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# THE KAPALAGULU LAYERED INTRUSION OF WESTERN TANGANYIKA

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## ABSTRACT

The Kapalagulu intrusion is approximately 4500 ft. thick, with near-vertical contacts and layering. The contacts appear to be tectonic, and there is no trace of a chilled margin. The intrusion comprises a Basal Zone, 400 ft. thick (olivine cumulates, with local sulfide and chrome-magnetite concentrations); an Intermediate Zone, 750 ft. thick (plagioclase, 2-pyroxene, olivine cumulates); and a Main Zone over 3000 ft. thick (2-pyroxene, plagioclase cumulates, with a 300 ft. anorthosite band in the lower part, and local concentrations of magnetite-bearing and pegmatitic facies near the top).

Rhythmic layering is pronounced in the Intermediate Zone and in the lower part of the Main Zone, and igneous lamination is also locally well-developed. There is slight cryptic layering throughout the intrusion ($An_{87\to79}$, $En_{85\to70}$), with anomalous variations over 1000 ft. including the anorthosite band in the middle of the layered series. These variations are attributed to sudden loss of volatiles from the magma. Interstitial micro-pegmatite occurs throughout the Main Zone, increasing in abundance upwards, and reaching 20–30% in the pegmatitic patches. A later suite of dolerite dykes is also characterized by a relatively large amount of acid mesostasis.

## INTRODUCTION

The Kapalagulu intrusion is close to the eastern shore of Lake Tanganyika (Fig. 1), about 70 miles south of Kigoma. Brief accounts of the geology have been given by Teale (1931, 1932), McConnell (1950), Wilson (1956), and Halligan (1957), whereas van Zyl (1959) has described the intrusion and surrounding rocks in considerable detail. The present study is based on ten weeks field work undertaken as part of the research programme of the 1959 Oxford University Tanganyika Expedition.

## COUNTRY ROCKS

The country rocks of the area comprise two principal groups, the basement gneisses of the Ubendian system and the sedimentary rocks (quartzites and phyllitic shales) of the Itiaso series. The contact between the two is faulted in the Kapalagulu region, but there is evidence elsewhere (Henderson, 1960) that the Itiaso series rests unconformably on the Ubendian. There is some controversy about the general stratigraphic position of the Itiaso series; McConnell (1950) and Henderson (1960) believe it to be part of the Bukoban system (possibly of Palaeozoic age), but the Geological Survey of Tanganyika (Quennell, 1956; Halligan, 1957) link it with the Karagwe-Ankolean system, which is considerably older than the Bukoban.

## THE INTRUSION

*General.* The Kapalagulu intrusion is exposed as a long, narrow belt, approximately 9 miles by 1 mile, trending NW.-SE. between the Ubendian gneisses and the Itiaso series, as shown in Fig. 1. The contacts of the intrusion are generally steeply-dipping, and approximately parallel to the foliation of the Ubendian gneisses and the bedding of the Itiaso sediments. Near the margins of the intrusion the igneous rocks have suffered extensive shearing, and there is no evidence anywhere of original roof or floor facies. All the layered features of the intrusion are also steeply-dipping (except at the southeastern end of the outcrop), but there can be little doubt that this is the result of tilting subsequent to the consolidation of rocks formed by gravitative accumulation of crystals. The original upward sequence can clearly be established from the mineralogical variations, and it is

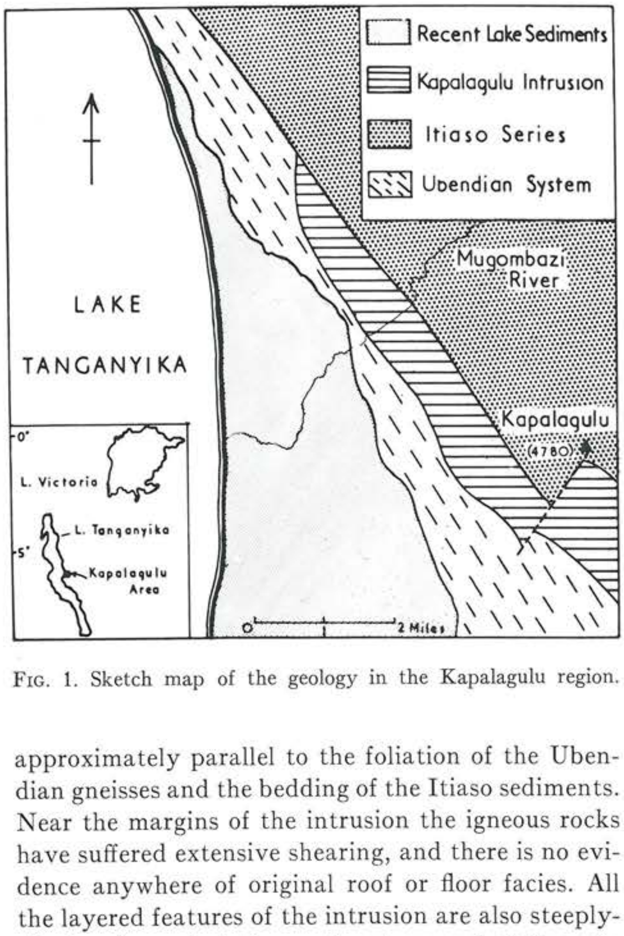

FIG. 1. Sketch map of the geology in the Kapalagulu region.

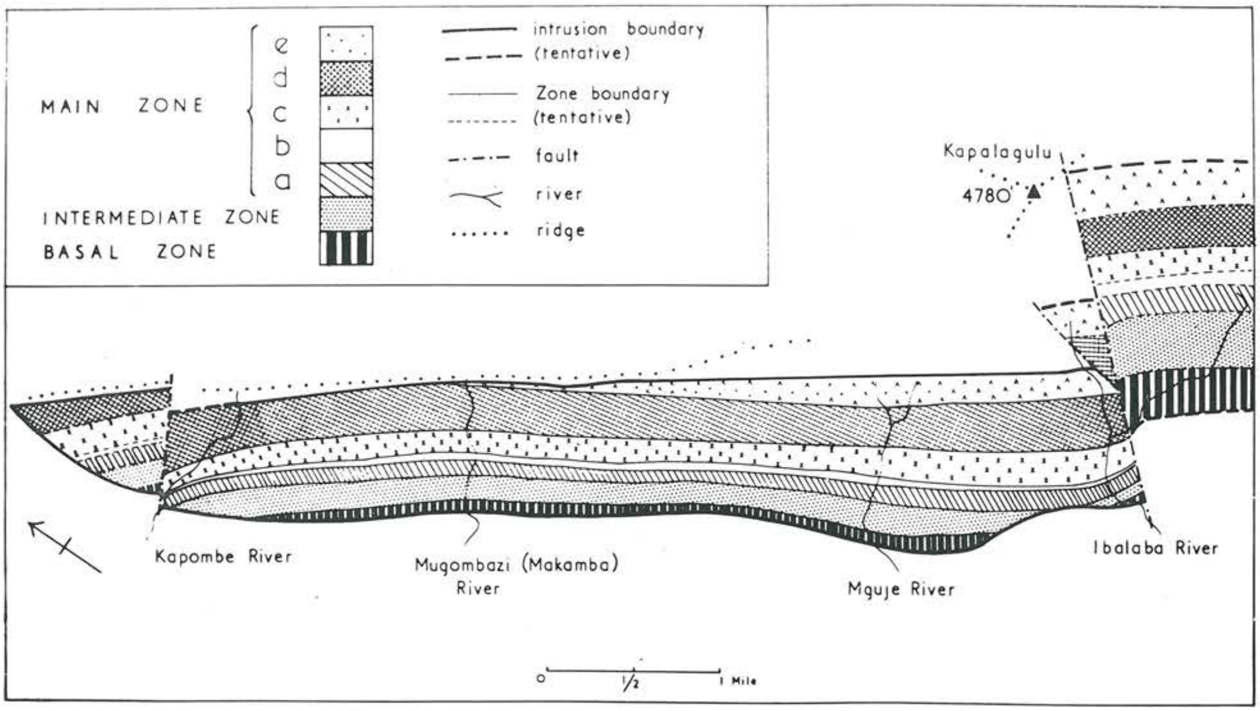

FIG. 2. Geological map of the Kapalagulu intrusion.

seen that the lowest members outcrop along the southwestern margin, adjacent to the Ubendian, and the highest members along the northeastern margin, adjacent to the Itiaso series.

On the basis of their field characteristics, van Zyl (1959) divided the layered series into three principal units, the Basal Zone, Intermediate Zone and Main Zone (containing a subsidiary Anorthosite Zone). These terms are all retained in the present account, but further subdivision of the Main Zone (into subzones a, b, c, d, e) has been found convenient. Main Zone (b) is equivalent to van Zyl's Anorthosite Zone. The nomenclature of the rocks themselves is based on the terminology introduced by Wager *et al.* (1960). A summary of the thickness and mineralogy of the principal subdivisions of the intrusion is given below:

| | | |
|---|---|---|
| MAIN ZONE | (e) plagioclase-augite-magnetite cumulates | 700 ft |
| | (d) plagioclase-2 pyroxene cumulates | 1300 ft |
| | (c) plagioclase-2 pyroxene cumulates | 500 ft |
| | (b) plagioclase cumulates | 300 ft |
| | (a) plagioclase-2 pyroxene cumulates | 550 ft |
| INTERMEDIATE ZONE | plagioclase-olivine-2 pyroxene cumulates | 750 ft |
| BASAL ZONE | Olivine cumulates | 400 ft |
| | Total | 4500 ft |

The most complete succession and the maximum thickness of layered series (4500 ft) is developed in the region of the Mguje River (Fig. 2). Northwestwards from here Main Zone (e), and possibly part of Main Zone (d), are progressively cut out. In the same direction the Basal Zone is roughly constant in thickness for about 3 miles, but the lower contact of the intrusion then swings to the north, cutting out the Basal Zone, Intermediate Zone, and part of the Main Zone in succession. At the north-western termination of the intrusion only Main Zone (d) is represented. To the south-east of the Mguje River the upper contact appears to be conformable to the layering, but the Basal Zone and the Intermediate Zone are locally cut out at the lower contact. In the Ibalaba River the succession appears to be complete again, but there is some evidence that the total thickness is reduced. In the vicinity of Kapalagulu Mountain the width of outcrop of the intrusion is much greater than elsewhere, but this is believed to be the result of generally low dips (20–25°). Poor exposure in this area prevented a detailed study of the succession or an accurate assessment of thickness, and further south-east the termination of the intrusion is completely obscured by drift.

The study of the mineralogical and petrological variation throughout the layered series is based on detailed traverses in the Mugombazi (Makamba) River where the succession is best exposed, and in

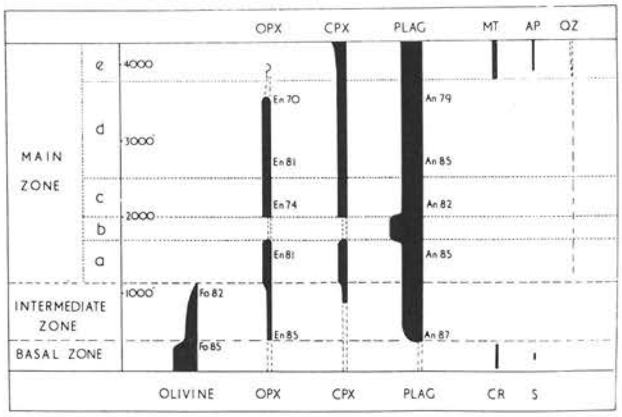

FIG. 3. Summary of the main mineralogical variations with height in the layered series. The dotted lines indicate minerals restricted to intercumulus occurrence. Major modal variations are indicated by changes in the thickness of the individual columns (Cr, chromite; S, sulfides).

the Mguje River where the maximum thickness is developed, but material from other traverses has been used to establish certain details of the succession.

*Phase layering.* The division of the layered series into zones and subzones is based on the major changes in the nature of the cumulus mineral assemblage. This type of variation has been termed "phase layering" by Hess (1960). The evidence is summarized in Fig. 3, where the appearance and disappearance of cumulus phases are related to stratigraphic position in the series, using an arbitrary height scale. An approximate indication of the cryptic layering and of the modal variations (disregarding the small-scale rhythmic layering) is also given in the same figure.

Olivine is the only important cumulus phase in the Basal Zone, although cumulus chrome-magnetite is commonly present in small amounts. The base of the Intermediate Zone is marked by the incoming of cumulus plagioclase and orthopyroxene, which increase in amount upwards at the expense of olivine, and are joined by cumulus augite in the upper part of the zone. Subzones (a), (c) and (d) of the Main Zone contain cumulus plagioclase, orthopyroxene and augite, but Main Zone (b) contains only cumulus plagioclase. The distinction between subzones (c) and (d) is based on changes in texture and mineral compositions. Cumulus orthopyroxene appears to be absent above 3600 ft, and the base of subzone (e) at 3800 ft is marked by the incoming of cumulus magnetite. Cumulus apatite appears a little higher in the succession, but the remainder of the Main Zone consists of heavily altered and sheared rocks.

*Cryptic layering.* The degree of cryptic layering in the intrusion has been determined in a preliminary way by measurements of the optical properties of the principal cumulus minerals. It is hoped to substantiate these results with chemical analyses of separated minerals in the near future.

### (a) Orthopyroxene

By far the most sensitive indicator of position in the layered series was found to be 2V of orthopyroxene (Fig. 4). This property appears to vary independently of changes from cumulus to intercumulus habit in the rhythmically layered sequences. However the variation is not simply the result of progressive iron enrichment from bottom to top of the intrusion. There is a gradual decrease in 2V from the intercumulus pyroxene at the top of the Basal Zone ($2V_\alpha = 85°$), throughout the Intermediate Zone and into Main Zone (a), followed near the top of this subzone by a very sharp reduction over approximately 100 ft from 74° to 58°. Intercumulus orthopyroxene in the anorthosite subzone is too heavily altered for measurement of 2V, but the relatively low angles (58–60°) are maintained throughout the 500 ft thickness of subzone (c). Above this there appears to be a gradational increase in 2V from 60° to 75° over 300 ft in the lower part of subzone (d), followed by a progressive decrease again throughout the remainder of the layered series, as far as fresh orthopyroxene is present. The highest recorded cumulus orthopyroxene, from 3600 ft, has a 2V of 55°; and the minimum value obtained was 44° from intercumulus orthopyroxene just above the base of subzone (e) at 3900 ft. Using the curves published by Hess (1960)

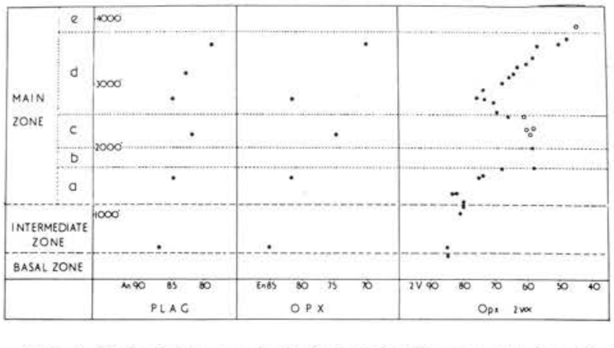

FIG. 4. Optical data on plagioclase and orthopyroxene from the layered series. Plagioclase compositions based on refractive indices of cleavage fragments using Tsuboi's curves. Orthopyroxene compositions based on measurements of $\gamma$ using the curve given by Hess (1960 Fig. 9). ○ indicates 2V measurements of inverted pigeonite.

to relate 2V to chemical composition the overall variation in the Kapalagulu orthopyroxenes appears to be from $En_{85}$ to $En_{50}$. However, refractive index ($\gamma$) determinations suggest that the true composition variation is less extreme than this, and is probably from $En_{85}$ to approximately $En_{70}$ (Fig. 4). They also confirm that the variation is not smoothly progressive throughout the layered series, but shows a marked reversal at the bottom of Main Zone (d).

Othopyroxene always contains fine exsolution lamellae of augite parallel to (100), but at two levels in the intrusion there is clear evidence, in the form of exsolution lamellae on original monoclinic (001) planes, that the orthopyroxene is inverted pigeonite. The lower occurrence comprises the top 300 feet of Main Zone (c), where the composition of the orthopyroxene is $En_{75}(\gamma=1.696)$ and the crystals are always poikilitic in habit. Lower in the same subzone, undoubted cumulus orthopyroxene, with no trace of relict monoclinic structures, has the same 2V as these poikilitic inverted pigeonites and is assumed to have the same Fe/Mg ratio. Inverted pigeonite also occurs in Main Zone (e), where the orthopyroxene is rarely fresh, and is always intercumulus in habit. Here the 2V of the inverted pigeonite is distinctly smaller (44°–47°) than in Main Zone (c).

### (b) Plagioclase

Cumulus plagioclase is consistently present from the base of the Intermediate Zone upwards. Preliminary results indicate that there is some cryptic variation (as determined from measurements of refractive indices of cleavage fragments, using Tsuboi's curves, and from extinction angles of albite twins) which parallels the orthopyroxene variation, but is less pronounced (Fig. 4). The overall change in composition is from $An_{87}$ to $An_{79}$, with a slight reversal from $An_{82-83}$ in Main Zone (c) to $An_{85}$ in the lower part of Main Zone (d). The results are not precise enough to indicate whether there is a sharp increase in Na content at the top of Main Zone (a), parallel to the iron enrichment of the orthopyroxenes.

### (c) Augite

Cumulus augite is present in the upper part of the Intermediate Zone and throughout the Main Zone (except for the anorthosite sub-zone), and is the only fresh cumulus phase in much of Main Zone (e). Precise compositions have not yet been determined, but preliminary results indicate that there is slight cryptic variation, similar to that of the feldspar.

### (d) Olivine

Olivine is restricted to the Basal Zone, where it is almost always heavily serpentinised, and the Intermediate Zone. Direct measurement of 2V shows that there is slight iron enrichment upwards throughout this range of 1150 ft. ($Fo_{85}$ to $Fo_{82}$), but van Zyl's suggestion (1959) that there is a reversal of this trend within the Basal Zone has not been confirmed.

## *Rhythmic layering and general petrography*

### (a) Basal Zone

The Basal Zone comprises approximately 400 ft of olivine cumulates which exhibit very little sign of rhythmic layering, except for occasional concentrations of chrome-magnetite. The principal intercumulus constituents are augite, orthopyroxene and plagioclase, all of which appear to be of high temperature composition and are generally unzoned, so that the rocks are essentially adcumulates. Individual pyroxenes are typically very extensive (2 or 3 cm across) but the plagioclase rarely forms large poikilitic crystals. Approximately in the middle of the Basal Zone there is a layer, 20 or 30 feet thick, in which sulfides (mainly pyrrhotite, with associated pyrite, chalcopyrite, sphalerite and pentlandite) are relatively abundant. Generally the sulfides occur interstitially, in places in quite large poikilitic patches, but locally sulfide globules are enclosed within poikilitic pyroxene crystals. Following van Zyl (1959) it is believed that the sulfides separated initially as an immiscible liquid phase.

### (b) Intermediate Zone

The base of the Intermediate Zone can be clearly located in the field by the incoming of abundant cumulus plagioclase, which just precedes cumulus orthopyroxene. Cumulus augite only appears in the upper part of the zone, at about 900 ft, but it was impossible to use this in the field as a basis for subdividing the zone, partly because of the difficulty of distinguishing augite from orthopyroxene in hand specimen, and partly because cumulus augite only occurs intermittently at first. Cumulus olivine and orthopyroxene occur together in a number of layers throughout the 750 ft thickness of the Intermediate Zone and show parallel iron enrichment upwards through this sequence. This persistent overlap of cumulus olivine and orthopyroxene may indicate that the two minerals were nucleating at different levels in the magma, as suggested by Jackson (1961)

FIG. 5. Typical rhythmic layering in the Intermediate Zone, near the Mguje River.

to account for thick olivine-orthopyroxene cumulates in the Ultramafic zone of the Stillwater complex.

Rhythmic layering is common in the Intermediate Zone. It is mainly characterized by variations in the amounts of olivine and plagioclase, and both these minerals are invariably present as cumulus phases. Olivine rarely comprises more than 40% by volume, except at the very base of the zone, and in many layers is less than 15%. Cumulus pyroxene is rather sporadic in occurrence, but when present usually comprises 20–30%. When both varieties of pyroxene are present as cumulus phases they are typically associated in roughly equal proportions, but occasionally augite occurs by itself. Individual layers are usually between one inch and a foot or two in thickness (Fig. 5) and show very little lateral variation in thickness or mineral proportions. Evidence of slumping was seen in one case only, and there was rarely any indication of gravity stratification. Weak igneous lamination of the plagioclase crystals is locally developed, but there is no preferred orientation of elongate crystals in the plane of lamination. Of the cumulus phases in the Intermediate Zone, olivine crystals are always distinctly larger (approximately 2–3 mm diameter) than the plagioclase or pyroxene crystals. The rocks are all essentially adcumulates (or heteradcumulates where cumulus augite or orthopyroxene is absent).

### (c) Main Zone

The subdivisions of the Main Zone have already been discussed. The boundaries between them cannot be fixed in the field within 30 or 40 feet because the major phase changes, such as the disappearance of cumulus pyroxene below subzone (b), are generally not abrupt. Rhythmic layering is mainly confined to subzones (a) and (c), where it consists of variations in the proportions of plagioclase to pyroxene. Both these phases are consistently present at all horizons throughout the Main Zone (except in the anorthosite subzone), but where there is rhythmic layering the total pyroxene content may vary from 15% to 70% by volume. The average content is about 30%. The relative distribution of augite and orthopyroxene is rather variable and in many layers only one cumulus pyroxene phase is present. This variation appears to be independent of the changes in the proportions of plagioclase to total pyroxene. The scale of the layering is generally finer than in the Intermediate Zone, with individual layers often less than an inch in thickness. Locally, there is evidence of lateral impersistence and current-bedded structures (Fig. 6), but there is no gravity stratification. Igneous lamination of plagioclase and pyroxene is common where rhythmic layering is developed, and at certain horizons where the orthopyroxene forms long bladed crystals (sometimes 5–6 mm in length, by 0.5–1 mm broad) there is a rough orientation of the *c* axes in the plane of lamination. The most perfect igneous lamination occurs in the upper half of subzone (c), where the rocks are plagioclase-augite cumulates with large poikilitic crystals of inverted pigeonite. This 300 ft thickness of distinctive cumulates conveniently marks the top of subzone (c), because the reversal of the cryptic layering (as shown by the variation in 2V of orthopyroxene) appears to start in the succeeding unlaminated cumulates.

There is a gradual upward change in the nature of the intercumulus material throughout the Main

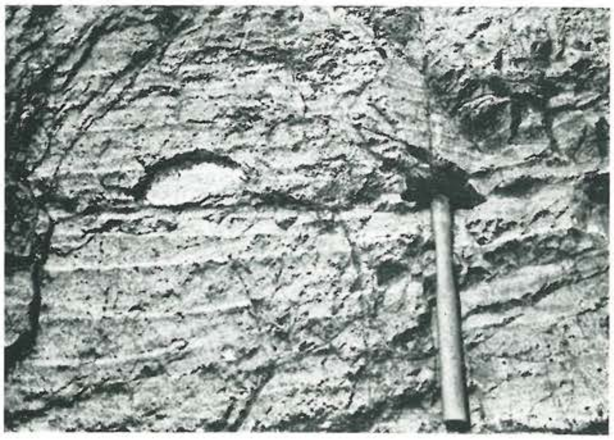

FIG. 6. Current bedding in rhythmic layering of Main Zone (c), Mugombazi River.

Zone. As in the Basal and Intermediate Zones, the rocks of the lower part of the Main Zone are essentially adcumulates. Small quantities of interstitial quartz first appear in Main Zone (a), but there is no trace of zoning of the plagioclase or pyroxene crystals, except in extremely thin films adjacent to the quartz. At horizons where only one pyroxene is present as a cumulus phase the other pyroxene forms extensive poikilitic crystals, but even these are unzoned and consist entirely of high temperature material. Such rocks are heteradcumulates.

Interstitial quartz increases in abundance upwards through the Main Zone, and is typically associated with alkali feldspar in micrographic intergrowth in Main Zone (d) above 2900 ft and in Main Zone (e), where micropegmatite reaches as much as 10% by volume. Even high in the Main Zone the plagioclase and augite are scarcely zoned, and the intercumulus orthopyroxene is not of significantly lower temperature composition than the associated cumulus minerals. There must have been considerable adcumulus growth before the interstitial liquid was completely trapped, and the rocks are probably best described as mesocumulates (Wager *et al*, 1960).

Small pockets and lenses of gabbro pegmatite are sporadically developed in the upper part of subzone (d) and in subzone (e). These are usually only a few inches across, and typically show a rough conformability with the steeply-dipping layered structures. They consist of large, heavily-altered plagioclase crystals, with cores of $An_{75-80}$ and strongly zoned margins, large augite crystals and a high proportion of quartz (up to 15%), much of it intergrown with alkali feldspsr. Sometimes the presence of inverted pigeonite can be detected from traces of augite exsolution lamellae, even though the host orthopyroxene has been completely altered. Iron ore and apatite are locally abundant.

*Sheared marginal rocks.* The southwestern margin of the intrusion is poorly exposed, and generally consists of heavily serpentinised Basal Zone cumulates adjacent to altered biotite-oligoclase gneisses of the Ubendian system. Within 50 to 100 feet of the contact both rock types are sheared, generally along steep planes roughly parallel to the margin of the intrusion. The same type of relationship is found where the Basal Zone is missing from the layered succession; sheared and altered rocks of the Intermediate or Main Zones are adjacent to the Ubendian. Shear zones also occur locally throughout the intrusion, and many of these are roughly parallel to the layering.

At the northeastern margin of the intrusion, heavily altered rocks of the Main Zone are in contact with quartzite (or, rarely, phyllitic shales) of the Itiaso series. In the igneous rocks, over a distance of approximately 250 ft from the contact, the plagioclase is always completely replaced by a turbid aggregate of clay minerals, and the orthopyroxene by chlorite. The augite is less readily altered and remnants of fresh augite are usually present to within 30 ft of the contact. Throughout most of this zone of heavy alteration there has been little deformation, and igneous textures are well preserved, but within 30 ft of the contact there has been considerable shearing, and the rocks are essentially chlorite-schists, with quartz (always strained), magnetite, and occasionally apatite as the only relict igneous minerals. The only traces of the original texture are small fragments of quartz showing micrographic intergrowth with altered alkali feldspar. In the Mugombazi River, where the actual contact is exposed, the modified igneous rocks appear to grade into a zone of quartz-rich cataclasite, 2–3 ft in thickness, adjacent to the massive quartzite of the Itiaso series. Some of the quartz in this cataclasite shows traces of micrographic texture and must have been derived from the Main Zone. However, the amount of quartz suggests that much of it was sedimentary material. Thus, there appears to have been mechanical mixture of the igneous and sedimentary rocks in a narrow fault zone at the upper contact of the intrusion. The main quartzite itself is generally unsheared, and appears to have acted as a relatively competent unit during emplacement of the igneous rocks.

*Dikes associated with the intrusion.* Numerous dolerite dikes cut the layered rocks and are distinctive in that they invariably contain a notable amount of interstitial quartz and alkali feldspar. This suggests a possible genetic link with the intrusion itself, and is also of importance in dating the intrusion, because similar dikes of post-Bukoban age are regionally important in Tanganyika. The plagioclase crystals have cores of $An_{75-77}$, with strongly zoned margins and are accompanied by augite, pigeonite and iron ore. A few heavily-chloritized crystals of orthopyroxene were seen in one dike. The amount of interstitial micropegmatite varies from dike to dike, but is usually between 10% and 20% by volume.

*Discussion of the cryptic variation and the anorthosite subzone.* The overall variation in mineral composition is clearly the result of fractional crystallization of basic magma. However, the pattern of the cryptic layering, with the rather abrupt reduction in Mg content of the orthopyroxene (and probably in Ca content of the plagioclase, although this is less well established) at the top of Main Zone (a), followed by a reversal at the base of Main Zone (d), is anomalous. Further, it seems likely that this anomalous pattern is in some way connected with the origin of the anorthosite subzone. On general grounds it is unlikely that the 300 ft thickness of plagioclase cumulates represents merely an extreme winnowing effect, especially as there is no sign of a complementary pyroxene-rich horizon beneath it. Therefore, it seems that there must have been an important change in the nature of the magma, which affected the composition, as well as the distribution, of the cumulus plagioclase and pyroxenes. One possibility is that the magma composition was changed locally by resorption of plagioclase crystals, as suggested by Hess (1960) to explain the anorthosites of the Stillwater Complex. However, it is difficult to account for the variation in the composition of the Kapalagulu orthopyroxenes on this hypothesis. Modification of the magma composition by contamination might have had the necessary effect, but there is no reason to suppose that material of the required composition was available. A more likely explanation is that the water vapor pressure changed. Yoder (1954) has shown that increasing water vapor pressure in the diopside-anorthite-water system causes the position of the eutectic point to be depressed and shifted towards the anorthite end of the system. Conditions during the precipitation of plagioclase-pyroxene cumulates of Main Zone (a) may be thought of as approximating to the eutectic point in the simple diopside-anorthite system. If there had been a sudden reduction in water vapor pressure, perhaps associated with volcanic activity at the surface, then there may have been a period during which plagioclase alone was precipitated before "eutectic" conditions were re-established. Further, consideration of the albite-anorthite-water system (Yoder *et al.*, 1957) indicates that reduction of water vapor pressure would favor the crystallization of a less calcic feldspar, and similarly a less magnesian variety of orthopyroxene might be expected. The variation in 2V of the orthopyroxenes indicates that the return to a more magnesian composition at the bottom of Main Zone (d) is more gradual than the pronounced iron enrichment at the top of Main Zone (a), and this pattern would fit well with the likely variation of water vapor pressure in magmas, where volatiles would probably be lost suddenly, but built up again gradually.

*Origin of the rhythmic layering.* The rhythmic layering, which mainly consists of variations in the proportions of plagioclase to mafic minerals, is probably the result of variable current action in the magma. This suggestion is supported by the occurrence of igneous lamination at many horizons, and also by the local development of current-bedded structures. However, this type of mechanism does not account for the fact that the two pyroxenes, which are of similar size, shape, and density, do not always occur together as cumulus phases in the upper part of the Intermediate Zone and in Main Zone (a), (c) and (d) although the large-scale pattern of phase layering indicates that they were both generally available in those parts of the layered series. It seems that there must have been minor fluctuations in the physicochemical conditions of the magma precipitating these phases, so that they did not both nucleate simultaneously all the time. There may have been slight changes in temperature or composition locally, perhaps due to convection, or non-equilibrium conditions may have been developed, at least periodically, so that differing powers of crystal nucleation (Wager, 1959) of augite and orthopyroxene could have been responsible for the patchy distribution of these phases in the resulting cumulates. Thus the rhythmic layering in the Kapalagulu intrusion may be the complex result of crystal sorting superimposed on a small-scale type of phase layering due to minor local variations in the magma conditions.

*The emplacement of the intrusion.* Various interpretations of the contact relationships of the intrusion have been suggested. McConnell (1950) indicates that the intrusion is younger than the Itiaso series. Wilson (1956) implies that the local cutting out of the lower zones along the south-western margin was the result of progressive overlap by higher zones during crystal accumulation. Van Zyl (1959) interpreted the upper contact of the intrusion as an unconformity, thus indicating pre-Itiaso emplacement. From the present study it is concluded that both the upper and lower contacts are tectonic, and that the evidence of their original nature has been destroyed by faulting and shearing. This would account for the absence of floor or roof facies, as well as the cutting out of certain zones. In particular the progressive disappearance of

Main Zone (e) to the north-west of the Mguje River is more reasonably explained on this basis than as the result of variable deposition. It is impossible to estimate how much of the original layered series is missing, but by analogy with other layered intrusions, a considerable thickness of cumulates higher than Main Zone (e) may have been present at one time. On the other hand it is possible that accumulation was disturbed soon after the deposition of Main Zone (e), and the remaining magma fraction dispersed elsewhere. In this connection it is possible that the dikes cutting the intrusion represent part of such a residual fraction. In either case it is assumed that the present layered series does not represent the entire crystallization products of the parent magma.

The age of the intrusion cannot be established on the available evidence, although its actual emplacement by faulting (and tilting) into its present position is clearly post-Itiaso. If the quartz-dolerite dikes cutting the intrusion are genetically related to it, and can also be equated with the regional post-Bukoban quartz-dolerite dikes, then the crystallization of the layered series was post-Bukoban too.

## ACKNOWLEDGMENTS

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