. In view of the exceptionally thick development of sediments preserved by this and later faulting, and the complete absence of sediments on plateau residuals above the present day Shire Highlands surface, the Cholo Fault must have developed close to the edge of the depression. It is probable that some sediments were upthrown on the north-east but have since been eroded. Dixey (1956) suggested that vast thicknesses of Karroo sediments covered the whole of the present Shire Highlands; this cannot now be accepted, not only because of the present absence of sediments from that area but also because of the nature of Karroo deposition in the Lower Shire/Zambezi basin.

*All the views expressed in this chapter are those of the junior author (R.D.W.).

This is typical of localized sedimentation in a downwarp showing cyclic variation caused by periodic sinking and relative uplift of the hinterland, the latter being the provider rather than the receiver of sediment. A similar situation existed in other Karroo basins, notably the Middle Zambezi as described by Taverner-Smith (1962).

By Upper Stormberg times the north-eastern boundary of the sediment-filled Karroo basin was the Cholo Fault, movement along which (and along numerous other fractures) gave rise to the extrusion into the trough, and probably into the marginal parts of the uplifted block, of considerable thicknesses of basalt lava *via* a swarm of dolerite dykes and volcanic necks. Pre-existing faults cutting the Karroo were infilled with dolerite and sills were emplaced in the sediments. The north-eastern extent of the lavas is not known since later uplift and erosion have removed them, but two features indicate that they either did not reach the present position of Mlanje Mountain or were only thinly developed there. The first is the reduction in the number of feeder dykes away from the Cholo Fault and the second is the absence of basalt xenoliths in the Mlanje plutons.

After the appearance of the Stormberg dolerites and basalts, southern Malawi, in common with the whole of Africa, then still part of Gondwanaland, suffered a period of denudation operating shallowly over a vast steppe of low relief (King, 1962). Planation across the Cholo Fault scarp with its covering of lavas reduced the level of the faulted block and probably contributed more sediment to the Lower Shire basin. These sediments have not been recognized in the Lower Shire area but in the Lupata Gorge of the Zambezi a thin deposit of sandstone lies on an eroded Karroo surface and is conformably followed by rhyolite lavas 166 ± 10 million years old, *i.e.*, Middle Jurassic (Flores, 1964). Dixey (1956) has suggested that the topmost parts of Mlanje Mountain were bevelled by the Gondwana cycle but this cannot have been so since subsequent age determinations have shown that the massif were not emplaced until early Cretaceous times (*see p. 53*).

With the break up of Gondwanaland, beginning in the late Jurassic and continuing into the Cretaceous, southern Malawi experienced further crustal warping which again resulted in a depression in the Lower Shire/Zambezi area flanked by uplands to the north-east. The results of the warping however were quite different from that preceding the Karroo deposition; only comparatively minor thicknesses of sediment were deposited in the basin, probably because of the closeness of the Cretaceous sea, and alkaline magmatism occurred. In the Luangwa Valley, another Cretaceous downwarp similarly initiated in Karroo times, Dixey (1926C) recognized the presence of early Cretaceous Dinosaur Beds lying unconformably on Karroo sediments and was led to the conclusion that the post-Gondwana erosion surface represented by various bevels (including that on Mlanje Mountain) lying below the Gondwana surface were Lower Cretaceous in age. The Dinosaur Beds south of Karonga were similarly thought to be Lower Cretaceous derived by post-Gondwana erosion of the Nyika area. In view of this the calcareous sediments (? Lupata Series) lying unconformably on the Karroo rocks in the Lower Shire area were correlated with the Dinosaur Beds and taken to represent the remaining trace of a great thickness of Cretaceous sediments which completely filled the valley. It has since been shown (Drysdall and Kitching, 1962) that Dixey's supposedly Cretaceous Dinosaur Beds in the Luangwa Valley are part of the Karroo succession. This, together with the early Cretaceous age of Mlanje, now casts grave doubts on an early Cretaceous age of the post-Gondwana surface on Mlanje and Zomba mountains and also on the age of the north Malawi Dinosaur Beds. It is now apparent that Mlanje could not have been bevelled until mid-Cretaceous times at the earliest.

Although the warping of the Gondwana surface does not appear to have given rise to significant sedimentation in the actual basins, the alkaline magmatism so initiated (the Chilwa Alkaline Province) gave rise to one of the most concentrated arrays in Africa of carbonatite, nepheline-syenite, syenite and granite complexes

and associated dykes. The first effect of warping was the deposition of thin continental sandstones, known outcrops of which occur in the Lupata Gorge (and possibly in the Lower Shire), overlying with strong unconformity the middle Jurassic rhyolites. Immediately following these sandstones in the Lupata Gorge are alkaline lavas 115 ± 10 million years old (Flores, *op. cit.*), broadly equivalent in age to the Mlanje plutons which have yielded ages between 128 ± 6 and 116 ± 6 million years. The Chilwa Alkaline Province has an age range from 105 ± 12 to 138 ± 14 million years (*see* p. 53). The fact that, in detail, the ages determined do not reflect known relationships deduced from field evidence (p. 53) shows that the age data must be treated with reservation and cannot be used indiscriminately. For example, alkaline lavas similar to the Lupata rocks also occur as inclusions in the quartz-syenite and granite of the Tuchila Plateau, Mlanje and it is tempting to suggest that in spite of a slight discrepancy in determined ages, both represent an early volcanic phase of the province, locally at least 4,000 feet thick.

Closely after the extrusion of the lavas, crustal warping had so reduced pressures beneath the crust that extensive partial melting occurred, possibly assisted by local abundance of water and carbon dioxide, followed by upward migrations of light fractions which converted the lower crustal rocks to syenite, quartz-syenite and granite. These migrated upwards by major stoping into the upper crust and into the overlying alkaline lavas eventually to form, for example, the Mlanje Massif. Extreme fractionation may have caused generation of carbonatite which rose explosively sometimes through already emplaced plutons. The relationship between crystal warping and alkaline magmatism has been considered by Bailey (1964) whose conclusions seem to be supported by the evidence from southern Malawi.

Interesting implications follow if it is accepted that the Chilwa Alkaline Province was initiated by warping. Apart from Salambidwe, Chuare and Muambe, all known complexes in southern Malawi and surrounding Mozambique lie in a belt some 50 miles wide trending north-west to south-east parallel to the Cholo Fault. There is therefore the possibility that, in early Cretaceous times an elongate cymatogenic arch (King, 1962) occupied the area between the present Lower Shire Valley and the southern part of Lake Malawi and the Chilwa depression. At that time, the Lake Malawi and Chilwa depressions would be continuous, and separated from the Lower Shire/Zambezi basin by highlands that occupied the sites of the present Shire Highlands and Middle Shire Valley. Drainage to the north of the arch may have flowed into the Malawi/Chilwa basin and thence direct to the coast in the vicinity of Quelimane while southern drainage would have flowed into the Lower Shire Valley thence into the Zambezi. Thus, there would have been two north-east trending depressions some 80 miles apart separated by a highland divide. Supporting evidence for the existence of high ground to the west of Zomba Mountain at a time shortly after the formation of the arch, when the cover of the Zomba pluton was partially removed, is recorded by Bloomfield and Young (1961). These authors, from a study of drainage development on Zomba Mountain, have suggested that the oldest plateau drainage flowed from the west from an upland area occupying the site of the lower part of the present day Upper Shire Valley.

During or very shortly after the emplacement of the Mlanje plutons, warping again probably resulted in further movement along the Cholo Fault and possibly also along the Chirobwe Fault on the north-eastern flanks of the arch. There is no sign of such fracturing alongside the Chilwa continuation of the Lake Malawi depression suggesting that this area of the crust remained competent. The further downdropping of the Lower Shire increased the erosion of the arch, the covering of volcanic rocks was stripped eventually leading to the destruction of the Cholo Scarp and the development of an undulating surface studded with hills where the tops of the major plutons were exposed. Most of the upper part of the Zomba intrusion was planed apart from a few resistant ridges but Mlanje, being larger and at a higher level, was only partially planed across the then exposed margins.

Most of the central parts of the massif then formed a group of hills rising to about 4,000 feet above the surrounding surface. The calcareous sediments provisionally correlated with the Lupata Series may have been deposited at this time but there is no evidence to confirm this.

After this first middle or possibly upper Cretaceous (post-Gondwana) erosion to form the highest bevels on Zomba and Mlanje mountains further uplift took place introducing a new erosion cycle which would ultimately result, by Miocene times, in the reduction of most of the area to a gently undulating surface (the African Surface) of low relief above which the cliff-bounded Zomba and Mlanje mountains stood largely in their present-day form. By this time the early Cretaceous arch would have been largely but not completely obliterated by the erosion of 4,000 feet of Basement Complex gneisses from the crest. Even so, the upper part of the Shire River might still have flowed north-eastwards into the Lake Malawi/Chilwa depression as would the bulk of the drainage from Mlanje. The Lower Shire would still be draining the south-western parts of the much reduced arch unconnected with the Lake Malawi/Chilwa depression. King (1962) has estimated the elevation of this widespread African Surface to be rarely more than 2,000 feet above sea level.

The stage was now set for another major transfiguration not only of southern Malawi but of the whole of East and Central Africa. In King's words: "... as the Cainozoic era drew to a close the surface began to heave in broad undulations, mostly along old-established lines. The previous divides were uparched again and the former depressions lagged and were deepened. At maxima of local displacement rift valleys were generated in Central Africa; but the continent as a whole was uplifted most in the south and least along the Mediterranean shores. Everywhere the relief was accentuated, and across the tilted and corrugated landsurfaces drainage patterns were ponded or rejuvenated. Though antecedent courses were maintained by the major rivers, many large captures of drainage were affected" (*op. cit.*, pp. 288-289). In southern Malawi, these Plio-Pleistocene disruptions had a profound effect. Most noticeable was further subsidence of the Lower Shire area by at least 2,000 feet of movement along the Cholo Fault and the upraising of the planed Shire Highlands block. Simultaneous movement of about 400 feet along the Zomba Fault downdropped the Upper Shire Valley and similarly upraised the western margins of the block. It is thus suggested, although the evidence is scanty and largely circumstantial, that the Plio-Pleistocene rifting, although broadly coincident with the areas of post-Gondwana warping, was not confined to the original depressions. Instead of a rift developing on the site of the Chilwa depression a new rift appeared west of Zomba Mountain to connect the Lower Shire Rift with that of the southern part of Lake Malawi. The Lake Chilwa depression was thus separated by a fault scarp, trending almost at right angles to the Cholo Fault, from the downdropped Lake Malawi and Upper Shire.

A drastic change was thereby brought about in the Lake Malawi outlet, which cut a new channel, the rocky Middle Shire section, into the old-established Lower Shire Valley. There is no evidence to suggest that the Middle Shire Valley has ever been sediment-filled in either the Karroo or Cretaceous times. Further, in contrast to the upper and lower stretches, which are mature and of low gradient, the Middle Shire Valley is youthful and is actively cutting back into the mature valley above Matope. Such a conclusion conflicts with the views of Dixey (1926) who considers the whole of the present Shire Valley, lower, middle and upper, to be a pre-Cretaceous feature infilled with Cretaceous sediments since removed. The thesis now put forward is that in Lower Cretaceous times the Middle Shire Valley did not exist but was an area of high ground, continuous to the north-west and south-east and separating the present day Lower Shire from the upper which was an *inlet* channel into the Lake Malawi/Chilwa basin, reaching its mature stage of development in Miocene times. Dixey himself (1926) has suggested that before rifting, Lake Malawi drained via Chilwa into the Ruo system and thence into the Lower Shire but the youthful nature of the Ruo Valley makes this unlikely.

With the development of the Shire Rift, essentially in its present form, the Shire Highlands surface became tilted, locally away from the bounding scarps but generally to the north-east with further effect on the Chilwa Basin. The presumed south-eastern exit was truncated and the lake began to drain into the Lujenda River system (in Mozambique) to the north-east. By this time however the Lake Malawi outlet had been captured by the Lower Shire leaving the Chilwa Basin catchment reduced to a vestige of its former extent. This resulted in a reduction in the flow into the Lujenda, the silting-up of the outlet and a gradual reduction in the size of the lake which eventually became land-locked and saline. The lake is still shrinking and will probably disappear in time.

Although the Shire Highlands surface was tilted to the north-east this was not sufficient for the old Miocene drainage north-east of the vestigial arch to maintain completely its original easterly or north-easterly direction. This was because the effects on the drainage of lowering the Lower Shire Valley by rifting were greater than those caused by tilting of the block. It has already been suggested that the Upper Shire was completely reversed. Those streams flowing into the original Chilwa depression from the Mlanje area were only partially reversed in their upper parts, entirely as a result of base-level lowering in the Lower Shire; the Tuchila and Malosa which at present flow into the Ruo system are such streams. Before rifting both flowed into the Chilwa depression, the Tuchila into the Palombe system and the Malosa eastwards directly into the proposed outlet. By headward erosion two Ruo tributaries encircling Mlanje, the Tuchila and Malosa, were captured forming two classic elbows of capture. The Ruo also captured several other streams to the east of Limbe. These diversions further reduced the volume of water flowing into Lake Chilwa and its chances of survival.