THE KAPALAGULU BASIC COMPLEX, TANGANYIKA TERRITORY.

By

COLIN VAN ZYL.

Presented in partial fulfilment of the requirements for the degree of Master of Science in the Faculty of Science, University of Pretoria, South Africa,

February 1956.

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ABSTRACT.

The Kapalagulu Complex is situated near the eastern coast of Lake Tanganyika, and some 70 miles south of Kigoma.

The Complex is sill-like to lopolithic in shape, intrudes the Basement System (Archaean), and is overlain by sediments of the Bukoban System. Locally, both the Complex and the country-rocks have been tilted to a sub-vertical position, and consequently they are exposed in stratigraphical cross-section along the land surface.

As a result of magmatic segregation during crystallization of the Intrusion, three 'conformable' zones are formed: (1) A Basal Zone of bronzite picrite; (2) An Intermediate Zone of banded olivine hyperite; and (3) A Main Zone, in which the most common rock-type is hyperite. The Main Zone contains an interstratified Anorthosite Band. Within the Basal Zone is a horizon along which there is a high concentration of sulphides. The sulphides of this Ore Zone are mostly pyrrhotite, and presumably they concentrated by settling on becoming immiscible in the magma.

CONTENTS.

ILLUSTRATIONS.

I: INTRODUCTION.

(1) Situation and general information.

As the area in question lies in somewhat unknown territory, it is the intention to give the reader more than the briefest details as to its location, existing means of communication and conditions in general.

The nearest European settlements (fig.1.) are Kigoma, Albertville and Mpanda.

Kigoma: A small port on the eastern shore of Lake Tanganyika. It is also the terminus of the Central Railroad which extends inland from Dar es Salaam. The population comprises approximately 25 Europeans, 400 Asiatics and many Africans. The Kapalagulu Intrusion is situated a few miles inland from Lake Tanganyika, and some 70 miles southwards of the town.

Albertville: Directly west of the Intrusion, in Belgian Congo. It is a relatively important port with a railway to Kabolo, so linking the port with the Congo rail-and river-network.

Mpanda: A small mining town 80 miles inland from the Intrusion. Between Mpanda and the village of Uvinza there is a road which is separated from Kapalagulu by 50 miles of rough and uninhabited terrain.

At present the most convenient means of communication is by a steamship which completes a circuit once every 21 days between Kigoma and the Northern Rhodesian port of Mpulungu. Arrangements can be made to be taken ashore at the little Arab-African trading post, Lagosa, which is about ten miles south of one's destination. In times of heavy rainfall a devious route from the shore may be necessary. The flat coastal belt of Lake Sediments tends to become flooded by overflowing of the Mugombazi and Leugele rivers (plate 1.).

There are numerous/.....

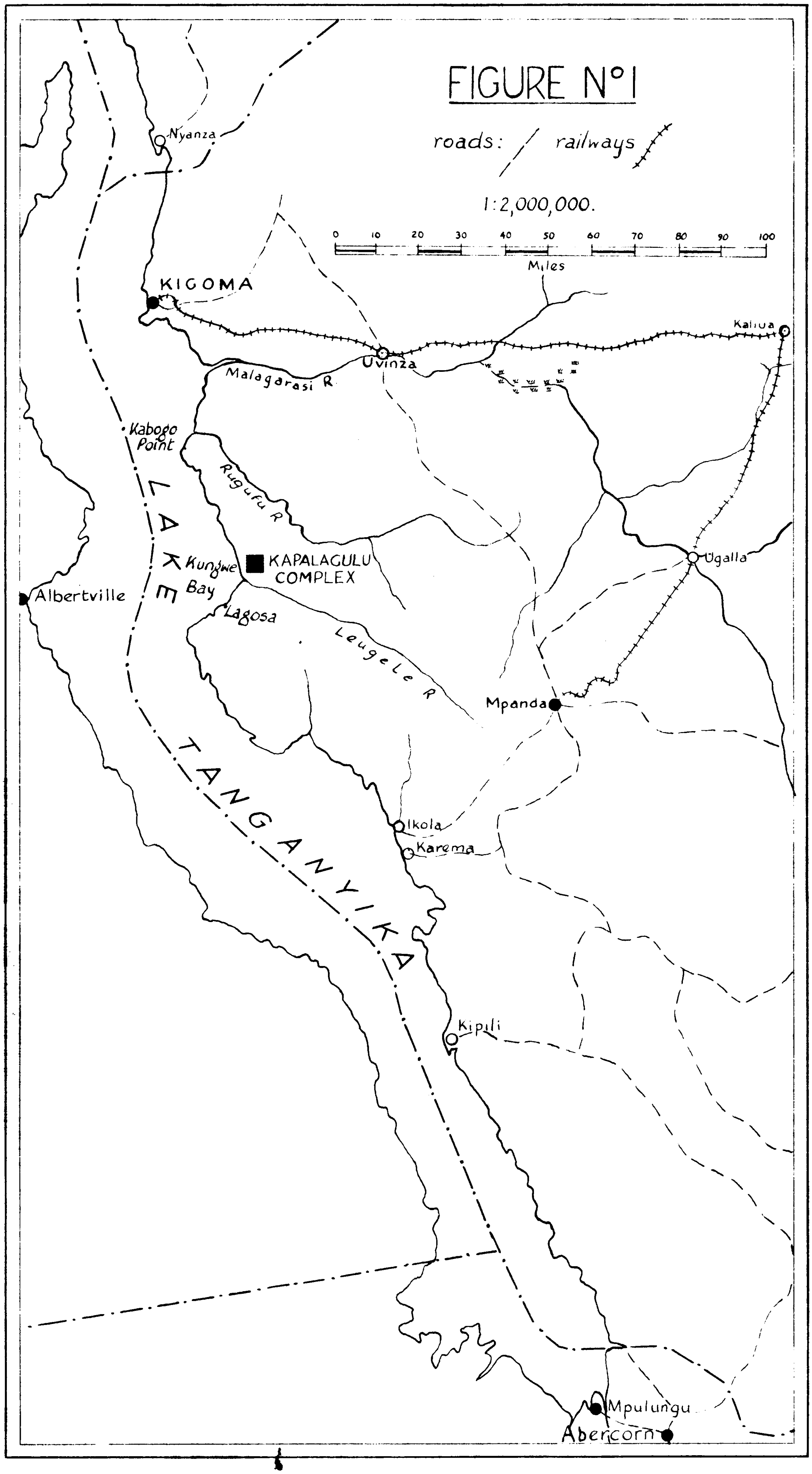
FIGURE N°1
roads:
railways
1:2,000,000.
0 10 20 30 40 50 60 70 80 90 100
Miles
Nyanza
KIGOMA
Uvinza
Kaliua
Malagarasi R.
Kabogo Point
Ruguvu R.
LAKE TANGANYIKA
Kungwe Bay
KAPALAGULU COMPLEX
Albertville
Lagosa
Leugele R.
Ugalla
Mpanda
Ikola
Karema
Kipili
Mpulungu
Abercorn

There are numerous footpaths and game -tracks, but away from these progress can become very difficult and even impossible unless the vegetation is cleared to some extent. This is most easily effected by burning the grass during the dry season.

Apart from the few Arabs at Lagosa, the inhabitants are Africans, mostly of the local Tongwe Tribe. With few exceptions all inhabitants are able to speak the "lingua franca", Ki-Swahili. The indigenous folk concentrate mainly on fishing in the Lake, or on small-scale farming on the relatively dry strips of land along the banks of the Mugombazi and Lougele rivers, which meander over the Lake Sediments. Livestock is limited to a few goats and fowls.

With the exception of the ten-odd Africans farming on a small clearing towards the south-eastern boundary of the area mapped in detail, it is devoid of human habitation. The black dense clay and numerous boulders associated with the Intrusion evidently render soil unsuitable for tilling.

The area is malarial and is also infested with tsetse-fly, against which precautions should be taken. One should also be prepared to meet big game.

The most suitable period for field-work is during the dry months which, in the writer's experience, is usually from July to late October. By the end of the year very damp conditions prevail and plant growth commences to flourish to a most distracting degree. The months March to May are most unsuitable for out-of-door life.

(2) Previous geological investigations.

Probably the first reference to the Kapalagulu Intrusion is as follows (Teale 1931, p41.): "A German file regarding mineral prospecting in 1914 records the occurrence in fair

quantity of nickeliferous ore/.....

near the shore of Tanganyika east of Kungwe Bay about six miles south of the Mukondozi *River. This occurrence has not yet been confirmed and examined by the Department, but the Director's journey recently into this region has proved a wide extent of basic rocks favourable both for the occurrence of nickel or copper. It is of interest in this connection that three of the concentrates from this region showed traces of nickel."

During 1927-'32 Sir E.O. Teale, who was at the time Director of the Tanganyika Department of Geology, made extensive traverses of Western Tanganyika, and a sketch-map (Teale —) of the Complex was produced.

A further report (Teale 1932, p28.), mentions the body as a "Noritic suite ranging from picrite through norite to dolerite", and short petrographical notes of some specimens were added.

In 1950 Elves and Wilson, in the interests of The International Nickel Company, made a reconnaissance of the Intrusion. They prepared an extremely useful little field-map (unpublished) showing the approximate boundaries and indicating geological horizons in the body.

During 1943-'47 Mc Connell made extensive traverses of Ufipa and Ubende in South-western Tanganyika. A 20 to 80 mile-wide belt along the eastern coast of the Lake was covered, extending from the Intrusion 220 miles southwards, to Abercorn. Mention of the Intrusion is very brief (Mc Connell, 1950; p15, 30 etc.), but his descriptions of Basement and Bukoban systems, which surround the Intrusion, are most comprehensive. It will be obvious from time to time in the present work that detailed mapping necessitates some minor alterations to his publication.

(3) Acknowledgements.

The nature of the writer's work was to assist in geological and diamond-drilling exploration during 1951-'53. He is indebted

to International Nickel Company/.....

*Probably Mugombazi River.

of Canada Limited, for permission to use the information in the way he has, and will always remember the encouraging and friendly interest of those who were at various times directly concerned with the project; amongst them Messrs. John Cilliers and Donald Campbell. A particular expression of gratitude to Mr. T.V. Baines, who controls the Company's interests in Central Africa, and to Mr. G.M. Stockley with whom the writer spent a few most happy and instructive months in the field.

Confidential information such as the location of bore-holes, bore-hole logs, assay values etc., are withheld for obvious reasons.

The greater parts of 1951 and 1953 were devoted to studies at the Department of Geology, University of Pretoria. Sincere thanks are tendered to Prof. B.V. Lombaard, formerly Head of the Department, and to the present Head and promotor Prof. J. Willemse and his staff for their willing guidance. In 1951 a generous grant from the Jan F.E. Celliers Bursary Fund enabled the writer to commence postgraduate studies.

II: GEOLOGICAL OUTLINE.

In the area encompassed by the present investigation, and excluding the Intrusive itself, there appear members of only two geological systems, namely the ancient Basement System and the considerably younger sedimentary Bukoban System. The rocks, especially those of the Basement System are covered in parts by recently deposited sediments, and also often by a thick mantle of decomposed material.

From Kigoma southwards, along the eastern coastline of Lake Tanganyika there is an extensive exposure of the Bukoban System (Stockley 1948 a.). Due to the resistant nature of these rocks, which are mostly sandstones and phyllites, and to rift-faulting the coastline is a very rugged one. This is particularly true of the terrain between Kabogo Point, some 40 miles south of Kigoma (fig.1.), and a position some 20 miles further south where the Bukoban System trends inland and Basement System appears for the first time on the shore-line. Along this 20 mile section the land descends precipitously to the water's edge. The writer considers that this feature is the effect of a continuation of the fault indicated by Mc Connell (1950) and which also appears on plate 1 of the present work.

With the appearence of Basement System, which is composed predominantly of gneisses and occasional quartzites, the shore-line swings gradually to an almost westerly direction, so forming Kungwe Bay. The change from Bukoban to Basement System also brings about a marked change in topography, vegetation and drainage; features readily detected in aerial photographs. The Basement System may also exhibit greatly contrasting relief, but whereas terrain occupied by Bukoban System is generally jaggard or angular, hills and mountains of Basement System,

though steep, are mostly/.....

rounded and have a smoother and more subdued profile.

As the change from Basement to Bukoban System is easily observed on aerial photographs, the contact between the two systems can be followed in this manner as it trends inland. The Bukoban quartzite dips steeply north-eastwards and for the most part forms prominent hogsback ridges immediately north of the contact (plate 1 and fig. 3.). Practically in the bed of the Tumba Stream, which is some six miles inland along the contact, lies the northern extremity of the Kapalagulu Complex.

On surface the Complex appears as a steeply dipping, long, narrow, somewhat boomerang-shaped body, with its long axis parallel to the regional strike of both the Bukoban and the Basement systems. The average width is approximately 5,000 feet and the total exposed area is approximately nine square miles. The country is one of contrasting elevations and is well wooded throughout; in some parts the vegetation being extremely dense.

On its upper, or northern side, the Complex is bounded by a high ridge of steeply inclined Bukoban sediments. This ridge is parallel to, and is a straight continuation of the ridge further north along the contact between Bukoban and Basement systems. This feature immediately brings to mind the possibility of a sedimentary contact between Bukoban System and the Intrusion; a feature which will be stressed subsequently.

From the ridge there is a steep and rather rugged descent, in parts over minor parallel ridges, to the southern or lower boundary of the Complex.. Thereafter there is usually an ascent again, now into country underlain by Basement System.

Drainage over the Intrusion is usually along deeply incised stormwater-gullies which follow the shortest route down to the lower contact. Along the lower contact it is common for clear streams to form. They flow parallel to the contact, for some distance before eventually cutting through into occasional low-lying parts in the Basement System.

The Complex is well/.....

The Complex is well layered and ranges from (a) under-saturated ultra-mafic rock types along the lower (Basement) contact, upwards through (b) olivine hyperite, (c) hyperite and norite, (d) anorthosite, (e) again hyperite and norite, to (f) sporadically developed quartz-bearing members which approach the composition of granodiorite. The layering strikes parallel to the length of the Intrusion and the dips are practically vertical in the northern part. The southern part has apparently undergone greater disturbance and the basal layers are overfolded and dip 50 degrees southwards.

As gravity-differentiation is considered responsible for the layering, one must conclude that the Complex was folded subsequent to its consolidation. The overfolding in the east is believed to be accompanied by rather obscure and complex faulting, including thrusting. A combination of tilting through very nearly 90 degrees, and erosion, has resulted in the exposure over a large area of a near-perfect cross-section of the body, the floor being the contact with the Basement System. It is pertinent to note that the floor is distinctly basin-shaped.

In places the layering is prominently reflected by the relief and the type of the vegetation. This is sometimes so marked that it is immediately obvious in aerial photographs (fig. 3.).

For descriptive purposes, it is considered advantageous to divide the Intrusion. The dividing boundary would be approximately parallel to, and in the vicinity of section-line AB(Plate 2.). In this manner the structurally complicated North-eastern Sector is separated from the North-western Sector.

III: TECHNIQUE AND METHODS IN FIELD-WORK.

(1) Mapping.

During August 1951-January '53 the area was mapped on a scale of 1:2,500, a theodolite, tape and stadia rod being used. As no survey beacons existed, use was made of an arbitrary grid, with north determined by simple balanced azimuth observations on the same star at equal altitudes.

Initially surface elevations were relative to an arbitrary datum. Subsequently, by means of a series of intersections between known points on the Intrusion and points specially constructed on the Lake shore, these elevations were corrected to elevations above mean sea-level. The Lake was assumed to be 2,534 feet above mean sea-level.

The construction of Plate 2 necessitated reducing 25-odd field sheets from 1:2,500 to 1:25,000 scale. Considerable detail had to be omitted.

(2) Magnetometric Survey.

When considered necessary, magnetometric traverses were made, usually normal to the lower contact and extending from within the Main Zone to well into the Basement System. Recordings were made on a Watts vertical variometer, at intervals not exceeding 100 feet. The traverses may be divided roughly into two categories, namely those over terrain where the geology and structure was to a large extent known, and those over terrain where the geology is obscured by soil or alluvium.

Where the geology and structure were known, the object of the traverses was to gauge the effect of the various zones when in different structural attitudes. In this respect traverses over and parallel to inclined boreholes were invaluable.

Although a large/.....

number of readings were taken over the rest of the Intrusion interpretations of the graphs constructed remained difficult and sometimes impossible.

The following are examples of the general trend under ideal conditions:-

The gabbroid rocks (norite, hyperite etc.), are inclined to give a constant figure of the order of 700 to 1,000 gammas, becoming slightly erratic on approaching the olivine-bearing zones.

In the ultra-mafic basal layers, there is one of two tendencies: There is either a gradual decrease to a few hundred gammas, followed by a relatively sharp increase, causing an easily recognised depression in graphical constructions, or extreme anomalies are registered, readings often catapulting hap-hazardly from positive to negative values, each of a few thousand gammas. These extreme differences were apparently always recorded over horizons containing concentrations of magnetite, and the anomalies are presumably the effect of dislodged fragments of this mineral, lying otherwise more or less in situ.

The effect of magnetic sulphides is uncertain. They are probably to a large extent responsible for the depressions already mentioned. In one particular instance, when a depression - type of curve was recorded, one of the readings was actually taken on an outcrop in which disseminated pyrrhotite was readily visible. However, for the most part magnetite is associated with the sulphide concentrations and presumably the effect of the magnetite is completely overshadowing.

Graphs of the anomalies over Basement System are generally characteristically smooth and consistent for some distance, a figure of +1000 gammas being most common. Exceptions were occasionally recorded over granitic veins in the gneisses. These are known to contain magnetite.

With the exception of traverses made over boreholes (to facilitate interpretation of subsequent traverses) magnetometric surveys were confined to the area of deeply covered rocks near/.....

the Mugombazi river, and to the south-eastern part of the Complex.

(3) Drilling.

Considerable diamond-drilling was done in conjunction with the field-mapping and, for economic reasons it was confined to the precincts of the floor of the Intrusion. Because of the steep dip of the layers, all holes were inclined, usually 30° to 60° to the horizontal. From the core the writer was able to select numerous specimens for laboratory examination. This was most fortunate, as surface exposures are poor, especially near the lower contact. Several structural features, especially faulting in the south-eastern part would not normally have been detected but were obvious in the core.

(4) Aerial Photographs.

The Intrusion is included in the part of Tanganyika Territory photographed by the Royal Air Force in 1947. Plate I was constructed solely from the photographs and their centres are indicated upon it. No control points were available away from the Intrusion, so the map was constructed by the simple procedure of piecing individual photographs together, aided by a stereoscope. Distortion was eliminated as far as possible under the circumstances. Fortunately there is considerable overlapping of adjoining photographs, but the scale of some traverses differed from neighbouring ones and corrections had to be made. To minimize error, the scale of the map was finally reduced almost by half, i.e. to 1:75,000. It should nevertheless be considered only sufficiently accurate to serve the purpose for which it was created, namely, to illustrate the structure of the region for some distance around the Intrusion.

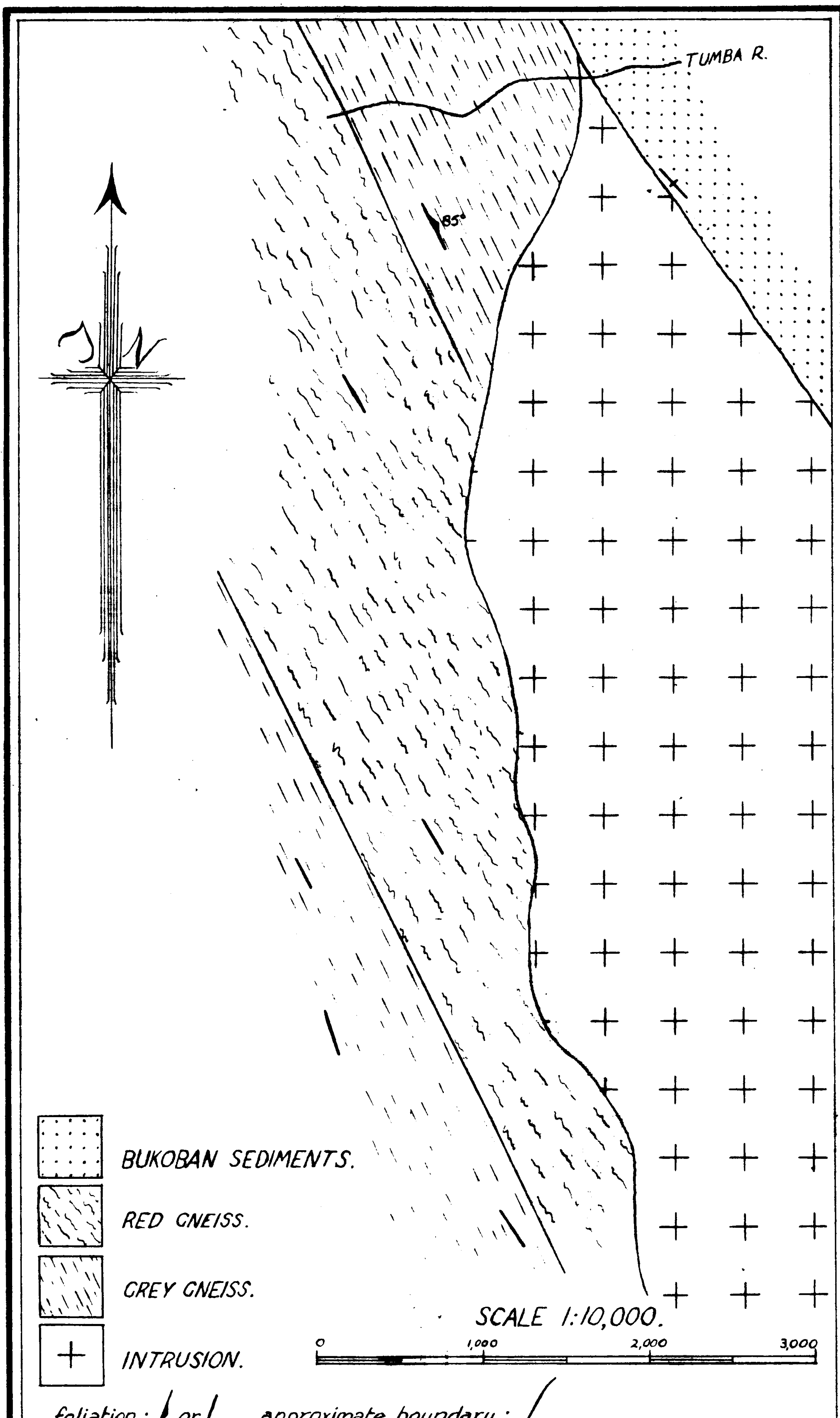

FIGURE 2 : GNEISS ZONES IN BASEMENT SYSTEM.

IV: BASEMENT SYSTEM.

From a point north-west of the Intrusion, and where Basement rocks first outcrop on the edge of the Lake (plate 1.), the coastline gradually turns westwards to form Kungwe Bay. The upper contact of the System continues south-eastwards inland, so that a large tract bordering on the Lake is occupied by this System.

In the Tumba Stream the Basement and the Bukoban systems are first intervened by the Intrusion. The Stream also roughly represents the northernmost limit of detailed mapping (plate 1.). For a thousand-odd feet downstream from the upper Basement contact, there are several outcrops of a medium to fine-grained dark grey gneiss, containing a network of red granitic veins. These veins vary from a few inches to a few feet in width and seldom exceed twenty feet in length.

Away from streams outcrops are rare, but country occupied by Basement System is distinctive. The soil is yellow to brown and is rich in coarse, easily recognisable gneiss fragments, and is well wooded by "miombo" (orchard bush, including genera Brachystegia and Isoberlinia). Grass is relatively sparse and of a distinctive appearance.

About 2,000 feet south-east of the Tumba Stream the presence of red granitic gneiss is indicated by a few outcrops and by soil containing fragments of this material. Although not readily apparent in the field, it is possible to zone the red and grey gneisses. Figure 2 is an example of this phenomenon in the northern part. The zones are not sharply defined, but are bounded by planes of rather vague outline. The planes are concordant with the foliation in the System.

Near the Mugombazi River there is a considerable encroachment of Lake Sediments, and outcrops of Basement System and Intrusion are so decomposed that it is difficult to differentiate them or determine their relationship. West of Kangoli Stream, which lies further south, exposures are plentiful and it is again/.....

possible to trace steeply inclined zones of gneiss.
Surface elevations increase southwards, culminating in the 3,500 feet-long Mgangamule Ridge, which is a hogback of very steeply dipping hard white quartzite. Viewed from the Lake the ridge resembles an inselberg, jutting some 650 feet above the monotonously flat Lake Sediments.

On plate 2 several occurrences of quartzite surrounded by gneiss are indicated. Rough extrapolation of the Mgangamule Quartzite joins it further southwards with several similar bodies lying parallel to the Kalaba Stream, yet enclosing each is an abundance of gneiss. This feature is particularly convincing just below the confluence of the Mguje and Kalaba streams. On the northern side is a quartzite hill sloping steeply down to the stream's edge. On the opposite side there is a 100-feet long ridge similar to Mgangamule and also with a steep quartzite crest. These two quartzite bodies are only 500 feet apart and are along the same stratigraphical horizon, yet in the stream between them there is a continuous section of grey sheared gneiss. Including Mgangmule Ridge, there is thus a 1-1/2 mile zone in which large masses of quartzite lie enclosed in gneiss. Situated between Mgangamule and the Intrusion is a similar but shorter, narrower and less distinct zone of quartzite outcrops.

It therefore appears that several concordant zones of red and grey gneiss exist, and that a possible third zone is one in which enclaves of quartzite occur. Following the H.H. Read school of thought, it is concluded that the gneisses are the products of metasomatic alteration of the original (semipelitic) layers of the System, and that the quartzites represent resistant undigested relics. The continuity of the zones (spectral layers), is accepted as proof that mobilization or parautochthonous intrusion played at the most a very insignificant role in the area so far discussed.

Another quartzite-gneiss zone/.....

Another quartzite-gneiss zone was followed for a distance of 1,500 feet, striking westwards from a position some 1,200 feet north of point A of section AB (plate 2.). It is possible that it is an extension of one of those previously discussed, and that its anomalous strike is due to an ancient fault, now masked or obliterated by the high grade of metamorphism to which the System has been subjected. Such a fault could lie parallel to section-line AB and 2,000 feet north-west of it.

The northern termination of the Mgangamule Ridge could possibly also be ascribed to such faulting. In this particular area the detailed mapping does not extend far beyond the border of the Intrusion, but reconnaissance observations left the impression that red gneiss and the northernmost quartzite outcrops are in juxtaposition. In other parts quartzite lies within red, rather than grey gneiss. It is emphasized however, that evidence is meagre and that the faults so far discussed are done so with hesitance.

Owing to the nature of the work and time limitations, only a minimum of detailed surveying could be conducted away from the Intrusion. Between section-line AB and the Ibalaba stream detailed mapping extended only a few hundred feet into the Basement System. Several journeys made from here over the hills to the Lake, left the impression that the regional strike and steep inclination of the Basement gneiss is maintained. This is also insinuated by the many outcrops down-stream from the lower contact of the Intrusion.

It has already been mentioned that the terrain occupied by Basement System, despite the paucity of outcrops is easily recognisable. Between Ibalaba Stream and the faulting indicated further east (plate 2.), float of several rock-types, including the following is seen: Sheared gneiss; banded ironstone; fragments of granitic material, probably derived from the/.....

veins which so commonly penetrate the gneiss; and a grey crystalline rock with a weakly developed gneissic texture. In the latter rock oligoclase-andesine is abundant, and the remaining major minerals are quartz and biotite (both interstitial). Accessories are chlorite, amphibole and very small amounts of epidote; all probably late alteration products. Megascopically, specimens deceptively resemble those of the Main Zone of the Complex. There are similar occurrences in the immediate footwall in the vicinity of section-line AB (plate 2); also near the quartzite in the Mguje stream; and also near the Intrusion, some 650 yards north of section-line CD.

With regard to the sheared gneisses mentioned, their texture is ascribed to the superimposition of a schistose texture upon the gneiss by shearing. It is pertinent to note that the trend of the intense shearing of the basal layers of the Intrusion is parallel to this schistosity. The impression is that both Intrusion and Basement System were subjected to a period of shearing which must necessarily be considerably younger than the formation of gneiss-textures in the Basement System. The shearing is also associated with overfolding and faulting east of section-line AB.

From a point 650 yards downstream from Kamatandala Settlement, Basement System outcrops all the way down the stream of that name, and commonly strikes ESE to SE. Within some of the outcrops are 2-3 feet wide vein-like and dyke-like occurrences resembling highly altered fine-grained diabase. They are of peculiar form, being irregular and impersistent both in length and breadth and often appear to taper out or fade into the gneiss. Although their orientation varies they are most commonly parallel to the foliation of the gneiss. It is presumed that they are local concentrations of mafic minerals of the gneiss. In this area float, but no outcrop, of amphibolite was also/.....

found. Megascopically it is medium-grained, rich in glittering amphibole, and spotted by interstitial felspar.

To the north of Kamatandala Settlement large tracts are covered by a soil mantle, devoid of outcrops. The most likely positions of geological boundaries are discussed comprehensively when the Intrusion is described. Suffice to mention now that the greater proportion of the buried area is considered to be Basement System.

The Mbugo Stream represents the eastern limit of the country mapped, and along it exposures of Basement System are plentiful. On progressing up the stream gneiss outcrops give way to ones of a leucocratic coarsely crystalline rock in which gneissic texture is considerably subdued. To this rock-type the field-term migmatite was given. Exposures of it are very limited, so virtually nothing definite could be ascertained regarding the shape of its occurrence. It is considered likely that it was formed by mobilization of part of the gneiss.

The following is a representative microscopic analysis (T.S. 711.): The predominant minerals are xenomorphic felspar and quartz, both with strongly undulating extinction. The felspar is considerably in excess, is extensively sericitized and saussuritized, although polysynthetic albite twinning is still discernable. Statistical measurements of the maximum extinction angles of albite twins are very low, indicating oligoclase. This is further substantiated by the closeness of the refractive indices of the felspar to those of quartz (deduced from becke lines in the thin section). Very minor amounts of fibrous dark green amphibole are present, and are semi-opaque as a result of a "peppering" by iron oxides. The accessory minerals are slightly tabular apatite, and zircon present as a few very small subhedral to anhedral grains.

It is possible that potash/.....

It is possible that potash felspar is present as highly altered grains, so passing undetected. However, oligoclase is so much in excess in the specimens that the rock is best termed trondhjemite (Rice 1950, p426.).

Some 200 yards north of the northernmost trondhjemite outcrop in the Mbugo Stream, there is a prominent hillock which is covered by boulders of quartz diabase. They are well rounded and megascopically closely resemble boulders of gabbro from the Intrusion. Several thin sections of the diabase were made, e.g., 709, 710 and 713. All the specimens are highly altered. The only definite primary mineral is weakly subhedral monoclinic pyroxene (positive, 2V circa 55°), which is largely replaced by green amphibole. The quartz is interstitial and has an undulatory extinction. The remaining parts of the sections are occupied by saussurite, chlorite and sericite (fig 17).

Sporadic concentrations of quartz diabase boulders can be followed from the hillock eastwards along a zone which is just over 500 feet wide. North of the zone the surface is soil-covered, but it contains some trondhjemite float, giving the impression that the quartz diabase is bounded on both its northern and southern sides by trondhjemite. The diabase tapers away to the east, but westwards it apparently ends abruptly in the vicinity of Mbugo Stream, as there is no sign of its continuation west of the hillock.

Approximately 1,000 feet north of the quartz diabase zone are the first outcrops of Bukoban System. The base of the System can be plotted with certainty as being immediately below the lowermost outcrop of sedimentary rock in the Mbugo Stream. West of the stream, two faults are inferred in order to account for the anomalous situation of a further occurrence of quartz diabase, which is presumably the displaced western portion of the diabase zone described in the previous paragraph.

As the throws on the faults/.....

As the throws on the faults differ in the Basement System from the throws in the Bukoban System, it is assumed that movement along them commenced in pre-Bukoban times, and that the faults were rejuvenated after deposition of the younger system upon a Basement peneplane.

Some similarity between the quartz diabase and the quartz-bearing members of the Complex is obvious. On the grounds of the considerable difference in the nature of metamorphism each has undergone, it is presumed that no genetic relationship exists. Evidence is meagre, but the diabase is tentatively relegated to the Basement System.

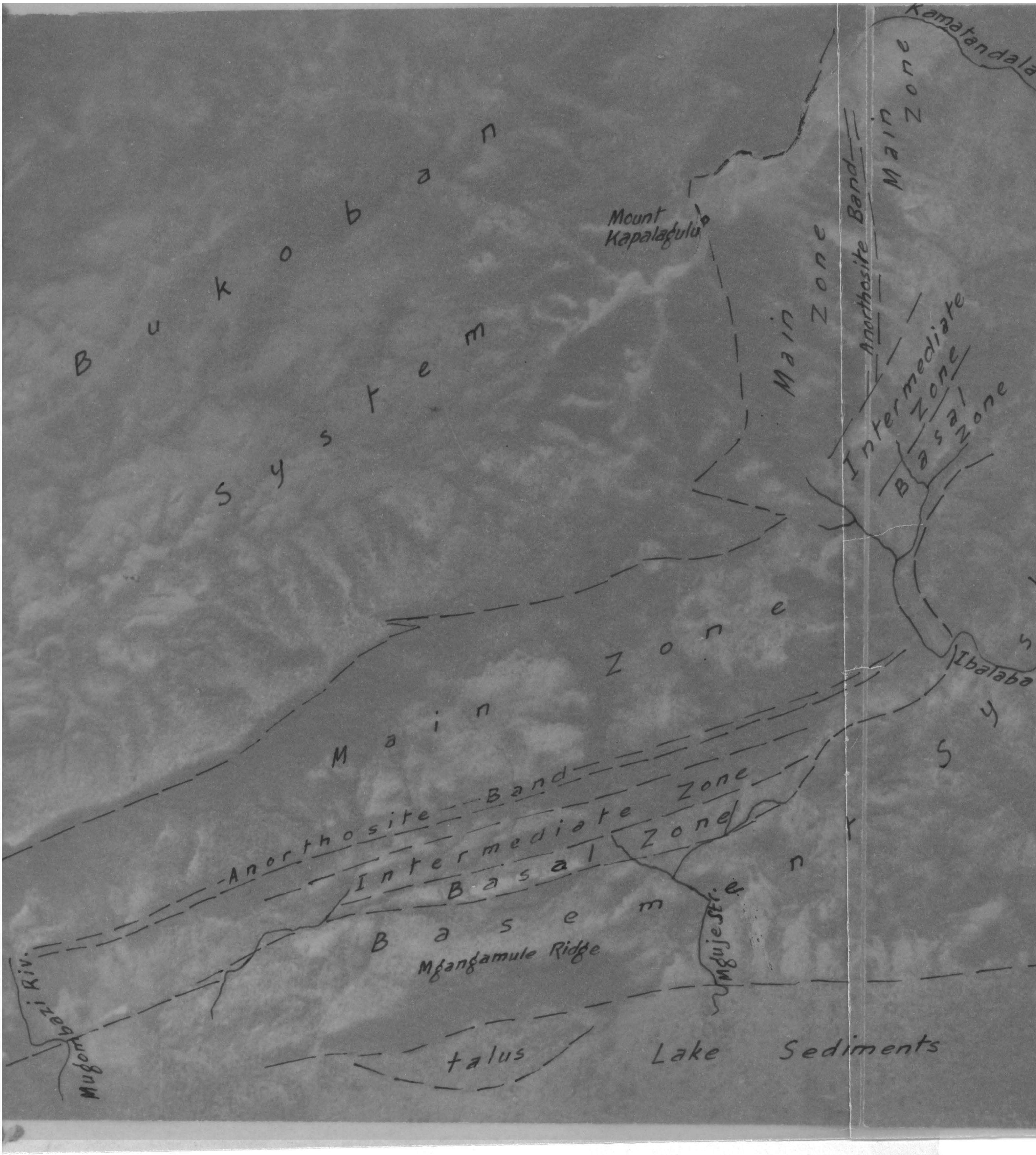

FIG. 3: AN AERIAL PHOTOGRAPH OF PART OF KAPALAGULU COMPLEX.

A striking example of the effect of the composition and structure of the various zones on the physiography.

GEOLOGY OF THE COMPLEX.

The Complex is divided into two sectors, namely the North-western Sector, which, apart from a tilting through approximately 90° is relatively undisturbed, and a North-eastern Sector which is complicated by intense faulting and folding. Their approximate mutual boundary is represented by section-line AB(plate 2.).

The two sectors are lithologically similar and in both, the following subdivisions or zones are recognised (see also plate 2.): (1) The Basal Zone, in which olivine is the predominant mineral; (2) An Intermediate Zone, in which the rocks are rich in mafic minerals and contain up to 20% olivine, and (3) the Main Zone, which constitutes the greater portion of the Complex and which is composed mostly of hyperite. Situated within the Main Zone, and parallel to it, is a narrow but persistent Anorthosite Band.

As the Complex in the North-Western Sector is tilted to a sub-vertical position, the present exposed surface also represents a cross-section of the Intrusion. The zone-effect in the Intrusion is ascribed to gravity-differentiation and the Basal Zone, as its name implies, forms the lowermost, and therefore first-formed differentiate. In parts it is separated from a footwall of Basement System by a Contact Zone of inconsistant thickness.

A. NORTH-WESTERN SECTOR.

(1) Basal Zone.

This zone is present almost throughout the entire length of the Intrusion, and commonly varies between 300 and 500 feet in surface width. Typical rock-specimens are melanocratic to hypermelanic and felspar grains, which are all interstitial, lack lustre and have a grey to dirty green tint. Olivine grains (usually between 60% and 80% by volume) are mostly rounded and have/.....

FIG. 4:

Banded olivine hyperite. The protruding bands contain a higher proportion of felspar than the remaining bands, which are rich in pyroxene and olivine. Differential weathering has accentuated the banded structure on exposed surfaces, and deep pitting is caused by the rapid decomposition of the ferromagnesian minerals, especially olivine.

Scale on the stadia-rod is in feet and tenths of a foot.

suffered extensive chloritization, in extreme cases the rock losing its granular appearence and possessing the earthy look of a typical serpentine. There is some variation, even laterally, in both concentration and composition of the constituents of the zone, but for the most part it is comprised of bronzite-picrite.

Because of the abundance of olivine and the low concentration and smallness of the felspar grains, weathered surfaces are not as pitted as in the case of the zones higher in the Complex. Water-worn surfaces of the Basal Zone are actually smooth and shiny. Away from the abrasive action of flowing water outcrops are invariably extremely decomposed and crumbly, and grade into a gravel of weathered fragments. In distinction to the other zones, spheroidal weathering is absent. The depth to which weathering penetrates varies considerably. In one instance, a borehole collared on a hillside of weathered bronzite picrite was sunk to a depth of over 100 feet before reaching solid rock.

(2) Intermediate Zone.

The difference between rocks of the Intermediate zone and the Basal Zone is most marked. In the Intermediate Zone the concentration of olivine rarely exceeds 20% and plagioclase increases to over 60%. The result is that the rapid weathering of the olivine causes characteristic deep pitting of exposed surfaces of the zone. Furthermore, there is a strong layering effect, due to alternating concentrations of light and dark minerals (fig. 4.). These rocks bring to mind the remarks of Wager and Deer when they first saw the Layered Series of Skaergaard and erroneosly concluded that they were of sedimentary origin. A further diagnostic feature is the tendency towards idiomorphism of the plagioclase grains.

Their is uncertainty as to the exact nature of the upper and lower boundaries of the Intermediate Zone. This is largely due to the paucity of outcrops in critical positions. The impression is that for the most part rapid or narrow transitional/.....

boundaries exist rather than sharp and possibly intrusive contacts. Petrofabric analyses show that platy flow structures are far more common than linear flow structures, rendering unlikely the possibility of this zone being intrusive, rather than having formed in situ by crystal fractionation.

Another distinctive feature of the Intermidiate Zone is its tendency to form long narrow ridges. North-west of Mguje Stream, for example, the zone forms a ridge 1-1/2 miles long (plate 2, and fig. 3.).

In the strict sense of the term, outcrops of Intermediate zone are rare, but some perfect ones are seen in the upper reaches of Kangoli Stream. Generally, the zone is characterized by a mantle of boulders and blocks. In many cases, judging from the similar orientation of the banding in the individual blocks, they could hardly have moved from their original position. Evidently weathering is most rapid along joint planes, so leaving remnants stacked in place, sometimes balancing most precariously. The "gravestone outcrops" about a third of a mile north-west of section-line CD (plate 2.), are unique. Weathering in the manner just described has resulted in several steeply dipping slab-like blocks, which project through the soil.

As in the other zones, there is slight variation in the mineral concentrations. As a rule the ratios of olivine, felspar and pyroxene remain constant, but the ratio of orthorhombic to monoclinic pyroxene varies both considerably and erratically. For the most part the orthorhombic variety is preponderant. Olivine hyperite is therefore the most common rock-type. Others present are olivine norite and olivine gabbro.

(3) Main Zone.

The Main Zone occupies the upper two thirds to three quarters of the Intrusion. Typical of the zone are boulder-strewn/.....

slopes intervening between a high ridge of Bukoban sediments which lie stratigraphically above the Intrusion, and the olivine-rich rocks which generally form a depression towards the base of the Intrusion. Outcrops of this zone are with few exceptions confined to deeply eroded water-courses, or occasionally project as dome-like bodies through the boulder-rich over-burden.

Both boulders and outcrops, when fresh, give a high metallic ring when struck by a hammer, and are extremely hard to break. A chipped specimen usually shows only a very thin skin of weathered matter, as distinct from the deeply pitted surface of the olivine-bearing rocks in the lower part of the Intrusion.

The fresh material is the typical blue-grey of a hyperite, norite, or gabbro and megascopically is holocrystalline, with the two major constituents, felspar and ortho-pyroxene exhibiting tendencies towards euhedrism. Igneous lamination is often detected on a weathered surface by the similar orientation of projecting relatively weather-resistant felspars. In fresh specimens platy parallelism of both felspar and pyroxene grains is in some instances so well developed that it completely controls the nature of fracture surfaces.

The rocks of the Main Zone are mostly hyperites of remarkably consistant megascopic appearance. Exceptions are usually from one of the following two sources:-

(a) Lying within the Main Zone is a conformable band of anorthosite. Immediately above this band there are occasional occurrences of rock ascribed to the Main Zone, but which are abnormally rich in ferromagnesian minerals. There is, for example, a concentration of felspathic hypersthenite rubble situated approximately half a mile south-east of Mugombazi River. There is also a lenticular outcrop of similar material about 1,200 feet in the opposite direction from the river, and another in the vicinity of section-line EF(plate 2.).

(b)/.....

(b) Towards the upper (sedimentary) contact of the Main Zone quartz is occasionally present. Analyses of thin sections show that, with increase in stratigraphical elevation, quartz commences to appear in the form of granophyric intergrowths, which gradually increase in volume until, in places, quartz occurs interstitially as a minor component. With increase in free silica content, the monoclinic variety of pyroxene becomes dominant. The anorthite content of the felspar also decreases so that quartz gabbro and eventually granodiorite ensue.

(4) Anorthosite Band.

Lying in the lower half of the Main Zone and conforming with the igneous stratification is a narrow but persistent band of anorthosite. Outcrops are confined to the Mugombazi River-bed, to the more extensively eroded slopes some 2,000 feet south-east of the River, and to isolated occurrences in and near Ibalaba Stream. For the rest, the zone is recognized only by an abundance of leucocratic boulders. This paucity of outcrops hampers observations on the nature of the boundaries. Found in the rubble are gradations from typical anorthosite, through leuco-hyperite to hyperite. This feature is sufficiently common to imply that transitional or gradational phases are present in at least some places.

Megascopically the anorthosite has the uniformly dull or lustreless appearence of an altered rock, and in colour it ranges from a near-homogeneous dirty white to instances where dark mottling is conspicuous. The intensity of the alteration is comparable only with the basal layers of the Intrusion. Virtually none of the specimens collected for microscopic analysis contained primary minerals which were not completely altered. Highly saussuritized plagioclase considerably exceeds the combined volume of the remaining minerals. Of these chlorite/.....

is most abundant and there is evidence of some of it being pseudomorphous after an interstitial or ophitic mineral, probably pyroxene. Irregular grains and veinlets of fresh quartz are sometimes present, and are presumably of secondary origin.

It may be coincidence, or it is possibly due to the similarity of the alteration, but often hand-specimens from certain parts along the basal contact of the Intrusion bear a remarkable resemblance to those typical of the Anorthosite Band. Geographically they are widely separated.

Some 2000 feet north-west of the Mugombazi River and wedging between the Basal Zone and the Main Zone, is a hillock of anorthosite. Although outcrops are weathered, fresh boulders are plentiful. As implied by the designation of this rock, felspar is predominant and the only other mineral in fair quantity is clino-pyroxene, which is in the form of large isolated poikilitic grains, so lending a mottling effect to the rock.

The relationship of this anorthosite is speculative. The following are salient features: (a) In distinction to the prominent Anorthosite Band and to the Leucocratic rocks of the Lower Contact Zone, this anorthosite is remarkably fresh. (b) The mass has a vaguely plug-like form, and (c) It lies in an area where the Intrusion is structurally disturbed.

(5) Lower Contact Zone.

In the early stages of field-work it was found that in some parts a bewildering variety of rock-types are situated between the Basal Zone and typical Basement System outcrops. With trepidation it was decided to consider them collectively as a zone, which appears as the Basal Leucocratic Zone on the field-maps. On the conviction that altered rocks of Basement System are frequently included, the writer has altered the name to Lower Contact Zone.

It is envisaged that the following course of events could have taken place: The Kapalagulu Intrusion formed a normal chilled/.....

contact against the Basement System. Part, if not all, of the granitization in the Basement System took place after the formation of the Intrusion. As the Intrusion possesses the elements of H.H. Read's conception of a resister, it is logical to assume that metasomatism could have been most effective along the base of the Intrusion and that, in extreme cases, even mobilization of Basement rocks could have taken place. North-west of Mugombazi River there is evidence of leucocratic rocks intruding into the melanocratic Basal Zone. In other parts small quartz bearing leucocratic "dykes" were penetrated in bore-holes situated within the Basal Zone.

Further evidence favouring metasomatism as outlined above is to be seen in the core of bore-holes which were drilled from the Basal Zone, through the Lower Contact Zone, into rocks typical of the Basement System, such as grey gneiss. The change from Contact Zone rocks to recognizable Basement rock sometimes extends over a length of tens of feet.

The most common type of rock found in the Contact Zone ~~is very~~ rich in highly altered (mostly sausuritized) plagioclase in which spectral remains of polysynthetic twinning are often discernable. The only other identifiable minerals are chlorite, epidote, biotite and variable amounts of quartz.

B. NORTH-EASTERN SECTOR.

Lithologically this sector does not differ from the North-western Sector. Structurally, the North-eastern Sector is considerably more disturbed, in fact to such an extent that the olivine-bearing zones and part of the Basement System are faulted, sheared and dip southwards as a result of overfolding.

(1) Basal Zone.

Drilling operations along the base of the Intrusion in the vicinity of section-line AB (plate 2.) exposed a thrust-fault. Continuation of the fault was confirmed by additional bore-holes/....

close to Ibalaba Stream. In one of the holes the Basal Zone and hyperite are juxtaposed. The entire removal of the Intermediate Zone indicates the horizontal displacement on the fault to be close on 1,000 feet.

Around Ibalaba Stream the strike of the Basal Zone rotates within a very short distance through 90 degrees to become slightly east of north. The whole zone also becomes intensely sheared. The shear-planes and the igneous lamination appear parallel and both dip away from the Intrusion. As the contact of the Intrusion forms an unbroken curve, the thrust-fault must necessarily curve sympathetically.

After a further half a mile both the basal contact and the Basal Zone revert to their original strike and at the same time the Zone increases in width. For this reason the fault is believed to continue northwards along a large irregularly shaped dolerite dyke. Drilling operations just east of the dyke confirm that no fault of comparable magnitude is present in the Basal Zone.

A half a mile east of the dyke a large wedge-shaped block of the Intrusion is displaced into the floor of Basement System. On limited evidence two faults are inferred to account for this disruption. Further eastwards, before disappearing below a thick mantle of soil, the last exposures of Basal Zone are intensely sheared parallel to the layering, which is inverted to 50 degrees southwards. The Basement System of the area is similarly affected. In parts the shearing is so intense that the gneiss is rendered schistose.

In the area where the Complex is completely covered by soil, an approximate lower contact was determined magnetometrically.

(2) Intermediate Zone.

Around section-line AB (plate 2.) a thrust-fault causes the Intermediate Zone to be overlain by the Basal Zone and this situation apparently persists for some distance eastwards, though observations are impaired by alluvium near Ibalaba Stream. The Intermediate Zone is exposed again east of the dolerite dyke, building a low ridge for some distance before being covered by the soil plain which forms

in the/.....

in the direction of Kamatandala. Some decomposed outcrops in Kamatandala Stream are tentatively ascribed to this zone. Near the dyke, olivine hyperite appears to overlie the Main Zone (hyperite and anorthosite), and a reverse strike fault is inferred. It is believed to be a branch of the fault detected in the Basal Zone.

(3) Main Zone.

In plate 2, the most striking feature of the Main Zone is its contact with the Bukoban System. The contact appears disconcertingly sinuous or irregular to one who, like the writer believes it to be sedimentary in origin. For a better conception of its actual attitude it is necessary to give a brief outline of the circumstances which prevailed when it was mapped: The writer was employed by a concern whose object was to determine the economic potentialities of the Complex, and naturally, they wished to do so at a minimum of expense and time. This circumstance, the inacessible nature of the area and the approach of the annual rains which terminated the field-season, resulted in only a rapid location of the contact.

The upper contact therefore, as it appears on plate 2, is only approximate and it is very likely that its unusual form is largely due to faulting and folding. When compared with the disrupted basal area, where considerable time was expended on careful mapping, it seems very likely that several structural disturbances remain undetected on Mt. Kapalagulu. The very presence of the mountain also suggests this: Lithologically both the sediments and the Main Zone on the mountain are identical to their counterparts over the rest of the Intrusion, yet there is over 1,000 feet difference in elevation between them.

(4) Anorthosite Band.

No outcrop of anorthosite was found in the North-eastern Sector, but the presence of a band is indicated by a distinct line of boulders along the slopes of Kapalagulu Mountain. Hand-specimens/.....

taken are in all respects identical to those from the North-western Sector. Towards the base of the Mountain geological features are buried by an accumulation of mixed talus and soil. It is nevertheless apparent that further west the anorthosite is overlain the Intermediate Zone and that obscure faulting is therefore present.

(5) The Eastern Boundary.

Around Kamatandala Stream and eastwards the country forms a large densely wooded plain. The surface material is either soil or laterite, and northwards the plain is culminated by the characteristic Bukoban ridges. The few outcrops present are confined to the beds of the Mougo and Kamatandala streams.

In estimating the eastern limits of the Complex, a traverse down the Kamatandala stream is most informative. From its source on the eastern flank of Kapalagulu Mountain, the stream follows the contact of the Intrusion and the Bukoban System, there being precipitous masses of sandstone on the left and igneous rock on the right. After about three-quarters of a mile the stream swings away from the Bukoban Range and flows southwards. In doing so, it forms the western border of a plain rich in sand and laterite. On the right the high range of hyperite continues another half mile dowstream.

Sandy (quartz-rich) soil is not the product of saturated or undersaturated mafic rocks and neither is a plain indicative of inclined erosion-resistant Bukoban strata, but both are typical of Basement System of the area. On these grounds it is concluded that the Stream now flows along, or close to, the contact between the Intrusion and the Basement System.

Just before reaching the Kamatandala Settlement, a small outcrop of olivine hyperite appears in the stream and boulders of this material lie scattered for 1,500 feet eastwards over the plain, which is now clay-rich.

Presumably, along this part the/.....

stream lies within the Complex and cuts across the layering towards the bottom contact. Downstream from a point 1,700 feet below the Settlement, outcrops of Basement System are abundant. It is believed that the lower contact of the Intrusion is not far above the uppermost of these outcrops of Basement System.

It is obvious therefore, that the Intrusion crosses into the plain east of Kamatandala Stream. The possibility of it projecting much further is curtailed by the exposures in the Mbugo Stream, which lies parallel to Kamatandala Stream and a mile east of it. Throughout its length Basement System outcrops intermittently.

Towards the Bukoban System in the most easterly part mapped, two broad zones containing numerous boulders closely resembling those of the Main Zone were located, and were originally correlated with it. Laboratory analyses show that they are highly altered quartz diabase. They are rich in amphibole, probably evolved by uralitization of what was originally pyroxene. It is concluded that these occurrences do not form part of the Intrusion, as the nature of their alteration differs entirely, and they are tentatively ascribed to the Basement System; possibly related to the plagioclase amphibolites (Mc Connell 1950).

C. DYKES AND SILLS.

There is a small isolated occurrence of bronzite-picrite in the vicinity of section-line EF (plate 2.). Other than this, no apophysis of the Intrusion was seen.

Owing to megascopic similarity, material related to the upper part of the Intrusion could remain unrecognized when lying in certain parts of the Basement System, such as in the less gneissose varieties, of the System, and in the quartz diabase. Around the Kamatandala Stream very small sill-like and vein-like occurrences of basic material lie within the gneiss, but these are considered as part of the Basement System. In the part of Bukoban System mapped, no igneous material is present. This, and the complete absence of/.....

thermal metamorphism in the sediments are taken as proof that the exposed contact of the Intrusion with the Bukoban System is sedimentary in origin.

The Ibalaba Dyke, near the stream after which it is named, is the only known dyke both situated within the Intrusion and exceeding 15 feet in width. Its outcrops are few and are mostly limited to stream-beds. It varies radically in width, attaining a maximum of nearly 400 feet, but is relatively short, probably not exceeding 2,000 feet. It in no way disturbs the unbroken line of the Basal Zone lying at its southern extremity, yet it cuts perpendicularly across the strike of the higher zones, separating hyperite from olivine hyperite. In the writer's opinion, the marked difference on either side of the dyke is the result of faulting; the dyke and fault plane being coincident in position.

Specimens of the dyke are dull black to grey in colour. When struck with a hammer the rocks fracture characteristically into small angular pieces whose surfaces in turn have a sheen of weathering on them. Apparently there are numerous fine joint-or shear-planes along which weathering penetrates deeply. As a result it is difficult to break a piece in such a way that a fresh surface is exposed. Microscopically, lath-like plagioclase, augite and small quantities of micropegmatite are recognized. The texture is holocrystalline, medium to fine-grained and hypidiomorphic. Saussuritization and uralitization are extensive. There is a petrographic resemblance to the quartz-bearing rocks near the upper contact of the Complex.

Within the Intrusion, especially near its base and in the Contact Zone, are numerous small dyke-, sill- and vein-like bodies. Such occurrences are particularily abundant between Mugombazi River and section-line EF (plate 2.). They are mostly a few inches to a few feet in width, seldom reach 100 feet in length, are often Leucocratic and are always extensively altered. Being light in colour, they are conspicuous in the melanocratic Basal Zone.

A classification of these/.....

A classification of these dykes and sills into three types has been attempted, but generally they differ very little from one another. The most distinct type is that which is most common in the Intermediate Zone. It is larger and more persistent in length than the others and is of doleritic composition. The remaining two types are differentiated only with difficulty. Both are leucocratic, are highly altered and are of narrow and often irregular form. One of these two types is believed to be confined to the precincts of the olivine-bearing layers of the Complex, whilst the other lies (and apparently originates) in the Lower Contact Zone and extends short distances into the Complex.

VI: BUKOBAN SYSTEM.

With the exception of members of the Primitive System, the Bukoban is the most extensively exposed System in Western Tanganyika. It forms a broad continuous strip of country from Bukoba, on the shore of Lake Victoria (Stockley 1948a, p13), to well south of Mpanda (McConnell, 1950, p15), a total distance of over 450 miles. Thereafter outliers occur intermittently to as far south as Lake Nyasa (Stockley 1948b, p19) and into Northern Rhodesia (Guernsey 1950, p137). The predominant members of the System are unfossiliferous, very poorly metamorphosed sediments, mostly sandstone and phyllitic shales. Within the sediments is a horizon of andesitic and amygdaloidal basaltic lava, at least 2,000 feet thick.

In South-Western Tanganyika the System is classified as the Ubende and Uha Series, which lies unconformably on the Primitive rocks and, according to most authorities, is separated from them by a vast geological time interval.

In the Kapalagulu vicinity the lower contact of the Bukoban System strikes from Lake Tanganyika south-eastwards inland (plate 1), towards Mpanda. The System covers a broad expanse to the north. A general characteristic of the System is its relatively undisturbed attitude but, as for example around Kapalagulu Mountain it has suffered intense local movement as a result of Rift Valley faulting.

Along its entire length the Kapalagulu Complex is capped by sub-vertically inclined sandstone, sometimes up to 500 feet thick. The sandstone is stained reddish-brown by iron oxides, is often strongly cross-bedded and towards its base there are small erratically developed pebble-bands. In the most easterly parts mapped the sandstone becomes argillaceous and laminated in sections.

In microscope sections of the sandstone the grains are rounded and tightly packed, and are cemented by finely distributed clay minerals. The texture, even to within inches of the Intrusion (e.g., T.S. No. fig.), is scarcely quartzitic.

This/.....

This is accepted as convincing evidence of the contact being a sedimentary one.

Mapping seldom extended further than the top of the sandstone ridge, but it was observed that a considerable thickness of purple to pale lilac-coloured phyllites and shales lie stratigraphically above the sandstone. From a study of the aerial photographs it is concluded that argillaceous sediments such as these completely occupy the broad synclinal valley north of the ridge (plate 1).

The age of the Bukoban System is not known with certainty and much of the published information leads one to conflicting conclusions. It is neither within the scope of the present work, nor is the writer sufficinetly conversant with the subject, to attempt any correlation, but for the purpose of illustration a brief outline of some recent data is given:-

In Tanganyika the general opinion is that the Bukoban is separated from the Primitive and the Muva-Ankolean Systems by a vast time-void (Stockley 1950a, p13). Its almost undisturbed structural attitude and the absence of metamorphism certainly suggest this. It is unfossiliferous and is considered pre-Karroo in age. In South-Western Tanganyika Bukoban and Karroo Systems are in close proximity, but lithologically they can easily be differentiated. In all respects the Bukoban System resembles the Waterberg System of South Africa and is in fact tentatively correlated with it.

The Bukoban System can be followed without a break into Northern Rhodesia where, in the vicinity of the country's northern border it is known as the Abercorn Sandstone (McConnell 1950, p15). It forms part of the Rhodesian Plateau Series (Guernsey 1950). In Guernsey's table of formations (p128) the Series is classified as pre-Bwana Mkubwa Series, but on his map it appears younger. From descriptions it is gathered that field information is limited and is of a contradictory nature.

In/.....

In Tanganyika the Bukoban System rests with a sedimentary contact upon, and is considered much younger than the Kate Porphyry (McConnell 1950 p14). In Northern Rhodesia the same porphyry, but known as Luapula Porphyry is also covered by these sediments. It is reported that volcanicity extended into Plateau times, and that the stratigraphical break is therefore short (Guernsey 1950, p137). Guernsey furthermore mentions a likelihood of the Plateau Series being older than Kundulungu Series (p136, p139), which is also implied in the structure north of Fort Rosebery. Here the Plateau Series and the Porphyry together undergo folding which is almost isoclinal, whilst the Kundulungu strata remain undisturbed, so forming an angular unconformity.

There is evidence that any time-break between the deposition of the Kundulungu and the older Upper Bwana Mkubwa Series must necessarily have been short (Guernsey p135). If then, as implied, the Plateau Series is pre-Kundulungu, it seems most unlikely that its great thickness of sediments could have been deposited during this short period. On the other hand, it seems even more unlikely that the Plateau Series is pre-Bwana Mkubwa. The accepted opinion is that the Systems Bwana Mkubwa, Schisto-Dolomitique (Congo), Lumagundi (S. Rhodesia), and Transvaal (S.Africa) are contemporaneous. The problem remaining is to ascertain with greater certainty the relationship of the Systems Kundulungu, Bukoban and Waterberg-Umkondo (S.A. - S.R.). The present tendency is to call Bukoban post-Transvaal, and probably of Waterberg age (inter alia Macgregor, 1948, p111).

VII: LAKE SEDIMENTS.

Along the rim of Kungwe Bay there are several almost perfectly flat plains which sometimes extend up to three miles inland. It is readily obvious that they are recent fillings of depressions in an old landscape of Basement System. The plain appearing on Plate I was inspected on many occasions. Underlying its thickly vegetated surface is monotonously homogeneous clay-rich soil in which no evidence of consolidation or bedding exists.

Along the plain's present shoreline the combined action of wind and waves has built an embankment of dunes which impede the drainage. As a result marshes have formed and river mouths are periodically closed by silting. In times of heavy rainfall, the overflowing of the rivers which meander across the plain cause a still further submergence of land; a feature profitably exploited in rice-growing by the local community.

The sediments can justifiably be termed lacustrine, but whether the Lake once extended as far inland as Mgangamule Ridge, and whether it is associated with the deposition of the deep alluvium covering the Intrusion east of the Mugombazi River (plate 2), is conjectural on present information.

VIII: PETROGRAPHY OF THE INTRUSION.

Most of the zones in Kapalagulu Complex possess certain characteristic features which render them recognizable macroscopically. Very significant, but not macroscopically visible is the variation in composition of the individual minerals along a cross-section of the Intrusive. This phenomenon and the volumetric proportions of the minerals are believed to throw much light on the genesis of the zones. After the essential features of the rocks forming the zones have been given, and in order to illustrate the mineral variation, there follows for each of the major minerals, a separate description of its properties through the Intrusion.

In/.....

In addition, a series of mineral variation diagrams is included.

In classifying the rocks of the Complex, especially those containing olivine, difficulty was experienced in arriving at a suitable nomenclature. This is due to the variation caused by graditional changes which are so common in mafic intrusives, and the considerable number of rock-names at present in existence. A new name after each and every little change in mineral proportions is obivously unwarranted. Only the nomenclature of peridotites, pyroxenites and other almost monomineralic rocks presents no difficulty. By universal definition they simply contain less than 10% to 12% (volume) light minerals.

It is when light minerals (i.e. virtually felspar only) exceed 12% that the variety of names becomes superfluous. Generally the names in this category rely further on the concentrations of orthorhombic and monoclinic pyroxenes. In the Basal Zone 15% to 20% felspar is general, but the ratio of orthopyroxene to clinopyroxene is so variable that a host of rock-names could apply. In the present work preference is given rather to the attractively simple system compiled by Scholtz (1936, p99), namely:-

(Abbreviations used below: fels. - felspar, ol. - olivine, o.p. - orthopyroxene, c.p. - clinopyroxene, gab. - gabbro.).

Fels. > 30% and ol. < 35%.		Fels. 5%-30% and ol. > 35%.	
ol.norite ...	(o.p.)	picro-norite ...	(o.p.)
ol.hyperite ...	(o.p.>c.p.)	(hypersthene - or	
ol.hypersthene gab.	(o.p.<c.p.)	(bronzite picrite.	(o.p., c.p.)
ol.gabbro ...	(c.p.)	picrite ...	(c.p.)

The table above is consistent with the following universally accepted classification:-

Norite: o.p. (and traces of c.p. permissible).
Hyperite : o.p. exceeds c.p.
Hypersthene gabbro: c.p. exceeds o.p.
Gabbro: c.p. (and traces of o.p. permissible).

A representative collection of specimens and thin and polished sections is in the posession of the University.

(1) <u>Basal Zone</u>./.....

(1) Basal Zone.

Into this zone fall all the occurrences in which olivine is the predominant mineral. It is, as implied, situated at the base of the intrusion, and it is considered to have formed by gravitational accumulation of olivine grains during the initial stages of the crystallization process of the Complex.

The olivine forms closely compacted, somewhat rounded grains, varying from 1mm. to 3mm., but usually 1.5mm. to 2mm. in diameter. The impression is that these grains were originally idiomorphic, were partially resorbed whilst in suspension, and then underwent partial replacement and embayment after settling. Furthermore, the majority of the grains are largely altered by secondary action in a typical manner to chloritic *material. On relatively fresh grains the olivine was determined as magnesium-rich; occasionally exceeding Fo_{90} and probably never being less than Fo_{70}. The olivine is therefore obviously the high temperature variety *(see Fig 5)*.

Filling the interstices are the remaining minerals, which are almost exclusively pyroxenes and felspar. Monoclinic and orthorhombic pyroxenes are in greatly variable proportions, but together comprise a fairly constant percentage. Owing to the extensive replacement of the orthorhombic variety by the other, only limited reliance can be placed on their indicated relative proportions. Large plates of clino-pyroxene up to and exceeding 1cm. are common, and poikilitically enclose olivine and ortho-pyroxene, but never felspar. The intimate relationship of olivine, ortho-pyroxene and clino-pyroxene is more extensively discussed later, together with the mineral variations. The orthorhombic pyroxene is also of the high temperature variety, as is the lime-rich felspar. The felspar is invariably very highly saussuritized.

Sulphides, with some notable exceptions, are completely interstitial (at the expense of felspar). When shearing is present the sulphides appear to be partly redistributed along the shear planes.

Deep/.....

*Including serpentine, antigorite, etc., (Winchell 1951, p381).

Deep brown biotite is a scarce late product which is often associated with the sulphide mineralization. Opaque oxides, presumably almost exclusively magnetite, are present both in crystalline form and as earthy alteration products associated with the olivine, and to a lesser extent, the pyroxenes.

The following conclusions regarding mineral concentrations in the Basal (melanocratic) Zone are drawn:-

Olivine:	Usually 40%-80% (vol.), most commonly 60%-70%, very occasionally exceeds 90% (peridotite)
Pyroxenes:	Usually 10%-40%, most commonly 15%-25%. Ratio o.p.:c.p. varies radically.
Felspar:	Usually 10%-30%, most commonly 15%-20%.

Mafic minerals together therefore commonly attain 80% by volume and consequently rocks of the zone are best classified as olivine-rich bronzite-picrite. Niggli's term hyperite-peridotite is also applicable, (Niggli 1932, p).

In the field the most important diagnostic features are the overwhelming abundance of olivine, and the interstitial nature of the felspar, both being readily noticeable with the naked eye.

(2) Intermediate Zone.

This zone follows upon the Basal Zone. The nature of the boundary is not always clear, but for the most part appears transitional over a width varying from a few feet to, in rare instances, as much as 100 feet.

The zone encompasses all the olivine-bearing rocks which contain felspar which is not wholely interstitial. It differs in this manner from the previous zone, and also in that the proportion of olivine is considerably lower; with a complimentary increase in plagioclase.

As previously, the olivine grains are rounded and embayed, and coronas of pyroxene are particularly common (fig. No.). Alteration to chloritic matter is less intense, but remains ubiquitous.

In/.....

In these respects it is similar to that in the Basal Zone. The only noteworthy difference is that the olivine is generally slightly richer in iron, indicating a lower temperature of crystallization. The sodium content of the orthopyroxene increases similarily.

It is in this zone that plagioclase first exhibits a tendency towards euhedrism . It crystallized at least contemporaneously with orthorhombic pyroxene and in many instances, as evidenced by a weakly poikilitic relationship, even preceded it.

In all minerals, the degree of alteration is considerably reduced, but remains of a similar nature to that in the Basal Zone. The fact that shearing too, is far more subdued is considered as evidence that the greater part of the alteration is largely the result of dynamic metamorphism, most intense towards the base of the Intrusion.

Distinctive of this zone is the remarkable developement of igneous layering. It is immediately evident that this is caused by alternating concentrations of light and dark minerals. These bands vary in width from a few millimeters to several feet. Differential weathering serves to accentuate this phenomenon and also causes exposed surfaces to become deeply pitted. Further details are given in a separate chapter devoted to the origin of the layering.

(3) Main Zone.

As with the Intermediate Zone, the nature of the lower boundary cannot be ascertained with certainty. The paucity of fresh outcrops prevented the collection of satisfactory laboratory specimens. The matter remains inconclusive, but field appearences favour a narrow transitional belt.

Ignoring a very small proportion of rocks which will be described shortly, and whose differences are ascribed to their close proximity to the contacts, the zone is remarkably uniform in appearence. Even typical specimens from both above and below the intervening anorthosite band are indistinguishable.

The rocks have the typical textural features of a norite or/.....

hyperite. Plagioclase and pyroxene are the only minerals of quantitative importance and are in monotonously regular proportions (figs 5,6). Towards the base the amount of pyroxene sometimes increases slightly. Widely separated vertical traverses may shew minor differences in mineral proportions, but along the greater length of any single traverse the constancy is readily obvious. Specimens from a traverse in the vicinity of Mugombazi River contain on average of 60% felspar and 40% pyroxene. The monoclinic variety of pyroxene is very subordinate to almost absent.

Throughout the zone, the monoclinic pyroxenes measured fell within the augite field (Winchell 1951, p408). In the lower horizons the composition closely approaches that of diopside and becomes progressively richer in iron towards the upper part of the Intrusion.

The minerals are of high crystallization temperature (e.g., En. and An. 70%-80%) - somewhat higher than usual for typical hyperite, norite or gabbro. The term eucrite is sometimes given to rock-types containing plagioclase with a composition approaching anorthite (Shand 1949, p436; Rice 1950). The eucrite occurrences at Kapalagulu are also unusual in that the dominant pyroxene is orthorhombic rather than monoclinic.

Lying within the zone are several small, isolated occurrences of rocks of anomalous composition and form. They are particularily prevalent just above the Anorthosite Band. There is, for example a concentration of felspathic hypersthenite rubble immediately above the anorthosite, approximately ½ mile southeast of Mugombazi River. Similar material also forms a lenticular outcrop about 1,200 feet in the opposite direction from the river, and there is another immediately above the anorthosite on section-line EF (plate 2).

The pyroxene in these examples forms elongated, but otherwise anhedral grains, commonly 1.5mm., and occasionally as much as 4.5mm. in length.

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In most of the specimens collected, the long axes of the pyroxenes lie roughly in a common plane, but rarely exhibit a directional tendency.

In some of the normal-looking specimens from immediately above the anorthosite, monoclinic pyroxene was found in unusually high concentrations, while the proportion of pyroxene to felspar remained virtually unchanged. The fact that the specimens with abundant pyroxene all lie approximately along the same stratigraphic horizon namely immediately above the anorthosite, is of possible significance in determining the age of the anorthosite relative to the Main Zone, in which it lies.

Towards the upper quarter, or less, of the exposed area of the Intrusion the relative proportions of the constituents commence a gradual, but decisive change. The pyroxene ratio (vol.% o.py.: total vol.% py.) decreases rapidly and gabbro ensues. Quartz makes an unobtrusive entry and in some instances reaches as much as 4% before monoclinic pyroxene becomes the dominant pyroxene. Initially the quartz is visible only as a granophyric intergrowth, accompanied by a sympathetic decrease in concentration of pure felspar grains. However, for the most part, gabbro free of quartz (except intimately associated with felspar), extends to the contact between the Intrusion and the Bukoban System.

Similarly, towards the upper contact of the Intrusion, the concentration of orthopyroxene decreases and eventually only clinopyroxene is present. The ratio Mg: Fe in the orthopyroxene decreases sympathetically and the last remnants of the mineral have a compsotion approaching En_{60}. The anorthite content of the plagioclase too, decreases form approximately An_{75} to near-pure albite. Extensive suasuritization in these parts prevents accurate determinations, but the presence of granophyric structures and resemblances of perthite suggest that the plagioclase present is sodium-rich. This is further substantiated by rough measurements of the maximum extinction angles of albite twins in the relatively fresh grains.

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The texture in quartz-rich specimens is generally hypidiomorphic, much of the augite and pure felspar showing a tendency towards definite crystal shapes. The remaining volume is occupied by completely anhedral quartz and granophyric material. In these specimens the augite has a rusty tint and is finely peppered by an abundance of iron oxide. Cleavages, especially the prismatic ones, are strongly accentuated by fillings of this matter. "Herringbone" twins are also very common, which is distinct from the pyroxenes in the rest of the Intrusion, which do not exhibit twinning at all.

It is obvious from the bending and undulatory extinction of grains that there are parts near the upper contact which have been subjected to considerable strain and even shearing.

In some of the upper localities there are abnormally high concentrations of magnetite. The impression gained is that the concentrations are patchy and of very limited extent. The magnetite forms subhedral as well as interstitial grains. The latter become still more irregular by corroding deeply into the earlier-formed minerals, especially augite. This, and the fact that these concentrations are confined to the upper known reaches of the Intrusion suggest that at least parts of them are of late magmatic formation (Shand 1947, Bateman 1942, 1951).

(4) Anorthosite.

Lying within the Main Zone is a poorly exposed horizon which is best described as anorthosite. Microscopic investigations confirmed the impression that this dull white rock is highly altered. In almost all the thin sections examined, alteration of the primary constituents is virtually complete, and in such cases identification is based largely on psendomorphous and similar structures. On the slopes of Mt. Kapalagulu one unusually fresh specimen (fig. 14). was obtained, and considerable attention was devoted to determining the composition of its felspar. By force of circumstance it is assumed that their composition, namely An_{85} is representative of the zone.

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It is noteworthy that this figure is similar to that obtained for the greater part of the Main Zone.

More than 90% of this section consists of closely packed subhedral plagioclase grains which shew only very little sign of strain or crushing. Alteration of the felspar differs from that in most of the Intrusion in that fine clearly defined patches and sub-parallel veinlets of epidote are plentiful. Occasional mottling is caused by a mineral of poikilitic form, but which is otherwise irrecognisably altered. It is presumed to have been pyroxene. The alteration product is a virtually isotropic variety of chlorite (n 1.62), identified as Diabantite (according to Winchell's classification of chlorites).

Situated some 2,000 feet north-west of Mugombazi River is an occurrence of anorthosite, of which the peculiar shape and location have already been described (chapter V). It is furthermore unusual in that it is still in a remarkably fresh state (fig. 15). In hand specimens the black mottling is distinctive, as are signs of preferred orientation or igneous lamination. The following are averages of a series of volumetric analyses:

Plagioclase	69.0%)	84.6%
Saussurite, epidote etc.	15.6%)	
Augite	1.8%)	14.3%
Chloritic matter	12.5%)	
Ore and others		1.1%
		100.0%

The forms of the individual felspars vary from completely interstitial to almost euhedral. Subhedral grains predominate. Generally, the better developed the crystal shape, the larger the grains, many attaining lengths of over 0.3mm. As may be expected with such a high concentration of felspar, the grains are closely packed, leaving very little interstitial volume, which is filled either by the irregular felspar, or by augite in poikilitic relationship.

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The anorthite content was calculated as 85% and cursory observations indicate little or no difference of optical properties between the well-shaped and irregular grains.

From one specimen three thin sections were cut at right angles to one another. They shew textural and volumetric differences, which suggest the presence of flow structures. Polysynthetic albite twinning is insufficiently common to enable a rapid detailed petrofabric analysis.

Alteration of felspar is in the form of patchy saussurite and minute but easily recognisable grains of epidote to chlorite and fine opaque matter, probably magnetite.

(5) Mineral Variation.

It is contended that the Kapalagulu Intrusion is a Complex formed mainly as a result of the grains crystallizing from the magma and being effectively separated and accumulated by gravity; that is, fractional crystallization. The more obvious supporting evidence, such as zoning and textural features, has already been given. Furthermore, the pattern of mineral variation in Kapalagulu is so convincing (figs. 5, 6 and 7), that it quite overshadows other possibilities.

In fig. 7 it is immediately noticed that, in progressing upwards from the lower contact to the Mineralized Zone[*] there is a steady decline in the concentration of olivine, and a complimentary increase in felspar content. There is also an analogous decrease in the concentrations of forsterite, enstatite and anorthite in the olivine, orthorhombic pyroxene and plagioclase respectively.

On reaching the mineralized zone both the proportions and the compositions of the minerals alter radically. All the minerals revert to their high temperature varieties and, at the top of this zone the volume of olivine is particularily large. Thereafter the variation-pattern is a repetition of that upwards from the lower contact of the Intrusion.

During fieldwork it was anticipated that the orebody developed by the settling of sulphides on becoming immiscible (vide chapter IX).

[*]The Mineralized Zone is the name given to a definite horizon within the Basal Zone, and along which sulphides are concentrated- the ore-body.

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The difficulty was to account for their concentration at an elevation considerably above the floor of the Intrusion. From the mineral variation outlined, it now appears very likely that the sulphides settled upon a plane which formed at an early stage in the crystallization history of the Intrusion. The formation of the plane could amongst others, be ascribed to a large influx of magma, and a consequent increase in overall temperature and a change of composition of the system. With the recommencement of crystallization there was a repetition of the original process.

Though not strictly applicable, the following rough calculation is useful: From a pure melt of olivine, crystals similar to those of Kapalagulu would form over a range of 1750° to 1600° = 150° C. In a multicomponent system the temperature range is generally reduced. It is obvious therefore that, under suitable conditions, a relatively small temperature increase can lead to considerable mineral variation.

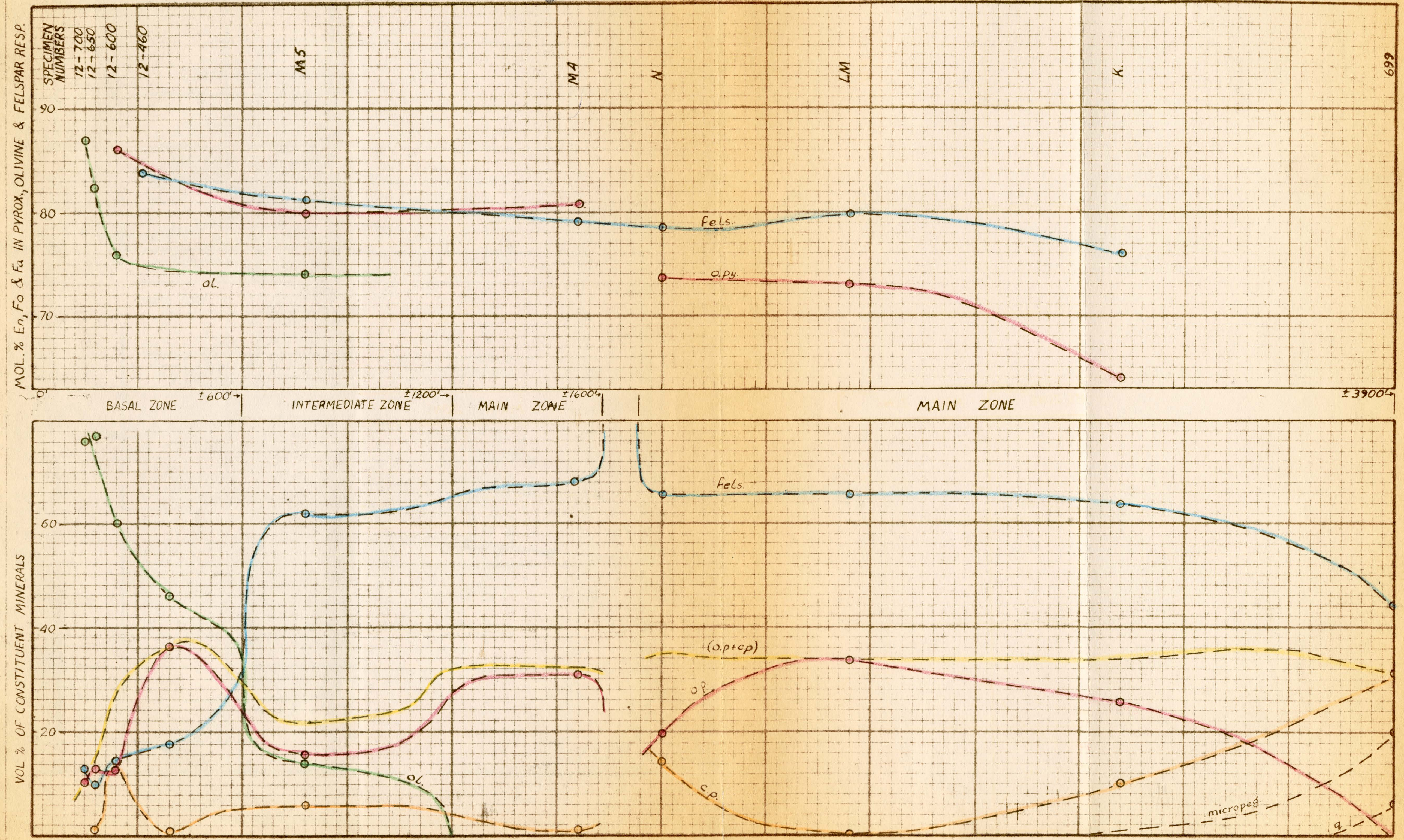
In the Intermediate Zone the olivine content decreases rapidly to a steady 15% - 20%, and felspar becomes (and remains), the predominant mineral in the rest of the Intrusion. The zone represents the stage where the last of the olivine precipitated, leaving a magma much enriched in salic components.

As illustrated in diagram 6, the anorthite content of the felspar in the Intermediate Zone, unexpectedly, is higher than that in the felspar of the Basal Zone. It therefore appears possible that the felspar in the Basal Zone was not the first felspar to crystallize. The following is a possible explanation of this anomaly: The felspar in the Basal Zone crystallized from salic magma trapped in a mesh of olivine crystals. Being in the Basal Zone, it must necessarily have been trapped during the early stages of crystallization in the Complex. It must therefore be more soda-rich than the felspar in the Intermediate Zone, as it must be closer in composition to the potential felspar-forming constituents of the original magma (i.e. the magma prior to the removal of anorthite-rich crystals by crystal fractionation).

In/.....

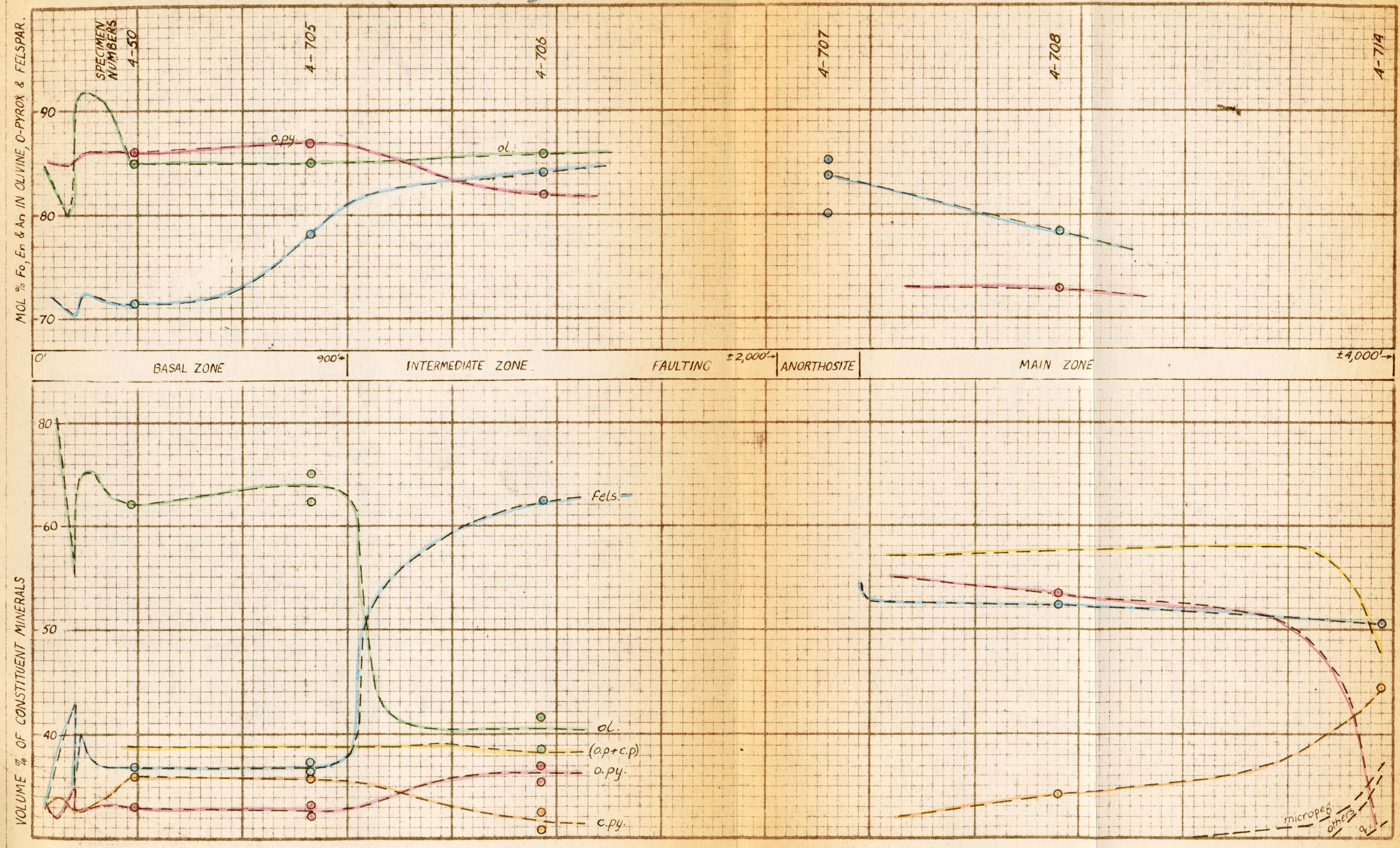
traverse 2

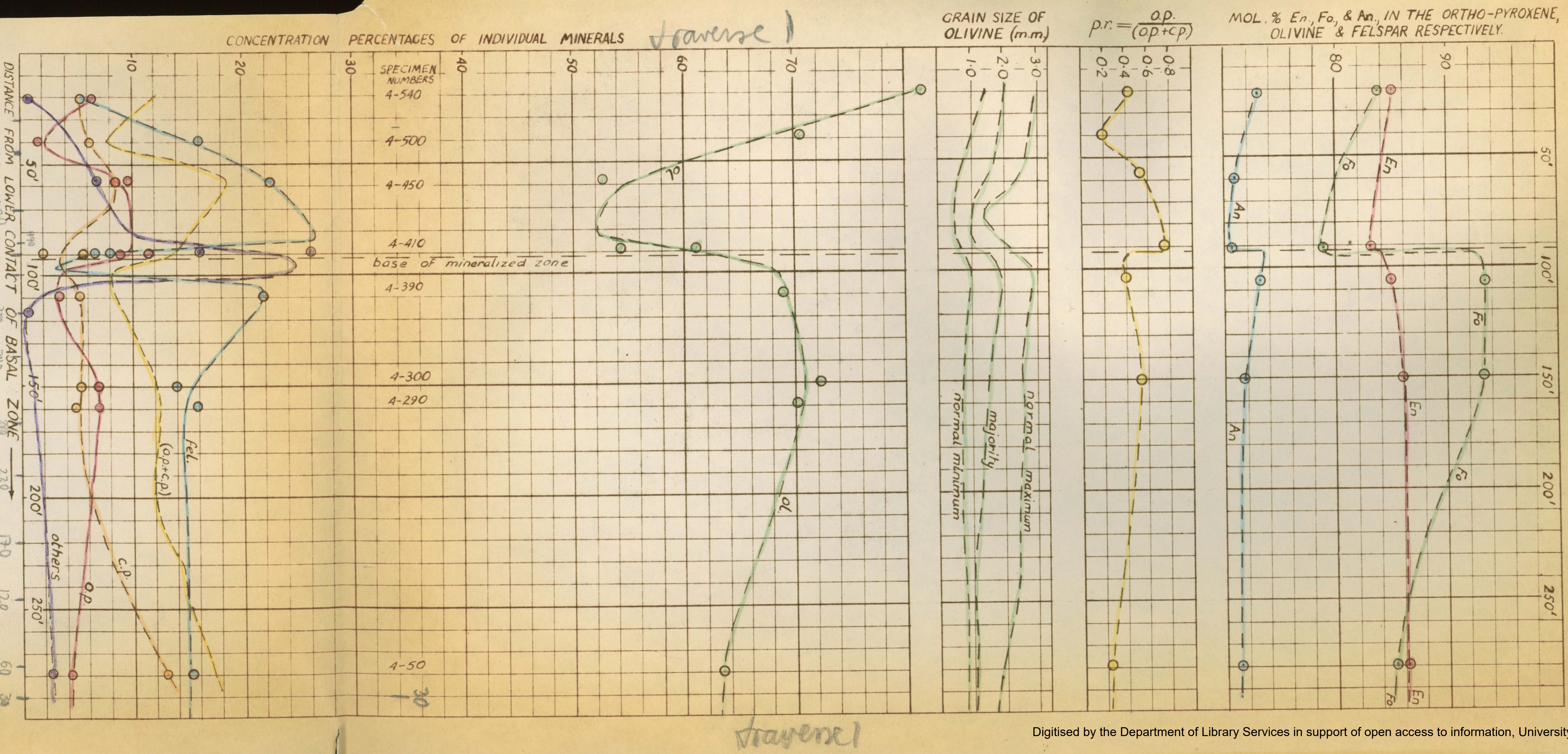
FIG. No. 5.



Traverse I

FIG. No 6.





CONCENTRATION PERCENTAGES OF INDIVIDUAL MINERALS
traverse 1
GRAIN SIZE OF OLIVINE (m.m.)
p.r. = o.p./(o.p.+c.p.)
MOL. % En., Fo., & An., IN THE ORTHO-PYROXENE, OLIVINE & FELSPAR RESPECTIVELY.
DISTANCE FROM LOWER CONTACT OF BASAL ZONE
SPECIMEN NUMBERS
4-540
4-500
4-450
4-410
base of mineralized zone
4-390
4-300
4-290
4-50
normal minimum
majority
normal maximum
fel.
(o.p.+c.p.)
c.p.
o.p.
others
ol.
En
Fo
An
traverse 1

FIG 7.

VARIATION OF MINERAL PROPERTIES IN KAPALAGULU INTRUSION.

Figure 5:

Traverse parallel to Mugombazi River.

Figure 6:

Traverse half a mile west of Kapalagulu Mountain.

Figure 7:

Basal Zone of the traverse featured in figure 6, scale considerably enlarged.

Traverses approximately normal to the basal contact of the Intrusion.

Figures 5A and 6A:

Tables of the optical properties of the minerals featured in figures 5 and 6-7 respectively.

FIG. 5A: OPTICAL PROPERTIES OF MINERALS APPEARING IN FIGURE 5.

SECTION NO.	ORTHOPYROXENE.	OLIVINE.	PLAGIOCLASE.
12-700		$N_Y \leqslant 1.683$, $2V 89^\circ$-90°: Fo_{87}.	
12-650		$N_Y \leqslant 1.703$, $2V_X 86^\circ$-88°: Fo_{83}.	
12-600	$N_Z 1.684$, $2V_X 84^\circ$: En_{86}.	$N_Y \leqslant 1.703$, $2V_X 84^\circ$-86°: Fo_{77}.	
12-460			$N_Y 1.574$, $2V_X 80^\circ$: An_{84}.
M5	$N_Y \geqslant 1.685$, $2V_X 70^\circ$-71°: En_{80}.	$N_Y 1.703$, $2V_X 83^\circ$-85°: Fo_{73-75}.	$N_Y 1.573$, $2V_X 79^\circ$-82°: An_{81}.
M4	$N_Y 1.685$, $2V_X 76^\circ$: En_{81}.		$N_Y 1.573$, $2V_X 81^\circ$-83°: An_{79}.
N	$N_Z 1.700$, $2V_X 60^\circ$: En_{74}.		$N_Y 1.570$, $2V_X 84^\circ$, Alb.Tw.An_{77}, Roc.Tw.An_{79}: An_{77}.
LM	$N_Z 1.699$, $2V_X 63^\circ$-66°: En_{73}.		$N_Y 1.573$, $2V_X 82^\circ$-86°: An_{78}.
K	$N_Z 1.712$, $2V_X 52^\circ$-54°: En_{64}.		$N_Y 1.572$, $2V_X 83^\circ$-86°, Alb.Tw.An_{75}: An_{76}.

Abbreviations:

- $\geqslant$: Slightly exceeds figure following the sign.
- $\leqslant$: Slightly less than figure following the sign.
- Alb.Tw. : Albite twins (followed by An-value).
- Roc.Tw. : Roc. Tourne twins (followed by An-value).
- C.Tw. : Carlsbad twins (followed by An-value).

FIG. 6A: OPTICAL PROPERTIES OF MINERALS APPEARING IN FIGS. 6&7.

SECTION NO.	ORTHOPYROXENE.	OLIVINE.	PLAGIOCLASE.
4-540	N_Y1.680, $2V_X 84^\circ$: En_{84-86}.	N_Y1.690, $2V_X 89^\circ$: Fo_{83-85}.	$N_Y \geq$ 1.568, $2V_X 86^\circ-88^\circ$: An_{73}.
4-450			$N_Y \geq$ 1.565, $2V_X 89^\circ-90^\circ$: An_{70-72}.
4-410	$N_Y \leq$ 1.685, $2V_X 88^\circ-89^\circ$: En_{80-86}.	N_Y1.685, $2V_X 84^\circ-87^\circ$: Fo_{76-82}.	$N_Y \leq$ 1.568, $2V_X 90^\circ$, Alb. Tw. An_{72}: An_{70}.
4-390	N_Y1.680, $2V_X 86^\circ$: En_{84-86}.	N_Y1.669, $2V_Z 86^\circ$: Fo_{93}.	N_Y1.568, $2V_X 88^\circ$: An_{73}.
4-300	N_Y1.678, $2V_X 82^\circ$: En_{86}.	N_X1.644, N_Y1.670, $2V_Z 88^\circ$: Fo_{93}.	N_Y1.568, $2V_X 84^\circ-88^\circ$: An_{73}.
4-50	N_Z1.682, $2V_X 89^\circ$(poor): En_{86}.	N_Y1.680, $2V_X 84^\circ$: Fo_{76-85}.	$N_Y \leq$ 1.568, $2V_X 87^\circ$: An_{73}.
4-705	N_Z1.683, N_Y1.675, $2V 90^\circ$: En_{85-89}.	N_Y1.683, $2V_X 89^\circ$: Fo_{84-87}.	N_Y1.572, $2V_X 85^\circ$: An_{76-78}.
4-706	N_Y1.686, $2V_X 83^\circ$: En_{80-84}.	N_Z1.686, $2V_X 89^\circ$: Fo_{85-87}.	N_Y1.576, $2V_X 80^\circ$: An_{84}.
4-707			N_Y1.571, $2V_X 82^\circ-85^\circ$, C.Tw. An_{80-85}: An_{77}.
4-708	N_X1.690, $2V_X 65^\circ$: En_{72-74}.		N_Y1.572, $2V_X 83^\circ$, Roc. Tw. An_{80}: An_{77}.

In the Intermediate Zone plagioclase [~~[illegible]~~] exhibits idiomorphic tendencies for the first time, and many of the grains obviously even preceded pyroxene in crystallization. From the layering it is envisaged that there were showers of An-rich felspar, orthorhombic pyroxene and olivine grains.

After the disappearance of olivine the greater part of the Intrusion consists of granular hyperite. Virtually the only two minerals are plagioclase and pyroxene, and they are remarkably constant in composition and concentration, though the ratio o.p.:c.p., is variable. In the upper reaches there is a gradual change to the lower temperature varieties of the minerals, and micropegmatite makes its first appearance. The ortho-pyroxene content dwindles to nothing and in places, free quartz may be present along the upper boundary of the Intrusion.

There is no readily obvious explanation for the presence of the anorthosite band within the Main Zone, but it is significant to note that patches of melanocratic hyperite, and even felspathic hypersthenite were found immediately above it. Also, the anorthite content of its plagioclase does not differ materially from that of the surrounding hyperite-norite.

(6) <u>Determinative Methods</u>.

Whenever possible, the refractive indices of the minerals were determined. A Fedorow universal stage was extensively used, and proved especially useful, for example, in determining optic axial angles of ortho-pyroxene and olivine; twinning relationships in felspars; and relationships of intergrowths or reaction structures of olivine - ortho-pyroxene - clino-pyroxene. Except where otherwise stated identifications are based on the data supplied by Winchell (1951). A point counter of the Glagolev type (Chayes 1949) was employed for calculating volumetric proportions, and proved rapid and admirably suitable.

Briefly, as regards individual minerals, the following methods were found most satisfactory:-

<u>Olivine</u>: Particular attention was paid to refractive indices,

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of their useful range, but alteration often limited accuracy. The nature of the alteration is typical: Chloritic minerals and iron oxides fill numerous wide fracture planes and cleavages and extend inwards so that usually only small cores of olivine remain in a large grain consisting mostly of alteration products. Even when finely powdered, it is difficult to find grains which are not coated by this matter.

The optic axial angles of olivine form an almost rectilinear function over 40^{o} (i.e. $2V_{X} = 55^{o}$ to 95^{o}). An error of 1^{o} in measurement of 2V is therefore equivalent to an error of $2\frac{1}{2}\%$ in the Fo-Fa content. In each specimen analysed, not less than five individual grains were measured and checked. By applying their average values, together with the refractive indices, the error is minimized to probably less than 2% either way. There are minor differences in the optic property tables supplied by various authors so, for uniformity, the results figuring in this work are based on the tables of Kennedy (1947).

Plagioclase: The factors contributing to error are similar to those of olivine, but the error is rendered still greater by the small range in refractive indices and the poor diagnostic value of optic axial angles. As checks, determinations were often also made on twinning, using Duparc and Reinhard migration curves.

Pyroxene: Orthorhombic pyroxenes are relatively fresh throughout the Intrusion and could therefore be determined with great accuracy by using the methods and diagrams of Hess (1940). The monoclinic pyroxenes, except in the quartz-bearing parts of the Intrusion, all lie in the augite field (Winchell, 1951, p408), and generally close to its diopside boundary. Because of their poor condition, determinations, even in a single thin section shewed fairly large divergences in optical properties. It can nevertheless be stated with assurance that there is a definite variation from Ca-rich towards Fe-rich augite in progressing upwards in the Intrusion. With regard to the compostion-relationship of the orthorhombic and monoclinic varieties, an extension of

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join in a triangular Wo-En-Fs diagram seemed closer to the wollastonite apex than to the Wo_{75} En_{25} suggested by Hess (1941) as being most common in mafic magmas.

IX: THE SULPHIDE ORE AND ITS GENESIS.

Usually up to two hundred feet above the lower contact of the Basal Zone there occurs a narrow conformable zone in which sulphides are in relatively high concentration. It is readily evident that virtually all the sulphide material is interstitial to the silicates of early formation. In this Ore Zone olivine commonly constitutes 55%, or more of the silicates, and orthorhombic pyroxene about 10%. The remaining 35% is formed by felsapr, monoclinic pyroxene and minor amounts of biotite, which is a late reaction product.

Volumetrically, felspar and sulphide shew a distinct antipathetic relationship, and it may be reliably stated that in the Ore Zone sulphides occupy interspaces which would otherwise have been occupied by felspar.

Particular attention was paid to the behaviour of these two minerals with respect to features such as replacement or magmatic corrosion when in contact with one another. There is certainly no evidence of large-scale hydrothermal action. Their relationship is more that of minerals which, if minor deuteric action is ignored, crystallized in a state of equilibrium. In this zone there is efficient packing of olivine grains and to a lesser extent orthorhombic pyroxene, so that the interstitial volume is in the form of numerous little compartments which are filled individually by either sulphide or felspar, but rarely by both. In the highly mineralized portions felspar is almost absent, the other silicates are less closely packed, and in extreme cases massive sulphide results.

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By far the greater proportion of the sulphide consists of pyrrhotite and also varying amounts of pentlandite, sphalerite and pyrite. Iron oxides appear as both well-shaped and irregular grains in both the silicate and sulphides, but in no greater quantity than in the remainder of the melanocratic Basal Zone. On some occasions half-inch to three-inch pieces of drillcore consisted entirely of magnetite, but the magnetite; apparently favoured no particular horizon in the melanocractic rocks. Much fine magnetite is closely associated with the alteration of olivine. When the sulphide-rich Ore Zone is sheared, small amounts of the sulphide are often redistributed along shear-faces and, in the ore itself, a filagree of chloritic matter and other alteration products is present.

It is maintained that the Ore Zone owes its origin to the separation and sinking of immiscible sulphides in the magma. Prior to determining the variation of properties of the silicates, there was one particular stumbling block in the interpretation, namely the location of the ore-body some distance above the floor of the Intrusion. The abrupt mineral variation (See p43) around this horizon is however beyond coincidence. It is possible that a large second influx of magma took place, which completely interrupted and stopped further crystallization for some time, and so led to a division in the Basal Zone. If this be the case, the major proportion of the ore must have separated at a stage subsequent to the interruption of crystallization, as the evidence points to the sulphide droplets having settled along the plane dividing the two generations of silicate crystals.

The theory of magmatic segregation was pioneered by Vogt around the turn of the century. Sulphides are only very slightly soluble in a magma and it is envisaged that through fractionation of early silicates saturation in respect to sulphide is soon achieved. As a result, minute globules form, could coalesce, sink and concentrate at the base of an Intrusion. Similar conditions are known to prevail in certain industrial slags.

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It is conceivable that these droplets of high density could permeate through the silicate crystal mesh to form an interstitial liquid near the base of the Intrusion. If in sufficient quantity, a sulphide layer could form by displacing the more buoyant silicates. Should differential pressure arise, the sulphide melt may well develop an intrusive attitude (Bateman 1942, 1947).

When sulphides reach the base of a crystal mesh they naturally displace the already-present interstitial liquid. In the case of Kapalagulu Complex this liquid is believed to have solidified before the sulphides, and formed, amongst others, interstitial felspar and some of the monoclinic pyroxene.

The interstitial silicate liquid must necessarly have been trapped in the high-temperature silicate mesh at a very early stage in the formation of the Complex. The liquid would therefore not be in perfect equilibrium with the crystals forming the mesh. It is pictured that, as cooling progressed, not only resorption, but, resulting from the release of fugitive constituents, even hydrothermal or deuteric alteration of the primary crystal differentiate could have taken place. Similarily, it is reasonable to assume that the ore would release fugitive constituents on solidifying and these too, would react with the silicates, including felspar. The effect would include small-scale hydrothermal action such as sericitization of felspar and the formation of biotite.

X: MECHANISM OF INTRUSION AND DIFFERENTIATION.

It is unfortunate that the upper contact of Kapalagulu Intrusion is a sedimentary one, as this phenomenon prevents an estimation of the original volume and composition of the body. It is quite possible for instance, that a large quartz-bearing fraction was eroded away in pre-Bukoban times. It cannot even be estimated with certainty at what depth, if any, the magma intruded. Members of the Basement System, which are predominantly gneissic, are the only intruded rocks exposed at present. Most of the features of Kapalagulu Complex (including a distinctly lopolithic base) favour a magma chamber deeply situated in the Basement System.

Assuming this to be the case, it is pictured that there were at least two injections of magma. As cooling proceeded after the first injection, olivine commenced to crystallize and the grains were effectively removed by gravity to form the olivine-rich Basal Zone. Separating this zone from typical Basement System is a relatively leucocratic zone of mixed basic types, namely the Contact Zone. The following agencies are believed to have been instrumental in the formation of the Basal Contact Zone: chilling of magma, hybridization and mobilization. The zone may even have resulted partly from granitization of the Basement System. Basic rocks constitute buffers or "resisters" to granitizing emanations and consequently intense metasomatism takes place along their boundaries.

There are two reasons for believing that there was a second injection of magma, namely the variation in composition and concentration of minerals and the elevated position of the Ore Zone. The second influx temporarily halted crystallization (during which time much of the existing crystal-mesh may have compacted and even consolidated), and then brought about a repetition of the initial process.

At a certain critical stage the depletion of silicate material by crystal fractionation resulted in a saturation with respect to sulphides in the magma. These sulphides percolated downwards through

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mesh of mafic crystals and occupied much of the interstitial volume towards the base of the crystal mesh formed by the second influx of magma. The first interstitial mineral to crystallize was felspar, followed some time later by the sulphides. The latter's release of fugitive constituents caused small-scale hydrothermal alteration of the silicates.

It is reasonable to suppose that structural disturbances took place before the complete consolidation of the Intrusion. A surge of melanocratic crystal-mush into cavities formed in the Basment foot-wall would explain the anomalous structure in the vicinity of section-line EF, plate 2.

Overlying the Basal Zone is a thick developement of an intensely layered Intermediate Zone, comprised chiefly of olivine hyperite. It is believed to be the stage where the last of the olivine crystallized accompanied by showers of orthorhombic pyroxene and plagioclase crystals. Many of the olivine grains exhibit large reaction rims, which indicate that imperfect chemical equilibrium once existed. The orthorhombic pyroxene and plagioclase too, are partially rounded by resorption. Compared with the Basal Zone, the crystal mesh of the Intermediate Zone is far more open textured, the crystals being almost in suspension in a more viscous magma, with which they reacted to a small extent.

The majority of the ortho-pyroxene and felspar grains lie with their longest morphological axes in random direction, but parallel to the base of the zone. From this platy flow structure it is deduced that quiescent conditions were prevalent.

The Main Zone follows upon the olivine-bearing rocks of the Intrusion. In distinction to the lower zones, it has a relatively granitic texture, from which it is concluded that its major constituents, pyroxene and felspar are of approximately contemporaneous crystallization. It represents attainment of the stage where the sinking of crystals ceased to play an important role, and it is significant that this zone constitutes the greater portion of the Complex.

In its upper reaches there are small quartz-bearing parts, and in other parts there are small occurrences rich in mafic minerals. If these are ignored, the zone is of remarkably uniform composition. It was previously stated that it is uncertain whether the present exposure of the Intrusion represents a complete cross-section of the original body. If it does, then the composition of the quartz-bearing part is that of the last remnants of the Intrusion to crystallize.

Situated approximately in the middle of the Main Zone is the Anorthosite Band, 90% or more of it consisting of rounded anorthite-rich plagioclase crystals. As with most monomineralic igneous rocks, its manner of formation is difficult to vizualize. The problem of anorthosite has received much attention in recent years and comprehensive outlines are obtainable by referring to the textbooks of, amongst others, Shand (1949, p282), Barth (1952, p226) and Turner (1951, p256).

From this literature it is obvious that intrusive anorthosites are rare occurrences, which form only under very special circumstances. The anorthosite of Kapalagulu Complex has the form of a narrow "conformable" layer which extends virtually throughout the length of the Complex. In thin sections the felspar grains are obviously rounded euhedral grains which have suffered very little bending or crushing These factors favour an origin in crystal fractionation rather than in separate Intrusion.

If the Kapalagulu anorthosite is assumed to have formed in situ by crystal fractionation in a practically stagnant magma, then the following aspects must be considered:-

For crystals to have congregated, they must either have sunk or risen in the magma. It seems doubtful that such a light layer could have formed alone by the sinking of crystals in a magma of relatively high specific gravity, and moreover to a horizon approximately in the middle of the Main Zone rather than near the base of the Intrusion. The fact that some small accumulations of heavy minerals (e.g. in felspathic hypersthenite), lie immediately above it renders the theory still less tenable.

If/.....

If the crystals rose, then a reason must be sought for their present elevation. This could be ascribed to a rise of the early-formed plagioclase crystals to an elevation where they reached density-equilibrium. Crystals formed at lesser depths could similarily sink to this level. It is questionable however whether the increase of density with depth is sufficient to cause such effective concentration.

The anorthosite layer, naturally, could not remain in chemical equilibrium with the magma for an indefinite period. This could account for both the large-scale resorption of crystals and the intense alteration present in the anorthosite.

It is not intended to favour any one theory to the exclusion of all others. Importance, however, is attached to the fact that a drift and accumulation of crystals in a stagnant magma as outlined above, fits best into the differentiation-pattern of the Intrusion as a whole. It is therefore considered rather unlikely that the Anorthosite Band intruded into the Main Zone.

Near Ibalaba Steam is the only relatively large dyke situated within the Complex. It is doleritic and contains granophyric intergrowths. It therefore closely approximates the composition of the quartz-bearing fraction of the Main Zone. It does not seem impossible that the Main Zone may have been the source of the dyke-material. Owing to the paucity of outcrops however, no conclusive field evidence is obtainable.

There are several small dykes and sills of impersistant length and breadth, which are confined to the precincts of the Contact Zone, Basal Zone and the lower horizons of the Intermediate Zone. The following theories are suggested for the origin of these small occurrences: (1) The Basal Zone was formed by gravity-differentiation. On compaction of the mesh of high temperature mineral grains, some of the interstitial liquid which was expelled found its way along channels, which now appear as small dykes and sills.

In/.....

In the Basal Zone, plagioclase is the mineral with the lowest temperature of crystallization (always interstitial), and consequently the intrusions are leucocratic. In the Intermediate Zone pyroxene and plagioclase are of contemporaneous crystallization (also evident in the texture), so that an expelled melt would be rich in both of these minerals. The resulting dyke is therefore doleritic.

(2) Another possibility is that during the stage when saturated magma overlaid the Basal Zone, cracks, such as caused by movement, were injected with this liquid. (3) These small occurrences may be a considerably later stage of Intrusion. (4) Some of the small Intrusions appear to extend from the Basal Zone into the Basal Contact Zone, where they cannot be distinguished from the leucocratic contact rocks. This feature is suggestive of hybridization, mobilization and eventually Intrusion near the basal contact of the Complex.

XI: ORIGIN OF LAYERING.

(1) Existing hypotheses.

Hypotheses based on crystal fractionation, for the origin of primary banding in basic plutonic rocks have periodically appeared in technical journals since the turn of the century. Hess (1938, p264) summarizes the features of layering as follows:-

1) Thickness: From a fraction of an inch, two or three crystals thick, to a number of feet.

2) Length: Bands can rarely be traced along the strike for more than a couple of hundred times their thickness.

3) Attitude: Approximately parallel to the floor of the intrusive.

4) Contacts: May be sharp or gradational; crystals interlock across contacts.

5) Relations between bands: They never cross-cut each other as dykes though they commonly lens out along the strike or may divide to form two or more individual bands.

6) Mineral variation across bands: The plagioclase and pyroxene maintain the same composition across the whole series, regardless of the proportions of the two constituents present.*

7) Orientation of the grains: The plagioclases are generally tabular and pyroxenes are more or less elongated parallel to their c-axes. The grains are well oriented with their longer axes parallel to the plane of banding, giving the rock a well-developed gneissic structure in any plane perpendicular to the banding. The elongate grains (with rare exceptions) show no linear orientation in the plane of banding.

8) Density gradations: A very common type of band is one which has sharp boundaries and grades from pyroxene-rich at the base to anorthosite at the top. This feature, which may be compared to gradational bedding in sediments, makes it possible to tell top from bottom in many banded outcrops.

Bands/.....

*The present writer wishes to add that a very gradual variation in composition does exist in at least some intrusives. The variation is generally evident in variation-diagrams.

Bands which show little or no gradation are also common, and even a few with reversed specific-gravity gradation can be found.

9) Regularity of bands: Most bands are remarkably straight and regular, but cases of disturbances of bands presumably during a crystal-mush state may occasionally be found. These irregularities, though uncommon, serve to throw some light on conditions during the formation of banding.

Assuming the specific gravity of the magma to be slightly less than that of the crystals forming from it, Coates (1936, p407) envisages the following: If two sorts of crystals are forming, both will settle towards the bottom, and under suitable conditions the sinking of the heavier ones will tend to displace the adjacent fluid upwards. Because of the viscosity of the liquid and the slow rate of settling of the lighter crystals, they are displaced upward and a layer richer in this constituent is formed. There is thus a partial separation of the light and heavy minerals. When the lighter layer becomes sufficiently thick it is able to support the newly formed dark crystals and a repetition of the process takes place.

In experiments, a layering effect was obtained from a settling of labradorite and hedenbergite in a mixture of bromoform and alcohol. Although doubtless possible, it is debatable whether large-scale igneous banding is commonly formed in this manner. Factors which are not taken into account in such experiments are viscosity and the fact that in magmas the grains crystallize from a melt with which they have to remain in equilibrium.

Hess (op. cit.) offers a solution which depends upon magma-chamber conditions similar to those of Coates, but in which the state of quiescence is periodically disturbed by short epochs of mild and irregular turbulence. These are believed to be sufficient to temporarily delay sinking of the lighter crystals.

J.S. van Zyl (1950, p72) independently evolved a mechanism similar in several respects to those of Coates and Hess, but he assumes the magma to have a specific gravity between those of the crystallizing minerals.

The/.....

The lighter minerals would therefore tend to rise in the magma. He states: "If the magma is relatively viscous, the crystals numerous and the rate of movement slow, it may be visualized that the crystals would mutually interfere with each other in the process of moving up and down respectively. In this manner planes of relative stagnancy may arise through mutual interference, forming a network of crystals, partly impenetrable to crystals moving vertically. At this stage there is a very delicate balance which may be easily disturbed by magma flow. However, salic constituents continuing to accumulate from below and femics being continuously added from above would serve to stabilize such a zone and would form a dark band above and a light one below the initial zone of relative impermeability. Then between any two such stabilized zones the process may be repeated......"

Daly (1933, p354) states that a slow basining of the floor of the chamber is a possible cause of rythmic layering. The basining would have the effect of oscillating the magma-temperature, resulting in successive showers of crystals.

In the case of Skaergaard, Wager and Deer (1939, pp 39, 120, 125, 172, etc.) ascribe the near-perfect banding of its Layered Series to the presence of currents (primarily of convection), and rythmic variation in their velocity. Strong streams would maintain the light crystals in suspension, wherafter any reduction of flow would lead to a shower very rich in these minerals. The conditions which prevailed are therefore different to those envisaged in such intrusions as Stillwater, Palisades, Insizwa, Garbh Eilean in the Shiant Isles, or Kapalagulu, where stagnant magmas are postulated.

Schwellnus (1939) very briefly draws attention to the close similarity between banding in basic plutons (including the repetition of chromitite seams in the Bushveld Complex), and the effects of the Leisegang phenomenon. His work is unpublished and to the knowledge of the present writer, a possible association of the two phenomena has not been entertained elsewhere. On its phsical-chemical aspects Van Hook (1944, p513) states: "The general conclusion of the prodigious amount of work following Liesegang's original announcement is that the phenomenon is not specific, but seems to be general for any/.....

deposition of matter under constrained conditions." Almost all precipitate reactions, crystals formed from melts or solvents (McMasters 1935), and solids settling from suspension (Ungerer 1921, Mendenhall 1923, Mason 1923), are liable to periodic development, giving rise to, amongst other things, banded structures.

(2) Metastable Conditions.

For the origin of banded structures in intrusives, it is intended shortly to submit a hypothesis which depends on metastable conditions prevailing during crystallization of a magma.

The temperature at which the solid phase of a substance changes to a liquid phase should be the same as that for the converse process. In practice however, this is seldom the case. It is more general for a melt to cool to below the temperature at which crystallization should commence, before the particular component actually does start crystallizing. The theory of this phenomenon of super-cooling in substances which do not form an isomorphous (continuous) series has received considerable attention, and is comprehensively described by, amongst others, Eitel (1952, p569), Glasstone (1948, p747), and Wahlstrom (1950, p187). To the knowledge of the present writer, very little data pertaining to super-cooling in isomorphous systems is available.

An attempt will now be made to follow a possible course of events during super-cooling of an isomorphous mixture. It is very likely that several factors, not necessarily favourable towards the hypothesis either, have been overlooked. If only serious consideration is given to the matter, even if it amounts to disproving its possibility, then it will be felt that the work has served a useful purpose.

A melt of composition X (fig. 8) may continue cooling to below T_0 without formation of crystals. It is assumed that this super-cooling continues to temperature T_1 say, whereafter there is an almost spontaneous reversion towards equilibrium, which is attained at T_2. The composition of the first crystal to form is presumably C_1. As the formation of crystals following super-cooling is an almost spontaneous

process/.....

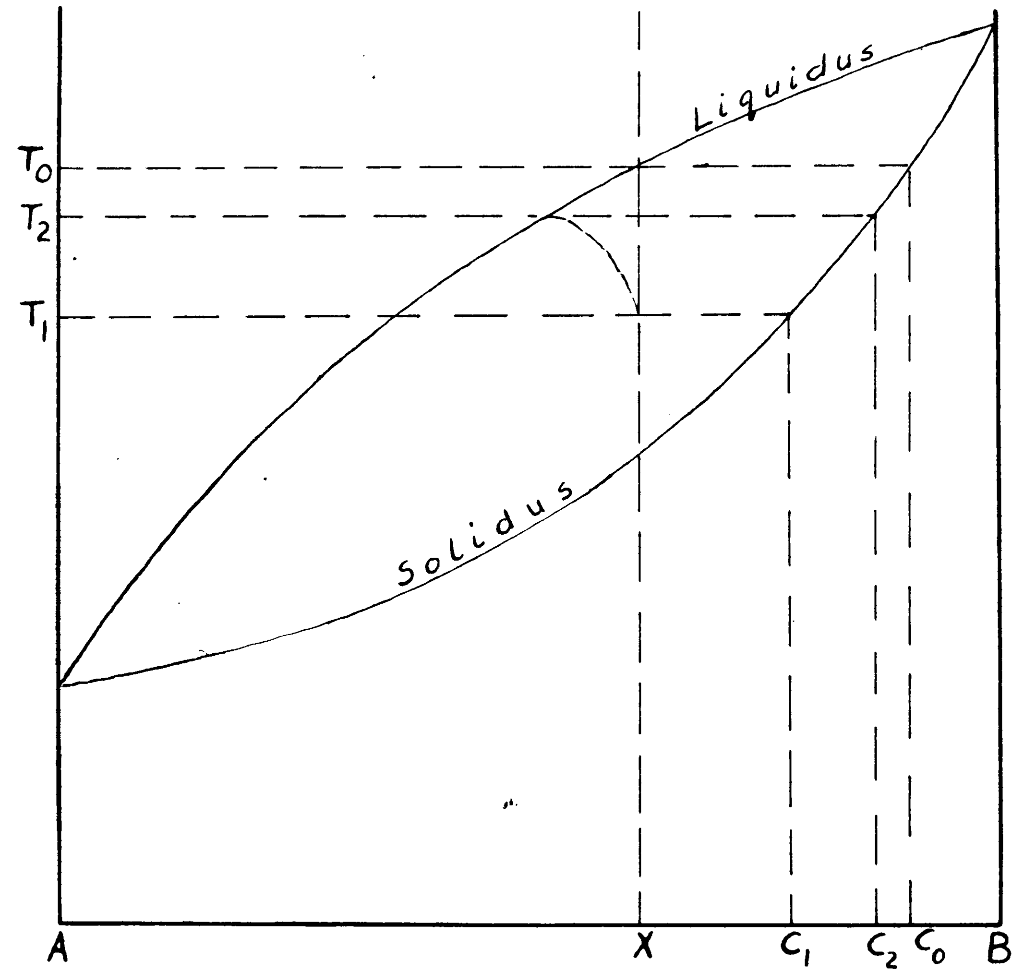


Figure 8.

Supercooling in a binary isomorphous system.

it is very unlikely that any resorption of crystals will take place. It is pictured rather, that retrogressively zoned crystals form, with cores of composition C_1, and surfaces of composition C_2.

It is extremely difficult to picture the effect of super-cooling in a magma in which several isomorphous minerals crystallize similtaneously. In the Intermediate Zone of Kapalagulu Complex, for example, there is evidence that plagioclase, pyroxene and olvine are of similtaneous crystallization. Importance also, is attached to the fact that in all layered igneous rocks, the alternation in concentration of minerals of isomorphous series is responsible for the layering effect. Such features lead the writer to wonder if super-cooling of one isomorphous series and the consequent fluctuation of temperature (T_1 to T_2 in fig. 8) could not disturb, and even halt, the crystallization of another isomorphous series in the magma. Super-cooling in the second series, in turn, could interfere with the crystallization - process of the series which originally underwent super-cooling. In this manner super-cooling, alternately in one and then in the other, could have numerous repetitions. The effect of layering would result from alternating showers of the individual minerals.

The variation of temperature during super-cooling (T_0-T_1) in figure 8, has been made large for convenience of description. In a magma the difference would probably be very small. Furthermore it is unlikely that the temperature T_2 will again be reached in a complex magma, as the heat generated by the comparitively small system AB would be largely absorbed by the magma as a whole. Instead of crystals varying in composition from C_1 to C_2, a relatively large volume of crystals of a composition approximating to C_1 will be formed in an extremely short space of time.

Another factor to be taken into consideration is that after one of these sudden surges of crystallization, the free ions which combine to form the mineral A_xB_y are widely dispersed in a magma which is rich in other ions.

If/.....

If the diffusion of the ions through the magma is greatly retarded (by their relatively low concentration, by the viscosity of the magma, etc.), the number of crystal "nuclei" will be low, and further crystallization will also be retarded, so that super-cooling may again intervene. The Liesegang effect is often obtained under similar circumstances in chemical precipitations (Eitel 1952, p450).

If the banding in intrusives owes its origin to super-cooling as so far outlined, then the following possibilities may be entertained:-

1) Super-cooling commences in the magma at a temperature where the first crystals would normally form. In Kapalagulu Complex the Basal Zone contains as much as 80% olivine. The remaining minerals are interstitial in nature and obviously crystallized in situ at a much lower temperature than the olivine. Intermittent showers of olivine grains only, will not lead to a noticeable banding effect. It is likely then, that the mechanism leading to banding is more common than was originally suspected, but that banding is only noticeable when accentuated by alternations of light and dark minerals.

2) Super-cooling may intervene after a large number of crystals have already formed. To initiate super-cooling it would be necessary for the magma to be free of crystals. This is possible through an additional influx of magma and a consequent rise in temperature of the main body of the intrusive.

Banding in the Kapalagulu Intrusive is develcped to near-perfection in the Intermediate Zone. It is in this zone that minerals other than olivine exhibit idiomorphic tendencies. In other words, at this stage in the cooling of the Intrusion, these minerals crystallized in a manner analogous to that of olivine, and were also able to sink towards the base of the Intrusion. The major minerals of the Zone are plagioclase, orthorhombic pyroxene and olivine. The light bands consist almost exclusively of felspar, and the dark ones, of pyroxene and olivine. The specific gravity of the felspar is 2.74 (in conformity with its optical properties), whereas those of olivine and pyroxene are in the vicinity of 3.4.

The/..

The minerals concentrated by gravity-fractionation are therefore 20% heavier in the dark bands, than in the light ones.

(3) Application of Hypotheses to Kapalagulu Intrusive.

1) If the specific gravity of the magma in the Intrusive was lower than that of felspar (ca. 2.74), then hypotheses of Hess, Coates, Schwellnus and the present writer may be considered. It is required that the crystals sank in the magma, but the various authors differ in opinion regarding the mechanism responsible for the rythmic arrangement of the felspars and the mafic minerals.

2) If the specific gravity of the magma was greater than that of the felspar, then the conditions existing were suitable for the process suggested by J.S. van Zyl. The formation of anorthosite at a high elevation can also be visualized if such conditions prevailed. The hypothesis of the present writer is also applicable in that felspar crystals formed near the base of the magma body, may have been prevented from rising by successive showers of mafic crystals, whilst those which were freely suspended were ether resorbed, or drifted upwards.

Unfortunately, no estimate of the specific gravity of the parent magma of Kapalagulu Intrusive can be made. The original proportion of the quartz-bearing rocks is conjectural, as the present upper contact of the Intrusion is of sedimentary origin.

XII: TECTONICS OF THE AREA.

The zoning of the Intrusive is believed to be a direct result of gravity-accumulations of minerals of early formation. It is therefore obvious that the whole Intrusive was subsequently tilted through approximately 90°. Both the Basement and Bukoban Systems of the area studied are similarily displaced.

Except for the tilt, the North-western Sector of the Intrusive is relatively undisturbed. North of Mugombazi River evidence of minor dip-faulting was found. The exposures are poor and their exact nature could not be determined.

A borehole alongside the Mguje Stream brought to light normal strike faulting with the downthrow on the south-western side (plate 2.) Scant evidence of similar faulting was traced by drilling operations for some 2,000 feet further southwards. Likewise, in the area traversed by section-line AB, distinct thrust faulting was revealed, as is illustrate in the section. These faults are all tentatively ascribed to a single fault-zone of the scissors - type, with its fulcrum between 1,000 and 3,000 feet north of the section-line.

The presence of thrust faulting is also evidenced by: (1) the narrowness of the Basal Zone, (2) the juxtaposition of the Basal Zone and the Main Zone, and (3) information gained from boreholes close to Ibalaba Stream.

Both the tilting of the Intrusive and the thrust faulting mentioned, indicate compressional, rather than tensional forces having played the major structural role in the area mapped. It is difficult however to reconcile this with the regional structure-pattern of Western Tanganyika. McConnell's maps (1950) indicate several normal (tension) faults of great magnitude. At least one of these faults skims narrowly past the south-eastern side of the Intrusion (plate 1.).

In the aerial photographs the geographical features suggest a possible connection between the fault at the foot of Kakungu Mountain and the disturbance around Ibalaba Stream. The writer will presently indicate that the Kakungu Fault may possess the elements of a tear fault, and that its "upthrow" (eastern) portion was not only moved vertically, but also northwards by lateral pressure.

A/......

A structural interpretation of the Ibalaba Area is given in a series of block diagrams. Figure 12 illustrates in a simple manner the effect of transverse movement. In this particular instance the vertical component is of no consequence, as the stratification of the Intrusion is also vertical. The already-mentioned scissors fault is also shown.

Figures 13 A to D are of the Ibalaba area, which covers the most faulted portion of the Intrusion:

A) The strata are in the initial stages of lateral folding as a result of pressure from the south.

B) The Basal Zone is extremely distorted, but is not entirely dislocated. Serpentinized olivine-rich rocks are generally pliable, and moreover there is much shearing parallel to the strike of the planes of igneous lamination. The movement may be likened to the bending of a pack of playing cards. The Bukoban sandstone and the remaining zones of the Intrusion are relatively brittle and, instead of bending, have faulted by tearing laterally (fault 1). The plane cutting across the block and represented by broken lines is the incipient thrust fault.

C) Faults 1 and 2 are in advance stages of development, and faults 3 and 4 have formed prior to waning of the pressure. Around the latter two fualts the Basal Zone is completely over-folded.

D) This diagram is the same as the previous one, except that the surface is planed down to a common level to illustrate approximately the present exposures of the various formations.

It is significant to note from the contours in plate 2, that the North-eastern Sector is considerably more elevated than the North-western Sector, despite the ravages of erosion. The North-western Sector lies on the downthrown side of Kakungu Fault.

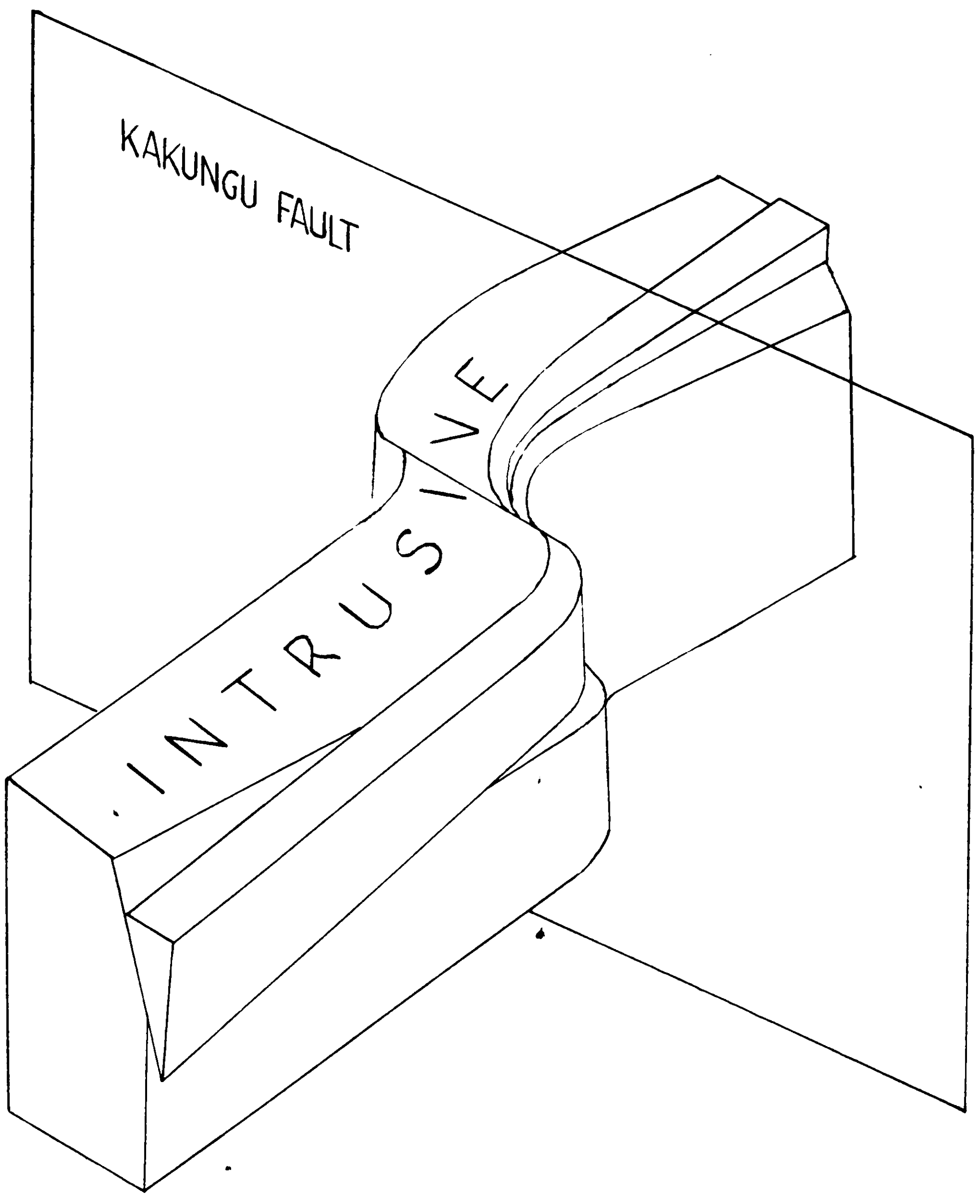


FIGURE 9.

FIGURES 10A to 10D.

Block diagrams interpreting the trend of faulting in the vicinity of Ibalaba Stream.

(Not to scale).

LEGEND:

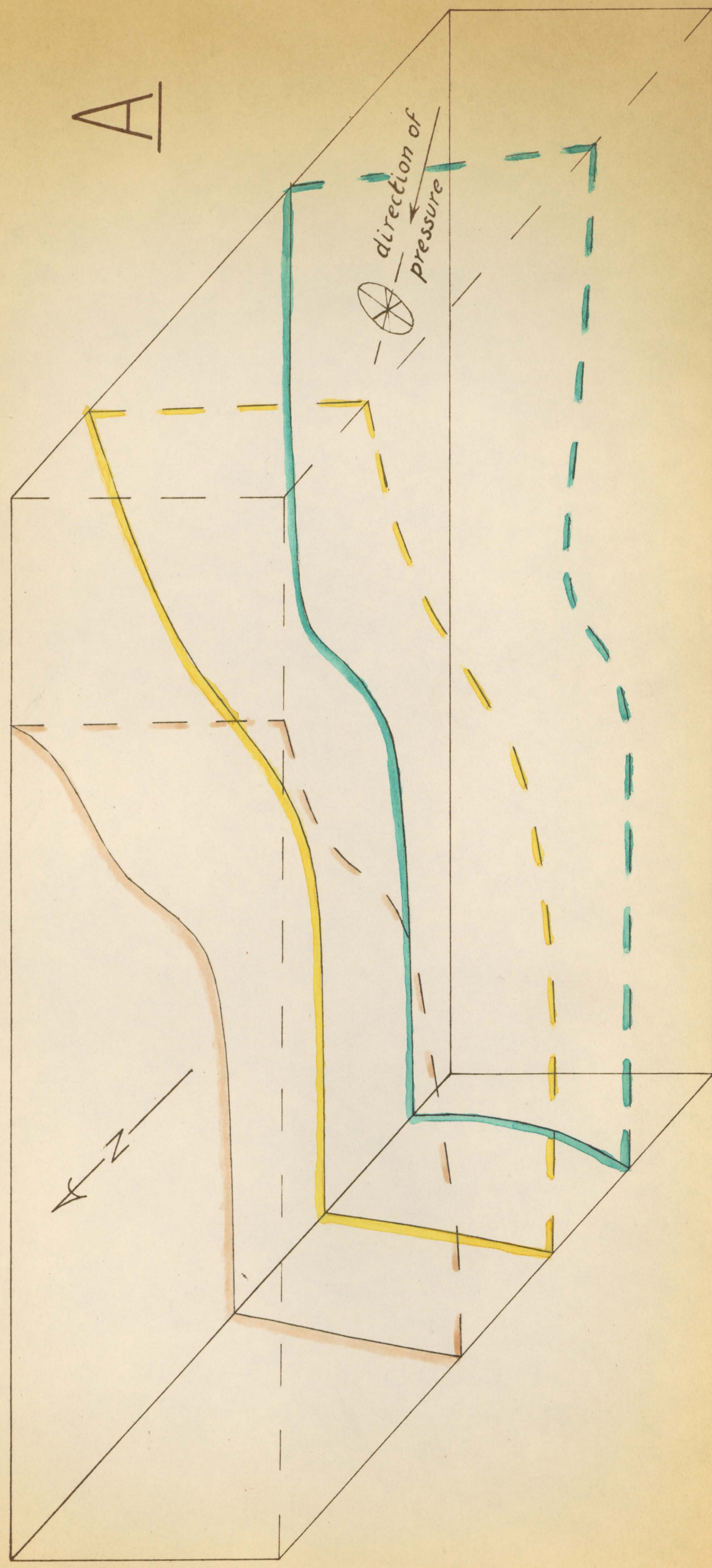
Bukoban Sediments .....

Main Zone .....

Anorthosite Band .....

Basal Layers .....

Basement System .....


A
direction of pressure
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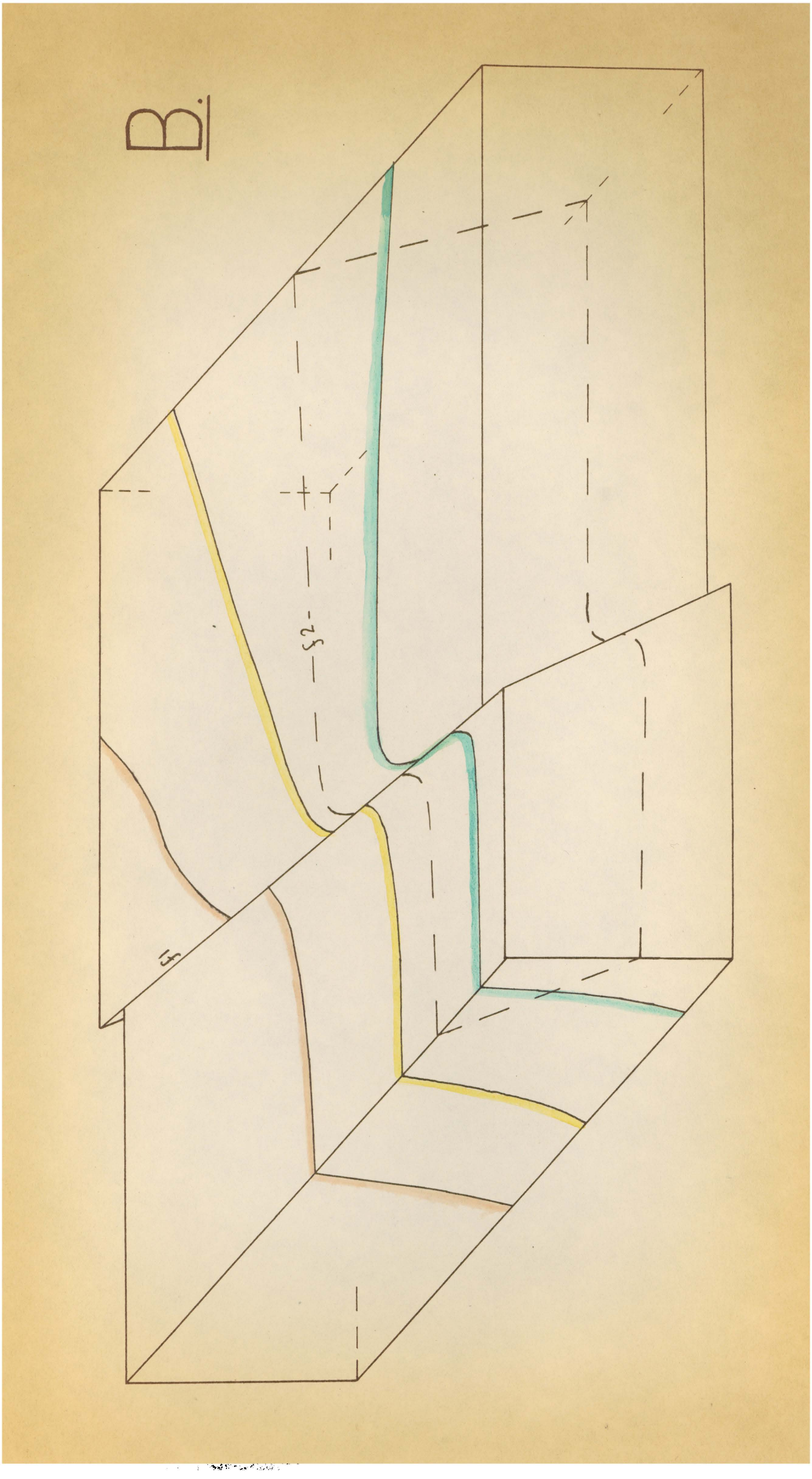
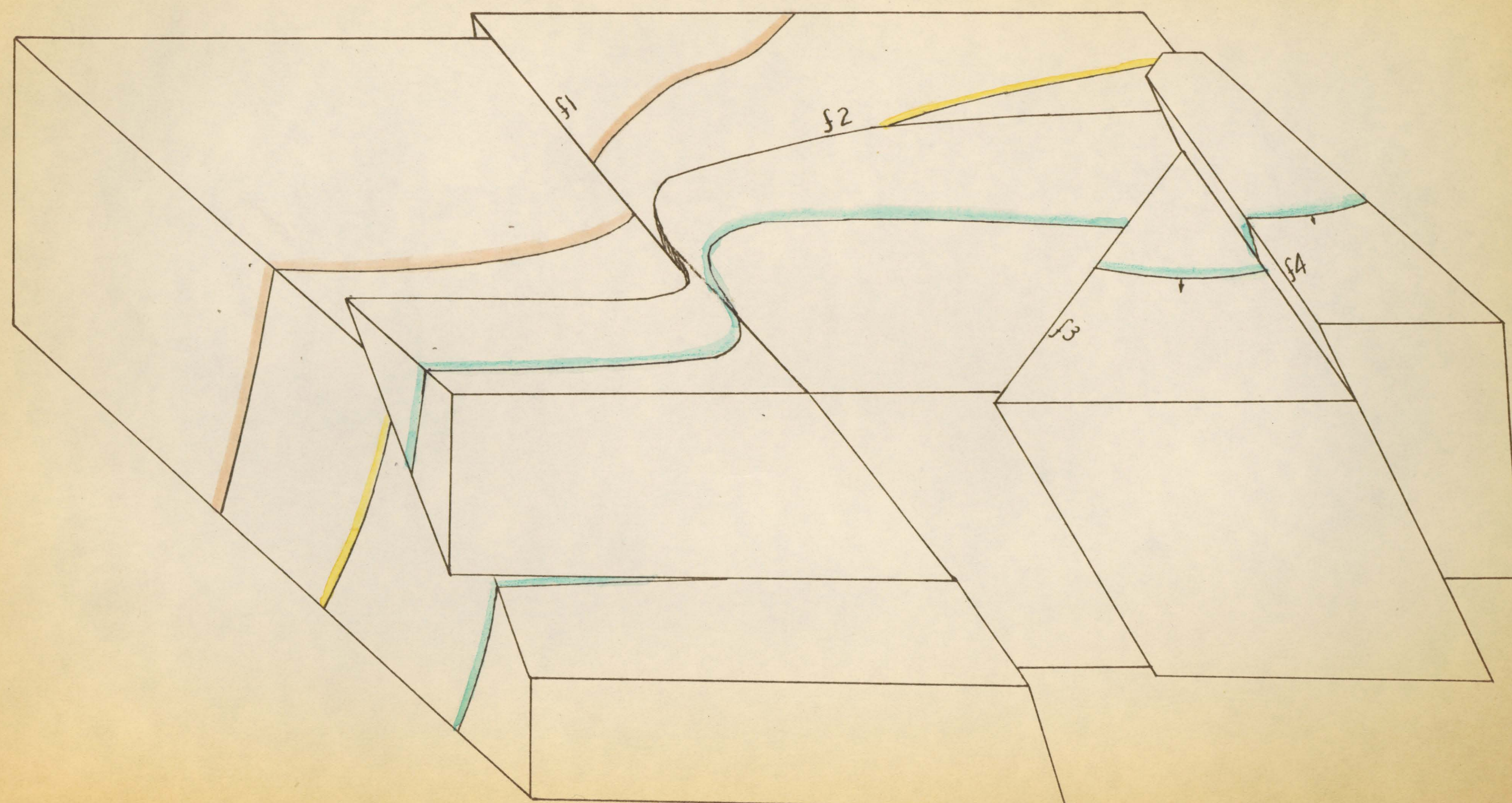

B.
f2
f1



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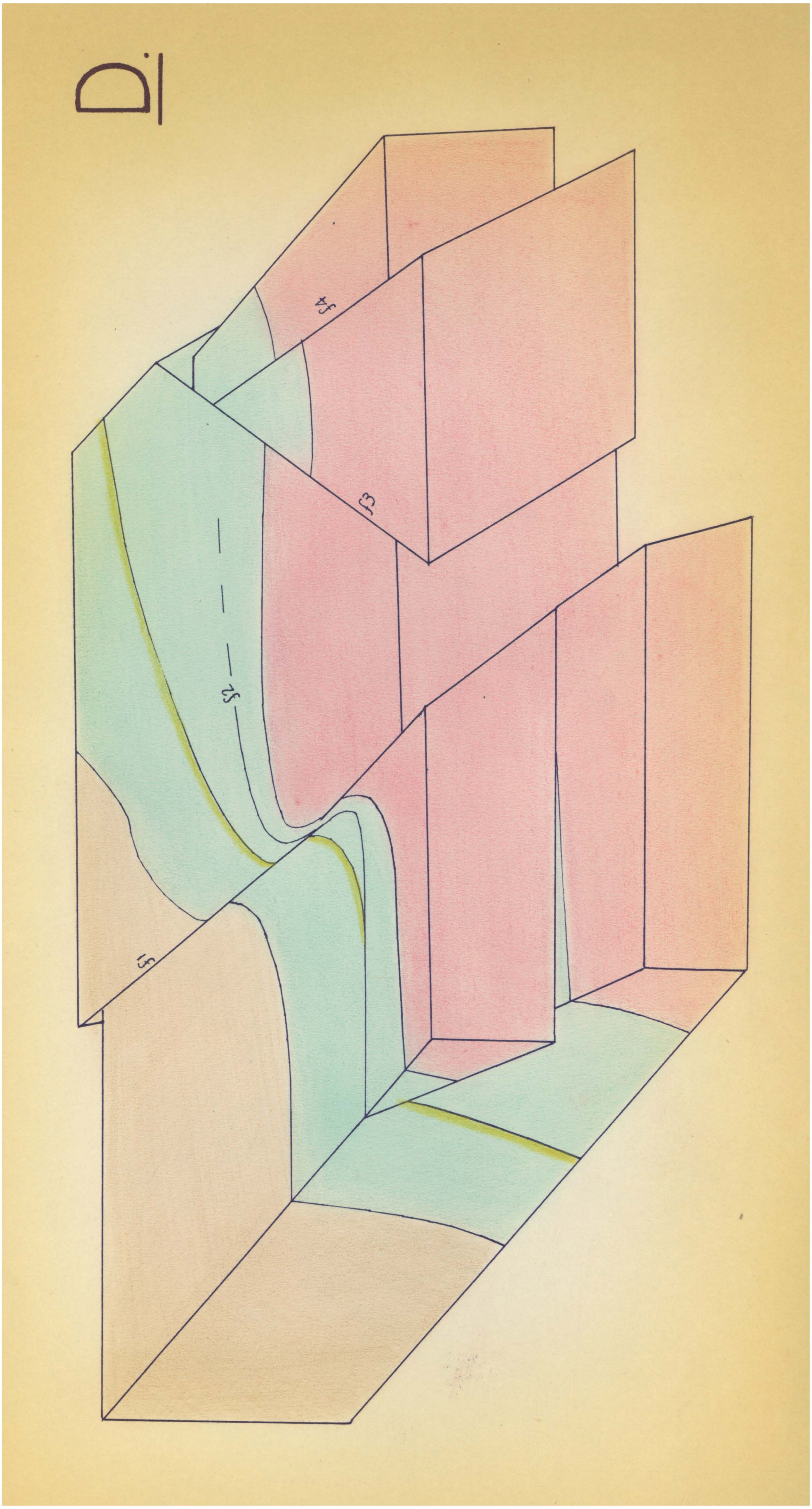
D.
f4
f3
f2

XIII: SUMMARY.

CHAPERS I TO III:

Kapalagulu Complex is a basic intrusion situated within the Basement (Primative) System, and is partially overlain by the sediments of the Bukoban System. Both the Systems and the Intrusion are exposed in cross-section as a result of tilting through 90°. The forces responsible for the tilt are tentatively correlated with rift faulting.

CHAPTER IV:

Locally the Basement System is predominantly gneissic. Zones of red and grey gneiss and enclaves of quartzite are discernable. The zones apparently formed stratigraphic horizons in the Basement System prior to its granitization. The enclaves are interpreted as resisters to granitizing elements. Gabbroidal material, for example quartz diabase, is present within the Basement System and away from Kapalagulu Complex but is not correlated with the Complex.

CHAPTER V:

A stratigraphical cross-section of the Complex is exposed. The exposed part of the Complex suggests that the lower contact is slightly concave, or basin-shaped. The Intrusion is strongly differentiated, and the following zones are recognized:

1) The Lower Contact Zone, which is a narrow and indistinct zone of rocks of varying origin. The rocks are derived partly from the Intrusion and partly from the footwall of Basement System.

2) The Basal Zone, consisting mostly of bronzite picrite.

3) The Intermediate Zone, in which olivine hyperite is predominant.

4) The Main Zone, which is mostly hyperite, and which forms the upper two thirds to three quarters of the Intrusion. Situated within the Main Zone is a narrow conformable Anorthosite Band.

The Intrusion is arbitrarly divided into a North-western and a North-eastern Sector. They are lithologically identical, but the North-eastern Sector is severly complicated faulting and folding.

CHAPTERS/.....

CHAPTERS VI AND VII:

A description of the sedimentary Bukoban System and the Recent Lake Sediments is given. An outline is given of the problem of ascertaining the age of the Bukoban System.

CHAPTER VIII:

In the Basal Zone an average of 60% to 70% of the volume is occupied by olivine in the form of large, partly rounded grains. Orthorhombic pyroxenes are partly interstitial and, together with monoclinic pyroxene form 15% to 25% of the total volume of the zone. Intergrowths and general appearence indicate that the monoclinic pyroxene is largely a reaction product of the other mafic minerals. Plagioclase is completely interstitial and occupies an average of 10% to 20% of the total volume of the zone. As the stratigraphic elevation increases, the forsterite, anorthite and enstatite content of the relevant minerals decreases. A few hundred feet above the base of the zone there is a distinct anomaly in this variation. The anomaly has a definite bearing on the situation of the Mineralized Zone. Bronzite picrite is the typical rock-type of the Basal Zone.

There is probably a narrow transitional boundary between the Basal Zone and the next zone in the stratigraphical succession, namely the Intermediate Zone. In the Intermediate Zone, 15% to 20% of the volume is occupied by partly rounded grains of olivine, approximately 60% by plagioclase, and the remaining 20% to 25% by orthorhombic and monoclinic pyroxenes in variable proportions. As in the olivine, orthopyroxene and plagioclase exhibit idiomorphic tendencies. Significance is attached to the fact that strongly developed layering is present in this zone, where three isomorphous minerals with idiomorphic tendencies are present.

The Main Zone, composed mostly of granular hyperite, follows upon the Intermediate Zone. Platy flow structures are common, and linear flow structures are locally developed in the Main Zone. Towards the upper (sedimentary) contact, micropegmatite makes an unobtrusive entry, and at uppermost elevations there are even small isolated occurrences of granodiorite.

Situated/.....

Situated in the lower half of the Main Zone is a narrow conformable Anorthosite Band. Very little information regarding the origin of the band could be obtained from specimens, because of their extensive alteration. In parts, the hyperite or norite above the band is abnormally rich in mafic minerals.

CHAPTER IX:

The theory of low miscibility and separation of sulphides by gravity is favoured for the formation of a conformable sulphide-rich Ore Zone near the base of the Intrusion. Pyrrhotite is the predominant sulphide. The fact that the Ore Zone is situated some 200-odd feet above the bottom contact of the Intrusion, is ascribed to the formation of two virtually identical layers in the Basal Zone. The upper layer evidently formed as a result of an influx of magma, which interrupted crystallization of the main body of the Intrusion, and led to a repitition of the crystallization-process (vide chapter VIII). The sulphides, on becoming immiscible, sank in the magma and settled along the top of the partially consolidated lower layer.

CHAPTER X:

The formation of zones is ascribed to gravity-fractionation. Olivine was the first mineral to crystallize, and concentrated at the base of the Intrusion, so forming the Basal Zone. After the greater proportion of the olivine had precipitated, plagioclase commenced to crystallize together with olivine and pyroxene. The result was the formation of the Intermediate Zone, in which the main rock-type is olivine hyperite. Granular hyperite and norite form the Main Zone, which is both the largest and uppermost zone of the Intrusion. The Main Zone represents the last known major phase in the crystallization of the magma. Within the zone is an Anorthosite Band of conjectural origin. Most evidence is in favour of it having formed in situ by crystal fractionation, rather than by intrusion into the Main Zone.

CHAPTER XII:

An outline is given of the theories offered by various authors for the origin of layering or banding in igneous rocks. It is also suggested that periods of metastability during the cooling of a magma may lead to such banding. Metastable conditions are very prevalent in experimental melts.

CHAPTER XIII:

Both the Intrusion and the country rocks were tilted through 90° to their present sub-vertical position. The North-western Sector of the Intrusion is relatively undisturbed, but the North-eastern Sector, especially in the vicinity of Ibalaba Stream, is intensely faulted and folded. The responsible forces are tentatively correlated with the regional rift faulting outlined by Mc Connell. There is evidence that, locally, the forces were compressional rather than tensional. There is, for example, folding and thrust faulting which is contrary to the general pattern of rift faulting.

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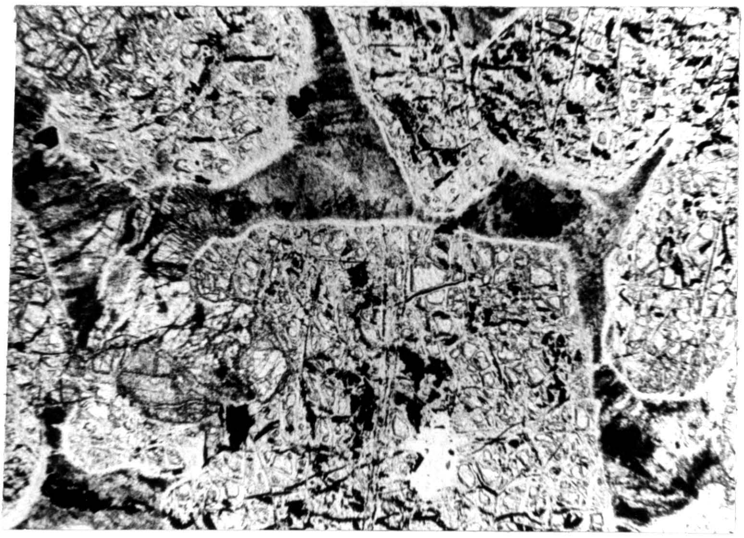
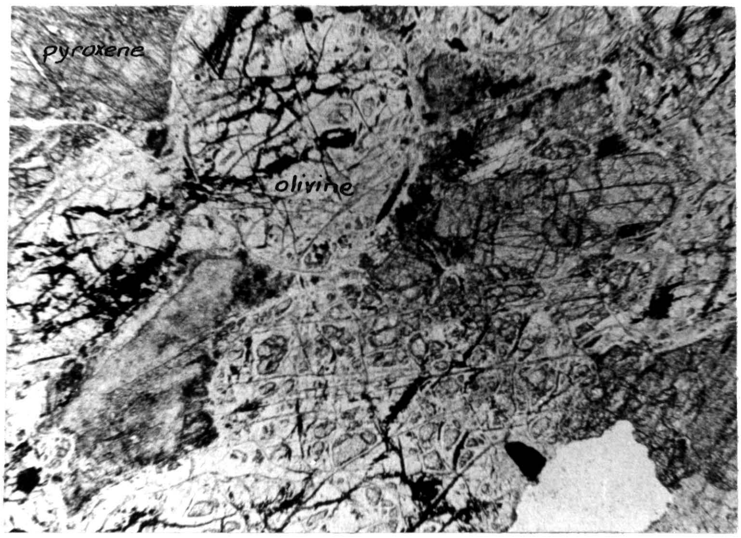
McMASTERS,/....

PHOTOMICROGRAPHS.





FIGURES 11A & 11B.

Bronzite picrite of the Basal Zone. Altered olivine forms large partly rounded grains. Orthorhombic pyroxene forms relatively fresh grains which are occasionally subhedral. The semiopaque interstitial matter is highly saussuritized plagioclase. 25 Magnification, crossed nicols. (T.S. 4-390).

PHOTOMICROGRAPHS.

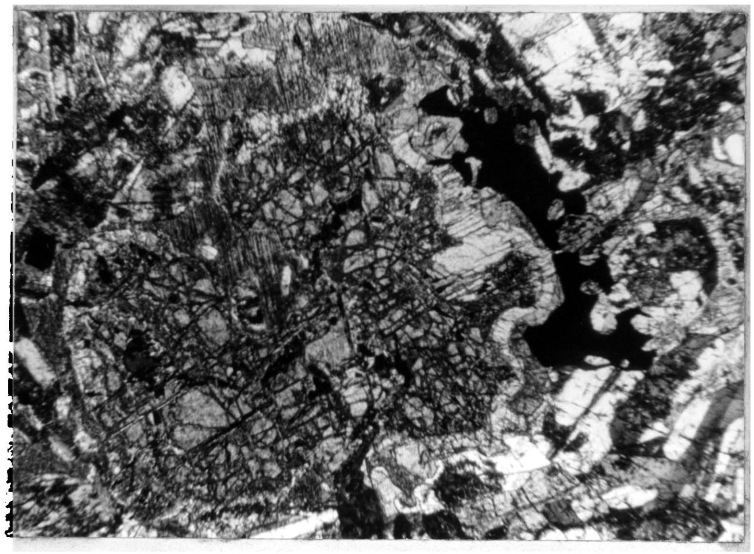


FIGURE 12: Olivine hyperite of the Intermediate Zone. The large olivine grain in the centre of the field is embayed and surrounded by concentric coronas of orthorhombic and monoclinic pyroxene. T.S: M.5. (crossed nicols, 25 magnification).

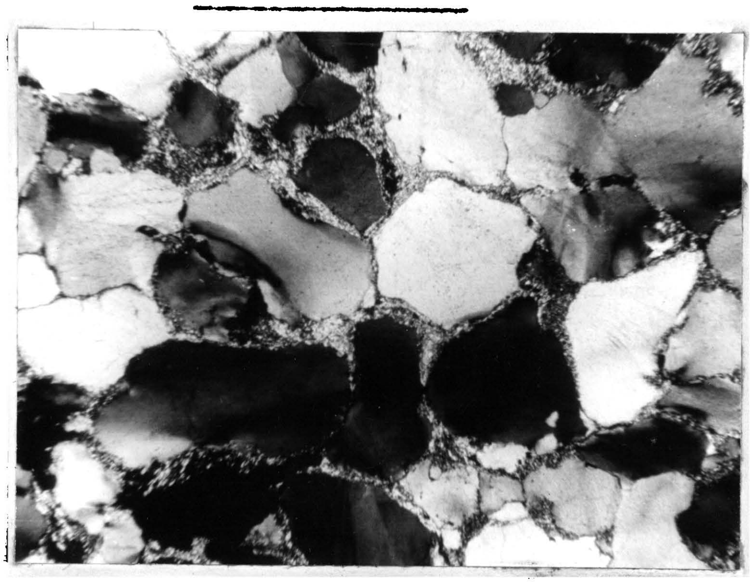


FIGURE 13: Bukoban sandstone from immediately above the upper contact of the Intrusion Cement composed of clay minerals and red iron oxides. T.S: B1 (crossed nicols, 25 magnification).

PHOTOMICROGRAPH.

FIGURE 14: A relatively fresh specimen from the Anorthosite Band. The saussuritized plagioclase crystals are idiomorphic, but partly rounded. There is a small amount of chlorite (diabantite) which in places poikilitically encloses the plagioclase crystals. T.S. 4 - 707 (crossed nicols, 110 magnification).

PHOTOMICROGRAPH.

FIGURE 15: Specimen from an unusual occurrence of anorthosite, near the base of the Intrusion and approximately ½ mile north-west of Mugombazi River.

The anorthosite is unusually fresh. The grains of plagioclase are large and partly idiomorphic. There are occasional large plates of augite, which poikilitically enclose the felspar grains, lending a mottling effect to the rock.

T.S. 4-702. (+ nicols, 25X).

PHOTOMICROGRAPHS.

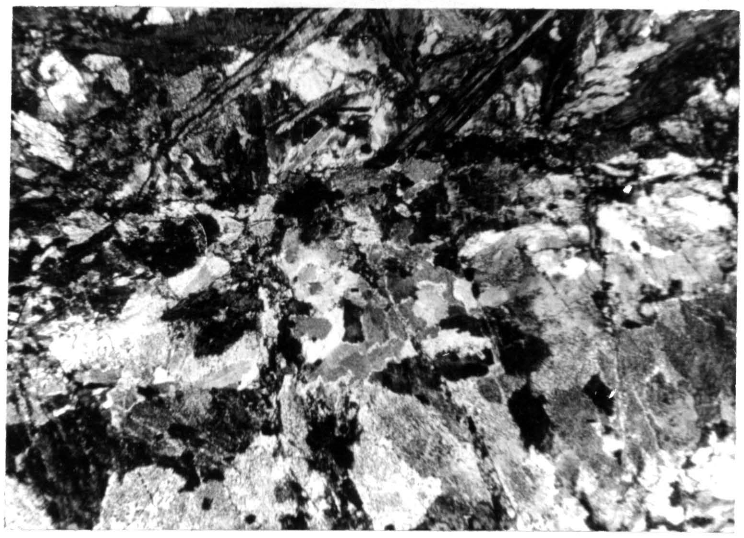


FIGURE 16A & 16B: Leucocratic dyke in Basal Zone: A highly epidotized plagioclase-rich rock. The epidote occurs as elongated (zoicite) grains and as patchy replacements in the felspar.

T.S: 4 - 670. (+nicols Large photo. 110X
Small photo. 25X).

PHOTOMICROGRAPH.

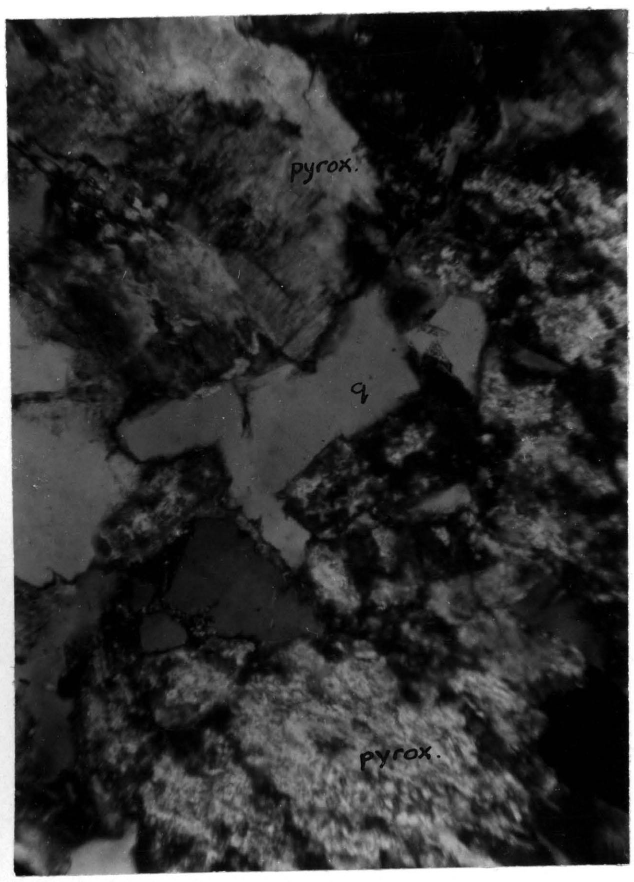


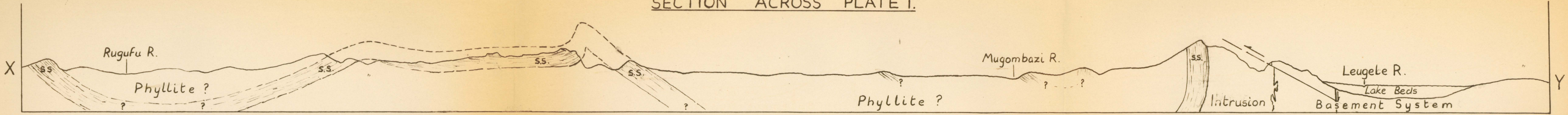
FIGURE 17: Quartz diabase. The only remaining transparent minerals are quartz, partly uralatized augite, and chlorite.

T.S. 4-670, + nicols 110X

PLATE I.

THE STRUCTURE AROUND MT. KAPALAGULU

SECTION ACROSS PLATE I.



KAPALAGULU BASIC COMPLEX

PLATE 2