THE PYROCLASTIC AND ASSOCIATED IGNEOUS ROCKS OF THE LEBOMBO MOUNTAIN RANGE SOUTH OF THE GREAT USUTU RIVER, ZULULAND.

by

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ABSTRACT.

A general geological and petrological study of the rocks of the Lebombo Mountains south of the Great Usutu River with a geological map is presented.

The name Lebombo Stage is proposed for the thick assemblage of dacite and andesite overlying the basalt of the Drakensberg Stage of the Karroo System. This new stage is subdivided into three suites. The rocks of the Lower Lebombo Suite have the composition of andesite, dacite, and some rhyolite, which occur as pyroclastic flow breccias, pyroclastic breccia dykes, massive, jointed, and vesicular lava, tuffaceous rocks, and minor intrusions. The Middle Lebombo Suite which consists of andesite, basalt, and dolerite intrusions is poorly developed in this area. The rocks of the Upper Lebombo Suite have the composition of trachyte, rhyolite, igneous quartz veins, and hypabyssal and plutonic equivalents of the trachyte and rhyolite, which occur as ignimbrites and associated tuffaceous deposits, pyroclastic flow breccias, massive lava, and fairly extensive intrusions. In addition there are minor sedimentary deposits of conglomerate and arkose.

The classification, nomenclature, and origin of the pyroclastic rocks, including ignimbrites, that were formerly unknown in South Africa, are discussed, and it is concluded that the ignimbrites were formed by nuée ardente eruptions.

The hypothesis is presented that the sequence of eruption of the rock suites was determined by tectonism. During phases of tension basic magma was unrestricted and could flow forth freely. When tension was released the flow of the basic magma was restricted causing its upper portions to assimilate some of the overlying Karroo sediments. Together with differentiation in the magma chamber this led to the production of the acid rocks in the sequence. These volcanic rocks are described with the aid of four new chemical analyses and micrometric data for the main rock types.

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I. INTRODUCTION.

A. General.

The Lebombo Mountain Range stretches for some 600 miles from Natal through Swaziland, Mozambique, and the Transvaal, to Southern Rhodesia.

The area was mapped by the author in conjunction with Messrs. L. M. Genis, R. F. Teichmann, D. B. Stulting, and H. S. Pienaar of the Geological Survey and covers the southern portion of the Lebombo Mountain Range from the Great Usutu River in the north to the termination of the acid lavas in the south, a distance of about 80 miles. The full width of the mountain range was covered from the basalt in the west to the Cretaceous deposits in the east, (Plates I and II), a total area of over 800 square miles.

The mountain range displays a surprisingly even skyline with a striking escarpment from the Great Usutu River to the Mkuzi River. The escarpment is an erosional feature about 500 feet high and below it there is a steep rubble-covered slope of 800 to 1200 feet to the Lebombo Flats. The major rivers in the area flow to the east and are the Great Usutu, Ngwavuma, Pongola, Mkuzi and Umsunduzi Rivers. These show no signs of being deviated by the mountain range and in some cases display incised meanders.

The structure of the range is that of a regularly tilted monocline dipping 15 to 20° E. This dip is fairly constant but tends to become steeper towards the south. The lavas, which were erupted during the formation of the monocline, indicate a region of tension along the site of the present Lebombo Mountain Range.

The rocks forming the mountain range belong to the Stormberg Series of the Karroo System. The necessity of distinquishing a new stage in the Stormberg Series becomes obvious in view of the fact that the acid lavas of the Lebombo Mountains represent a higher stage in the Stormberg Series than the underlying Drakensberg basalts. It is proposed to call this the Lebombo Stage. This stage comprises three rock suites termed the Lower, Middle and Upper Lebombo Suites. The sequence is shown in table 1.

If the stratigraphic sequence of the Lebombo Stage were considered the stage could be subdivided into sub-stages. However, in this thesis the

Stormberg Series (including associated intrusive rocks)	Lebombo Stage	Post-Upper Lebombo Suite		dolerite (basalt)
		Upper Lebombo Suite	Upper Bumbeni Phase	igneous quartz veins soft pyroclastic rocks rhyolite microgranite granite microsyenite syenite
			Middle Bumbeni Phase	laminated tuff massive ignimbrite laminated ignimbrite
			Lower Bumbeni Phase	Bumbeni conglomerate and arkose pheno-trachytic lava
		Middle Lebombo Suite		andesite basalt
		Lower Lebombo Suite	Upper Lava Phase	dacite andesite
			Pyroclastic Phase	red sedimentary beds pyroclastic flow breccia vesicular, massive and jointed lava tuff
			Lower Lava Phase	rhyolite dacite andesite red tuff
	Drakensberg Stage			andesite basalt
	Cave Sandstone Stage			
	Red Beds Stage			
	Molteno Stage			

chronological sequence of the rocks is being considered. This is often the same as the stratigraphy especially in sedimentary deposits, but in volcanic areas where intrusions are included, and dated relative to the surrounding rocks, stratigraphic subdivisions cannot be used. In this thesis the subdivisions of the Lebombo Stage will be termed suites. The rocks in a suite are closely associated in time and space. (Wells and Wells, 1948, 355).

The acid lavas of the Lower Lebombo Suite cover all but about 100 square miles of the range. They were extruded from numerous, long, north-trending fissures now choked by pyroclastic breccia dykes. These pyroclastic breccia dykes become less abundant towards the southern end of the range.

The Lower Lebombo Suite is divisible into three phases, termed the Lower Lava Phase, the Pyroclastic Phase, and the Upper Lava Phase, which lie slightly oblique to the strike of the mountain range (Plate III) and overlie the Drakensberg Basalt.

The Lower Lava Phase consists of numerous thin flows of either massive or jointed lava. The initial flows are andesite and dacite, and the later flows are slightly more acid.

The Pyroclastic Phase is characterised by pyroclastic flow breccias. Although, quantitatively, they form a minor portion of the succession, they provide valuable markers. The succession of beds in this phase usually begins with thin beds of volcanic ash or tuff, but these are not always present. They are followed by flows of massive, and/or jointed and/or vesicular lava. In the lower parts of this phase the lavas are andesite and dacite, towards the top of the phase they are a little more acid. In some cases these reach a total thickness of over 500 feet. These are overlain by the pyroclastic flow breccia which is usually 70 to 120 feet thick. Occasionally the upper surface of the pyroclastic flow breccia displays erosion. In the northern parts of the area this sequence is present only once but in the south it is repeated up to eight times.

The Upper Lava Phase is very similar to the Lower Lava Phase and consists mainly of numerous flows of massive andesite and dacite. It also has thin layers and lenses of vesicular dacite and black pitchstone intercalated with the massive dacite. The lava has a very uniform composition ranging from andesite at the bottom, to dacite at the top.

The Middle Lebombo Suite represents a return to more basic flows and consists of basalt and andesite. This suite is well developed in Mozambique and, although it is present south of the Great Usutu River, it is never abundant being found only in two small patches. (Plates I and II).

The Upper Lebombo Suite forms a complex suite of rocks in the Bumbeni area and represents a large variety of rock types. It is divisible into three phases termed the Lower, Middle and Upper Bumbeni Phases. (Plate IV).

The Lower Bumbeni Phase contains the initial extrusions of fine-grained pheno-trachytic lava followed by the deposition of coarse-grained conglomerate with lenses of chloritic sandstone containing fossil wood.

The Middle Bumbeni Phase represents a violently explosive phase during which ignimbrites were erupted. The fine ash from these eruptions was deposited over large areas and now forms laminated tuff overlying the ignimbrite. After this the activity became less violent with the extrusion of massive trachyte and pyroclastic flow breccias which are now intimately associated with each other.

The Upper Bumbeni Phase represents an intrusive phase which began with the intrusion of microsyenite and small plutons of syenite. These now form a ring intrusion elongated in a north-northwesterly direction. (Plate IV). Emplaced within the ring intrusion on its western side is a granite pluton characterized by the presence of biotite. Numerous small flows of rhyolite and dykes of microgranite outside the Bumbeni area are probably genetically related to ~~associated with~~ this granite. (Plate IV).

The top of the Upper Bumbeni Phase is represented by soft pyroclastic flow breccia, preserved in topographic hollows, and intrusive igneous quartz veins. (Plate IV).

Dolerite dykes intruded into the rocks of the Upper Lebombo Suite may represent the feeders of a later outflow of basic material which may have formed a further suite of rocks, now completely removed by erosion. (Plate IV).

B. Physiography.

1. Location of Area Investigated.

From the Great Usutu River to the Mkuzi River the large Native Reserve 16, which falls within the Ingwavuma and Ubombo magisterial districts, covers the full width of the Lebombo Mountain range, except for the area around the town of Ingwavuma. From the Mkuzi River to the Umsunduzi River the mountain range lies in Native Reserve 2 in the west and the Mkuzi Game Reserve in the east, both of which fall within the Ubombo magisterial district, except for the area around the town of Ubombo. South of the Umsunduzi River there is farm land which falls within the Hlabisa magisterial district. The only sizable town in the mountain range is the new construction camp at

Jozini Dam, just south of the Pongola River.

For the sake of convenience the geology of the mountain range is discussed according to the eruptive sequence shown in table 1. The result is that there are two main sections:

(a). the Lower Lebombo Suite and (b). the Upper Lebombo Suite, the Middle Lebombo Suite falling mainly outside the area under discussion. (Plate II). Rocks of the Lower Lebombo Suite form the Lebombo Mountain Range from the Great Usutu River in the north to the termination of the range in the south over an area of about 700 square miles. (Plates I and II). On the eastern side of the mountain range, both north and south of the Umsunduzi River, about 100 square miles are underlain by rocks of the Upper Lebombo Suite. Several associated rhyolite flows and microgranite dykes occur south of the Bumbeni area proper. (Plate IV).

2. Topography.

Throughout the whole length of the Lebombo Mountain Range, and especially in the area south of the Great Usutu River, the general topography follows a constant pattern. From west to east there is a natural three-fold division:

a) the Western Lebombo Flats, up to 6 miles wide, underlain by basalt, and ranging in altitude from about 500 feet above sea level in the north to somewhat less south of the Umsunduzi River;

b) the narrow Lebombo Mountain Range; and

c) the coastal plain east of the mountains underlain by horizontal Cretaceous deposits, sloping gently seawards towards the Coastal dunes, and ranging in altitude from 200 to 300 feet in the north to 100 to 200 feet in the south.

The Lebombo Mountain range changes topographically from the Great Usutu River southwards. Above the escarpment and to the east of it there is a narrow plateau, about 2 to 3 miles wide, with an average altitude of about 2000 feet between the Great Usutu River and the Mkuzi River. The width of the mountain range between the Great Usutu River and the Mkuzi River ranges from about 14 miles near Ingwavuma to about 5 miles near Ubombo. (Plate I).

The altitude of the mountain range decreases gradually south of the Mkuzi River from 1500 feet to about 1000 feet at the Umsunduzi River. South of the Umsunduzi River the mountain range dwindles to a series of low hills with a general altitude of about 700 feet and a few peaks of 1000 feet. About 4 miles south of the Umsunduzi River the low range of hills narrows rapidly from just under 5 miles wide to about 2 miles wide. For a further 5 miles the remnants of the mountain range can be traced by the sporadic occurrence of a few low hills which become smaller in size and altitude and eventually disappear altogether.

From the Great Usutu River to the Mkuzi River the western edge of the range is marked by a west-facing escarpment with a strikingly even skyline. This Lebombo Escarpment consists of a cliff about 500 feet high and below this a steep rubble-covered slope of 800 to 1200 feet to the Lebombo Flats. (Plate V). The origin of this escarpment has been the subject of considerable controversy. There are two main schools of thought: one is that the escarpment was formed by faulting; the other is that it is an erosional feature. The lines of evidence for and against these theories have been clearly given by De Blij (1960, 175 - 187), who favours an origin by faulting, although no faults to account for this feature have been found. Evidence favouring an erosional origin is the absence of faults and the more weather-resistant acid lavas forming much higher ground than the less weather-resistant basalt.

South of the Mkuzi River the topography of the mountain range changes abruptly with the disappearance of the escarpment and the narrow plateau above it. Even though the escarpment is no longer present the western edge of the mountian is steep. The change in topography is due to the type of pyroclastic breccia present. North of the Mkuzi River along the edge of the escarpment a weather resistant, sub-vertical, pyroclastic breccia dyke (defined later) is present whereas south of the Mkuzi River the less weather resistant, sub-horizontal, pyroclastic flow breccia (defined later) is present along the western edge of the mountains. (Plate I). South of the Umsunduzi River, foothills appear on the western as well as the eastern side of the range.

The pyroclastic breccia dykes sometimes form low, narrow, bush-covered ridges, but more often they form "troughs" or deep narrow gorges. The form they take depends on the type of material that fills the feeder channel or fissure. The low ridges, as found for example along the Lebombo Escarpment, contain hard, indurated material that is more weather resistant than the country rock. The "troughs" or deep narrow gorges are formed in feeder channels filled with unconsolidated or partly consolidated pyroclastic material that is less weather resistant than the country rock.

These feeder channels are relatively narrow fissures filled with pyroclastic material ranging from a few feet to about 200 feet in width and may extend in a north-south direction for many miles. Generally there are narrow zones of contorted flow bands in the dacite which are extremely variable in width on either side of these breccia dykes. These are usually more weather resistant than the pyroclastic material as can be seen where the feeder channels form deep gorges with steep weather-resistant sides. Where the feeder channels form only shallow "troughs" these weather resistant flow bands give the valley a U-shaped appearance.

The pyroclastic flow breccias are less weather resistant than the andesite and dacite and thus produce very distinctive features. They form low hills with cappings of weather resistant dacite with a gentle eastwardly slope usually conformable to the general dip of the strata. The east-west extent of the pyroclastic flow breccias may in places appear to be greater than the north-south extent, but this is due to erosion. The western sides of these hills have a steep rise above a terrace which normally has more grass and fewer bushes than the surrounding country. (Plate VI). This terrace often follows the contours of the hills and its dip to the east conforms to that of the rocks in a particular area. The thickness of the pyroclastic flow breccias range from less than 50 feet to about 200 feet. They may cover any area up to many square miles.

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The Rooi Rant is a low range of hills about 400 miles long west of the Lebombo Flats and parallel to the Lebombo Mountain Range. It is formed by a swarm of dolerite dykes intruded into the Drakensberg Basalt over a width of 2 to 3 miles.

The Lebombo Flats lie between the Lebombo Mountain Range and the Rooi Rant. They consist~~s~~ of undulating country about 6 miles wide from east to west with gentle divides between the rivers.. They have a general altitude of 500 feet above sea level which becomes a little less in the south. The Lebombo Flats are underlain by Drakensberg Basalt which is also intruded by dolerite dykes although less so than the Rooi Rant. Few outcrops occur as the basalt is extensively weathered and covered with thorn scrub and grass.

East of the Lebombo Mountains are the flat lying Makatini Flats. After passing through the Lebombo Mountains the Pongola River flows northwards parallel to the coast taking in all the streams and rivers with it. (Plate II). South of the Pongola River all the rivers and streams turn southwards towards Lake St. Lucia. Although the reason for this is not yet clear it is probably due to structural control or longitudinal warping of the Cretaceous deposits.

According to King and King (1959, 30), lagoons and drowned mouths of the rivers, as well as a positive anomaly of 40 milligals indicate that the coastal plain is subsiding.

3. Drainage.

The drainage pattern of the area presents features of great interest. Drainage from the interior passes through the range from west to east by means of fourteen poorts. The rivers do not deviate from their eastward course on entering the poorts and seldom take advantage of any structural features; even the low ground of the Lebombo Flats and the gentle divides between the east-flowing rivers do not have an effect on the drainage pattern, nor are there any signs of river piracy.

In the 80 miles from the Great Usutu River southwards there are six rivers which pass through the range by means of poorts that are at least 5 miles long and generally only as wide as the river bed. In the south these poorts are closer together than in the north. The altitude of all the rivers in these poorts is less than 500 feet, and all have a very low gradient..

These rivers are clearly antecedent to the Lebombo Mountain Range. They were probably originally consequent streams formed by the uplift of the continent before the formation of the mountain range. As the rivers do not underfit their poorts they are probably no smaller in size and volume than they were before the formation of the mountain range.

From the summit of the mountains the country has a gradual easterly slope with the result that several eastward-flowing consequent streams have developed. Many of the north-trending pyroclastic breccia dykes are easily eroded and form subsequent streams tributary to both the consequent streams and the major rivers. The consequent and subsequent streams often form gorges several hundred feet deep with steep sides covered with thick bush making it impossible to reach the bottoms of many of them.

C. Previous Work on the Lebombo Mountain Range.

The Lebombo Mountain Range has been known for many years but there has been surprisingly little written about its geology. A review of the work done shows that most of it applies to the Lebombo Mountains north of the Great Usutu River. No detailed work has been done on the full extent of the Lebombo Mountain Range south of the Great Usutu River.

Anderson (1902, 1904 and 1907) mapped a large portion of Natal and Zululand at the turn of the century, but most of this work is of a general nature.

Young (1920) was the first writer to mention the Little Lebombos east of the main range in Mozambique (Plate II). Much of his paper is devoted to a small intrusion of nepheline syenite porphyry just east of the Little

Lebombos.

Du Toit (1930) gives a very general but most useful and informative discussion on the Lebombo Mountains. He also deals with the possible genesis of the range.

Lombaard (1952) has made a petrological study of the area north of Komatipoort. He gives several chemical analyses and regards the dacites as being of magmatic origin.

A small outcrop of "upper basalt" just south of the Great Usutu River was discovered in 1951 and, in addition, it was found that some of the small pans on top of the mountains give a high "geophysical" anomaly (Meyer, 1951).

Hunter and Urie (1958) briefly discuss the petrography of the acid volcanic rocks and suggest the petrogenesis of Stormberg Volcanicity in Swaziland~~, to the C. C. T. A. Southern Regional Committee for Geology~~. At the C. C. T. A. meeting held in Leopoldville in 1958, the South African, Swaziland and Mozambique members of the Regional Committee decided to co-operate and intensify their investigations of the rocks of the Lebombo Mountain Range; subsequently De Assuncao and others (1959 and 1962) discussed the petrology of the Mozambique portion of the Lebombo Mountains.

Frankel (1960) gave a preview of unpublished thin-section work by V. and E. Gorsky who consider the acid lavas of the Lebombo Mountain Range to be metasomatised portions of the Drakensberg Basalt.

The detailed geology of a small area around the Jozini Dam was presented in two unpublished reports by Steenstra (1961 and 1963).

II. NOMENCLATURE OF IGNEOUS AND PYROCLASTIC PROCESSES AND ROCKS.

A. Igneous Rocks.

The term rhyolite is often applied loosely to mean a silicic extrusive rock without taking into consideration its actual composition. This is the case with the rocks of the Lebombo Mountains, which have been, and still are, often referred to as the "Lebombo rhyolites". South of the Great Usutu River true rhyolite is almost absent from the Lower Lebombo Suite and only a small amount is present associated with the Upper Lebombo Suite.

Here the term rhyolite will be used as applied by Shand (1947, 370), i.e. as a rock which generally contains small phenocrysts of quartz and/or sanidine or orthoclase, and a dark mineral in a glassy or fine-grained groundmass. ~~It~~ Rhyolite contains over 10 per cent quartz and over 50 per cent of the felspar must be potassium felspar. By using the term rhyolite in this sense the "Lebombo rhyolite", south of the Great Usutu River, is in fact more basic consisting mainly of dacites and even andesites.

The names applied to igneous rocks of the same composition vary greatly, nor are the arbitrary divisions between the different groups by any means fixed. The general names of extrusive rocks used here and the division between the different extrusive rock types are shown in table 2. (after Shand, 1947, 369).

Shand's classification is applied because there is a lack of chemical data and the presence of certain minerals was used to name the rock. According to Shand (1947, 370) 10 per cent of quartz is taken as the arbitrary division between such rocks as trachyte and rhyolite or andesite and dacite.

Table 2.

	Over 10% free silica	Under 10% free silica
Or > An	Rhyolite	Trachyte
An > Or	Dacite	Andesite (leucocratic)
		Basalt (mesotype)

The plutonic and hypabyssal representatives of the extrusive rocks in the Upper Lebombo Suite are given below:-

Extrusive	Hypabyssal	Plutonic
Rhyolite	Microgranite	Granite
Trachyte	Microsyenite	Syenite

In some cases the matrix of the rock is glassy or cryptocrystalline and its mineralogical composition cannot be determined under the microscope. Such rocks often contain a fairly high proportion of phenocrysts which can be easily determined. When the rock is named on the basis of the phenocrysts **only** the prefix "pheno-" is used, e.g. pheno-trachyte (Rittmann, 1952). This is done because a determination based on identification of the phenocrysts alone may give a very wrong idea of the real mineralogical composition of the rock.

B. Pyroclastic Rocks.

The nomenclature of the pyroclastic rocks in general and of the ignimbrites in particular is in a rather chaotic state. For this reason the classification followed is outlined and some of the terms used in connection with the pyroclastic rocks are defined.

1. Volcanic Breccia.

Wentworth and Williams (1932) group the various pyroclastic rocks according to the size of the fragments. However useful this size classification may be in dealing with fragments, it is not so useful when dealing with volcanic breccias because there may be a large range in the size of the fragments within a single volcanic breccia, and also volcanic breccias formed under totally different conditions may have fragments of the same size. Volcanic breccias can be more precisely grouped when consideration of their mode of fragmentation is taken into account.

Fisher (1960) groups volcanic breccias into three main categories according to their mode of fragmentation:
(a) autoclastic volcanic breccia, formed by a quiet non-explosive fragmentation or brecciation of lava in a semisolid or solid form by confinement beneath the surface or by unconfined movement of lava on the surface; (b) epiclastic breccia contains volcanic fragments produced by any form of rock fragmentation followed by transport (e.g. by wind or water) or gravity transfer; and
(c) pyroclastic breccia, formed by the explosive ejection of solid and/or liquid material from a volcanic source.

The pyroclastic material of the Lebombo Mountains falls under this last group. Of the pyroclastic breccia group only pyroclastic flow breccias and pyroclastic channel breccias were noted. Both these terms are defined below.

The term pyroclastic dyke breccia ~~dyke~~ is proposed for the rocks filling the sub-vertical to vertical feeder channels of the pyroclastic flow breccias. These breccia dykes represent the fissures through which volcanic material was explosively emitted, and which subsequently remained choked with unsorted pyroclastic material. This material may be unconsolidated, consolidated, indurated or cemented by fine-grained lava. It is similar to the material of the pyroclastic flow breccias.

The pyroclastic flow breccias form sheets or layers of heterogeneous pyroclastic material ranging in size from fine dust to large blocks produced by the explosive extrusion of a solid-liquid-gas mixture. The fragments consist of essential and/or accessory and/or accidental material usually consolidated and indurated or cemented by fine-grained lava. These fragments have not been reworked by agents such as wind or water (Fisher, 1960).

The process which produces the pyroclastic flow breccia as well as ignimbrites and tuff deposits is a nuée ardente flow which may be described as a highly heated mass or spray of gas-charged lava, explosively ejected more or less horizontally, from a vent or pocket, onto a slope where it continues its course as a glowing avalanche. The mobility of the mass is due to the disintegration of the lava into small discrete particles and the envelopment of the particles in a highly compressed gaseous atmosphere. During the descent of the avalanche there is thus developed a violently expanding cloud of gas and ash ~~which is~~ enhanced by the explosive expansion of entrapped air. The clouds of gas and ash roll upwards in great cauliflower-like masses from the hidden avalanche along the ground which gives rise to it. (American Geological Institute, 1960, 200).

There are three major types of constituents in pyroclastic rocks.

According to Wentworth and Williams (1932), the term "accessory" is used for pyroclastic material derived from previously solidified volcanic rocks of consanguineous origin. ~~(Wentworth and Williams, 1932)~~.

The adjective "accidental" is used to designate pyroclastic material derived from volcanic rocks non-consanguineous with the magma involved during an eruption or from other metamorphic or sedimentary rocks through which the vent or feeder channel was developed. (Wentworth and Williams, 1932).

Pyroclastic material, whether loose or indurated, which is of immediate juvenile or primary magmatic origin, is termed "essential."

2. Ignimbrites.

The term ignimbrite was first proposed by Marshall (1932). The term "ignimbrite" is apparently derived from the corruption of the Latin words ignis (fire) and imber (shower). Marshall considered that ignimbrites were formed from immense clouds or showers of intensely heated but generally minute fragments of lava. Although these rocks vary greatly, Marshall (1932, 200) considered them to belong to a single group for which he proposed the name ignimbrite.

A microscopic examination of these rocks show that they are fine-grained and consist mainly of glass particals in which crystals of felspar with lesser amounts of quartz, hypersthene or hornblende are embedded. The glass particals bend around the crystals indicating that they were still viscous when deposited (Marshall, 1932, 198). This description, however, does not define ignimbrites.

It is clear that Marshall (1932 and 1935) was defining a group of rocks rather than a single rock type, and yet it has since then been taken as a definition of a single rock type. The term ignimbrite should be used as a general term in the manner that Marshall first proposed it. Rast, Fitch and Beavon (1959, 116) apparently understood this because they redefined the term ignimbrite as embracing all the strictly primary fragmental volcanic rocks in which the great majority of constituent framents have not been transported by wind or water and consequently have neither sedimentary grading or bedding. They included both welded tuff deposits and the non-welded sillars in this definition. Subsequently there was considerable concern about this definition as it was felt that the term ignimbrite was being extended to include many different types of rock. However, it still embraces essentially the same group of rocks as was included in Marshall's original definition.

Steiner (1960, 10) prefers to use the term ignimbrite as a nongenetic term. He defines ignimbrite as a descriptive term for acid volcanic rocks showing gradational vitroclastic-like texture and characterised by the presence of two contrasting glasses, which are usually devitrified. Steiner's discovery of two contrasting glasses in these rocks, while interesting, is not new (Fitch 1961, 996); but his proposal that the principal agent in ignimbrite formation is liquid immiscibility in a lava flow is new. His main argument appears to be that no observed nuée ardente flow has produced an ignimbrite deposit. In this argument, Steiner assumes that an ignimbrite is a welded rock, discarding the non-welded variety of ignimbrite or sillar deposits.

Marshall's definition is genetic and non-descriptive while Steiner's definition is descriptive and non-genetic.

In the recognition of ignimbrite there are a number of factors that may be usefully applied:-

a) there is an absence of bedding planes;

b) glass shards are present which are usually but not necessarily devitrified; and

c) the material is of primary magmatic origin, i.e. the fragments are essential and not accessory or accidental constituents.

There is no clear-cut classification or nomenclature of ignimbrites and the term ignimbrite has been used in a varying sense. For this reason the term ignimbrite is used here to include all rocks produced by a common process involving primary fragmentation of magmatic material, transportation by a method such as a nuée ardente or ash flow, and subsequent deposition of the heated magmatic particles. The heat of these particles together with the pressure of the superincumbent load may cause welding. The temperature of such deposits is probably not quite as high as was first postulated by Marshall (1932, 198), who thought that fragmented particles may be heated to such an extent that they weld upon deposition. The temperature is low enough to allow some minerals to crystallize before extrusion, but not high enough to recrystallize the volcanic glass in the deposit

Welding is common in ignimbrites and is closely related to temperature but it is not always clear what is meant by welding. Welding is the phenomenon of the adhering together of the particles and commonly takes place between the particles in the deposit of a nuée ardente flow. When two particles are in intimate contact the ~~ions~~ atoms of both particles will diffuse along their boundaries and cause welding. This takes place when the necessary threshold mobility of the atoms along their boundary zones has been achieved. The temperature of the exchange of place, under the action of thermal energy, is a function of fusion points. In solid particles this implies adequate reduction of viscosity, which is dependent on temperature, pressure and volatile content.

In the Bumbeni area, of the Lebombo Mountain Range, there are two distinct types of ignimbrites, the one flow-laminated the other welded massive.

The flow-laminated ignimbrite displays a directive structure in the hand specimen in so far as the constituents have a preferred orientation. This structure may be "eutaxitic", "fluidal" or "turbulent" (Plate VII). It is not possible to subdivide the flow-laminated ignimbrites according to their ~~texture~~ structure as they often apparently grade from one type into another over short distances and even within a single outcrop. Furthermore it is seldom possible to determine exactly whether they are flow-laminated or not, and in these cases they are then referred to as "laminated ignimbrite".

The welded massive ignimbrite is far finer grained and has no characteristic directive structure. In the hand specimen it appears massive and fine-grained. Welded massive ignimbrite is essentially a fine tuff containing a vast number of glass shards. In the Lebombo Mountains these glass shards are always devitrified. There may be porphyroclasts of felspar and quartz. This ignimbrite will be referred to as "massive ignimbrite".

One of the most common secondary processes in ignimbrites and associated tuffaceous deposits is devitrification. Following the terminology of Marshall (1935) and Steiner (1960) this devitrification may be referred to as pectinate, axiolitic, radial or spherulitic.

Pectinate devitrification occurs when minute slender felspar needles or crystals develop at right angles to the surface of the glass particle and grow inwards. When the needles become stouter and are well developed, so that the core becomes distinct, axiolitic devitrification is produced.

Radial devitrification is similar to pectinate devitrification except that in radial devitrification the crystals tend to radiate from a central point, and it is usually circular. Spherulitic devitrification occurs when spherulites, showing distinctive black crosses between crossed nicols, are produced.

The devitrification may be "cryptocrystalline", as in those spherulites in which individual crystals cannot be resolved; this is probably a secondary recrystallization. On the other hand the devitrification may be "microcrystalline" as in the pectinate devitrification, where distinct minerals can be made out. The microcrystalline devitrification is probably contemporaneous with the deposition of the ignimbrite or tuffaceous material when the material was still hot enough to form crystals large enough to be distinquished.

The result of Silicification is usually present in varying amounts and may obscure the characteristic features of an ignimbrite. The secondary silica first occupies the gas vugs and cracks in the rock, after which it begins to affect the texture of ignimbrite. Unlike devitrification it does not present a definite shape or form.

3. <u>Tuff.</u>

Laminated tuff is the term proposed for rocks formed by the sedimentary deposition of fine ash or tuffaceous material by wind or water. They have a distinctive and fine sedimentary layering or bedding which is often folded (Plate VIII) and in some cases brecciated (Plate IX).

III. METHODS OF INVESTIGATION.

The geological maps (Plates I and IV) were made by mapping on aerial photographs (scale about 1:30, 000) and transferring the details, with a pantograph onto a topocadastral base map (scale 1:50, 000). The map of the Bumbeni area (Plate IV) which shows great detail has a ~~had its~~ scale of ~~kept at~~ 1:50, 000 while the geological map of the whole area covered (Plate I) was photographically reduced to a scale of 1:100, 000. Rock samples for microscopic investigation and analysis were taken throughout the range. In the Lower Lebombo Suite no attempt was made to map out the different areas of "massive lava", "jointed lava" or "vesicular lava" as these grade indiscriminately into one another, even in a single flow and it is not always possible to determine exactly which type is present. Similarly in the Bumbeni area the intimately associated pyroclastic flow breccia and trachyte could not be mapped as separate units.

The compositions of the felspars in the various rocks were determined by the Michel-Lévy method and by measuring extinction angles of combined carlsbad-albite twins normal to (010). The compositions of some felspars were checked on the universal stage by using the method described by Turner (1947, 389-410). ~~The compositions of the pyroxenes were determined by measuring β and 2V and using the diagram of Hess and Phillips (1940, 289)~~.

Eight volumetric compositions were determined by counting at least 1000 points per thin section with a Zeiss mechanical point counter.

To estimate the percentage amounts of minerals present in a large number of samples a point count of 200 to 300 points per thin section was taken and the results plotted on triangular diagrams (Plate X). In cases where 20 per cent or more of the slide is glassy or cryptocrystalline and could not be determined the slide was not used to obtain the amounts of the minerals.

Four unaltered samples of dacite, rhyolite and microgranite were chemically analysed by E.C. Haumann. In three cases when only a very small amount of zeolite was present it was spectrographically analysed by H.S. Pienaar.

Fresh, compact and unaltered rocks were obtained from the bore-holes at Jozini Dam and on the new road from Jozini Dam to the Lebombo Flats. The specific gravities of these rocks were obtained by weighing them in air and in water with a chemical balance. Although there was no temperature control, the results (Plates XX and XXI) nevertheless serve as a rough basis of comparison.

IV. GENERAL GEOLOGY.

A. General Stratigraphy.

The Stormberg Series is the uppermost division of the Karroo System as shown below:-

Tertiary to Recent Deposits .... Miocene Beds of Zululand.

Cretaceous System	Upper Cretaceous Beds of Zululand	(sandstone, shale, limestone, marl).
	Ndabana Zone and other Lower Cretaceous Beds of Zululand	(conglomerate, sandstone, shale, limestone)
	Lebombo Stage. → namely	Acidic phase
Karroo System	Stormberg Series	(volcanic rocks, sandstone, shale, mudstone, marl).
	Beaufort Series	(shale, mudstone, sandstone, limestone)
	Ecca Series	(shale, sandstone grit, coal)
	Dwyka Series	(tillite, shale)

The Stormberg Series is subdivided into:-

Drakensberg Stage,

Lebombo

Cave Sandstone Stage

Red Beds Stage

Molteno Stage (Du Toit 1954).

The Drakensberg Stage is by far the most extensive of these four stages. It represents volcanic activity during the Jurassic and apart from a few notable exceptions consists of vast outpourings of basalt. The most prominent of these exceptions are the vast outpourings of acidic rocks in the Lebombo Mountain Range. These acid rocks overlie the basalt and can themselves be subdivided. It is proposed to introduce a new stage in the Stormberg Series comprising the full succession of mainly acid volcanic rocks overlying the basalt. This is the Lebombo Stage. This gives a five-fold subdivision of the Stormberg Series.

If the Lebombo Stage were to be regarded as a sub-division of the Drakensberg Stage it would have to be termed the Lebombo Sub-stage and the various units would then have to be tabulated as follows:-

Lebombo Sub-stage (or Suite)	Upper Lebombo Zone	Upper Bumbeni Beds Middle Bumbeni Beds Lower Bumbeni Beds	Each of these beds to be further sub-divided into smaller units
	Middle Lebombo Zone		andesite and basalt
	Lower Lebombo Zone	Upper Lava Beds Pyroclastic Beds Lower Lava Beds	Each of these beds to be further sub-divided into smaller units

On the other hand if the Lebombo Stage is regarded as a sub-division of the Stormberg Series the resulting classification is as follows:-

Lebombo Stage	Upper Lebombo Suite	Upper Bumbeni Phase Middle Bumbeni Phase Lower Bumbeni Phase	Each of these phases can be further sub-divided into beds.
	Middle Lebombo Suite		andesite and basalt
	Lower Lebombo Suite	Upper Lava Phase Pyroclastic Phase Lower Lava Phase	Each of these phases can now be further sub-divided into beds.

Preference is given to the latter sub-division which gives a five-fold sub-division in place of the previous four-fold sub-division of the Stormberg Series in the region covered by the Lebombo Mountain Range. In this five-fold sub-division the three lower stages, i.e. the Molteno, the Red Beds, and the Cave Sandstone Stages, represent a sedimentary sequence. The upper two stages, the Drakensberg and Lebombo Stages represent a volcanic sequence. With this in mind preference is given to the use of the term "suite" for a sequence of related volcanic rocks.

The broad outline of the stratigraphic sequence in the Lebombo Mountain Range, south of the Great Usutu River is fairly straightforward The acid rocks of the Lower Lebombo Suite overlie the basic rocks of the Drakensberg Stage.

In the northern part of the area (Plates XI and II) the Lower Lebombo Suite can be divided into the Lower Lava and the Pyroclastic Phase. The Upper Lava Phase is not present in the northern part of the area. This may be due to either erosion or to the fact that it was never extruded in the north.

The Pyroclastic Phase is overlain by basalt of the Middle Lebombo Suite. The Middle Lebombo Suite occupies a very small area just south of the Great Usutu River before it is covered by the Cretaceous beds (Plate I). Basic rocks of this suite are not found again until much further south, in the Bumbeni Area. The reason for this is either that they are present east of the

Lebombo Mountains but are not exposed being covered by the Cretaceous System, or that they were never extruded in this area.

In the southern part of the area (Plates XI and II) the Lower Lebombo Suite can be divided into the Pyroclastic Phase and the Upper Lava Phase. The Lower Lava Phase is not present in the south and this may be due to either erosion or the fact that it was never extruded in the south. Towards the southern end of the range the Pyroclastic Phase pinches out leaving the Upper Lava Phase overlying the Drakensberg ~~Stage~~ basalt. (Plate III).

The Upper Lava Phase is overlain by the Middle Lebombo Suite which in the south consists of andesite.

Overlying the Middle Lebombo Suite in the south are the acid rocks of the Upper Lebombo Suite. (Plate I). The initial phase of the Upper Lebombo Suite, the Lower Bumbeni Phase, consists of flows of pheno-trachyte overlain by a conglomerate. The Middle Bumbeni Phase started with ignimbrites and associated tuffaceous rocks and closed with trachyte and pyroclastic flow breccias. Following on this is an intrusive phase comprising granite intrusions. Towards the close of the intrusive phase further pyroclastic rocks and small flows of rhyolite of the Upper Bumbeni Phase were produced.

The Upper Lebombo Suite is tentatively correlated with the acid rocks of the Little Lebombo in Mozambique which overlie the thick basalt flows of the Middle Lebombo Suite in that area (Plate II).

Intruded into the acid rocks of the Upper Lebombo Suite are a few isolated dolerite dykes. The dolerite dykes are considered to represent possible feeders of yet another suite of lavas which may have consisted of flows of basalt but which have subsequently been removed by erosion.

East of the Lebombo Mountain Range the volcanic rocks are unconformably overlain by Marine Cretaceous rocks (Plate I). Very few contacts between the Cretaceous System and the Lebombo Stage are visible, but there are sufficient exposures to show that the Cretaceous System overlies all the volcanic rocks.

The Cretaceous strata belong to the Ndabana Zone and are probably Cretaceous of Aptian age. The best exposure of these rocks is the conglomerate north-east of Ubombo, about two miles east of the Ubombo-Otobotini road (Plate I). This conglomerate consists of well rounded water-worn rhyodacite and dacite boulders and pebbles ranging in size up to about 1 foot in diameter. They are generally about the size of a pigeon's egg (Plate XII) and are set in a light-yellowish fine-grained matrix. The conglomerate has an easterly dip of about 5 degrees, is unsorted and is not well consolidated. It also contains abundant fossilized wood, but no Trigoniae or other fossils, which could be expected in the Ndabana Zone (Van Hoepen, 1926, 1929).

Tertiary deposits are not at all common in the Lebombo Mountains or the surrounding areas. In one area just north of the Umsunduzi River and east of the mountain range a small area of Tertiary deposits occurs (A.W. Keyser, personal communication 1963) overlying the Lower Cretaceous, but their extent is not yet known.

Recent, superficial deposits are found throughout the mountain range. The oldest of these is ferricrete followed by surface drift derived from the weathering of the acid lavas. The most recent deposits are alluvium along the banks of the rivers.

B. Stormberg Volcanicity in South Africa.

The Drakensberg Stage of the Stormberg Series consists mainly of basalt and reaches it largest know extent in Basutoland where a thickness of 4000 feet is preserved and covers an area of approximately 10,000 square miles. The extent of the Stormberg Series in Southern Africa is shown in Plate XIII. According to Poldervaart (1952) there is a possibility that beneath the Kalahari sands of the Bechuanaland Protectorate is preserved the largest single area of Karroo basalts on the African Continent. This basalt may possibly reach 30,000 square miles in extent. Drakensberg lavas cover a large area of the Rooi Rand, the Lebombo Flats and Lebombo Mountain Range and they also extend into Swaziland and Mozambique.

The lower flows of Drakensberg lava show intercalations of Stormberg sediments, tuff, and agglomerate. Towards the end of Karroo sedimentation a period of great aridity set in, and the Drakensberg lava was poured out over the fine-grained aeolian deposits of Cave Sandstone. It appears that the relationship of the lava to the Cave Sandstone was an intimate one and that while sand was still invading the region volcanoes were from time to time breaking forth into eruption. The presence of intercalated lava flows, the inclusion of ashy material, and the occurrence of volcanic bombs in the upper part of the Cave Sandstone point to volcanic outbursts during the final deposition of the sandstone (Du Toit, 1954, 301).

For such enormous masses of lava to well up through numerous fissures of considerable length there must have been a state of tension in the earth's crust which caused the formation of cracks in the underlying rocks. In Basutoland Stockley (1940) found the largest fissure to be 900 feet wide, but they vary greatly in width. The main injection of Karroo dolerite in South Africa has been into Karroo strata. The Karroo basin is riddled with dolerite dykes and sheets intruded contemporaneously with, or immediately following the eruptions of the Drakensberg lavas. Many dolerite dykes as they enter the Drakensberg lavas pass imperceptibly into basalt flows.

According to Du Toit (1954, 304), the petrography of the Drakensberg lavas throughout South Africa is so uniform that they can be described together. The majority of them are basalts but quite a large number approach augite-andesite and a few are even less basic being enstatite-andesite with a brown glassy base.

C. Structure.

1. The Monocline.

According to Du Toit (1930), the axis of the Lebombo Monocline lies oblique to the range, and was traced by him from ½ mile east of Ressano Garcia to 5 miles west of the range on the Pongola River. This monocline affects the full succession of Karroo beds including the basalts and acid lavas.

The formation of the monocline has been attributed to the drifting apart of Gondwanaland (Du Toit, 1930). However continental drift is still a controversial theory. ~~The author~~ attributes the formation of the monocline to a graben structure in which the trough is situated off the coast to the east of the Lebombo Mountain Range, and more or less parallel to the range. This graben may in turn have been formed by the drifting apart of the continents. The Lebombo Mountains situated on the edge of the proposed graben show a monoclinal structure bent down to the east as a result of the formation of the graben. This graben could be connected to the Limpopo and Zambezi troughs, the Lake Nyasa depression and the African Rift Valleys.

The cause of the formation of the Lebombo Monocline is not obvious, nor is the exact period in which it took place obvious. Du Toit (1930, 210) produces fairly convincing evidence that the warping took place during the eruption of the dacite. He bases his theory on the supposition that dykes in general deviate little from the vertical on injection. The dolerite dykes of the Middle Lebombo Suite must have been the feeders of the extrusions of basalt and as these dip steeply to the west the complete formation of the monocline could not have preceded the extrusions. The dykes, in the axial part of the monocline, are not perpendicular to the tilting of the extrusive rocks; thus the complete formation of the monocline could not have followed the emplacement of the dykes. From this Du Toit concludes that the warping could have occurred only during the eruptive period. Wager and Deer (1938, 41) found a similar situation in Eastern Greenland where the dip of the dykes is not perpendicular to the lava flows indicating a connection between the period of earth movement and the magmatic activity producing the dykes.

2. Gravity Anomalies.

Bouguer gravity anomalies show some striking features towards ~~as they near~~ the Lebombo Mountains. They are bunched together and range from minus 50 milligals west of the Lebombo Mountains through zero to plus 50 milligals at the axis of the monocline in the Lebombo Mountains, south of the Great Usutu River (Plate XIV). This high gravity anomaly may indicate that the region is not tectonically stable and that deformation has not yet ended (King and King, 1959, 29-30). The gravity anomaly lines lie parallel to the strike of the mountain range, and at a slight angle to the coast line. This indicates a possible future hinging action along the present axis of the Lebombo Monocline.

3. Stratified Rocks.

The general strike of the lava flows, pyroclastic rocks and sedimentary rocks ranges from due north to N 20 E in the northern part of the area. Southwards it gradually changes till in the southern part of the area it ranges from N 20 W to N 30 W. The zone of agates in the pyroclastic flow breccia east of Ingwavuma, however strikes N 30 E (Plate I).

The dips towards the east of the lava flows, pyroclastic rocks, and sedimentary rocks throughout the range become less towards the eastern flats while they are usually steeper towards the western escarpment. This does not hold true in the north near the Great Usutu River, here the dips of the lava flows and pyroclastic rocks are flatter near the western escarpment than towards the centre of the range. This indicates that the axis of the monocline lies within the acid lavas at the Great Usutu River and passes into the basalts between the Great Usutu River and Ingwavuma River (Plate I). This is in general agreement with that Du Toit had found in 1930 (209). The exact location of the axis could not be determined, partly because reliable dips could not always be obtained and partly because the difference in the dips is small.

Just south of the Great Usutu River the dips are about 15° eastwards near the western escarpment. They ~~This~~ increase to about 20° eastwards near the centre of the range and then decrease again to as little as 7° eastwards just before the lavas are covered by the Cretaceous sediments.

South of the Ngwavuma River the dips near the western escarpment range from 15° eastwards to about 25° eastwards, but are generally about 17°

to 18° towards the east. They become distinctly less towards the eastern flats being about 10° to 12° towards the east.

At the Umsunduzi River and southwards the steepness of the lavas increases sharply. On the western side of the mountain range the contact between the basalt and overlying agglomerate dips about 35° eastwards. Further to the south and east, within the mountain range proper, the dips of the lava range from 51° to 59° towards the east. One very steep dip of 66° eastwards was recorded. The dips remain steep up to the termination of the range.

Towards the Bumbeni Area the dips of the lava become erratic changing abruptly over small distances from 42° to 50° towards the east. Within the Bumbeni Area few reliable dips could be measured, but on the whole they were considerably less than those recorded to the west of the area, ranging from 5° to 35° towards the east. (Plates I and IV).

4. Dykes.

East-west tension along the east coast of South Africa during Jurassic times caused the outpouring of lava from numerous fissures and tilting of the coastal area produced the Lebombo Monocline. As a result of the tension the dykes of dolerite and ~~channel~~ pyroclastic breccia have a strong north-south alignment which is in agreement with the strike of the lava flows ranging from N 20 E just south of the Great Usutu River to N 30 W towards the southern tip of the range.

No reliable measurements of dip could be obtained for the dolerite dykes, but it was observed that they dip towards the west at a steep angle.

The inclination of the pyroclastic breccia dykes could only be measured reliably in a few areas. Their dip ranges from 70° to 80° towards the west and is in general agreement with the dips of the lava flows through which they cut. Near the Umsunduzi River a copper-bearing pyroclastic breccia dyke dips 72° westwards which is rather steep for that area but may indicate that it was formed at a slightly later stage than most of the breccia dykes. This is strong evidence that the feeder channels were vertical when formed and became tilted with the rest of the beds of the Karroo System during the formation of the Lebombo Monocline.

5. Faults.

Considerable north-south strike faulting has taken place in the Lebombo Mountain Range, but the presence of pyroclastic flow breccias and pyroclastic breccia dykes obscures these faults, and the absence of consistent marker horizons makes it almost impossible to measure the amount of displacement. In the Ubombo area and southwards the strike faults cause the Drakensberg ~~Stage~~ basalt to occupy a relatively higher position in this area. A number of strike faults were observed from the Ubombo area southwards and the downthrow is to the west. The strike of the faults is generally due north, but ranges from N 12 W to N 40 E (Plate I).

In some localities slickensiding (Plate XV) or zones of crushing indicate the presence of faults, but without the aid of marker horizons the direction and amount of displacement could not be satisfactorily measured.

Faults perpendicular to the strike of the range are not common but do occur in a few areas. The most notable of these is about a mile south of Majozini beacon, on the western side of the range, where there is an indeterminate fault zone, about 50 yards wide, consisting of at least six small faults (Plates XVI and I). These small faults are seldom more than 10 feet long and their strike ranges from N 69 E to N 74 E; one very small fault here strikes due north. The southern side of the fault zone has a horizontal displacement of about 100 feet to the east.

D. Mineral Resources.

1. Metallic.

Mineralisation in the Stormberg Series is limited and no mineral deposits of economic value have yet been found. However the mineralisation of the Messina copper mines situated in the Northern Transvaal has been considered to be genetically related to the Karroo volcanism of the Lebombo Belt (Söhnge, 1946, 162).

Small indications of copper mineralisation have been found in the area under consideration. On the farm Ingagalu (Plate IV) near the Bumbeni area, in the western foothills of the mountain range, a thin copper-bearing pyroclastic breccia dyke occurs in agglomerate. Its strike is N 35 E and its dip ranges from 72° to 80° W. It is heavily stained with malachite and azurite. The copper minerals occur exclusively in the numerous cracks and in the sparse gas vugs indicating a later hydrothermal mineralisation. It has a length of about 7 feet and a maximum width of about 3½ feet. A small prospecting pit about 5 feet deep had been dug in the mineralised zone and the mineralisation appears to peter out towards the bottom of this pit. South of this pit the thin pyroclastic breccia dyke can be followed for 900 feet but shows no mineralisation.

In the Bumbeni area, on the mountain range, a very small amount of indistinct and indefinite malachite staining occurs in the more quartz-rich portions of the igneous quartz veins.

Copper mineralisation also occurs at the Pongola Poort. Here minute specks and granules of native copper and chalcopyrite up to 0.25 inch in length occur in a few of the bore-holes drilled at the dam site. This mineralisation was only found in the jointed lava at a depth of about 200 feet below the surface, where it has an andesitic composition.

2. Non-Metallic.

Perlite or volcanic glass devitrifies in time, and this is most important because, if crystals and the products of devitrification are present beyond certain low limits, the deposit of perlite will be commercially unusable. For this reason few deposits older than Cretaceous are known. The acid lavas of the Lebombo Mountain Range were produced during the late Jurassic. Up till 1962 little interest was taken in perlite in South Africa and consequently no deposits were known. Volcanic glass of probable trachytic composition has however been found South of the Umsunduzi River in the Upper Lebombo Suite (Plate IV). Some of the glass is devitrified and other deposits are very small, but there are a few occurrences which contain perlite that may be of commercial value. This glass in all cases shows perlitic cracks. It is dark olive-green, black and also cream to pink in colour, and in some cases contains a few white phenocrysts of altered felspar. It is brittle and usually splinters when struck with a hammer. It swells when heated, but the amount of swelling could not be determined. Some perlite was also found in the Lower Lebombo Suite but this has been altered by devitrification to such an extent that it is no longer of commercial value.

The cost of production of the crude perlite in the Lebombo Mountain Range would be fairly low as open-pit quarry methods could be used and the overburden is generally very thin. In most cases, however, roads would have to be constructed for a short distance.

Volcanic glass.
Perlite of commercial value is known and has been excavated on a small scale in Mozambique. Perlite of possible commercial value is also known in the Lebombo Mountains of Swaziland in the Stegi District (Hunter 1962).

V. SEQUENCE AND PETROGRAPHY OF ERUPTIVE AND ASSOCIATED ROCKS.

A. The Drakensberg Stage.

No detailed study was made of basalts of the Drakensberg Stage. West of the Lebombo Mountain Range, south of the Great Usutu River (Plate I) they are massive and fine-grained, varying in colour from black to olive-green and dark brown, and contain white and yellow amygdales that consist of quartz, chalcedony, zeolites and calcite.

The individual basalt flows are about 30 to 40 feet thick. Towards the upper portion of the Drakensberg Stage the flows consist of basalt at the base but become slightly more acid towards the top of each flow. At the top of the last three flows before the so-called "transition zone" is reached, the rocks form layers of reddish material with an andesitic composition (Plate XVII).

The basalt has a porphyritic texture and a microcrystalline to cryptocrystalline groundmass. The phenocrysts consist of plagioclase
labradorite
(An 50 to An 60). Smaller in size and less abundant than the plagioclase, but also present as phenocrysts are the monoclinic pyroxenes pigeonite ($2Vz = 25^{o}$) and augite ($2Vz = 46^{o}$) which is more abundant. The groundmass consists of plagioclase (labradorite), altered pyroxene, and varying small amounts of magnetite. No ultrabasic rocks are present in the Drakensberg Stage of this region.

B. The Transition Zone.

The transition from outpourings of basalt to extrusions of acid lava can be seen at the entrance of the Pongola Poort and on the new road to Jozini Dam. (Plate I).

The lowest flow in the Poort is massive basalt and is about 30 feet thick. It is dark, drab, greenish-grey in colour and contains irregular reddish-brown lenses which are due to iron-oxide staining. It consists of a fine-grained mosaic of plagioclase (An 50), clinopyroxenes (pigeonite and augite), and magnetite set in an extremely fine-grained groundmass. This basalt contains numerous amygdales of secondary quartz and calcite.

This basalt grades into a flow (about 25 feet thick) of dark grey vesicular andesite which contains small phenocrysts of plagioclase (An 32), magnetite, and accessory amounts of pyroxene, set in a cryptocrystalline groundmass. It is cut by thin veins of secondary quartz which in places contains hairlike masses of probable dumortierite.

The vesicular andesite is ~~apparently~~ overlain by a fine-grained, dull, reddish-brown tuff, but no contact is visible. This is a thin bed ranging in thickness from 8 to 20 feet. It consists of quartz fragments up to 0.2 mm. long a few plagioclase laths (An 24), and a little magnetite. The fragments generally show ~~little or~~ no weathering and are not rounded. The fragments are set in a matrix which is very fine-grained and appears to consist largely of altered felspar.

This reddish-brown tuff is ~~apparently~~ overlain by about 20 feet of andesite but no contact is visible. The lava is very similar to the lower andesite except that it is not vesicular, but instead is finely jointed or layered. These fine joints, generally 1 to 2 mm. in width, were probably caused by contraction when the lava cooled. Secondary iron oxide deposited in these joints gives them a reddish appearance. It is in this rock that native copper and chalcopyrite are found further east in the bore-holes at the dam site. Over the last 5 or 6 feet the andesite grades into dacite, overlain by andesite which rapidly grades after only about 5 feet into dacite of the Lower Lava Zone.

Thus the succession upwards from the basalt of the Drakensberg Stage through the transition zone to the acid extrusions of the Lower Lava Phase is as follows:-

a) andesite which grades rapidly into dacite (Lower Lava Phase),
b) jointed andesite grading upwards into dacite,
c) fine-grained dull reddish tuff,
d vesicular andesite ,
e) basalt of the Drakensberg Stage.

The total thickness of this transition zone is about 100 feet. From the top of the tuff bed it is about 25 feet to the acid lava of the Lower Lebombo Suite. This may represent the true transition zone, the tuff bed belonging to the final eruptions of the Drakensberg Stage.

The andesite and basalt ~~is~~ are fairly uniform. It is porphyritic and the grain size becomes gradually finer until at the top of each flow it is extremely fine-grained to glassy. The felspar is plagioclase which shows a definite increase in its sodium content from the bottom upwards. In the lower flow of the transition zone the plagioclase ranges from An 59 to An 48; and in the upper flow of the transition zone it ranges from An 44 to An 32. Quartz makes an appearance towards the top of each flow in the transition zone , being more plentiful in the upper flow, but it is never very abundant. Pyroxenes (pigeonite and augite) and magnetite are fairly abundant, but show a slight decrease from the bottom upwards.

The specific gravity shows the changes that take place in the transition zone very clearly. Table 3 gives the specific gravity and the distance from the "upper contact" at which each sample was taken on the new road to Jozini Dam. The results are shown graphically in plate XX.

Table 3.

Sample No.	Distance from Upper Contact in feet	S. G.	Composition	Remarks
12	10	2.47	dacite	Lower Lebombo Suite
11	5	2.57	dacite	
10	½	2.66	andesite	6 ins. above upper contact in Lower Lebombo Suite
------	Upper	Contact between the transition zone and Lower Lava Phase.		
9	½	2.40	dacite	6 ins. below upper contact in transition zone
8	5	2.54	dacite	
7	10	2.82	andesite	
6	20	2.83	andesite	
5	30	2.74	andesite	
4	45	2.84	andesite	
3	60	2.88	basalt	
2	75	2.89	basalt	75 ft. below upper contact and 5 ft. above lower contact in transition zone.
------	Lower	Contact between transition zone and Upper Lave Phase.		
1	82	2.69	andesite	2 ft. below lower contact in Drakensberg Stage.

Apart from the localities at Pongola Poort and on the new road to Jozini Dam, the contact zone between the basalt and acid extrusions on the mountain face can seldom be examined closely owing to the difficult terrain and a covering of thick bush and loose boulders. In most cases the acid lava of the Lower Lava Phase which is invariably andesite appears to lie directly on the basalt. Under the microscope it is porphyritic with a cryptocrystalline groundmass. The plagioclase is oligoclase-andesine (An 23 to An 36). Orthoclase and quartz are occasionally present in small amounts. The mafic minerals are pyroxenes (pigeonite and a little hypersthene or augite), and magnetite.

Andesite = Andesite = Not Bimodal

C. The Lower Lebombo Suite.

The Lower Lebombo Suite of the Lebombo Stage can be divided into three phases (table 1) which transgress unconformably over the basalt of the Drakensberg Stage so that each of the three phases overlies the basalt in turn. (Plate III and XI).

The Lower Lava Phase of the Lower Lebombo Suite is situated between the Great Usutu River and the Mkuzi River. (Plate III). In the west it is in contact with the basalt of the Drakensberg Stage whereas in the east it is in contact with the Pyroclastic Phase of the Lower Lebombo Suite. This contact is not sharp and its exact position could not be determined but it lies oblique to the strike of the mountains. In the north at the Great Usutu River the Lower Lava Phase covers the greater width of the mountain range. The Lower Lava Phase then becomes pregressively narrower up to its termination at the Mkuzi River. (Plate III).

The Pyroclastic Phase of the Lower Lebombo Suite is situated east of the contact with the Lower Lava Phase and south of the Mkuzi River. (Plate III). It lies directly on the basalt of the Drakensberg Stage, except near the Lower Lava Phase, where it overlies the latter. The contact between this phase and the Upper Lava Phase of the Lower Lebombo Suite again lies oblique to the strike of the mountain range, and the contact is again not sharp. The Pyroclastic Phase **becomes** progressively narrower and terminates south of the Umsunduzi River. (Plate III).

The rest of the range is composed of the Upper Lava Phase except for about 100 square miles on the eastern side of the mountain range north and south of the Umsunduzi River, where the Upper Lebombo Suite occurs. The Upper Lava Phase again overlies the Drakensberg Stage basalt. (Plate III).

1. The Lower Lava Phase.

The Lower Lava Phase represents a quiet eruptive phase and consists of thick layers of massive andesite, dacite and rhyolite or lava exhibiting contorted flow lines, or jointed lava with joint sets ranging in strike from N 20 E to N 80 W and N 60 E to N 15 W.

The colour of the dacite and rhyolite is generally reddish-brown, varying from dark reddish-brown to light pinkish-brown. Less commonly fresh surfaces are light grey or light greenish-grey. The massive lava often has a mottled appearance which is due to small felspar phenocrysts or volcanic glass or irregular concentrations of iron oxide.

The transition zone on the western side of the mountain range, between the acid lavas and basalt of the Drakensberg Stage cannot ~~be~~ often be seen but its position can be readily discerned from the Lebombo Flats as the pyroclastic breccia dykes which cut through the Lower Lava Phase, form a cliff whereas the basalts form a steep talus-covered slope. (Plate Vb). This transition zone is usually found two-thirds of the way up the escarpment but in a few areas it is a little lower down.

Just south of the Great Usutu River at the foot of the escarpment there are apparently unconnected outliers of dacite. (Plate II). These are elongated in a north-south direction, their strike corresponding to that of the mountain range. The height of these outliers is at least 200 feet below that of the contact between the andesite and basalt. ~~contact~~. One of these small hillocks was examined and found to consist of jointed dacite. This corresponds to the lava east of it in the mountain range. These bodies probably indicate an interfingering between the dacite and basalt at the initial outpouring of the flows of the Lower Lebombo Suite.

Amygdaloidal dacite occurs occasionally in the massive dacite. The amygdales are generally small, irregular and may be either partly or wholly filled with quartz. North of Ngwavuma River a few small elongated geodes with amethyst crystals were found.

Volcanic glass, obsidian, and pitchstone, while by no means typical, are fairly common in the Lower Lava Phase. The colour of these rocks is dark olive-green, dark grey, or black with a vitreous lustre. They generally have a well developed perlitic structure and contain a few scattered phenocrysts of quartz, felspar and augite. Devitrification products are seldom absent. These occurrences are small in extent.

Tuff deposits are not common in the Lower Lava Phase but one significant tuff deposit occurs at the top of the Lower Lava Phase about 2 miles south of the Great Usutu River towards the eastern side of the range. (Plate I). This is a laminated tuff that has undergone ~~suffered~~ compaction and cementation mainly by secondary quartz. It is only about 10 feet thick and covers an area of less than 30 square yards. However, there are other small outcrops away from the main outcrop indicating that this tuff probably covered a considerably larger area before erosion ~~set in~~. This tuff deposit occurs at the top of the Lower Lava Phase and may belong to the Pyroclastic Phase.

Andesites also occur in this phase but are less common than the dacites and where present always occur towards the base of the succession. The lavas tend to be more basic towards the bottom of the succession becoming more acid towards the top. Generally dacite and a little andesite are found towards the bottom of the succession and the plagioclase is more calcic (andesine), while towards the top of this succession dacite and a little rhyolite appears and the plagioclase becomes more sodic (oligoclase). Quartz also increases from the bottom upwards. On the other hand pyroxenes tend to decrease from the bottom upwards and this is particularly noticable in the lower portions of the succession. In fact pyroxenes tend to be found only in the lower portions of the succession being absent, or very rare, in the upper portions. Another general trend is that the lavas tend to be slightly more acid in the north near the Great Usutu River, becoming more basic southwards. Near the Great Usutu River the more acid rocks are rhyolite whereas in the south near the Mkuzi River the more acid rocks are dacite.

The texture of the rocks is invariably porphyritic and the groundmass is generally cryptocrystalline or felsitic. An intergranular or intersertal groundmass also occurs.

The phenocrysts of these lavas are felspars and quartz with lesser amounts of magnetite. Pyroxene is common in the lower rocks of the succession and may be pigeonite, augite, or hypersthene. The pyroxene is more usually found as small phenocrysts or in the groundmass. The felspars consist of plagioclase (An 15 to An 49) and orthoclase which is not always present and is subordinate to the plagioclase except in the rhyolite found in the north.

Titaniferous magnetite and ilmenite may be present in the andesite and dacite in sufficient quantities to affect a magnetized needle strongly. On the northern bank of the Ngwavuma River about two miles from its entrance into the poort there is a small "beach" of light-coloured sand. Here thick black streaks of magnetite, ilmenite and rutile occur in the light coloured sand, but these heavy minerals may have been derived from the basalts to the west.

The essential constituents of the lavas of the Lower Lava Phase are plagioclase of oligoclase-andesine composition, orthoclase, quartz and magnetite. Of the accessories only pyroxene and, less commonly, biotite may be present in any quantity. Other accessories in small amounts are: lamprobolite, rutile, sphene, apatite, and zircon. The secondary minerals which are present in only very small amounts, are: quartz, chalcedony, opal, calcite, chlorite and zeolites.

Occasionally a variation within a single lava flow can be observed. South of Pongolapoort near the escarpment large felspar phenocrysts up to 6 mm. in length occur in a fine-grained groundmass of dacite. A concentration of these crystals are observed at the base of the flow and could be due to crystal settling. Also within a single flow a variation in composition can occasionally be observed but it is usually not very marked. Where it is observed it usually consists of an increase, from bottom to top, in the quartz content of the rock and may also include a slight increase in the sodic content of plagiolase. No change in the amount of potassium felspar was noted from bottom to top in a single flow. The amount of mafic minerals generally decreases slightly from the base upwards.

Following the general north-south strike of the rocks are a few small light-grey to white-coloured dykes. These dykes are narrow, seldom being as wide as two feet, and usually pinch out within 10 yards. They have a cryptocrystalline texture and contain small veins of secondary quartz. A qualitative spectrographic analysis gave mainly silicon, a little aluminium and a little calcium.

Intruded into the dacite about half a mile north of the Ngwavuma River is a small pluton of granodiorite-porphyry, elongated in a north-south direction. (Plate I). It is about 3/4 mile long and has a maximum width of 100 feet.

The rock is mottled reddish-grey to greenish-grey in colour and is porphyritic with a fine-grained granitic groundmass. The essential minerals in decreasing order of abundance are: plagioclase (An 30), far less orthoclase, quartz, pyroxenes (augite and a little pigeonite), and magnetite. The plagioclase often shows zoning as well as albite twins. The pyroxenes are often surrounded by rims of magnetite and are sometimes overgrown by it.

3.2. The Pyroclastic Phase.

The Pyroclastic Phase, of the Lower Lebombo Suite is characterized by pyroclastic flow breccia intercalated with dacite.

At the Jozini Dam site, the bore-holes give valuable information on the sequence of formation of the Pyroclastic Phase. The first bed to form was a thin, fine-grained, unconsolidated, red tuff or ash bed. This is followed by flows of vesicular, jointed, and massive dacite. The total thickness of these flows is generally about 500 feet. Over these lava flows comparatively thin beds of pyroclastic flow breccia were laid down, followed occasionally by thin beds of fine-grained, brownish-red sediments. The sequence is repeated starting with ash and tuff beds followed by vesicular and/or jointed and/or massive dacite and pyroclastic flow breccia and ending with a minor unconformity and a thin deposit of reworked pyroclastic material. The tuff beds lie directly on the pyroclastic flow breccia when the sedimentary beds are absent, as is usually the case. The full sequence of beds is not often present throughout the Pyroclastic Phase. Using the pyroclastic flow breccia as a marker this sequence is repeated a maximum of eight times.

Although the Pyroclastic Phase is characterized by the pyroclastic flow breccias, they are not the most important components quantitatively. The various maximum and minimum thicknesses of the beds obtained from various bore-holes at Jozini Dam shows the following:-

	Maximum thickness in feet	Minimum thickness in feet
Banded andesite	57.6	10.0
Ash and tuff	50.0	3.9
Pyroclastic flow breccia	102.8	38.0
Ash and tuff with pyroclastic flow breccia	116.2	71.3

Massive and/or vesicular and/or jointed dacite about 500 feet.
This great thickness of dacite does not represent a single flow, but a number of thin flows ranging from 10 to 60 feet thick.

If the banded andesite is included with the dacite flows then their thickness would be about 510 to 560 feet; the thickness of pyroclastic material (tuff and pyroclastic flow breccia) is about 70 to 120 feet.

The massive, jointed, and vesicular dacite forms a series of fairly thin flows. The vesicular dacite is light reddish-brown to dark reddish-brown and sometimes has a mottled appearance due to irregular concentrations of iron oxide or the presence of small weathered felspar phenocrysts. It contains numerous round, oval or elongated gas vugs due to the expansion of gas bubbles. The gas vugs range in size from about 0.1 in. up to about 6 inches in diameter, the most general size being about 0.25 in. in diameter. The large gas vugs are not usually associated with the smaller ones, and also the large gas vugs are situated further apart from each other than the small gas vugs which are very numerous and usually close together. Where these vesicles are elongated they are orientated with their long axes either parallel or at right angles to the "layering" of the rocks.

The majority of these vesicles are partly infilled where they contain the common secondary minerals, zeolites (laumontite and natrolite), calcite, or silica in the form of chalcedony, opal, agate or quartz. Other secondary minerals are gypsum, barite, chalcopyrite and pyrite.

The massive and jointed dacite is the same as the dacite found in the Lower Lava Phase. In a small area west of Ubombo the massive dacite has a corrugated surface. The distance between ridges is about 2.5 inches, and the height of the ridges is just over 0.5 inch.

From the bore-holes that were drilled at Jozini Dam core was taken at intervals of ten feet between two pyroclastic flow breccias. The rock consists of massive to slightly jointed dacite with no indication of different flows and little indication of change in composition. The specific gravity was determined on samples weighing between 100 and 200 gm. The specific gravity determinations at the different ~~depths~~ heights from the base of the dacite is given in table 4. The variations in the specific gravity are shown graphically in Plate XXI.

Table 4.

Sample No.	Depth in feet	S. G.	Sample No.	Depth in feet	S. G.
(Top of massive dacite)					
50	529.3	2.52	25	250.8	2.58
49	525.3	2.52	24	240.8	2.52
48	515.3	2.47	23	230.8	2.50
47	507.3	2.52	22	220.8	2.52
46	499.3	2.45	21	201.8	2.54
45	463.3	2.52	20	191.8	2.50
44	457.3	2.51	19	181.8	2.52
43	434.3	2.56	18	171.8	2.52
42	425.3	2.54	17	161.8	2.55
41	416.3	2.56	16	151.8	2.52
40	404.3	2.47	15	141.8	2.53
39	399.3	2.48	14	131.8	2.52
38	376.3	2.58	13	121.8	2.54
37	366.3	2.54	12	111.8	2.56
36	355.3	2.60	11	101.8	2.52
35	345.3	2.53	10	91.8	2.54
34	336.3	2.54	9	81.8	2.58
33	326.3	2.51	8	71.8	2.56
32	316.3	2.56	7	61.8	2.54
31	306.3	2.56	6	51.8	2.63
30	300.3	2.54	5	41.8	2.56
29	290.8	2.56	4	31.8	2.54
28	280.8	2.52	3	21.8	2.56
27	270.8	2.52	2	11.8	2.54
26	260.8	2.56	1	1.8	2.84
				(Base of massive lava)	

These points show a certain amount of scattering but even so a definite pattern can be seen. The conclusions that can be drawn from this are:-

The lava between the two pyroclastic flow breccias does not represent a single flow but consists of at least six flows and possibly more. This is shown by a gradual decrease in the specific gravity followed by an abrupt increase when passing from one flow to the next. The thickest flow is about 200 feet thick and may very possibly consist of a number of smaller flows that are not shown up by the specific gravity variation.

Over the whole thickness there is a general but small decrease in specific gravity from the bottom upwards indicating a tendency to become more acid and to contain fewer ferromagnesium minerals towards the top. This tendency, although less obvious, was also seen in slides made from these samples.

There is very little sign of differentiation within single flows.

As in the Lower Lava Phase the composition of the lavas in the Pyroclastic Phase becomes slightly more basic from the Great Usutu River to the Pongola River, after which the composition remains constant. This change in composition is not as marked as it is in the Lower Lava Phase. The lava is generally found to consist of dacite. A slight increase in the quartz content and an increase in the sodic content of the plagioclase (from An 43 to An 26) was noticed from the bottom of the succession upwards.

Pyroclastic flow breccias occur in layers conformable with the general trend of the dacite. The size of an individual pyroclastic flow breccia varies greatly. It may cover an extensive area of many square miles. In thickness it ranges from 7 feet to about 200 feet. It could not be determined whether the thick pyroclastic flow breccias are the result of a single flow or a series of flows.

Three miles west of Jozini Dam a new road cutting has exposed a pyroclastic flow breccia in cross section. The lower contact is uneven and here the pyroclastic flow breccia overlies massive dacite. Parts of this massive lava appear to have been reheated and possibly remelted by the pyroclastic flow breccia.

About 8 miles south of the Great Usutu River on the eastern side of the range the upper contact of a pyroclastic flow breccia is exposed. Its surface is much weathered and is light yellow with reddish-brown patches of vesicular dacite. Overlying this is a rock composed of smaller fragments of dacite set in a red tuffaceous ground-mass. The weathered surface of the pyroclastic flow breccia indicates a time lapse after its eruption during which weathering and denudation took place. This was confirmed by bore-holes drilled at the Pongolapoort dam site.

The pyroclastic flow breccias are very similar to the pyroclastic breccia dyke which fill fissures from which eruption took place. The pyroclastic flow breccia consists of a heterogeneous assemblage of pyroclastic material containing scoriaceous blocks of dacite, angular fragments of dacite, lumps and lenses of volcanic glass and volcanic ash set in a matrix of fine-grained dacite.

The pyroclastic flow breccias were produced by explosive eruptions from feeder channels and flowage in which fragments of partly solidified lava became welded together by the still fluid parts of the same magma. During the outpouring and flowage pieces of country rock were broken off the walls of the fissure or picked up by the flowing material and carried or rolled along to produce the heterogeneous nature of the pyroclastic flow breccia. The origin of the pyroclastic flow breccias is not envisaged as being produced only by a nuée ardente type of flow, but also by a flow of scoriaceous lava. The lava was in a viscous state at the time of flowage as is indicated by the streaky appearance and contorted flow lines of the cementing lava.

Throughout the range there are numerous dyke-like bodies of pyroclastic breccia which are thought to represent the filled feeder channels of all the pyroclastic deposits and of at least part of the dacite and rhyolite. These dykes are numerous throughout the range although they are more concentrated on the western side/ (Plate I). They are long and can sometimes be traced individually for several miles. The dykes vary in width from a few feet up to 200 feet. The width of an individual dyke is never constant but it thins out or swells to form pockets. In places it splits up as can be seen just above the escarpment near Ubombo. Towards the southern tip of the range in the Upper Lava Phase these dykes are not as numerous and tend to be rather narrower.

The strike of the breccia dykes is parallel to the general strike of the mountain range, but may deviate from this by as much as 10 degrees. As stated earlier, when discussing the structure of the mountain range, these bodies dip steeply (between 65° to 85°) to the west.

The feeder channels are filled with a heterogeneous assemblage of pyroclastic fragments of all sizes and textures cemented together by lava and secondary material (Plate XXIIa). When the interstices and cavities are not filled in by the lava they become filled in by a weathered clayey material and cemented by secondary quartz or calcite. Impure opal is often present.

The numerous pans found in the mountain range, generally in the Lower Lava Phase and Pyroclastic Phase, are associated with the breccia dykes being either in or at the side of these feeder channels. They usually average about 150 feet in diameter although pans as large as 400 feet and as small as 45 feet in diameter occur. They have a slight north-south elongation. The dips of the pyroclastic material at these pans are usually indistinct and could not be measured accurately. However the pyroclastic material in some cases dips towards the centre of the pan from all directions around the edge whereas away from the pan the strata dip away from the centre in all directions (Plate XVIII). These pans probably represent local centres of eruption or gas vents. The outer edges of the depressions give high magnetometric anomalies.

On either side of the breccia dykes there are zones of highly contorted flow structure in the otherwise massive or evenly bedded dacite. (Plate XIX). It appears as though the wall rock had assumed a state of partial viscosity due to the pressure and heat of the eruptive action. These contorted flow structures do not cease abruptly but appear to die out rapidly away from the pyroclastic breccia dykes. The dacite on the eastern side of a pyroclastic breccia dyke is generally more contorted than on the western side. The zone of contorted flow structure varies greatly in width but is narrower than the pyroclastic breccia dyke. In a number of cases a narrow zone of contorted flow structure occurs only on the eastern side of the pyroclastic breccia dyke, being absent to the west.

The zone of contorted flow structure is highly resistant to weathering. It often forms the cliff face of the Lebombo Escarpment and is responsible for the steep krantzes along the north-south trending river valleys.

Near the breccia dykes, and sometimes in the zone of contorted flow structures, a few inclusions occur. These inclusions are fine-grained and often show glass around their edges. They are accidental fragments of basalt of the Drakensberg Stage and consist largely of plagioclase (An 56), with fairly abundant magnetite and pyroxene. They have no effect on the composition of the fine-grained dacite in which they are enclosed.

In the Pyroclastic Phase, associated with the dacite flows, are flows of volcanic glass. These are usually very small although three occurrences of notable size were found (Plate I). The one is north of the Ngwavuma River towards the eastern side of the range at Nonjingigazi Store. Another small patch of volcanic glass is present about 9 miles due north of the store just south of the Great Usutu River. The third occurrence is south of the Pongola River near Majozini beacon on the western side of the range. The first of these occurrences forms a sheet of dark-brown to black volcanic glass almost 2 square miles in extent and occurs just north of Nonjingigazi Store (Plate I). It has a very uniform appearance. A few small patches of this volcanic glass were found as far as 1.5 miles south of the main deposit, indicating that it may have covered a far larger area at one time.

The glass has a vitrophyric flow-banded texture. Dark to light brown bands of volcanic glass can be seen. These bands became highly contorted near the larger phenocrysts. Almost 50 per cent of a thin section of the glass is occupied by phenocrysts. The most abundant phenocrysts are felspar, orthoclase being rather less abundant than plagioclase (An 12). Other phenocrysts are quartz, augite, pigeonite, and magnetite. This gives the glass a pheno-dacite composition with a refractive index of n = 1.509. The small patch of glass north of this is very similar.

The other area of prominent dacitic glass, about 4 miles south-west of Jozini Dam and just north-east of Majozini beacon, is elongated in a north-south direction in accordance with the general strike of the mountain range and covers an area of almost 2 square miles. It forms the final volcanic extrusion in this area. It overlies the Lower Lava Phase and over most of its extent is banked up against the earlier rocks of the Pyroclastic Phase. In some places it is banked up against a highly vesicular dacite which also forms four small "islands" in the glass. Apparently the glassy lava flowed around these hillocks.

The glass is dark brown to dark reddish-brown with a vitreous lustre which gives it the appearance of pitchstone. It has a porphyritic texture with a glassy groundmass containing thin needle-like laths of indeterminable felspar which sometimes gives an indication of flow. The phenocrysts are mainly plagioclase (An 27 to An 38), and a little orthoclase, quartz, augite, and magnetite are also present. As about 50 per cent of the rock consists of isotropic glass the rock can be described as a ~~pheno~~ pyroxene pheno- dacite. The glass has a refractive index of n = 1.518. The chemical analysis (appendix 1 analysis 7) corresponds to an iron-rich dacite.

Scattered irregularly throughout the upper surface of this glass are volcanic bombs and lapilli which are roughly spherical in shape. They have a bread-crust surface appearance and range in size from 0.25 in. up to 7.5 in. in diameter. They are fine-grained, dull, red rocks containing phenocrysts up to 1 mm. in length. Under the microscope they cannot be distinguished from the glass.

The upper portions of the pyroclastic flow breccias and the massive dacite are sometimes associated with volcanic bombs and lapilli. These are generally spherical and have a diameter of 0.2 in. up to 4 inches in diameter. It has a "basket-of-eggs" appearance (Plate XXIIb). The bombs are fine-grained, dull, reddish-brown/dacite and their composition corresponds to that of the host lava. The dacite is porphyritic with a very fine-grained intersertal to glassy groundmass. The phenocrysts are plagioclase (oligoclase-andesine), a little quartz and magnetite. The groundmass contains similar plagioclase, quartz, and magnetite set in a matrix of brown devitrified dacitic glass.

Covering a small area near Nonjingigazi is a dacite with thin light and dark coloured layers (Plate I). It is associated with the rocks of the Pyroclastic Phase. It consists of layers of a light-brown glass and a darker brown fine-grained dacite.

The glassy material is almost completely devitrified giving an indefinite cryptocrystalline type of devitrification. The dacite is porphyritic with a cryptocrystalline groundmass having a contorted flow structure. The glass appears to form layers in the lava, but it can be seen that the layers, after an inch or two, peter out to form elongated lenses. The thickness of the lenses is generally 1 to 2 mm. but they range from a fraction of a millimetre up to several inches thick. The greater their thickness the greater their length. The lava encloses the lenses and patches of glass.

A gas-rich stage in the eruption of the pyroclastic flow breccia produced more or less spherical cavities in the rock. These are especially numerous at the bottom contacts of the pyroclastic flow breccias east and south-east of Ingwavuma. (Plate I). The cavities here are filled with agates, quartz and occasionally light-coloured amethyst. The agates are often banded, white and grey being the most common varieties, but beautiful orange and red varieties are also present. These linear zones of agates strike N 30 E. The secondary growths indicate that solution and circulating silica-rich fluids must have been particularly active in this area. Although agates are found throughout the range they are nowhere as concentrated as here.

In some rare cases the agate may appear in unusual forms. For example the upper portion of the geode may contain normal concentric banding of the agate (Plate XXIII, D part i) while the lower portion has horizontal, parallel bands across the vesicle (Plate XXIII, D part ii) making an angle of about 70° with the long axis of the vesicle. These bands are sometimes inclined ~~to~~ at an angle of about 20° to each other (Plate XXIII, D parts ii and iii). The vesicles in these cases are titled towards the east.

It is more normal to find the three types as separate geodes (Plate XXIII, A, B and C). The orientation of the bands may often indicate when the agate was probably formed. In Plate XXIII B and D, part ii, the agate was probably formed after the tilting of the land had formed the Lebombo Monocline. In Plate XXIII C and D, part iii, the agate had probably formed before tilting had taken place.

Agates of the type D in plate XXIII are found mainly south-east of Ingwavuma while agates of type A, B and C in plate XXIII are found throughout the range, agates of type B and C being most common near Otobotini.

4.3 The Upper Lava Phase.

The Upper Lava Phase of the Lower Lebombo Suite consists of dacite and andesite and represents a quiet phase of eruption, which in appearance is similar to the Lower Lava Phase. It is composed of thick layers of massive dacite and andesite intercalated with thin layers and lenses of vesicular dacite and andesite. Individual flows range from a few feet up to almost 50 feet in thickness.

The dacite and andesite is generally reddish-brown varying from dull maroon to light reddish-brown. The massive lava often has a mottled appearance which is usually due to small felspar phenocrysts, but in a few cases is due to roughly circular patches 0.1 mm. to 1.5 mm. in diameter of volcanic glass that has been devitrified. In the vicinity of the feeder channels the massive lava is occasionally intruded by thin veins of a younger and finer-grained dacite of the same composition.

The vesicular dacite and andesite contain~~s~~ vesicles that vary in number from a few scattered gas vugs to a rock that is almost like pumice (Plate XXIVa). The highly vesicular lava is soft and weathers easily. The vesicles are small and can often only be seen under the microscope. The largest vesicles are 4 cms. in diameter. These vesicles are often partly or completely filled with quartz or chalcedony with brown rings around a core of quartz.

Dark olive-green to black pitchstone is fairly rare in the Upper Lava Phase; it occurs irregularly in a few small lenses. It is partly devitrified but distinct perlitic cracks can be seen under the microscope. The composition of these rocks is fairly uniform.

From the bottom upwards there is a slight increase in acidity. The rocks are mainly dacite and a little andesite towards the base of the succession. The lower parts of the succession contain augite which are not present in the upper portions.

The dacite and andesite ~~is~~ are porphyritic with a cryptocrystalline groundmass. A glassy groundmass is occasionally present and consists of brown glass often containing numerous small spherulites up to 3 mm. in diameter. The phenocrysts consist mainly of plagioclase (An 22 to An 46). Phenocrysts in smaller amounts consist of quartz and orthoclase. Far smaller in size but coarser grained than the groundmass are the accessory minerals, magnetite, which is always present, and pyroxene (augite and occasionally pigeonite), which is not often present. Secondary quartz is common in these rocks and they are often silicified to a high degree.

The Upper Lava Phase lies directly on the basalt of the Drakensberg Stage (Plate III). The contact between the acid lava (andesite) and basalt varies from between the base up to half-way up the western slope of the foot-hills of the Lebombo Mountains. The thickness of the contact zone could not be measured.

Lying directly on the basalt of the Drakensberg Stage is a weathered andesite of the Upper Lava Phase. It is porphyritic with a felsitic to cryptocrystalline groundmass. The phenocrysts are plagioclase (An 35), and secondary chlorite and calcite fill in vesicles. The groundmass consists of a mat of plagioclase (An 35 to An 45), accessory amounts of magnetite, altered augite and secondary chlorite. There is also some devitrified volcanic glass.

Overlying the andesite is a pyroxene-dacite. It is porphyritic with a felsitic to cryptocrystalline groundmass. The phenocrysts are plagioclase which range from oligoclase (An 27) to andesine (An 38). Other phenocrysts are quartz and augite. The groundmass consists of minute felspar laths, quartz, augite and magnetite set in a cryptocrystalline matrix. This dacite becomes more acid towards the top by an increase in the amount of quartz as well as an increase in the albite content of the plagioclase and a decrease in augite. Overlying the pyroxene-dacite are normal dacites of the Upper Lava Phase.

Intruded into the Upper Lava Phase are small light-coloured dykes of microgranite which give rise to lava flows of rhyolite. These occur south of the Umsunduzi River and are considered to belong to the Upper Lebombo Suite.

D. The Middle Lebombo Suite.

The Middle Lebombo Suite generally consists of dolerite dykes and upper basalt flows.

Upper basalt is fairly abundant in the northern areas of the Lebombo Mountain Range, especially on the eastern side of the mountain range in Mozambique (Plate II). It is clear that this overlies the acid lavas of the Lower Lebombo Suite (De Assuncao et al. 1959 and 1962).

1. The Upper Basalt.

South of the Great Usutu River only two occurrences of upper basalt have been discovered. The one occurrence, just south of the Great Usutu River, was discovered by Meyer (1951) (Plate I). It is 1.75 miles long and 200 yards wide. (Plate II). This is at the contact between the Cretaceous System and the Lebombo Stage, and it is quite possible that much of the basalt of the Middle Lebombo Suite has been covered by the Cretaceous System. An analysis of the basalt is given in appendix 1, analysis 3.

Within the Bumbeni area on the eastern side of the range the rocks immediately underlying the Upper Lebombo Suite are andesite, which lies unconformably on the dacite of the Upper Lava Phase (of the Lower Lebombo Suite). The andesite covers a small area towards the west of the Bumbeni area along the banks of the Umsunduzi River (Plate IV). It lies within the Upper Lebombo Suite area, but it probably belongs to the Middle Lebombo Suite. It is taken as being equivalent to the "upper basalt".

The thickness of the andesite is about 150 feet, it is generally fine-grained and dark brownish-grey to black in colour, although towards its upper contact near the Mantondo Caves, it tends to contain amygdales and in places becomes highly vesicular and lighter in colour. These rocks form the base of the hill at the Mantondo Caves and consist of andesite with a little intercalated amygdaloidal andesite. The amygdales consist of secondary quartz and calcite, mostly elongated in the direction of dip.

The andesite is porphyritic with an intergranular to cryptocrystalline groundmass. A little glassy material is present in patches and shows spherulitic devitrification. The phenocrysts consist of plagioclase with the same composition as the plagioclase in the groundmass. It usually shows good albite twinning and in a few cases it is zoned. Low down in the andesite flow the plagioclase is An 48, whereas towards the top of the flow it is rather more sodic (An 35). Augite which is largely altered to chlorite and calcite is common. Magnetite and iron-oxide staining are fairly abundant throughout the andesite. Accessories in small amounts are quartz and orthoclase. A point count from slides of a typical holocrystalline sample fairly low down in the succession gave the results shown in appendix 1, no. 6

The chemical composition calculated from this is given in appendix 1 analysis 6.

In the west the andesite is partly capped by conglomerate which is also banked up against the andesite. In the east it is overlain by ignimbrite and trachyte. No fissures or feeders could be found for the andesite.

2. Dolerite Dykes.

Intruded sporadically into the acid lava of the Lower Lebombo Suite are dolerite dykes of the Middle Lebombo Suite. They are far fewer in number and smaller in size than the dolerite dykes in the Rooi Rand or Lebombo Flats. They are usually 6 inches to 4 feet wide and can seldom be followed for very great distances. They are exposed in road cuttings and in river channels but, owing to their easy weathering, outcrops are seldom found. Their presence can often be detected by their typically yellowish-red soil and their tendency to form gullies due to differential weathering (Plate XXIVb). The strike of these dykes is north-south corresponding to the general strike of the mountain range. The dolerite also occasionally forms sills. This is seldom seen owing to the weathering of the dolerite, but it was found in one area, along the mountain pass that leads to Ubombo.

The dolerite is a dark greenish-grey to reddish-grey, fine-grained crystalline rock. It has a fine-grained intergranular texture. The plagioclase laths (An 60) and clinopyroxene (augite and a little pigeonite) are present in quantities of almost equal amounts. Magnetite and glass are usually present in varying but fairly small amounts. Quartz is occasionally present in very small accessory amounts. Olivine is absent.

At Jozini Dam pieces of dacite and breccia are often enclosed in the dolerite confirming that it was intruded subsequent to the dacite of the Lower Lebombo Suite. The dolerite has a very uniform composition. throughout the mountain range. The chemical analyses of two samples taken north and south of the Great Usutu River is given in appendix 1, analyses 4 and 5.

E. The Upper Lebombo Suite.

1. The Lower Bumbeni Phase.

a. Pheno-trachytic Lava

The lowest rocks in the Upper Lebombo Suite occupy a small area north of the Umsunduzi River in the Bumbeni area (Plate IV). They are much altered but probably have a trachytic composition. They unconformably overlie the andesite of the Middle Lebombo Suite.

These rocks have a distinctive red to reddish-brown colour which is caused by secondary iron staining. The lava varies from fine-grained and highly vesicular to fine-grained and massive. It sometimes shows rather poor flow lines and banding but invariably contains distinct lines, streaks and lenses of secondary iron staining.

These rocks have been much altered and not a great deal can be determined under the microscope. They are porphyritic with a ~~very fine-grained~~ crypto-crystalline to glassy groundmass. The phenocrysts, which are not very abundant, consist mainly of subhedral orthoclase. Also present as phenocrysts, but less abundant are plagioclase (An 30), quartz, magnetite, and biotite. In the groundmass individual minerals can sometimes be determined, and these consist of laths of orthoclase and indeterminable plagioclase. A considerable amount of magnetite and iron staining is always present and a little accessory quartz is also sometimes present. Devitrified volcanic glass is common, sometimes with spherulites and sometimes with an indefinite patchy extinction between crossed nicols.

There is a preferred orientation in these rocks. Where they are vesicular the gas vugs are elongated in the probably direction of flow. Where they are massive the groundmass shows a very definite preferred orientation and can be seen to "flow" around the phenocrysts. The phenocrysts also generally show a slight preferred orientation in agreement with the general direction of flow, which is mainly eastwards.

These rocks are fine-grained lava flows probably with the composition of latite to trachyte. The phenocrysts indicate a trachytic composition but may not reflect the true composition and for this reason they are called pheno-trachytes.

b. Bumbeni Conglomerate and Arkose.

Just north of the Umsunduzi River, in the western parts of the Bumbeni area, there is a conglomerate which overlies the lower part of the andesite of the Middle Lebombo Suite and also a small part of the dacite of the Lower Lebombo Suite (Plate IV). It is also banked up against the andesite in the river bed. The conglomerate obscures much of the eastern contact between the andesite and the dacite of the Lower Lebombo Suite. This conglomerate reaches a height of about 180 feet above the river bed. The boulders of the conglomerate give a good indication of its age. The two most abundant types of boulders belong to the pheno-trachyte and andesite of the Middle Lebombo Suite. Other boulders belong to the Lower Lebombo Suite and Drakensberg Stage. Boulders of ~~from~~ the intrusive rocks, the ignimbrites, and the laminated tuff (of the Upper Lebombo Suite) are not present. As the rocks from which the boulders come often occur close to the conglomerate, the conglomerate is considered to be older.

The boulders and pebbles of the conglomerate are water-worn and are generally sub-rounded to well rounded. They show a very slight gradation in size from the base of the conglomerate upwards. At the base the boulders reach a size of almost 3 feet in diameter, the intersticial space being filled by smaller pebbles as well as the cementing matrix (Plate XXV). Higher up in the conglomerate the constituents have a rather more uniform and smaller size although some large boulders do appear. The poorly stratified conglomerate has an indefinite dip of about 10 degrees to the north-east.

The conglomerate contains large lenses of a greenish-grey fine-grained arkose and also grades upwards into a similar light greenish-grey, fine-grained chloritic arkose which is fairly soft. The cementing matrix of the conglomerate is very similar to the arkose except that the arkose is a little darker in colour. Fossilised wood is found frequently in the arkose and infrequently in the matrix of the conglomerate "logs" of fossilised wood up to 2 feet long and 3.5 inches in diameter have been found. No other fossil remains are present.

The arkose consists of small angular to subangular fragments and crystals set in a fine-grained groundmass consisting largely of secondary minerals. The ~~primary~~ minerals are orthoclase, which has been much altered, slightly less plagioclase (An 28 to An 38), and about an equal amount of quartz. Magnetite ~~both primary and secondary~~ is common. The other mafic minerals (pyroxene and biotite) have been almost completely altered to secondary minerals. The large proportion of orthoclase present could only have been derived from the pheno-trachytic rocks.

The two most abundant types of boulders, in the conglomerate which are present in almost equal amounts are andesite and pheno-trachyte. The andesite consists mainly of plagioclase (An 35), greatly altered pyroxene and magnetite and is very similar in appearance to the andesite of the Middle Lebombo Suite. The andesite boulders have probably come from the upper portion of the andesitic lava. The pheno-trachyte is very greatly altered but apart from its alteration products it contains orthoclase and a little plagioclase (An 31). Dacite boulders from the Lower Lebombo Suite are also fairly common. Other boulders are not common but those found, in decreasing abundance, are amygdaloidal basalt from the Drakensberg Stage; a small amount of rhyolite similar to that found just west of the mountain range; a little rounded and cracked rose quartz; and very little agate.

2. The Middle Bumbeni Phase.

a. Laminated Ignimbrite.

The laminated ignimbrites cover fairly extensive areas south and north of the ring intrusion. (Plate IV). They overlie the andesites of the Middle Lebombo Suite at the Mantondo Caves, but do not appear in the conglomerate at the Umsunduzi River and so are most probably younger than the conglomerate. Laminated ignimbrite is intimately associated with the thunder eggs and lenses of volcanic glass which commonly occur towards its upper surface. The laminated ignimbrite grades upward into, and is overlain by laminated tuff in some areas, whereas in other areas it is overlain by trachyte with associated pyroclastic rocks. North of the Umsunduzi River it is overlain by massive ignimbrite.

The laminated ignimbrites are usually light brown or light grey, but shades from off-white grey or brown to dark brown and almost black do occur although they are rare.

Euhedral to anhedral "phenocrysts" of twinned and untwinned orthoclase are fairly common but they are generally broken or cracked. The "phenocrysts" should more correctly be called intratelluric crystals. In some cases they show slight signs of albitization, and in a few cases slight resorption is evident. Rare but also present in small amounts as intratelluric crystals in some areas north of the Umsunduzi River, is biotite which is partly or completely replaced by magnetite. Magnetite occurs as specks throughout the rock but is nowhere abundant.

The groundmass is cryptocrystalline and was probably glassy at one time, but it has been completely recrystallized and devitrification products are common, spherulites and radial devitrification of the cryptocrystalline and microcrystalline types are common. Silicification is present throughout these rocks and is sometimes extremely widespread. With such a fine-grained groundmass the true composition cannot be determined but the intratelluric crystals indicate that the rock originally had a trachytic composition.

No shards of glass could be seen under the microscope as they have been completely altered by the intense secondary recrystallization. The previous existence of glass shards can be deduced from the numerous microscopic black lines in the slides made from these rocks (Plate XXVI). These fine lines follow the direction of flow in the rock and are rather similar to felspar laths, except that the lines are far thinner. These thin black lines represent the matrix of the rock while the devitrified material represents the recrystallized shards. This has been noticed by students of the devitrification of ignimbrites. According to Steiner (1960, 22) the matrix sometimes only forms thin streaks or films between the shards. The matrix is first cloudy, then alters into rows of transparent globulites which with time become opaque and finally appear as dark lines. The photomicrograph that Steiner gives of the "mesostasis" or matrix forming dark lines separating the glass shards is very similar to what is seen in the Bumbeni ignimbrites.

The laminated ignimbrites, overlying the andesite of the Middle Lebombo Suite at the Umsunduzi River and in which the Mantondo Caves are formed is a little different from the other laminated ignimbrites. It consists of a "fluidal" type of laminated ignimbrite. The intratelluric crystals are the same except that at the Mantondo Caves a little plagioclase (An 22 to An 28) makes its appearance and a small amount of primary quartz is also present. It is also richer in ~~iron ore~~ magnetite and biotite. The groundmass contains altered glass shards and the products of devitrification and silicification are similar to those previously described.

Inclusions, which are generally small (about 0.1 in. in diameter) and range up to about 1 in. in diameter, are present in this laminated ignimbrite. The inclusions although widespread, are not abundant and occupy about 8 per cent of the volume of the rock. The most common inclusions are dark coloured and contain silicified felspar crystals set in an iron-rich cryptocrystalline groundmass. These inclusions commonly show reaction along their rims and look like part of the underlying andesite. Other inclusions, which are less abundant, are of a rather altered quartzitic material. They are surrounded by later quartz crystals. This ignimbrite has undergone a greater deal of secondary silicification than the other ignimbrites.

b. Massive Ignimbrite.

The massive ignimbrite covers a large area north of the Umsunduzi River (Plate IV). It overlies the laminated ignimbrite and is found to the west of it till it is covered by the laminated tuff beds. A very small patch of massive ignimbrite overlies the laminated ignimbrites south of the ring intrusions and this may indicate that it covered a far larger area before erosion reduced its extent. The massive ignimbrite is fine-grained and massive in the hand specimen. Rarely, a highly vesicular patch is present, while in other areas the rock becomes more glassy. It varies in colour from creamy to yellowish-green to a dull red. On weathering it forms a white material like unglazed porcelain in appearance; in fact the name Bumbeni means "place of clay".

The rock contains euhedral to subhedral phenocrysts of orthoclase with lesser amounts of plagioclase (oligoclase), a little biotite, magnetite, indeterminable pyroxene and quartz. The crystals are usually cracked but sometimes not and never are they much broken. The ignimbrite has a trachytic composition.

The ignimbrite contains a few lumps of glass up to 3 mm. in diameter. These glass lumps are not devitrified, and have a fairly sharp contact with the devitrified surrounding groundmass (Plate XXIXa). Secondary silicification is present and secondary quartz can be seen filling in some of the vugs and cracks.

The groundmass of the massive ignimbrite contains fairly flattened devitrified glass shards set in a cryptocrystalline ~~and recrystallized~~ matrix. There are fewer shards in the massive ignimbrite than in the laminated ignimbrite. The shards are all aligned in the same direction giving a distinct eutaxitic texture under the microscope. The glass shards have been completely devitrified and contain innumerable small spherulites of cryptocrystalline devitrification. Devitrification usually destroys the shard structure but in this case it enhances it (Plate XXIXb). The shards are generally rod shaped and often bent although a few imperfect y-shaped shards are present.

c. Thunder Eggs and Volcanic Glass.

Thunder eggs are geode-like bodies which may be hollow or may contain agate, opal, chalcedony or zeolite and which have been weathered out of ignimbrite or lava, (A.G.I. Supplement 1960, 67). They were called thunder eggs by the Red Indians of North America because during a thunderstorm the soft matrix was washed away leaving the "egg" behind (C.M. Schwellnus, personal communication, 1961).

The thunder eggs in the Lebombo mountains are found in some of the lenses of glass in the upper portions of the ignimbrites and laminated tuffs.

This glass is found mainly in two areas. South of the ring intrusion it forms many lenses up to 300 feet long and 100 feet wide elongated in a north-south direction. The other area is north of the Umsunduzi River on the southern part of the Empileni Hills where the glass forms an elongated body larger than the lenses in the south being almost a mile long and about 0.25 mile wide.

The colour of this glass is a drab light grey to dark green, olive-green, brown, reddish-brown, or creamy-green. The glass contains a few subhedral phenocrysts of orthoclase with considerably less plagioclase (An 33).

The glass shows perlitic cracks. In a few areas a little devitrification has started. When fresh this glass has a refractive index of $n = 1.501$, and a specific gravity of about 2.42. Where the thunder eggs are well developed they occupy as much as 60 per cent of the surface of the glass (Plate XXVIIa). Their size is generally fairly uniform being 1 or 2 in. in diameter (Plate XXVIIb), but they may vary from 0.1 up to 18 in. in diameter. They are spherical in shape although in a few cases one side may be slightly flattened. The exterior surface generally has a cauliflower-like or botryoidal appearance (Plate XXVIIIa).

The rims of the thunder eggs consist of volcanic glass. A qualitative spectrographic analysis of this material ~~showed~~ gave the following elements in order of prominence: Si, Al, Ca, Na, K and Fe.

The thunder eggs are often broken open exposing the interior. The interiors of the thunder eggs are hollow and are partly or completely filled with secondary minerals, the most common being silica in the form of quartz crystals or agate (Plate XXVIIIb). Other secondary minerals present are calcite and zeolite. Under the spectrograph the zeolite ~~showed that it has~~ gave the composition of thompsonite. In a few unusual cases the interior of the thunder eggs were filled with devitrified volcanic glass which has broken into fragments along perlitic cracks, the fragments themselves also showing perlitic cracks. The thunder eggs represent centres of devitrification for the glass. The rim is formed by incipient crystallisation.

d. Laminated Tuff.

There is a gradational change from the massive ignimbrite into the overlying laminated tuff.

Laminated tuff deposits are thin deposits up to about 60 feet thick, although where they fills hollows or depressions in the former landscape they are undoubtedly thicker. These deposits cover a small area. North of the Umsunduzi River the deposits cover the Empileni Hills in the Mkuzi Game Reserve, an area of about 2 square miles. The laminated tuff covers a small area south of the Umsunduzi River (Plate IV). They were probably connected with the laminated tuff north of the Umsunduzi River before erosion in which case they would have covered a total of at least 20 square miles.

The widespread laminated tuff consists of fine layers of tuffaceous material laid down in horizontal laminae which seldom exceed 1 mm. in thickness and are generally less than 0.5 mm. thick.

In some areas the laminae display incompetent folding or internal slumping (Plate VIII), especially just north of the intermittent Munywana stream. These minute structures include intraformational recumbent folds, overturned folds, monoclinal folds and flexure folds. The forces causing these folds did not act from only one direction as a set of minor folds can sometimes be seen approximately at right angles to the main folds. The strike of the axes of the main folds is variable although the majority seen were approximately north-south. Some larger folds are also prominent. It is here that some laminated tuff was found that displays ripple marks, which may be the result of slumping or gliding under water.

Around the ring intrusion, especially to the south-west and west of the syenite and granite intrusions (Plate IV), the laminated tuff has been indurated and has become extremely hard, ringing under the hammer, but it shows no signs of recrystallization or alteration other than silicification. In a fairly large area in the south-west and west and in one isolated patch just to the north of these plutons, the laminated tuff has been brecciated in situ, probably by the intrusion of the plutons. The size of the fragments seldom reach 2 inches in diameter and are generally well under 1 inch. This brecciated material was also reheated and hardened by the intrusions (Plate IX).

The laminated tuff contains a few crystals, but it is more usually devoid of them. When crystals are present they are usually fairly small in size and are broken or cracked, they seldom display a good euhedral shape and usually give the impression of being sub-rounded. Of these crystals quartz is the most common, followed by far lesser amounts of orthoclase and plagioclase (oligoclase to andesine). The matrix consists of a very fine-grained volcanic dust. In all cases this has undergone severe silicification. At the axes of most folds and occasionally in the horizontal layers there are abundant growths of secondary quartz crystals.

Fragmental inclusions are rare but where present are small in size, up to 6 mm. in diameter. They are crystalline or cryptocrystalline and usually extremely rich in iron ore, in contrast with the laminated tuff, in which they lie and which contains very little ~~iron ore~~ magnetite and virtually no mafic minerals. These fragmental inclusions generally show a down-bending and disturbance of the layers upon which they rest while the layers above them are less disturbed.

The laminated tuff was probably deposited as subaqueous deposits of volcanic ash and dust as a result of the explosive eruptions that produced the ignimbrites.

e. Trachytic Lava and Associated Pyroclastic Flow Breccia.

Trachytic lava flows and their associated pyroclastic flow breccias of the Middle Bumbeni Phase cover a fairly large area. They cover almost the whole area within the ring intrusion, some of the area south of the ring intrusion, mainly south of the Munywane Stream, and a small area east of the ring intrusion up to where they are covered by rocks of the Cretaceous System (Plate IV).

The trachytes were erupted at a later stage than the laminated ignimbrites and laminated tuff as they are found overlying these rocks. No contact between the trachyte flows and the massive ignimbrite could be found, but the trachyte must have been later than the massive ignimbrite as it overlies the laminated tuff which in its turn overlies the massive ignimbrite.

The colour of the trachyte is light but variable from almost white to light grey or light brown to dull red. It is invariably mottled owing to the felspar phenocrysts set in a fine-grained groundmass. Where the lava has been brecciated to form brecciated trachyte the fragments are occasionally greater than 1 inch in diameter but are most usually less than 0.5 inch in diameter.

Most of the trachyte is massive but in the south of the area it often exhibits highly contorted flow lines, which in some cases enables the direction of flow to be determined. The direction of flow in the south was towards the south as well as towards the west. This is unusual because in most areas throughout the range the direction of flow, where it could be determined, was towards the east. In a few small areas the rock becomes glassy with a perlitic texture, or highly cellular to form a rock that is almost as vesicular as pumice.

In the south various areas in the trachyte exhibit flow lines that give the rock an almost laminated appearance. The strike of these flow lines is generally north although they vary from N 70 E to N 50 W. A fresh surface of this rock shows a preferred orientation of flow lines but the strong lamination is not seen.

As stated earlier these lavas are associated with pyroclastic flow breccias. The pyroclastic rocks are most abundant within or near the ring intrusion as patches or fairly large areas of indeterminable extent intimately associated with the trachyte and the pyroclastic material and the rocks tend to grade indiscriminately from the one into the other. The fragments are accessory having the same composition as the lavas. Occasionally the fragments themselves contain accessory fragments indicating at least two periods of fragmentation.

The effect that the intrusions have on the pyroclastic rocks is clearly shown at the north-eastern "corner" of the ring intrusion. Here the pyroclastic flow breccia is found to both the east and west of the syenite pluton and it grades into an apparent trachyte lava near the pluton. There is a strip on either side of the pluton of recrystallized trachytic pyroclastic flow breccia that has been recrystallized to such an extent that it now appears to be a trachyte. The gradation could be observed from a pyroclastic flow breccia to a true lava.

The trachyte and fragments in the associated pyroclastic flow breccias are porphyritic with a fine-grained groundmass. The phenocrysts consist of subhedral to anhedral, twinned and untwinned orthoclase. Occasionally a few small phenocrysts of quartz and plagioclase (An 25 to An 33) are present.

The groundmass of the trachyte contains innumerable small microlites and laths of potassium felspar which have a strong preferred orientation and "flow" around the phenocrysts. A little interstitial quartz is generally present and although it is seldom more abundant than about 5 per cent it does reach quantities of over 10 per cent towards the upper surface of some lava flows. This shows that although the lavas generally have a trachytic composition they tend to grade upwards into rhyolite. Often present in small quantities in the groundmass is plagioclase, which usually shows good albite twins and is occasionally zoned. There are two varieties of plagioclase, found in different places, albite-rich oligoclase (An 10 to An 13) and andesine (An 25 to An 33) and both may be overgrown to some extent by orthoclase. The plagioclase where present seldom constitutes as much as 10 per cent of the total felspars of the rock, although towards the base of a few of the lava flows it is as abundant as about 45 per cent of the total felspars. This gives the rock a range of composition in the trachyte field which grades upwards into rhyolite. Cryptocrystalline material, probably recrystallized from glass, is present in variable but small amounts. This sometimes shows radial devitrification of the microcrystalline type.

All these trachyte lavas are singularly poor in mafic minerals. Magnetite is always present but is seldom abundant. It is sometimes secondary after possible biotite or pyroxene. In one area, just inside the southern margin ~~end~~ of the ring intrusion, the magnetite is concentrated in streaks and patches which have the effect of swinging a Brunton pocket compass through as much as 180 degrees when the compass is 4 inches or less above the rock. In this case the magnetite is rather more abundant than elsewhere although still not very plentiful. A few small crystals of partly altered indeterminable pyroxene are present in some places. The only other accessory mineral seen was one small crystal of apatite. Calcite is sometimes present as an alteration product but is never abundant.

On the southern margin of the Bumbeni area there is a small volcanic plug which cuts through the trachyte. It forms a small hillock roughly circular in shape with a diameter of about 100 feet and about 60 feet high. It consists of a vesicular whitish devitrified glass incorporating approximately spherical lumps of red glass. These generally have a diameter of 2 inches to 1 foot although a few have diameters up to about 4 feet. The white material, which is only slightly more abundant than the red glass, is devitrified red glass. It has undergone patchy microcrystalline devitrification and silicification.

The ~~glass~~ rock is too glassy to determine its composition, but it has a refractive index of $n = 1.482$, which may indicate rhyolite or obsidian (Wahlstrom, 1955, 286).

3. The Upper Bumbeni Phase.

The final phase of the Upper Lebombo Suite is represented largely by a series of intrusions which became progressively more acid until it closed with the emplacement of very quartz-rich rocks. Also towards the close of the Upper Lebombo episode there was an eruption of pyroclastic rocks which are non-indurated and soft.

a. The Ring Intrusion.

This ring intrusion is a complex which consists essentially of a large intrusion of syenite, with a chill phase outside it represented by microsyenite. The syenite was later intruded by granite. The rocks of the ring intrusion are syenite, microsyenite, granite and aplite (Plate IV). As a group their position in the sequence is fairly clear. They are intruded into the trachyte and pyroclastic flow breccias of the Middle Bumbeni Phase. The most recent extrusion, the soft pyroclastic rocks, contains fragments of the intrusions among which syenite fragments are especially prominent, while igneous quartz veins are intruded into the syenite and granite. This makes the syenites and granites earlier than the igneous quartz veins and soft pyroclastic~~s~~ rocks.

There are a few aplite dykes cutting the granite, thus the aplite was intruded after the granite, as would be expected. The granite is probably younger than the syenite. At the northern margin of the granite pluton, the granite invades the syenite pluton in parts.

The granite forms a fairly large pluton elongated roughly north-south and is situated on the western side of the ring intrusion. To the west and east of the granite is a syenite pluton (Plate IV). To the south-east~~h~~ and the east there is again syenite, the ring intrusion being almost closed by microsyenite dykes. The microsyenite also forms dykes branching away from the ring intrusion to the north and to the south and often cuts obliquely across the country rock. The syenite ranges from light brown to dark brown on the weathered surfaces, and is light greyish, dark grey or dark green when fresh.

The syenite is usually porphyritic with a fine-grained to fairly coarse-grained granitic groundmass. At the edges and in the thin syenitic offshoots from the plutons the groundmass becomes very fine-grained and micrognanitic. Less commonly the rock has an even-grained granitic texture.

The phenocrysts consist of subhedral to anhedral twinned and untwinned phenocrysts of orthoclase which show incipient alteration. In a few cases the phenocrysts show regrowth.

The groundmass consists almost exclusively of orthoclase, which has suffered from incipient alteration. Plagioclase is invariably present in small amounts, ranging from An 18 to An 41 in different samples. It is usually present in amounts of much less than 10 per cent of the total felspars; however it was found in one sample up to 25 per cent of the total felspars.

Quartz is usually present but is never more than 10 per cent and usually much less.

Mafic minerals are also scarce, but magnetite in small amounts is present throughout the syenite. A little altered pyroxene is often present and is mostly overgrown by magnetite. In one case a little altered amphibole probably hornblende, was seen. Minute accessory amounts of zircon and apatite also occur. A few specks of biotite were seen occasionally.

Secondary minerals are sometimes common especially in the more altered rocks. These are most usually secondary quartz and in lesser amounts secondary chlorite which imparts a greenish colour to some of the rocks.

The microsyenite varies from light brown to light grey to a darker brownish-grey. In the hand specimen it contains prominent phenocrysts of felspar set in a fine-grained groundmass which gives it a slightly mottled appearance. It is very uniform in texture and mineral composition and varies little throughout the whole complex.

It is porphyritic with a fine-grained trachytoid groundmass. The phenocrysts consist of twinned and untwinned subhedral and anhedral orthoclase crystals, showing incipient alteration and sometimes slight exsolution Smaller in size, but larger than the crystals in the groundmass, is plagioclase (An 24). These are usually present but are never more abundant than about 10 per cent of the total felspars. The groundmass consists of a fine mat of orthoclase laths with quartz in quantities up to about 5 per cent. Also present in small amounts are the mafic minerals, which consist of magnetite and a little altered pyroxene. Primary quartz is not at all common, but secondary quartz is always present, sometimes in fairly high quantities.

The composition of the microsyenite is almost identical to the trachyte, except where the latter grades into rhyolite.

The granite is found inside the ring intrusion on the western side. It forms one large pluton and is found nowhere else in the area (Plate IV). It is extremely uniform with a fairly coarse granitic texture and is even grained and non-porphyritic. It consists mainly of pink and white coloured orthoclase felspar, much less colourless quartz and small patches of dark minerals.

The ~~rock~~ granite consists mainly of twinned and untwinned crystals of orthoclase. Plagioclase (An 26 to An 35) is present in varying amounts from nil to as much as 15 per cent of the total felspar.

There are two minerals which distinguish the granite from the syenite in the Bumbeni area. The one is quartz which is always present in amounts over 10 per cent in the granite, whereas it is always less than 10 per cent in the syenite. The other mineral which distinguishes the granite from the syenite in the Bumbeni area is biotite which has a light-brown to green or almost black pleochroism. Biotite is present throughout the granite, usually in fairly small amounts, of about 5 to 10 per cent; and in one small area on its western edge the granite contains about 20 per cent of biotite. In the syenite biotite is absent or present in amounts of less than 5 per cent.

The only accessory mineral, apart from the mica, which is present throughout the granite is magnetite. Other accessory minerals which are sometimes present in small amounts in decreasing abundance are: hornblende, pyroxene (possibly aegirine-augite, $C \wedge X = 30^{\circ}$), zircon, apatite and sphene. The secondary minerals are calcite and quartz which are not always present.

The aplite that is intruded as a few thin dykes a few inches wide into the granite has a fine-grained granitic texture. Its composition is very similar to that of the granite. Biotite is present in small quantities, although it is highly altered and overgrown by the magnetite. Quartz is rather more abundant in the aplite than it is in the granite constituting about 30~~%~~ per cent of the rock.

The volumetric composition of typical syenite and typical granite ~~are~~ is given in appendix 1. This indicates the major differences and the similarities between these two rocks. The chemical compositions as well as the Niggli values are given in appendix 1, analyses 19 and 23.

b. Rhyolite Flows and Microgranite Dykes.

In the Upper Lebombo Suite rhyolite occurs only in one place within the ring intrusion as a lava flow associated with microgranite (Plate IV).

The rhyolite was formed later than the syenite as one of the microgranite dykes intrudes a microsyenite dyke. The rhyolite's relationship to the granite and younger rocks could not be determined. The rhyolite may well represent a satellitic body of the large granite pluton, although its mineral assemblage differs slightly from that of the granite.

Rhyolitic lava flows and their intimately associated microgranite dykes are found in small amounts west of the Bumbeni area where microgranite is intruded into the Upper Lava Zone of the Lower Lebombo Suite, and in much larger amounts south of the Bumbeni area also intruded into the Upper Lava Zone. The rhyolite and microgranite are found south of the Umsunduzi River. The intrusions take the form of long north-south trending dykes up to more than 300 feet wide, of which the larger ones form prominent hillocks that can often be followed for several miles.

The dykes swell or pinch out. The lava flows usually take the form of small irregularly shaped bodies that were apparently extruded from a vent situated on these dykes although no remnants of such a vent could be found. The lava was viscous and never flowed any great distance and may thus give the impression of a plug.

The rhyolite and microgranite are both light coloured, displaying various shades of light grey, brown and reddish brown. The microgranite is massive and fine-grained, with rather prominent felspar phenocrysts.

The rhyolite ~~lava~~ flows, on the other hand, invariably display distinctive flow lines and sometimes have an indistinct ropy structure. The rhyolite is fine-grained with a cryptocrystalline to glassy groundmass and is often porphyritic although the phenocrysts are less prominent and smaller than they are in the microgranite. The microgranite is porphyritic with a granitic or micrograntic groundmass. The rhyolite shows flowage which is lacking in the microgranite.

The phenocrysts in the rhyolite and microgranite consist of untwinned and twinned orthoclase and quartz. Smaller in size is quartz and occasionally plagioclase (An 28).

The groundmass of the rhyolite and microgranite is fine-grained and consists mainly of orthoclase and quartz with a small amount of plagioclase (oligoclase). Plagioclase although usually present is never abundant. Where the groundmass of the rhyolite is glassy it shows spherulitic devitrification.

There are several accessory minerals. Of these magnetite is always present in varying small amounts. In small amounts but not always present is biotite. It is usually slightly coarser than the fine-grained groundmass. A little indeterminable pyroxene is present with a parallel or almost parallel extinction indicating an orthopyroxene. A rare constituent is schorlite with its distinctive pleochroism from slate blue to buff, olive green or light green. Also seen were zircon, apatite and one small euhedral crystal of topaz.

Some alteration and silicification has taken place in these rocks, but there are some parts which appear to have escaped silicification and where alteration is not far advanced. Two samples from such parts have been analysed and the results are given in appendix 1, which also shows the Niggli Values and C.I.P.W. norm. Sample 22 is from one of the more northerly microgranite dykes just to the west of the Bumbeni area, and sample 16 is rhyolite from near Bobbejaankop, south of the Bumbeni area. These two samples, taken a number of miles apart, indicate the high degree of uniformity found in these rocks.

The volumetric composition of rhyolite from within the ring intrusion is given in appendix 1 with the chemical composition (No. 17) calculated from its mineral weight composition.

c. Rocks in the Lebombo Flats.

Just west of the Lebombo Mountain Range in the Lebombo Flats there is an area of rocks of the Upper Lebombo Suite, the largest outcrop covering an area of about 12 square miles (Plate IV). The strike of the outcrop follows that of the mountain range, and is about N 20 W here.

The rocks in this area are placed under the Upper Lebombo Suite because they are rhyolites similar in composition to the rocks of the Upper Lebombo Suite elsewhere, although it could not be determined what position these rocks occupy in the eruptive sequence. They unconformably overlie the Drakensberg basalt and so are definitely later than the Drakensberg Stage.

Most of this area is occupied by an agglomerate (Plate XXXa). The more numerous and larger fragments in the agglomerate occur in the largest outcrop between the farm-house Ingagalu and the Umsunduzi River. (Plate IV). These become smaller and less numerous south and east of this place. The fragments are usually sub-angular but are not water worn. The fragments and matrix of the agglomerate have the same composition as the rhyolite.

The rhyolite is porphyritic with a microcrystalline to cryptocrystalline groundmass. The phenocrysts generally consist of orthoclase and a small amount of quartz.

Quartz and orthoclase are common in the groundmass and a little plagioclase (oligoclase-andesine) is always present. Magnetite is a common accessory. Biotite is present throughout in accessory amounts and is sometimes partly overgrown by magnetite. Towards the south of this area euhedral hornblende, which is pleochroic from light to dark green, is present in small amounts as phenocrysts.

The volumetric composition of a typical sample of rhyolite from the Lebombo Flats is given in appendix 1 with the chemical composition calculated from this, analysis 15.

Where the Umsunduzi River enters the western area there is a small deposit of conglomerate. The constituents are generally an inch or two in diameter but many range from a fraction of an inch up to about one foot in diameter (Plate XXXb).

The constituents of the conglomerate are rhyolite and rhyodacite in fairly equal amounts. The rhyolite is similar to that found in this area. The rhyodacite is very fine grained and consists of orthoclase felspar set in a mat of plagioclase (An 30 to An 38) and orthoclase and interstitial quartz and magnetite. The rhyodacite contains numerous small gas vugs, which together with the crystals show strong preferred orientation. It was noted that the rhyodacite pebbles were generally smaller in size than the rhyolite pebbles. The rhyodacite most probably belongs to the Upper Lava Zone of the Lower Lebombo Suite. There are also a few small basalt pebbles. This conglomerate is completely unsorted.

d. Soft Pyroclastic Rocks.

The soft pyroclastic rocks cover a large area as pyroclastic flow breccias both north and south of the ring intrusion (Plate IV). The exposures of soft pyroclastic rocks are probably the remnants of what may have once been a far larger deposit. The rocks are soft and not at all weather resistant with the result that they form poor outcrops and are usually found preserved in hollows.

Their exact stratigraphic position cannot be accurately determined. They overlie the trachyte and its associated pyroclastic flow breccia which is a clear indication that they are post-trachyte and thus later than the Middle Bumbeni Phase. They were also erupted after the intrusions of syenite and granite as many accessory fragments of these rocks as well as older rocks are found in them. They do not include any fragments of rocks younger than the granite and so they are very tentatively placed after the ring intrusive phase of the Upper Bumbeni Phase but before the final emplacement of the quartz veins. No feeder channels for the soft pyroclastic rocks could be found.

The soft pyroclastic rocks are non-indurated and are consequently weathered with a clayey appearance and feel, especially when wet. Their colour varies greatly from white or cream to dull pink, light brownish-red, red, and terracotta. The fragments have the same colours and may also be dark grey or black. The very numerous fragments which occupy well over 50 per cent of the rock, range in size up to about one inch in diameter.

The fragments are all angular or sub-angular and some fragments exhibit a rim around them. The most common fragments are of laminated ignimbrite, massive ignimbrite, laminated tuff and trachyte. Also present but not as common are fragments of the syenite and granite. A few pumice fragments were seen associated with the massive ignimbrite. There are also a few essential fragments of glassy material which contain phenocrysts of orthoclase.

The intratelluric crystals in the soft pyroclastic rocks consist mainly of subhedral twinned and untwinned orthoclase. Present in very small amounts as intratelluric crystals are plagioclase (An 18), quartz, and biotite.

The groundmass consists of a fine cryptocrystalline tuffaceous material with small amounts of glass and numerous specks of magnetite and sometimes iron-oxide staining. Also present in varying quantities are glass shards. These glass shards are not flattened but have various shapes such as lunulate, rod-shaped and y-shaped. They are still glassy and have not been devitrified.

Although this rock contains glass shards it cannot, according to Marshall's definition, be called an ignimbrite as it contains such a high proportion of accessory fragments. According to Fisher's (1960) classification, which is being followed (see Section II B on Nomenclature), it is a pyroclastic flow breccia.

e. Igneous Quartz Veins.

In the northern part of the ring intrusion, and just outside it south of the Umsunduzi River, there are distinctive igneous quartz veins (Plate IV). They tend to follow the general northerly to north-westerly strike, but also lie oblique to the general strike. They are vertical or very nearly so.

These quartz veins represent a late phase of the volcanic cycle and cut through all the rocks in the Bumbeni area.

The quartz veins range from thin stringers a few inches wide up to a dyke-like body about 50 feet wide that can be followed for several hundred yards. They can be easily seen in the field ~~due~~ owing to their light colour.

The igneous quartz veins contain large patches of quartz in an allotriomorphic granular groundmass due to cataclastic effects. They also commonly display brecciation which has taken place in situ, probably due to later movement or cooling, in which cracks were filled by secondary quartz.

By far the most abundant mineral is quartz which occupies between 80 and 100 per cent of the rock. The next most abundant mineral is orthoclase which seldom occupies more than 10 per cent of the rock. Plagioclase (oligoclase-andesine) is present in very small amounts, and may be due to contamination from the country rock. Seldom present but found as accessory minerals in some of the veins are magnetite and indeterminable pyroxene. In one quartz vein a very small amount of possible malachite staining could be seen.

The volumetric composition of the igneous quartz veins are shown in appendix 1. The chemical composition (24) calculated from the volumetric composition is given in appendix 1.

The quartz veins may be regarded as due to the expulsion of residual fluid, not only into the marginal parts of the igneous bodies, but also into the surrounding country rocks, as is commonly the case with pegmatitic bodies. The pegmatites of granitic intrusions are commonly composed mainly of quartz and alkali felspar. Felspar may almost disappear, leaving a residuum of silica which may crystallize as an igneous quartz vein (Tyrrell, 1929, 162).

F. Dykes of the Post-Lebombo Suite.

There are a few small isolated dolerite dykes in the Bumbeni area intruded into the Upper Lebombo Suite (Plate IV). It is highly likely that a few of the dolerite dykes found in the Lower Lebombo Suite and placed in the Middle Lebombo Suite in fact belong to this later period of intrusion. The basic rocks of the different suites are so similar that it is not possible to distinguish between them. In the Bumbeni area the few isolated dykes can defintely be placed as post-Upper Lebombo as they are intruded through the acid rocks of the Upper Lebombo Suite. It is thought that these dolerite dykes may have been the feeders to flows of a final basic suite overlying the rocks of the Upper Lebombo Suite.

These dolerite dykes are only a few feet wide and can seldom be traced as far as 100 yards along their strike. Their strike corresponds to that of the mountain range but it is impossible to determine what their dips are. They are usually so much weathered that no coherent sample can be taken.

The dolerite has a fine-grained intergranular texture. By far the most common mineral is plagioclase (An 52) which occupies about half the volume of the rock. Clinopyroxene is also very common occupying about 35 per cent of the rock, and is augite with a little pigeonite.. Light to dark-green pleochroic biotite and magnetite are also present in almost equal proportions. Chlorite is a common alteration product.

VI. MINERALOGY AND CHEMISTRY.

Of the basalt and andesite in the various subdivisions of the Stormberg Series, the basalts of the Drakensberg Stage are the best developed, but they lie mostly outside the area investigated. A petrographic study of the basic rocks that are present reveals a great deal of mineralogical uniformity in those belonging to the Drakensberg Stage, the Middle Lebombo Suite and the post-Lebombo Suite.

In the Lebombo Stage the rocks that are really well developed, south of the Great Usutu River, are the dacites of the Lower Lebombo Suite and Upper Lebombo Suite.

In the andesite and lower dacite of the Lower Lebombo and Upper Lebombo Suites mafic minerals are present in fairly large amounts, but in the upper dacites very few mafic minerals are present, except for magnetite. In the Lower Lebombo Suite magnetite is extremely common and is often present in sufficient quantities to affect a compass needle. In the Upper Lebombo Suite magnetite is also present but not in such large quantities and in a few of the more acid portions of the rocks it is almost absent. The two suites have virtually the same mafic minerals. In some rocks of the Upper Lebombo Suite and especially in the granitic pluton a fairly high proportion of biotite and amphiboles are present which are very rare in the Lower Lebombo Suite.

The upper half of Plate X shows quartz, orthoclase and albite plotted on a triangular volume percentage diagram. These points are plotted from the results of point counts and not chemical analyses.

The upper half of Plate X shows the range in composition of the Lower Lebombo Suite (andesite, dacite and rhyolite) compared with the Upper Lebombo Suite (trachyte, rhyolite and the intrusive equivalents) with respect to the volume percentage of quartz, potassium felspar and albite in the rock. The composition of the Lower Lebombo Suite ranges from andesite through dacite to rhyolite. The plate incorporates a few samples from rocks of the Middle Lebombo Suite and post-Upper Lebombo Suite. These are situated in the basalt field with a few in the andesite field and have been included for the sake of completeness, and also to show the close relationship of the basic rocks to the rocks of the Lower Lebombo Suite. The range in composition of the Upper Lebombo Suite is through trachyte and rhyolite to vein quartz. In this plate the range in composition of the Lower Lebombo Suite only just overlaps the range in the composition of the Upper Lebombo Suite.

A concentration of points which is likely to be partly due to sampling, is present in the Lower Lebombo Suite in the dacite field and in the Upper Lebombo

Suite in the trachyte field.

In the lower half of Plate X the volume percentage composition of the felspars in the Lower Lebombo and Upper Lebombo Suites are compared. This diagram represents the type and amount of felspar present in the andesite, dacite, trachyte, rhyolite and intrusive equivalents.

In the Lower Lebombo Suite the majority of felspars are concentrated below 5 per cent potassium felspar and between An 25 and An 55. However the felspars may contain as much as 60 per cent potassium felspar and range from soda-rich oligoclase to labradorite. On the other hand the composition of the majority of felspars in the Upper Lebombo Suite is concentrated at over 95 per cent potassium felspar. This concentration is so great that the position of a large number of samples could not be shown on Plate ~~VIII~~ X. There are very few rocks in the Upper Lebombo Suite that contain less than 7.0 per cent potassium felspar of the total felspars. Where the rocks of the Upper Lebombo Suite contain plagioclase they have much the same range in composition as the plagioclase of the Lower Lebombo Suite.

Appendix 1 gives the chemical analyses of various rock types in the Lebombo Mountains. The chemical compsition calculated from point counts of various rocks is given where no chemical analysis is available. The volumetric composition of these rocks ~~are~~ is given but these are not available for the glassy or cryptocrystalline rocks. The Niggli values and C.I.P.W. norms are given with the analyses.

The analyses were plotted on the variation diagram advocated by Larsen (1938, 505-515); that is the variable major oxides are positioned by one-third SiO_2 and K_2O minus the sum of MgO, CaO and total iron calculated as FeO. This diagram gives a uniform curve for differentiation in a volcanic province in which silica increases regularly such as from basalt to rhyolite, (Plate XXXI).

In Plate XXXI the chemical analyses are shown as circles while the chemical composition calculated from point counts ~~are~~ is shown as crosses. The calculated compositions give less reliable results, which is to be expected as in the calculations the assumption was made that the minerals have an ideal end-member composition whereas in nature they seldom have an ideal composition,

In the volcanic province of the Lebombo Mountain Range there are some very definite trends. SiO_2 shows a sharp increase from the femic end to the salic end of Plate XXXI while K_2O shows a gentle increase and Na_2O shows only a very slight increase. FeO and CaO both show definite decreases. MgO which is especially low shows an abrupt decrease which levels off towards the salic end. Al_2O_3 is slightly erratic but in general shows neither an increase nor decrease. A slight scattering of the points on the curves may be due to contamination from the assimilation of either Karroo sediments or Archean granite.

VII. PETROGENESIS.

A. Hypotheses of Origin of the Lebombo Rock Suites.

Before presenting the hypotheses for the petrogenesis of the various rock types found in the Lebombo Mountain Range a summary of some of the more important facts that may have a bearing on the petrogenesis should be considered:

(a) There is a high gravity anomaly along the side of the Lebombo Mountain Range (Plate XIV) indicating a large wedge of basic material at a relatively shallow depth in this area.

(b) The north-south alignment of the structures probably indicates a region of strong east-west tension.

(c) The volcanic rocks of the Stormberg Series are underlain by the Karroo ~~System~~ sediments (Plate X).

(d) There is an alternation of basic and acid lava which may be broadly outlined as follows:-

Post-Upper Lebombo Suite	basic
Upper Lebombo Suite	acid
Middle Lebombo Suite	basic
Lower Lebombo Suite	acid
Drakensberg Stage	basic

(e) There is sometimes an intercalation, with sharp contacts, of acid and basic lava when passing from one Suite to another, as for example between the Lower Lebombo Suite and the Middle Lebombo Suite.

(f) The pyroxenes present in the more basic lava flows in the Lebombo Mountains give~~s~~ an indication of the temperature of extrusion and show that the rocks have not been metamorphosed. The pyroxene is mainly augite with a little pigeonite. As the pigeonite shows no inversion to hypersthene it probably underwent rapid cooling in the fine-grained lava flows before the temperature reached the clinopyroxene-orthopyroxene inversion temperature, (Hess, 1941, p. 583). Pigeonite contains a maximum of 70 per cent Fe SiO_3, and so the temperature of the lower portion of the rocks of the Lower Lebombo Suite must have been above 1010°C when they were extruded, (Plate XXXII). Furthermore, the pyroxene, which is present in the lower rocks of the Lower Lebombo Suite, shows no alteration to amphibole, thus indicating lack of metamorphism and absence of contamination, (Barth, 1952, 328). In the Upper Lebombo Suite, although mafic minerals are not common, the pyroxene in a few cases does however, show alteration to hornblende.

(g) All the rocks of the Drakensberg Stage and the Lebombo Stage represent a volcanic period at the close of the Karroo period and as such they are related. It is very unlikely that the various rock suites could have been produced by unrelated processes.

1. Magmatic Differentiation.

Simple differentiation of a basaltic magma probably produced at least part of the dacite. It has been stated (Hunter and Urie, 1958, 6), that the proportion of basalt to acid lavas is approximately 1:1. Recent work on gravity anomalies by the Geological Survey of South Africa (Smit, Hales and Gough, 1962, 371-374) indicates that this is incorrect. Working on the gravity anomalies and by taking the width of the outcrops and densities of the rocks into account these authors have been able to obtain fairly accurate estimates of the thicknesses of these rocks. The basalt they estimate to be 8 km (26,246 feet) thick, and the dacite 5 km (16,204 feet). The proportion of basalt to the acid rocks is therefore 8:5.

There is thus sufficient basalt to have produced a considerable portion of the acid rocks, which are mainly dacite, by differentiation. The production of syenite and granite at the close of the volcanic phase could be expected from differentiation.

2. Assimilation.

Assimilation of siliceous rock by the tholeiitic magma could have led to the formation of part of the acid volcanic rocks. The assimilated material could be either Precambrian granite or sediments of the Karroo System. If assimilation has taken place it must have been fairly complete for few relicts of the assimilated material have been found and little evidence of contamination, such as the development of amphiboles, has been encountered.

The main objection to the assimilation hypothesis is that if assimilation of granite or sandstone alone is envisaged a greater uniformity of the rock types might be expected. Frankel (1960, 568), after doing comparative heavy-accessory mineral studies in nearby Basement granite and in the volcanic rocks themselves, found that the results did not support the assimilation theory. If Frankel's findings are accepted it seems unlikely that Precambrian granite was assimilated. Any assimilation that did take place would thus most probably have been assimilation of Karroo Sediments.

3. Alteration of Tuff.

The alteration of tuffs is a process suggested by Hunter and Urie (1958) as one of the possible modes of origin of the dacites. It is envisaged that the acid rocks are formed by the welding, refusion, and devitrification of pre-existing tuffs. This hypothesis was presented to overcome the problem of the viscosity of rhyolite. However it should be noted that the acid lavas are not all rhyolite, but are mainly dacites generally with a fairly low silica content which considerably reduces the viscosity.

The main objections to this theory is that it fails to explain; (a) the origin of such large quantities of dacites; (b) the presence of contorted flow lines in the lavas; (c) the large amounts of pyroclastic flow breccia and (d) tuff beds overlain by lava flows and having a sharp contact with the lava (Plate XXXIII). Furthermore the tuffaceous beds, which in some cases have undergone secondary welding, still retain their tuffaceous appearance and can be easily distinguished from the acid lavas under the microscope and usually also in the field.

4. Alteration of Basalt.

V. and E. Gorsky have done detailed thin-section work on the dacites of the Lebombos, but they have not yet published their findings. A preview of their main hypothesis on the origin of the acid rocks is given by Frankel (1960, 568). This hypothesis is that the dacite may well be a metasomatised portion of the basalt sequence. According to Frankel the process that the Gorskys envisage is that the dacites instead of being lavas and pyroclastic rocks, have all been derived from basalt through intermediate stages of leaching, chloritization, uralitization, saussuritization, felspathization and silicification.

Evidence of the processes that the Gorskys claim to have altered the basalt is not often present. Chloritization has taken place in a few areas as can be seen from the secondary chlorite present, but it is not at all wide spread. Very little evidence of uralitization, in which pyroxene is altered to hornblende, could be found. Saussuritization, in which plagioclase is replaced by aggregates of chlorite, albite, calcite, sericite, and zeolites could not be found. These minerals can also be observed filling gas vugs, especially south-east of Ingwavuma. Silicification is the only process which is widespread, but secondary quartz is subordinate to primary quartz. The products of these processes are not present in all the acid lavas and most certainly could not have produced the vast thickness of dacite from the basalts.

The abundant relict basaltic textures and ghosts of original felspar with an average composition of An 58 that the Gorskys claim to be present could not be found. It was found that plagioclase laths from An 20 to almost pure albite, (Frankel, 1960, 569) stated to be frequently present are very rare indeed. Furthermore, the Gorskys state that there is no typical composition of the rhyolites, but quite what they intend to indicate by this is not clear. A range in composition is to be expected from a chamber extruding acidic material over a lengthy period. The range in composition is shown on Plate X.

The basalts are fairly uniform in character and no controlling factors or preferred areas for alteration were observed. Contacts between the acid lavas and the basalt are not at all common, but where they are present they are found to be sharp. Also, the dolerite dykes cutting the acid lavas have sharp contacts. This means that, either the metasomatic action did not affect the dolerite, or else the metasomatic action took place rapidly before the intrusion of the dolerite. Sharp contacts between the acid and basic rocks would be rather a surprising feature if the acid rocks had been formed by metasomatic alteration of the basalts. Furthermore, volcanic breccias and tuffs are very common among the acid lavas while in the basalts they are very rare. The tuffaceous beds are unaffected by metasomatic processes that might have operated.

B. Proposed Sequence of Events.

After the formation of the Cape Folded Belt, basic magma was forced to a higher level in the sial (Du Toit, 1930, 212). East-west tension formed a zone of weakness where the Lebombo Mountain Range is now situated, and into this zone a great wedge of tholeiitic magma was driven.

The initial outpouring of basalt of the Drakensberg Stage took place through fissures under conditions of tension. The basalt was unrestricted and could flow forth freely. Towards the close of the Drakensberg Stage the tension began to wane causing a certain amount of restriction on the easy extrusion of the lava. This gave an opportunity for differentiation to take place and the upper portions of the last few flows of lava of the Drakensberg Stage acquired an andesitic composition.

With the waning of tension the volcanic action decreased and basic wedges were intruded into the basalt to consolidate as gabbro in the Rooi Rant. As a result of this the locus of fracturing moved eastwards.

The reduction of tension that caused a restriction on the outpouring of the basaltic lava also caused the hot magma to come into and remain in contact with the overlying Karroo sediments. As a result of this the tholeiitic magma while undergoing differentiation under conditions of high temperature and pressure also assimilated Karroo sediments causing the eruptive material of the Lower Lebombo Suite to become more acid. Under conditions of only slight tension these eruptions were sometimes explosive giving deposits of pyroclastic rocks.

Under conditions of only slight tension, and pressure of volatiles built up by differentiation and assimilation in the magma chamber, fracturing took place east of the basalts. This fracturing tapped the acid portion of the magma chamber. Although there were various explosive eruptions, as can be seen from the tuffaceous layers, essentially quiet eruptions took place in this initial period and produced the massive and jointed dacite of the Lower Lava Zone of the Lower Lebombo Suite. Most of the lava flowed towards the east following the tilt of the land.

The continual building up of pressure, owing to the concentration of volatiles as a result of differentiation, caused a series of explosive eruptions of tuffaceous and other pyroclastic materials interspersed with quiet flows of dacite. This formed the Pyroclastic Zone.

A return to basic extrusions occurred when tension was renewed allowing an unrestricted flow of undifferentiated lava from the chamber of tholeiitic magma. In the north,especially north of the Great Usutu River, and on the eastern side of the range, this produced the vast deposits of upper basalt and andesite of the Middle Lebombo Suite.

When tension was again released differentiation of the tholeiitic magma and assimilation of the overlying rocks again took place. If the composition of the assimilated rock was different from that previously assimilated the composition of the resultant lava would probably also be different. That is probably the reason why the acid material of the Upper Lebombo Suite differs from that of the Lower Lebombo Suite.

The initial outpourings of trachyte of the Lower Bumbeni Phase were followed by a dormant period when the Bumbeni conglomerate was deposited. After a build-up of volatiles explosive eruptions took place producing the nuée ardente flows which gave rise to the large ignimbrite deposits. Laminated tuff was probably also produced by these eruptions. With the release in pressure the eruptions became less violent producing pyroclastic flow breccias intimately associated with trachyte flows. This was followed by the intrusions of microsyenite, syenite, granite, aplite, and microgranite with small extrusions of rhyolite.

It was probably during this extremely active period that the acid magma was erupted on the western side of the mountain range, where the Umsunduzi River is now situated. This gave rise to an agglomerate with a rhyolitic composition and a more quiet eruption of rhyolite.

A quiet period may have followed. Although volcanic activity had been greatly reduced it had not completely ceased. Volatiles once more built up to a small extent and caused restricted explosive eruptions with the production of the soft pyroclastic deposits. With the final waning of activity the extremely acid igneous quartz veins were emplaced.

With a final renewal of tension a little basaltic lava again erupted in Mozambique. South of the Great Usutu River the effects of this tension were hardly noticed, and could only be observed by the author in the Bumbeni area where it is represented by a few isolated dolerite dykes. This concluded the volcanic history of the area.

C. Origin of Ignimbrites.

1. The Nuée Ardente Hypothesis.

A nuée ardente is an eruptive "avalanche" which engulfs, rolls over, draws in and momentarily entraps air. In this way the front part of the mass is constantly "fluidized" by fresh supplies of air that on heating expand progressively and explosively as they rise through the avalanche. Within the rolling mass blocks are carried along as they are in a mud flow, buoyed up in a dense turbulent mixture of rock particles and expanding air. The rear part, less effectively "fluidized", deposits a layer of hot clastic rocks along the track of the nuée ardente. Also the rate of a nuée ardente is so rapid that not a great deal of heat will be lost from the time of eruption until deposition. Thus it can be seen that a nuée ardente may quite conceivable contain a fairly high proportion of volatiles when it is laid down which would substantially reduce the welding temperature. When the clastic material is essential in origin the deposit would form an ignimbrite.

In the field the ignimbrite deposits are sometimes overlain by finely laminated tuff deposits which have subsequently become compacted and cemented. This probably indicates that after the eruption of the ignimbrites the fine volcanic ash that had been carried aloft by the expanding air in the nuée ardente, settled down to form a laminated tuff deposit over the ignimbrite. Much of this may have been lost by erosion but where the tuff is still present it has become compact and hard as a result of secondary cementing. The ignimbrite deposits in the Lebombo Mountains are envisaged as having been produced from the lower portion of the nuée ardente, that is an "avalanche", rather than the upper portions, which were the expanding clouds that produced the laminated tuff deposits.

The main objection (Steiner 1960) against the nuée ardente hypothesis is that none of the observed nuées ardentes have produced an ignimbrite, although they do produce sillars which are the non-welded variety of ignimbrites.

Another serious objection to the nuée ardente hypothesis is based on the probable temperature of formation. It has been shown from experiments by Shepherd (1938, 343) and Keller and Pickett (1954, 90) that the welding temperature of glass fragments that have been devolatilized would be about 1200^{o}C. This is considerably higher than the temperature usually associated with acid lava at near surface conditions. Also the temperature of the nuée ardente erupted from Mt. Pelé on 8th May 1902 was about 800^{o}C. A nuée ardente which is large enough to produce an ignimbrite would probably have a temperature a little above 800^{o}C although probably well below 1200^{o}C. The presence of water in solution in the glass would be expected to substantially reduce the welding temperature. It has been assumed that a nuée ardente would be practically devolatilised because the volatiles must escape to keep the flow buoyant. However McTaggart (1960) has shown by experiments that the gas emission of nuées ardentes is only a very minor part of the process, thus the mass would not become devolatilised.

2. Current Hypotheses and Their Drawbacks.

Most of the hypotheses on the origin of ignimbrites depend on a lava flow to some extent. Iddings (1899) with his hypothesis of welded pumice considers that flow had taken place; Grange, (1934) considers that ignimbrites were formed from a lava flow in the conventional sense; Vlodavetz (1963) imagines a lava flow to be extruded after mechanical unmixing from a subterranean explosion; and Steiner (1960) postulates a quiet fissure eruption and lava flow in which liquid immiscibility takes place. There are several features that are not in accordance with any type of lava flow:-

(a) Ignimbrites generally form extensive thin sheets, whereas it is a well known fact that acid lavas such as rhyolite are far too viscous to flow over several miles and spread out widely. Against this it may be argued that the lavas were extruded from fissures and did not have to flow great distances, or that they had a high water content which would have reduced their viscosity, or that immiscibility reduced the viscosity, as in the hypotheses of Vlodavetz and Steiner.

(b) The shape of an ignimbrite body is unlike that of an acid lava flow. Walker (1962, 280) found that the length to thickness ratio ranges from about 3:1 in some rhyolite domes to about 100:1 in rhyolite flows of the greatest horizontal extention. In contrast with this the ignimbrites which he studied in Iceland showed a corresponding ratio of about 2,000 to 3,000 : 1. Furthermore, acid lavas usually terminate abruptly with a steep flow-front, while ignimbrites thin gradually.

(c) The macroscopic flow-folding or ropy structure characteristic of acid lavas is not seen in ignimbrite deposits.

(d) The fragmental nature of ignimbrites, whether macroscopic or microscopic, distinguishes them from lava flows. This characteristic may not always be obvious, especially in fine-grained and devitrified ignimbrites.

(e) Most of the above features could perhaps be overcome by Steiner's hypothesis of liquid immiscibility and lava flow. However there are certain textural features of the shards, brought to light by Rast (1962) which conflict with Steiner's hypothesis.

The shape of individual glass shards varies in cross-section. They may be lunulate, rod-shaped, y-shaped or cross-shaped. These may occur individually or together although in many ignimbrites y-shaped shards are more abundant. There are cases where one shape occurs almost exclusively (e.g. Ross and Smith, 1961, fig. 17). This segregation of the shape of shards cannot be explained by Steiner's mechanism where the shards would have to originate in the lava flow.

Rast (1962, 101) found from thin sections orientated at right angles to each other that the rod-shaped shards are in fact plates, and that more of the shards show a preferred orientation such as would be expected if the shards were produced by flow rather than welding.

(f) The ignimbrites in the Lebombo Mountains contain a high proportion of intratelluric crystals or phenocrysts. These intratelluric crystals often show embayments. The explosive character of the eruption can be deduced from the fact that many of the intratelluric crystals are cracked and broken.

(g) The ignimbrites sometimes appear to be laminated, a feature never seen in lavas.

VIII. SUMMARY.

The Lebombo Mountain Range south of the Great Usutu River occupies the site of a monoclinal flexure, the axis of which cuts obliquely across the range at a small angle and passes from the mountains into the Lebombo Flats between the Great Usutu River and the Ngwavuma River.

The rocks of the mountain range dip under the Cretaceous sediments to the east. To the west they form a steep escarpment of probable erosional origin in which the pyroclastic breccia dykes form cliffs whereas the pyroclastic flow breccias form steep slopes. The long north-trending pyroclastic breccia dykes represent the feeders of the pyroclastic flow breccias, and also partly of the dacite. The northerly trend of all the structures in the mountain range is probably the result of east-west tension during monoclinal flexuring in the Jurassic.

The name Lebombo Stage is proposed for the thick assemblage of volcanic and sedimentary rocks overlying the basalt of the Drakensberg Stage of the Karroo System. The Stormberg Series in this area is thus divided into the Molteno, Red Beds, and Cave Sandstone Stages and the essentially volcanic successions represented by the Drakensberg and Lebombo Stages.

The Lebombo Stage can be sub-divided into the Lower Lebombo, Middle Lebombo and Upper Lebombo Suites. The Lower Lebombo Suite covers the major part of the mountain range in the area under consideration. It can be sub-divided into (1) a Lower Lava Phase, which consists mainly of massive and jointed lava; (2) a Pyroclastic Phase, which consists mainly of massive, jointed and vesicular lava and also pyroclastic flow breccias; and (3) an Upper Lava Phase which consists of massive, jointed, and vesicular lava.

The composition of the Lower Lebombo Suite ranges from andesite through dacite to rhyolite. The dacite of the Lower Lebombo Suite does not lie directly on the basalt of the Drakensberg Stage, but there is a transition zone, 50 to 100 feet thick, consisting of andesite which grades upwards into dacite. Most of these lavas flowed towards the east.

The Middle Lebombo Suite is poorly developed in the mountain range south of the Great Usutu River. It is represented by two small patches of basalt and andesite and intrusions of dolerite dykes. It is well developed in Mozambique.

The Upper Lebombo Suite covers an area of just under 100 square miles of the mountain range in the Bumbeni area both north and south of the Umsumduzi River. The lowermost rocks of the Upper Lebombo Suite are pheno-trachytic lavas overlain by an unsorted conglomerate. Above this there are ignimbrites and associated tuffaceous rocks which pass upwards into pyroclastic flow breccias and trachyte. Intruded into the lower rocks of this succession are plutons of syenite and granite and dykes of microsyenite and aplite. Dykes of microgranite and flows of rhyolite are present but occur mainly outside the Bumbeni area proper in rocks of the Lower Lebombo Suite. Further extrusions consist of soft pyroclastic rocks. The final phase of this Suite was the emplacement of igneous quartz veins.

Dolerite dykes intruded into the Upper Lebombo Suite may represent the feeders of a possible later suite of basic rocks.

Marshall's definition of ignimbrite as a nuée ardente type of deposit of essential magmatic material is accepted and used. For the pyroclastic breccias containing accessory or accidental fragments as well as essential fragments Fisher's nomenclature and classification is adopted.

It is concluded that the volcanic rocks of the Lebombo Stage were formed by differentiation and assimilation of Karroo sediments and Archean granite by basaltic magma, the heat being supplied from a great wedge of magma emplaced to a shallow depth in this area as a result of great east-west tension probably associated with the fragmentation of Gondwanaland.

The dacite of the Lower Lebombo Suite represents a period of reduced tension during which differentiation and assimilation took place to produce these acid rocks. The rocks of the Middle Lebombo Suite were erupted in response to east-west tension which led to unrestricted extrusion of basic magma. Then followed a period of reduced tension, during which differentiation and assimilation again took place and produced the acid rocks of the Upper Lebombo Suite. Further assimilation and possible differentiation led to the development of more quartz-rich rocks towards the top of the Upper Lebombo Suite. The final phase was the emplacement of igneous quartz veins in the older volcanic rocks.

A further renewal of east-west tension produced outpourings of basalt and andesite. These rocks are represented in Mozambique but are virtually absent from the area south of the Great Usutu River, where they are represented by a few dolerite dykes in the Upper Lebombo Suite.

Very little mineralization of economic importance is present. Some copper mineralisation was found at the Pongola and Umsunduzi Rivers. These showings are small in extent and not of any economic interest.

Perlite of possible commercial value is present in the Bumbeni area but has not yet been thoroughly investigated. It may prove to be of a reasonably high grade but transport costs may make exploitation uneconomical.

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Analyses.

Oxides.

SiO_2	49.21	50.49	48.44	50.42	51.43	47.29	65.22	68.06	62.17	64.12	67.74	72.20	68.28	68.01	63.78	74.92	67.75	49.33	61.92	61.2	71.56	74.03	65.00	94.25
Al_2O_3	15.09	15.19	14.54	13.32	13.10	15.26	12.87	12.86	13.21	13.07	12.57	12.19	13.33	12.89	15.92	13.55	14.10	22.46	17.44	13.7	12.60	13.56	15.84	2.92
Fe_2O_3	4.51	4.18	3.56	5.15	4.27	15.10	5.17	5.58	4.64	5.21	5.37	3.19	3.56	4.68	6.15	1.45	3.38	3.79	4.36	9.9	2.96	2.33	3.70	0.83
FeO	7.53	6.39	7.79	8.52	10.61	9.89	1.94	1.01	3.96	2.21	0.63	0.94	2.37	1.01	2.70	0.14	2.60	1.48	2.12	5.6	1.15	0.00	1.20	0.44
MgO	5.24	4.61	8.21	5.89	3.21	2.77	0.82	0.97	1.39	0.72	0.49	0.42	0.70	0.31	0.22	0.39	0.88	1.45	0.20	1.0	0.40	0.35	1.00	0.05
CaO	8.70	9.06	11.56	10.70	7.57	4.68	2.75	2.04	4.07	2.76	2.34	1.53	2.22	1.68	0.90	0.45	0.44	3.95	0.26	2.2	1.43	0.83	1.90	0.16
Na_2O	3.30	2.85	2.50	2.63	2.37	4.80	3.24	3.28	3.40	3.64	3.37	3.25	3.71	3.64	1.70	3.81	0.23	6.53	0.16	3.1	3.38	3.77	0.40	0.25
K_2O	1.31	0.92	0.19	1.22	0.96	0.12	3.88	0.53	3.60	3.57	4.58	4.83	4.01	4.80	8.49	3.78	10.70	4.88	13.48	3.3	4.75	3.42	10.00	1.80
TiO_2	2.35	1.64	0.97	1.18	2.20		0.64	3.66	1.48	0.68	0.48	0.28	0.59	0.79	0.02	tr.		0.41	0.01		0.44	tr.	0.02	
P_2O_5	0.28	0.22	0.14	0.20	1.28		0.15	0.13	0.54	0.22	0.13	0.12	0.16	0.18		0.04			0.02	0.2	0.06	0. 5	0.10	
MnO	0.21	0.13	0.20		0.27		0.16	0.17	0.19	0.14	0.17	0.23	0.15	0.09		tr.					0.10	tr.		
CO_2	0.10	0.83	0.10		0.11		0.40	0.57		0.10	0.10					0.20						0.36	0.20	
H_2O	2.76	3.69	1.46	0.61	2.45		3.60	1.18	1.90	2.96	0.72	1.18	1.38	1.99	0.03	0.84		5.24	0.01		1.24	1.24	0.04	
Total	100.50	100.20	99.66	99.84	99.83	99.91	100.84	100.04	100.55	99.40	99.59	100.36	100.46	100.07	99.91	99.57	100.08	99.52	99.98	100.2	100.07	99.94	99.47	100.70

Volumetric modes (from point counts where obtainable).

Quartz						2.2									13.2		17.6		1.2	20.0			15.2	84.0
Orthoclase						1.0									59.4		76.6		92.9	25.0			71.1	12.6
Plagioclase						69.8									22.0		2.8		1.7	42.0			2.0	2.8
Pyroxene						14.0											0.4		0.6	4.6			2.9	0.2
Amphibole																							1.2	
Magnetite						13.0									4.6		2.6		3.2	8.0			1.4	0.4
Biotite															0.8				0.2				5.6	
Apatite																			0.2	0.4			0.2	
Calcite (secondary?)																							0.4	
Total						100.0									100.0		100.0		100.0	100.0			100.0	100.0

APPENDIX 1 (cont.)

Sample Number.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Niggli Values.																								
al	22	24	19	18	21	21	33	38	29	33	28	38	33	36	38	48	38	40	44	28	39	47	40	40
fm	44	41	48	47	49	56	30	33	34	30	39	21	32	23	30	12	28	19	18	47	20	13	22	24
c	24	26	27	27	23	12	13	11	16	12	10	9	10	9	4	3	2	12	1	8	8	5	9	4
alk	10	9	6	8	7	11	24	18	21	25	23	32	25	32	28	37	32	29	37	17	33	35	29	22
Si	124	135,	108	119	145	111	283	337	232	273	254	386	284	327	259	455	310	150	263	210	373	428	281	2217
mg	0.45	0.45	0.57	0.80	0.39	0.17	0.23	0.29	0.31	0.19	0.08	0.21	0.61	0.10	0.05	0.24	0.22	0.32	0.07	0.11	0.15	0.24	0.26	0.06
k	0.21	0.18	0.05	0.23	0.26	0.01	0.44	0.08	0.41	0.39	0.48	0.49	0.42	0.46	0.77	0.37	0.97	0.33	0.98	0.41	0.49	0.37	0.95	0.83
c/fm	0.55	0.63	0.56	0.57	0.47	0.21	0.43	0.33	0.47	0.40	0.40	0.43	0.31	0.39	0.13	0.25	0.07	0.63	0.06	0.17	0.40	0.38	0.41	0.17
qz	-16	-1	-16	-13	+17	-33	+87	+165	+68	+73	+62	+158	+84	+99	+47	+207	+82	-66	+25	+42	+141	+198	+65	+1989
C.I.P.W. Norm.																								
Quartz	0.48	6.66		1.80	11.64	2.76	26.10	46.72	20.22	24.94	27.72	31.62	26.16	26.16	19.38	39.96	22.08		8.94	24.42	30.66	38.22	20.04	85.50
Orthoclase	7.68	5.56	1.11	7.23	6.12	0.56	22.80	2.78	21.13	20.57	27.24	28.36	23.91	28.36	50.04	22.24	63.38	28.91	79.51	19.46	28.36	20.02	58.94	10.56
Albite	27.67	24.10	20.96	22.01	19.39	40.87	27.25	28.77	28.82	30.92	27.82	27.77	31.44	30.92	14.15	29.34	2.10	17.82	1.57	25.68	28.30	31.96	3.14	2.10
Nephline																		20.16						
Anorthite	22.52	25.85	27.80	20.85	21.96	19.74	8.90		10.01	8.90	4.73	4.45	7.51	1.67	4.45		2.22	17.79	0.56	10.01	5.28	0.83	7.23	0.83
Diopside Wo	7.66	5.45	11.72	13.11	4.06	1.39	0.58		2.78	1.28		1.04	1.04	0.58				0.81			0.46			
Fn	4.80	3.60	7.20	7.70	1.60	0.70	0.50		1.90	1.10		0.90	0.70	0.50				0.70			0.40			
Fs	2.38	1.45	3.83	4.75	2.51	0.53			0.66				0.26											
Hypersthene En	8.40	7.90	8.90	7.00	6.40	6.20	1.60	2.40	1.60	0.70	0.80	0.20	1.00		0.60	1.00	2.20		0.50	2.50	0.60	0.90	2.50	0.10
Fs	4.22	4.75	4.22	4.49	10.16	5.28			0.66				0.26				1.98		0.26	2.11				0.13
Olivine Fo			3.64															2.86						
Fa			1.43																					
Ilmenite	4.56	3.04	1.82	2.28	4.26		1.22	3.43	2.89	1.22	2.77	0.61	1.22	2.52	0.15			0.76			0.76		0.15	
Magnetite	6.50	6.03	5.10	7.66	6.26	22.04	1.62		6.73	5.34	0.93	2.78	5.34	1.89	8.58	0.46	4.87	3.48	6.50	14.38	2.78		3.71	1.16
Hematite							4.16	6.60		1.60	4.80	1.28		3.84	0.16	1.12		1.44			1.12	2.24	1.12	
Apatite	0.67	0.34	0.34	0.34	3.02		0.34	0.34	1.34	0.34	0.34	0.34	0.34	0.34		1.01			0.34	0.34	0.34	0.34	0.34	
Calcite	0.20	1.90	0.20		0.30		0.90	0.40		0.20	2.30					0.50						0.80	0.50	
Corundum								6.94			0.31				2.35	3.77	1.22		2.24	1.33		3.37	1.73	0.20
CO_2 gas								0.40																
Water	2.76	3.69	1.46	0.61	2.45		3.60	1.18	1.90	2.96	0.72	1.18	1.38	1.99	0.03	0.84		5.24	0.01		1.24	1.24		
Total	100.50	100.32	99.73	99.83	100.23	100.07	100.57	99.96	100.84	100.07	100.48	100.43	100.56	100.07	99.89	100.24	100.05	99.97	100.43	100.23	100.30	99.92	100.40	100.58

1. "Basic Series", average of 18 analyses of basalt (de Assuncao and others, 1962).
2. Basalt, Drakensberg Stage, from Lebombo Flats, average of 5 analyses (Hunter and Urie, 1958).
3. "Upper basalt" just south of Great Usutu River, Middle Lebombo Suite (Meyer, 1951).
4. Dolerite, dyke, Middle Lebombo Suite, north of Great Usutu River (Henderson, 1909).
5. Dolerite, dyke, Middle Lebombo Suite, south of Great Usutu River (Meyer and Engelbrecht, 1951).
6. Andesite of Middle Lebombo Suite (calculated from a point count, T.S. 107).
7. Pyroxene pheno-dacite, just south of Pongolapoort, Lower Lebombo Suite (T.S. 78, analyst E.C. Haumann).
8. Dacite from Pongolapoort bore-hole, Lower Lebombo Suite (Q10, analyst E.C. Haumann).
9. Dacite from outlier just south of Great Usutu River, Lower Lebombo Suite (Hunter and Urie, 1958).
10. Glassy dacite, Lower Lebombo Suite (Meyer, 1951).
11. Typical dacite from near the Great Usutu River, Lower Lebombo Suite (Meyer, 1951).
12. Dacite, north of Ngwavuma River, Lower Lebombo Suite (Hunter and Urie, 1958).
13. Dacite, north of Great Usutu River, average of four analyses (Hunter and Urie, 1958).
14. "Rhyolitic Series", average of 23 analyses of dacite (de Assuncao and others 1962).
15. Rhyolite, Upper Lebombo Suite, west of Bumbeni area proper, (calculated from a point count, T.S. 131).
16. Rhyolite, Upper Lebombo Suite, Bobbejaankop just west of Bumbeni area proper. (T.S. 194 analyst E.C. Haumann).
17. Rhyolite, Upper Lebombo Suite (calculated from a point count, T.S. 160).
18. Nepheline syenite, Little Lebombos, average of two analyses (Young, 1920).
19. Syenite, Bumbeni area, Upper Lebombo Suite (calculated from a point count T.S. 125).
20. Granodiorite-porphyry, north of Ingwavuma, Lower Lebombo Suite, (calculated from a point count. T.S. 12).
21. Granodiorite, north of Great Usutu River. (Hunter and Urie, 1958).
22. Microgranite, Upper Lebombo Suite west of Bumbeni area proper (T.S. 211, analyst E.C. Haumann).
23. Granite, Upper Lebombo Suite (calculated from a point count, T.S. 300).
24. "Impure" quartz vein, Upper Lebombo Suite (calculated from a point count, T.S. 103).

P L A T E S.

PLATE III.

Sketch of the Lebombo Mountain Range south of the Great Usutu River showing diagramatically the three-fold sub-division of the Lower Lebombo Suite, and showing the relationship of these three phases to the Drakensberg Basalt.

LEGEND

UPPER LEBOMBO SUITE

UPPER LAVA PHASE
PYROCLASTIC PHASE
LOWER LAVA PHASE

LOWER LEBOMBO SUITE

SCALE 1 : 1,000,000

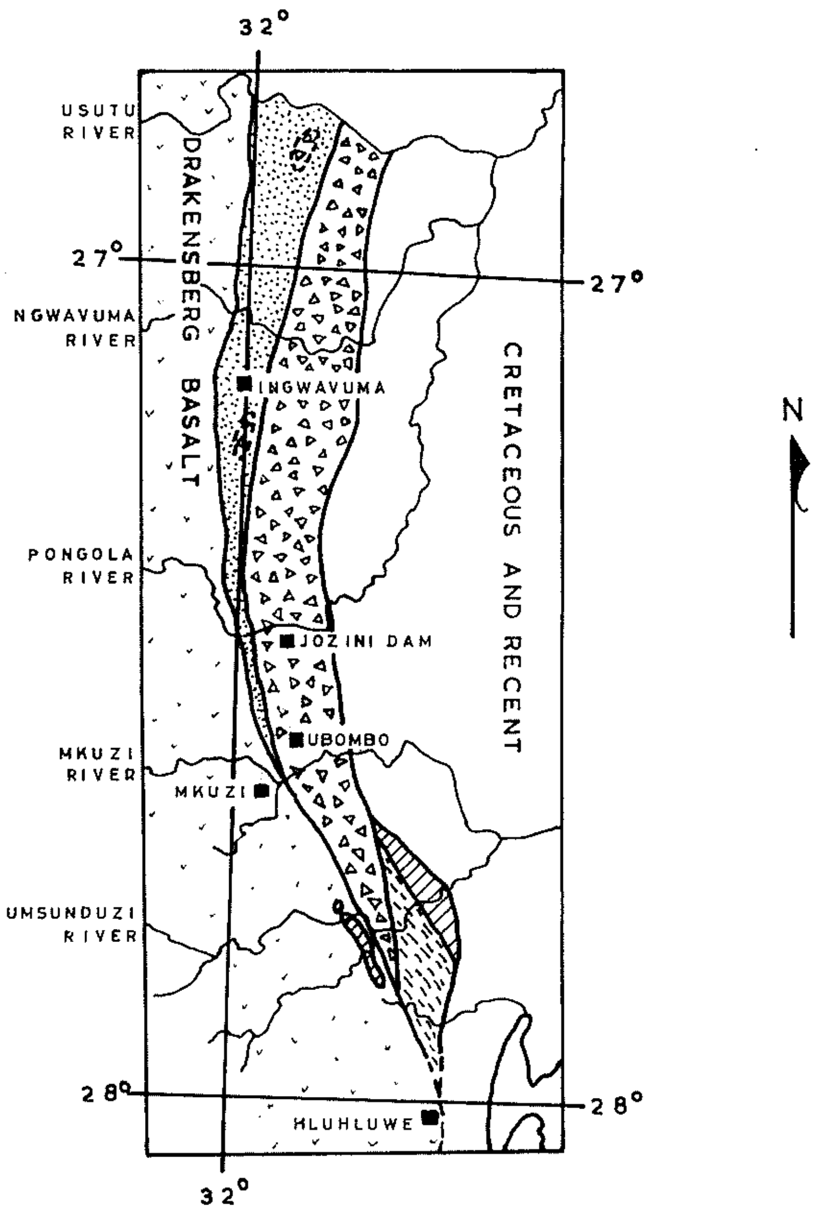


PLATE. V.

Lebombo Escarpment.

(a) The Lebombo Escarpment from the road in the Lebombo Flats just north of the Mkuzi River.

(b) The Lebombo Escarpment showing the cliff, the Lebombo Flats, and the Rooi Rant in the distance.

PLATE V

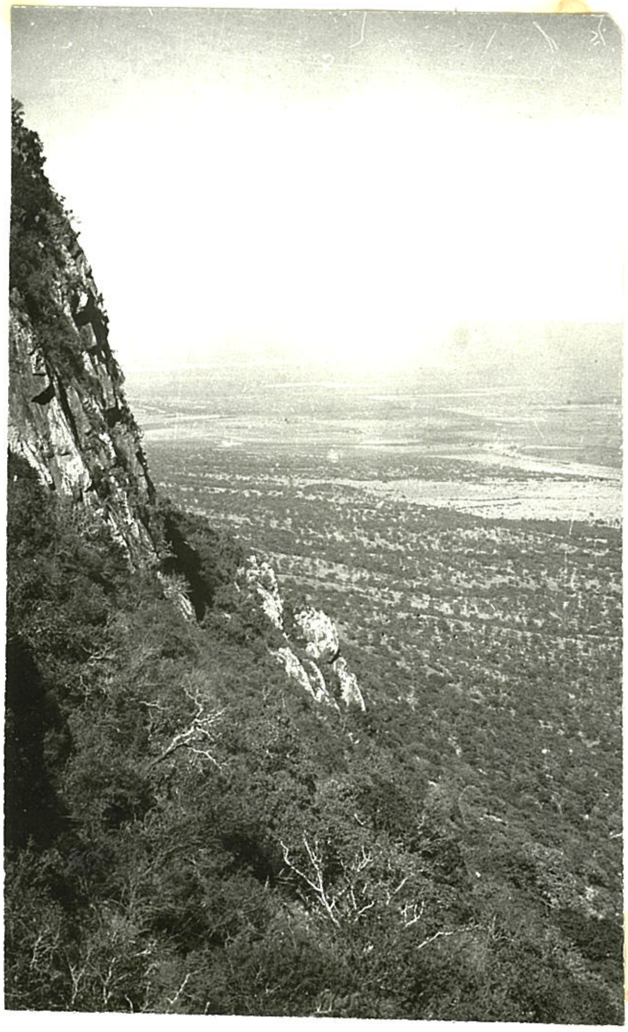


PLATE VI.

The grass-covered pyroclastic flow breccia which is bare of bushes, east of Majozini beacon.

PLATE VI

PLATE VII.

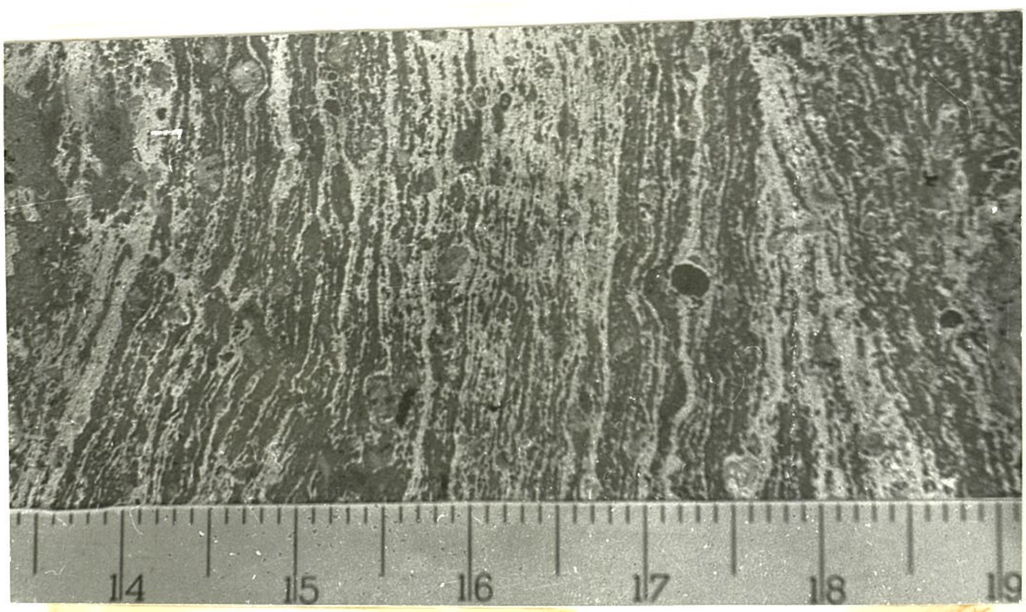
The structure of flow-laminated ignimbrites of the Upper Lebombo Suite, Bumbeni area. Scale in cm$.

(a) Eutaxitic structure.

(b) Fluidal structure.

(c) Turbulent structure.

PLATE VII



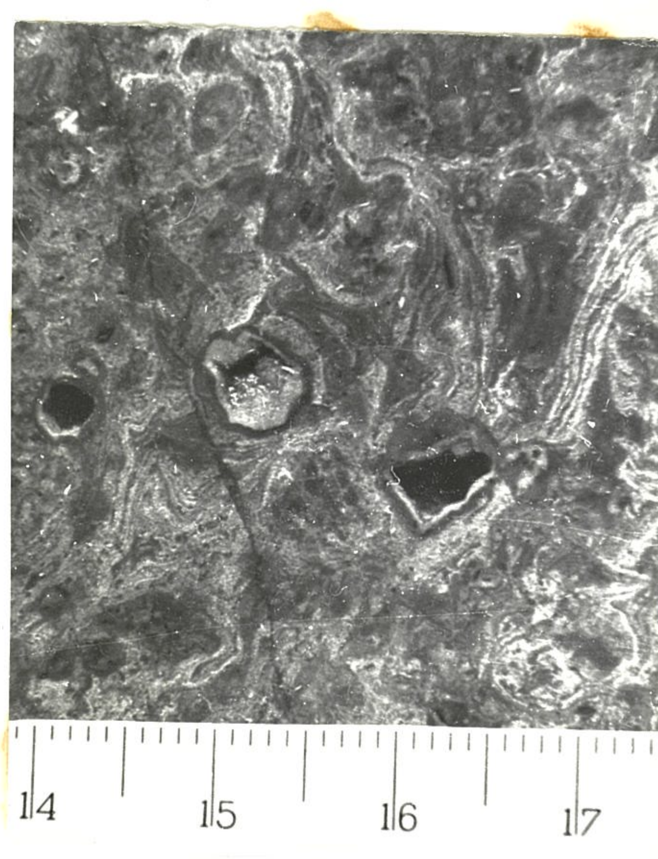


PLATE VIII

Laminated tuff, Upper Lebombo Suite, near Munywane Stream; the two photographs form an angle of 70° to each other. Scale in cms.

PLATE VIII

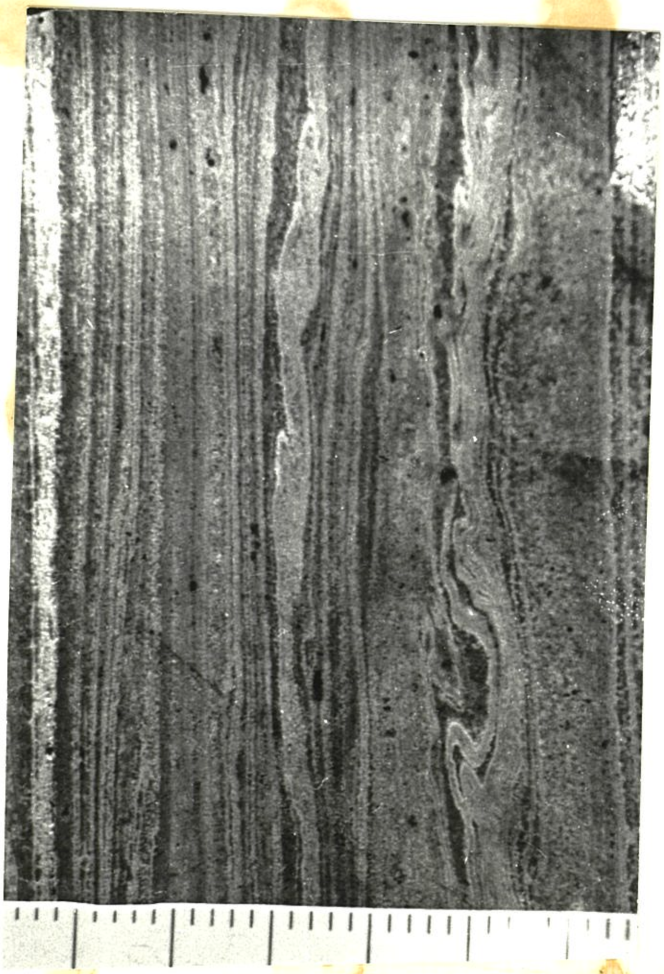


PLATE IX.

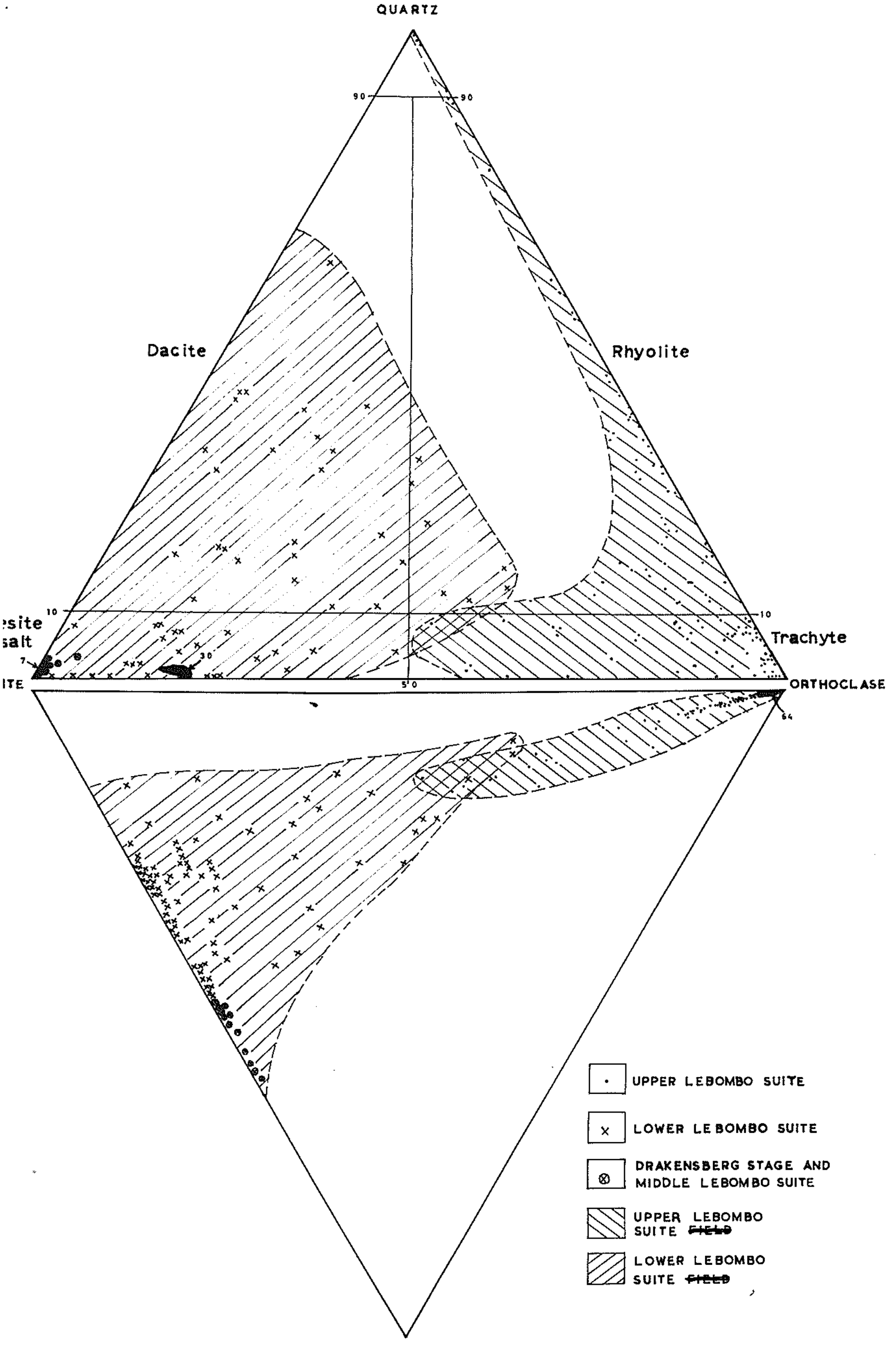
Brecciated laminated tuff, Upper Lebombo Suite, Bumbeni area.

PLATE IX

PLATE X.

Range in volumetric composition, of the Upper and Lower Lebombo Suites, in the systems quartz-albite-orthoclase and albite-anorthite-orthoclase.

PLATE X



QUARTZ
90
90
Dacite
Rhyolite
10
10
Trachyte
7
30
ORTHOCLASE
50
64
ANORTHITE
UPPER LEBOMBO SUITE
LOWER LEBOMBO SUITE
DRAKENSBERG STAGE AND MIDDLE LEBOMBO SUITE
UPPER LEBOMBO SUITE ~~FIELD~~
LOWER LEBOMBO SUITE ~~FIELD~~

PLATE XI.

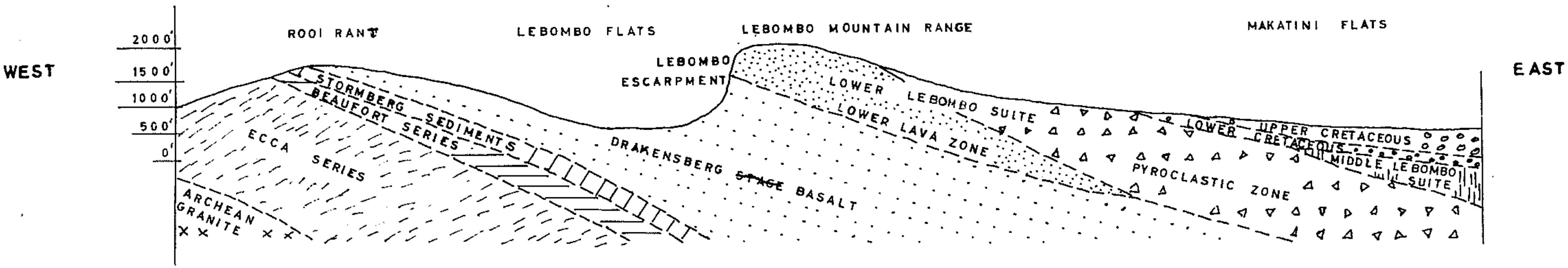
Idealized schematic section through the Lebombo Mountain Range and surrounding country excluding intrusive rocks and faults.

A. North of Ngwavuma River.

B. At Umsunduzi River.

PLATE XI

A. NORTH OF NGWAVUMA RIVER.



B. AT UMSUNDUZI RIVER.

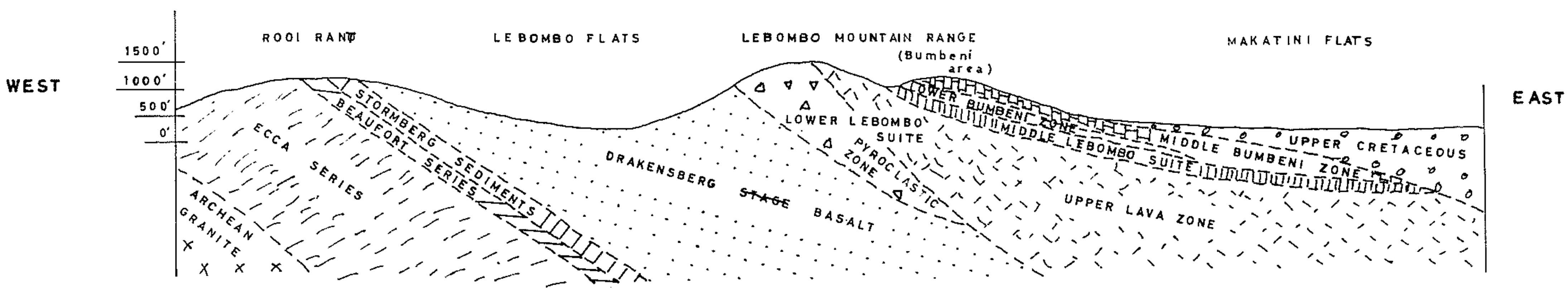


PLATE XII.

Ndabana conglomerate, east of Ubombo-Otobotini road.

PLATE XIII.

Distribution of Stormberg Series in South Africa. The area investigated is shown stippled. After Hamilton and Cooke, 1954, 218.

PLATE XIII

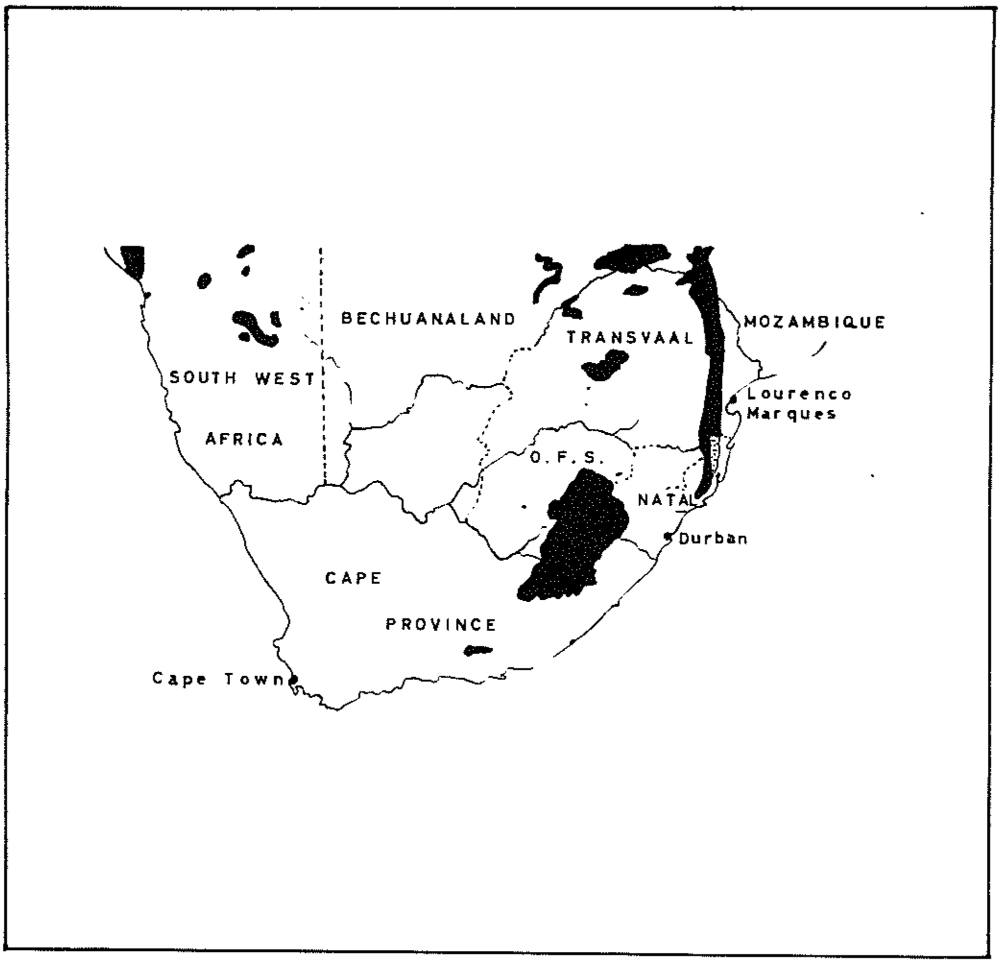

BECHUANALAND
TRANSVAAL
MOZAMBIQUE
SOUTH WEST
AFRICA
Lourenco
Marques
O. F. S.
NATAL
Durban
CAPE
PROVINCE
Cape Town

PLATE XIV.

Bouguer gravity anomalies of the Lebombo Mountain Range, south of the Great Usutu River, and surrounding areas at 10 milligal intervals. Drawn from the Gravity map of South Africa, 1958.

MIDDLE LEBOMBO SUITE

LOWER LEBOMBO SUITE

DRAKENSBERG STAGE

H GRAVITY HIGH

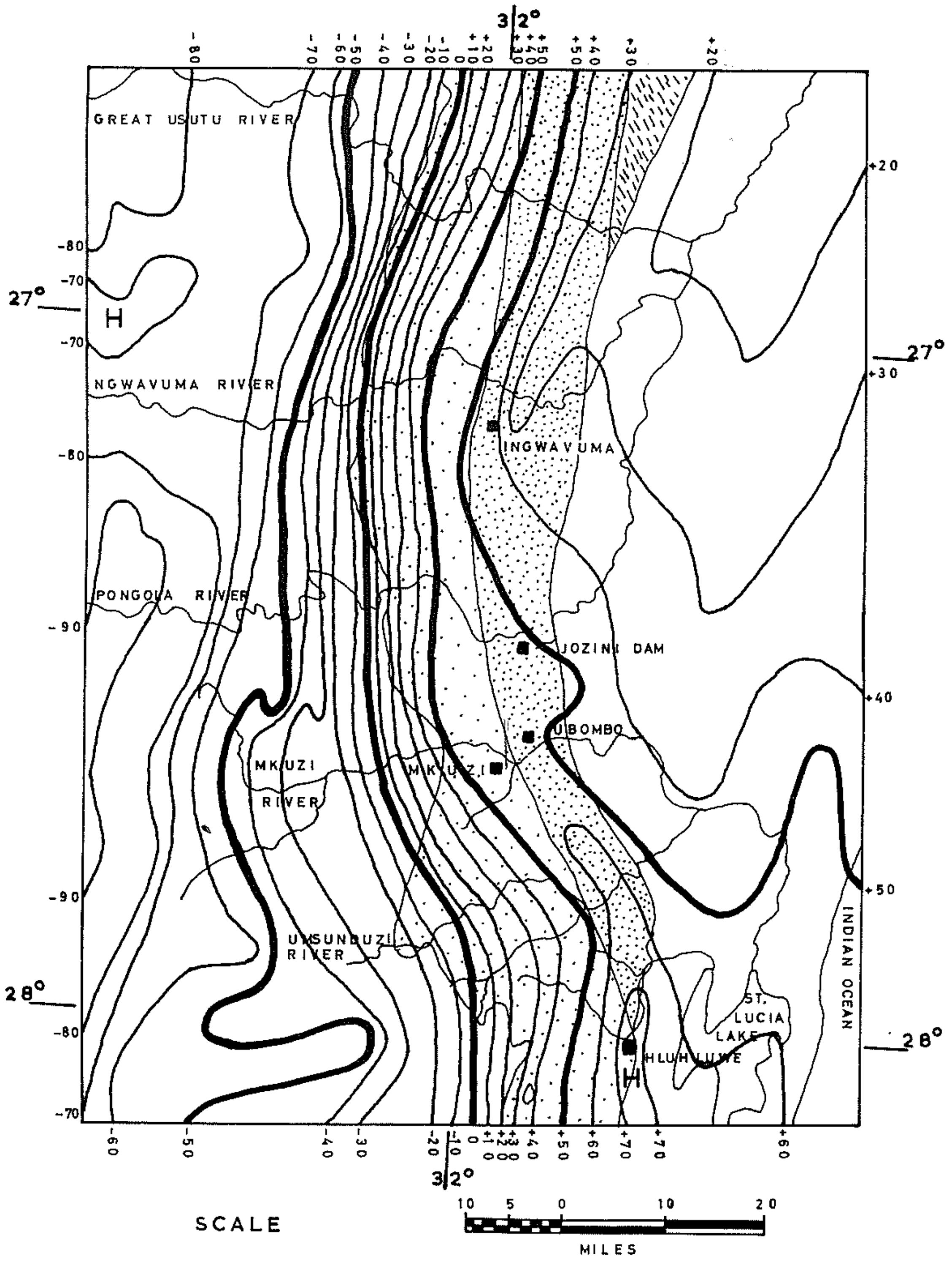


PLATE XV.

Slickensiding in pyroclastic breccia dyke, just south of the Great Usutu River.

PLATE XVI.

Sketch of the indeterminate fault zone south of Majozini beacon.

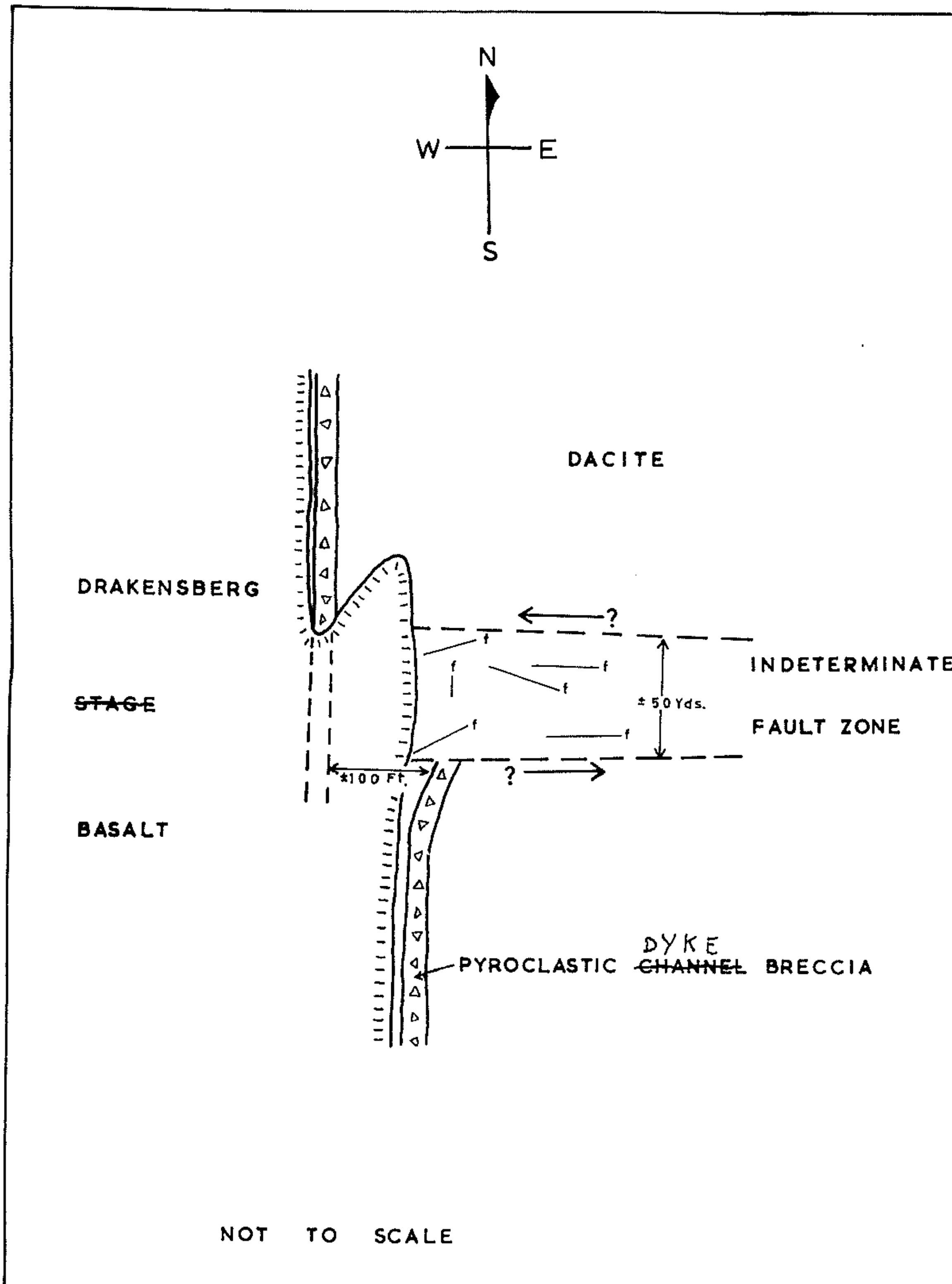

N
W
E
S
DACITE
DRAKENSBERG
~~STAGE~~
BASALT
?
INDETERMINATE
FAULT ZONE
± 50 Yds.
±100 Ft.
f
PYROCLASTIC DYKE ~~CHANNEL~~ BRECCIA
NOT TO SCALE

PLATE XVII.

Contact between second last and last flow of lava in the Drakensberg Stage, on the new road to Jozini Dam.

PLATE XVIII.

Sketch showing the general dip of the lava around the pans, not to scale.

PLATE XVIII

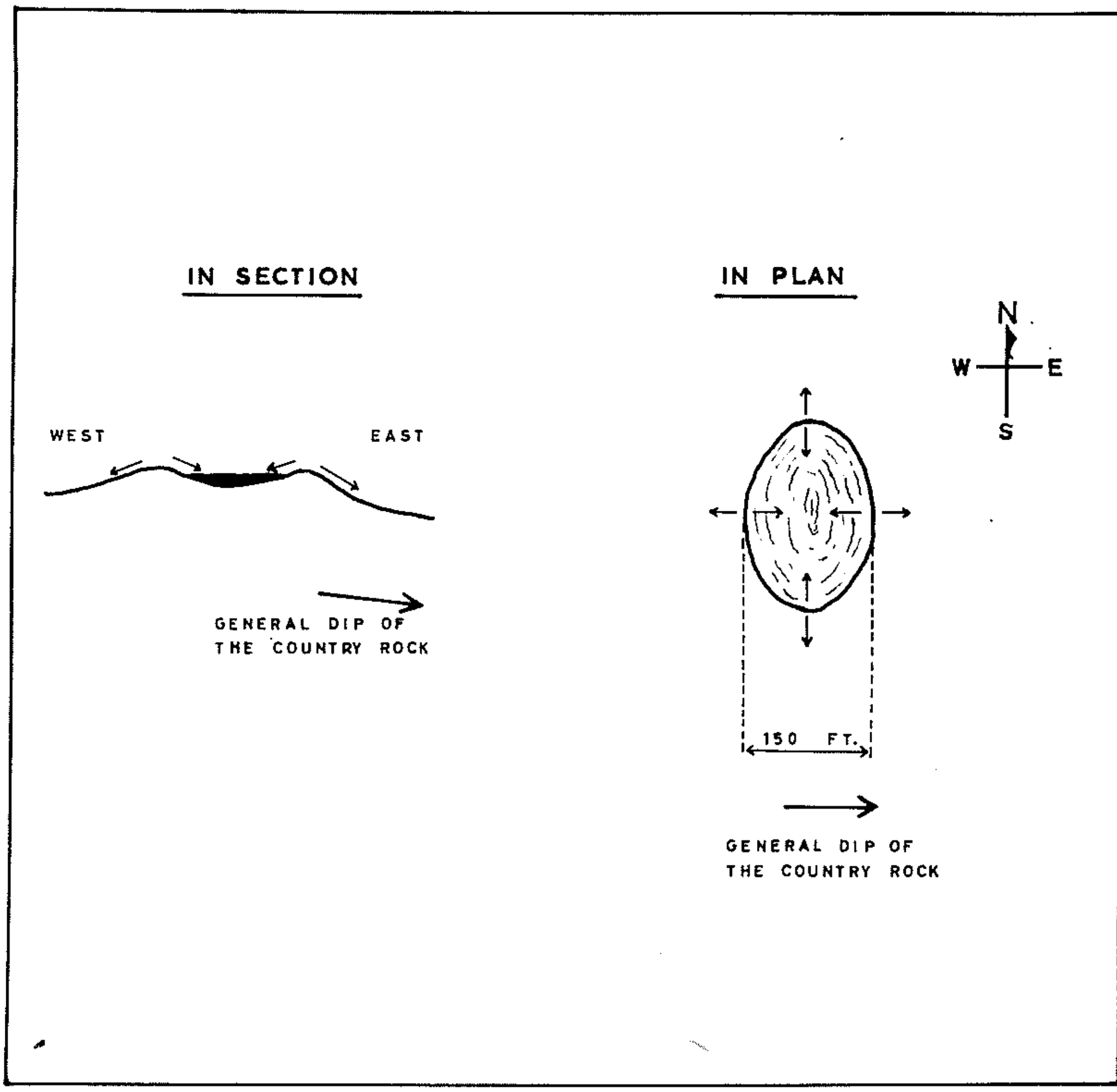

IN SECTION
WEST
EAST
GENERAL DIP OF
THE COUNTRY ROCK
IN PLAN
N
W
E
S
150 FT.
GENERAL DIP OF
THE COUNTRY ROCK

PLATE XIX.

Contorted flow structure, just north of Pongolapoort.

(a) Brecciated flow structure at the edge of a pyroclastic breccia dyke.

(b) Contorted flow structure a short distance from a pyroclastic breccia dyke.

PLATE XIX

PLATE XX.

The specific gravities of rocks in the transition zone plotted against the depth below ~~height from~~ the upper contact at which the sample was taken. Numbers of points correspond to numbers in table 3.

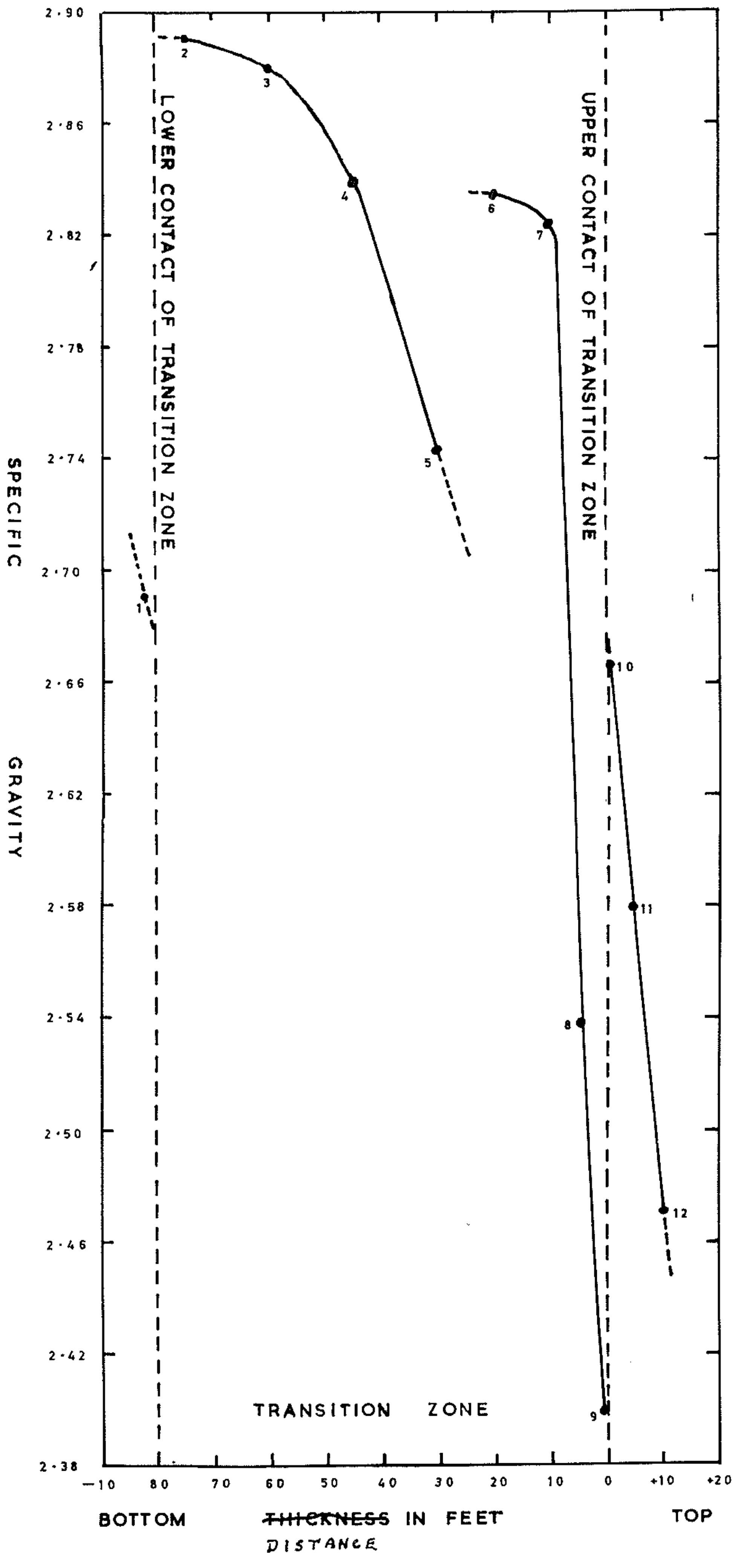

SPECIFIC GRAVITY
2·90
2·86
2·82
2·78
2·74
2·70
2·66
2·62
2·58
2·54
2·50
2·46
2·42
2·38
LOWER CONTACT OF TRANSITION ZONE
UPPER CONTACT OF TRANSITION ZONE
TRANSITION ZONE
1
2
3
4
5
6
7
8
9
10
11
12
−10
80
70
60
50
40
30
20
10
0
+10
+20
BOTTOM
~~THICKNESS~~ IN FEET
DISTANCE
TOP

PLATE XXI.

The specific gravities of massive lava in the Pyroclastic Phase of the Lower Lebombo Suite between two pyroclastic flow breccias plotted against the height ~~from~~ above the lower pyroclastic flow breccia. Numbers of points correspond to numbers in table 4.

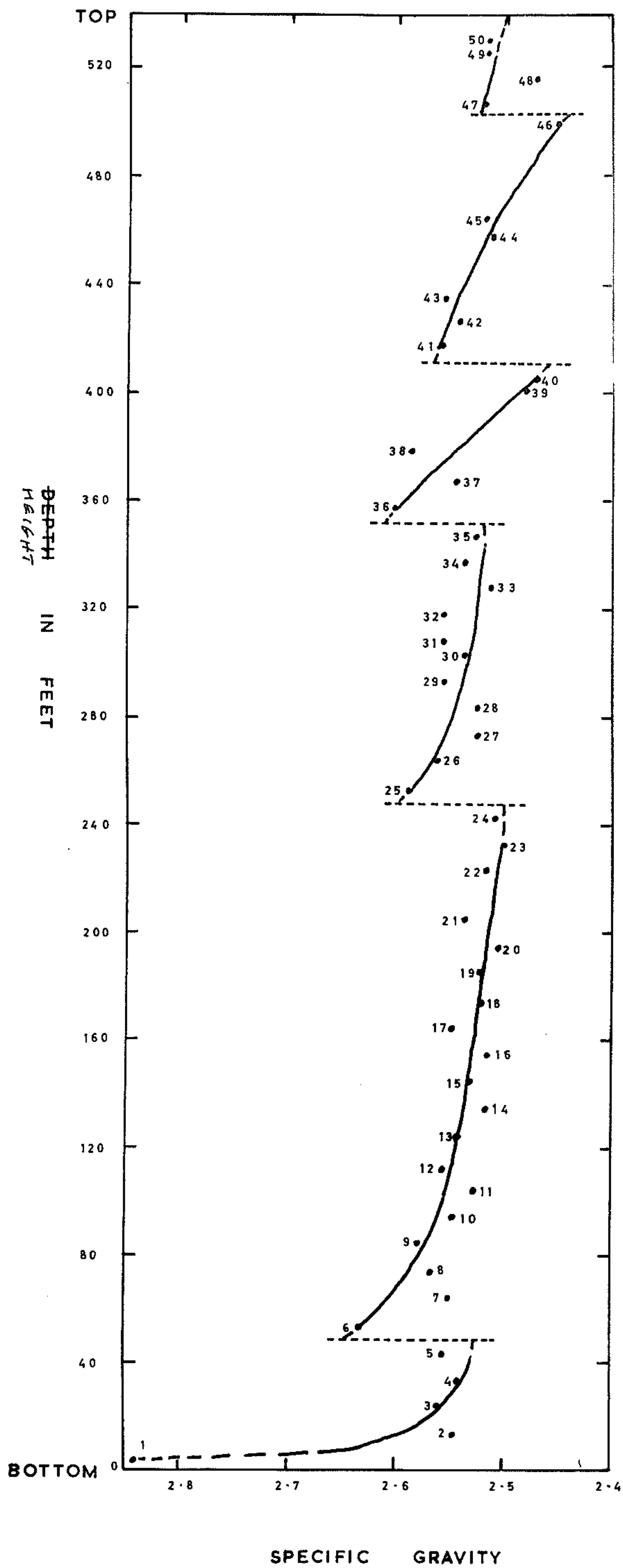

TOP
BOTTOM
~~DEPTH~~ HEIGHT IN FEET
SPECIFIC GRAVITY
0
40
80
120
160
200
240
280
320
360
400
440
480
520
2·8
2·7
2·6
2·5
2·4

PLATE XXII.

(a) Breccia from pyroclastic breccia dyke, near the Ngwavuma River, on the eastern side of the mountains.

(b) Volcanic bombs in dacite. North-east of Majozini beacon.

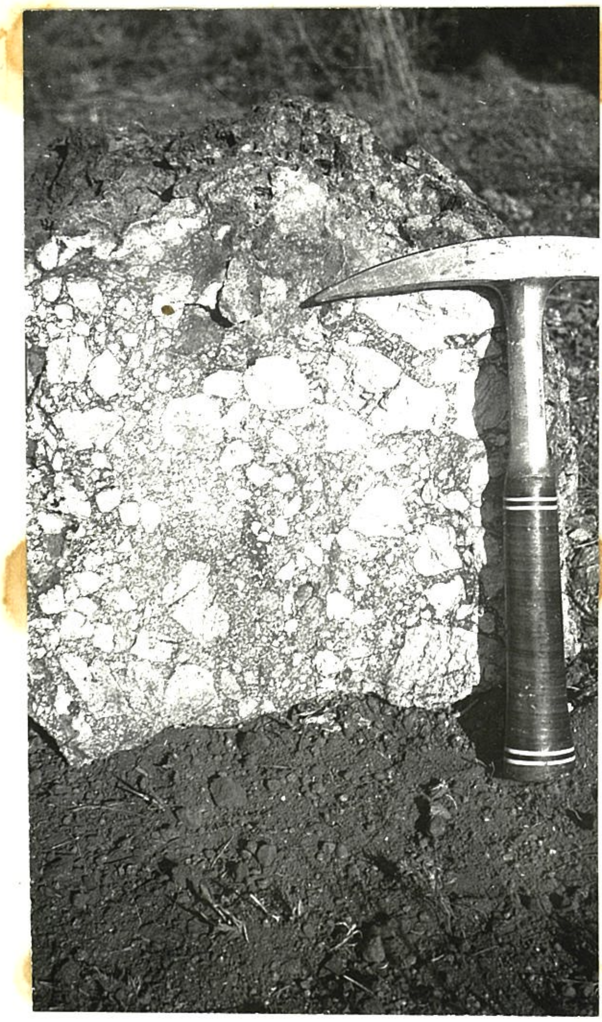


PLATE XXIII.

Various forms of concentric and horizontal banding of the agates in the Lebombo Mountains.

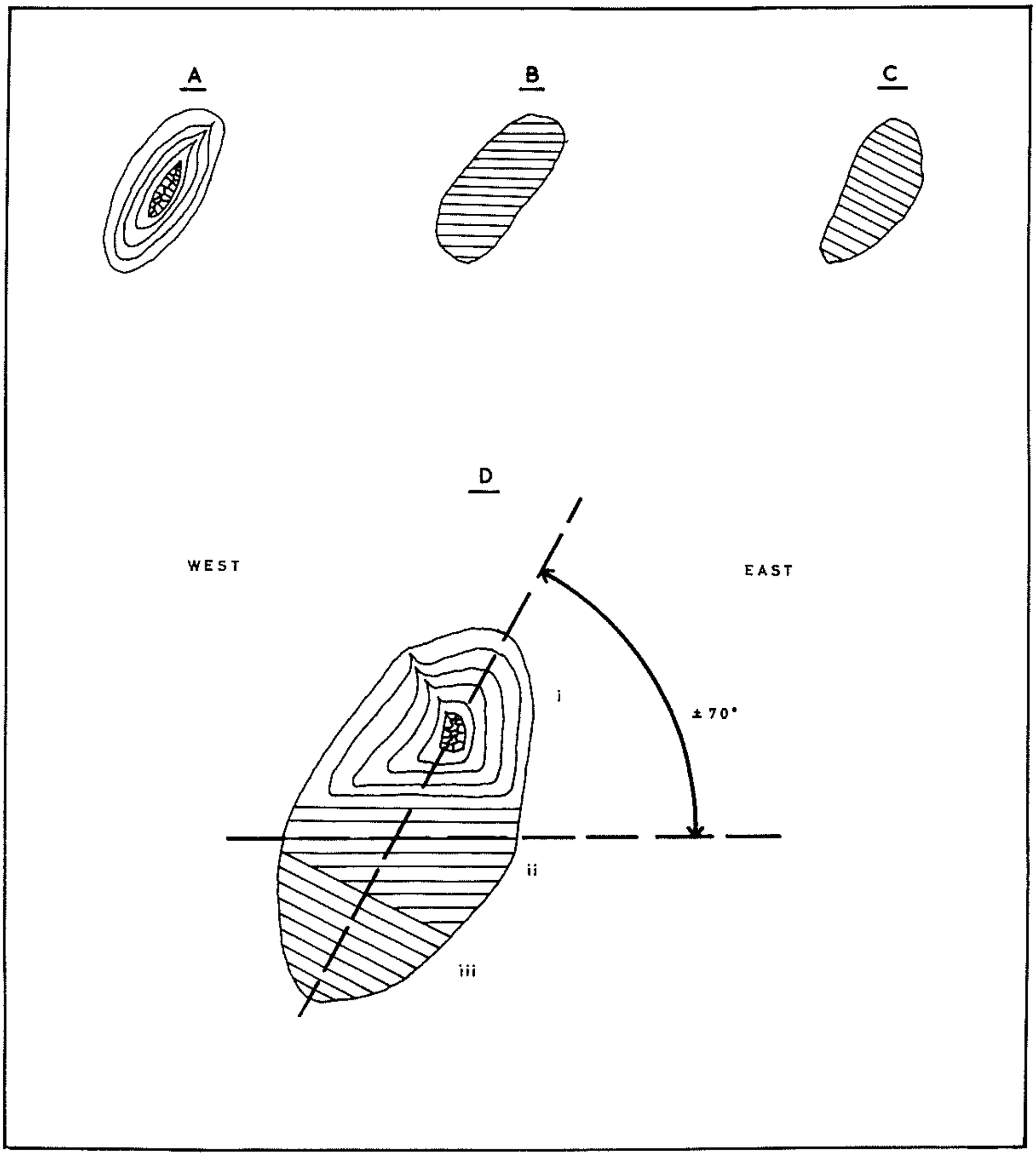

A
B
C
D
WEST
EAST
i
± 70°
ii
iii

PLATE XXIV.

(a) Vesicular dacite, north-east of Majozini beacon.

(b) Dolerite dyke in dacite, emphasised by differential weathering, in a small stream bed south of Pongolapoort.

PLATE XXIV

PLATE XXV.

Bumbeni Conglomerate.

(a) The conglomerate on the northern bank of the Umsunduzi River, on the eastern side of the mountains.

(b) Close-up of the conglomerate in the same area showing how unsorted it is.

PLATE XXVI.

Photomicrograph of thin black lines due to devitrification in laminated ignimbrite.

1 MM.

PLATE XXVII.

(a) Thunder eggs in field just north of Munywane Stream.

(b) Cluster of thunder eggs showing uniformity in size.

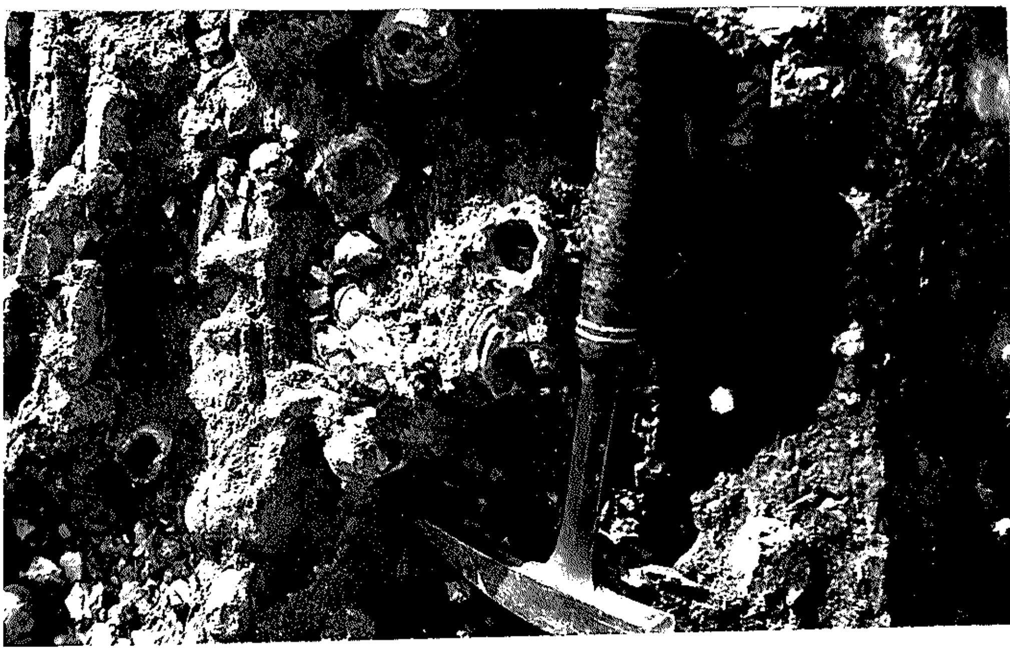
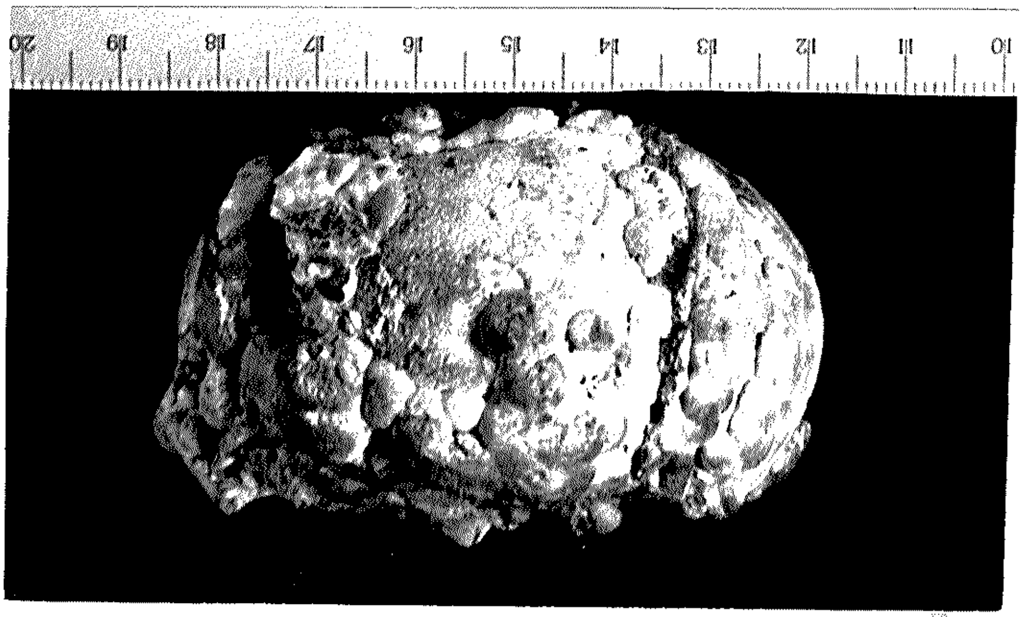
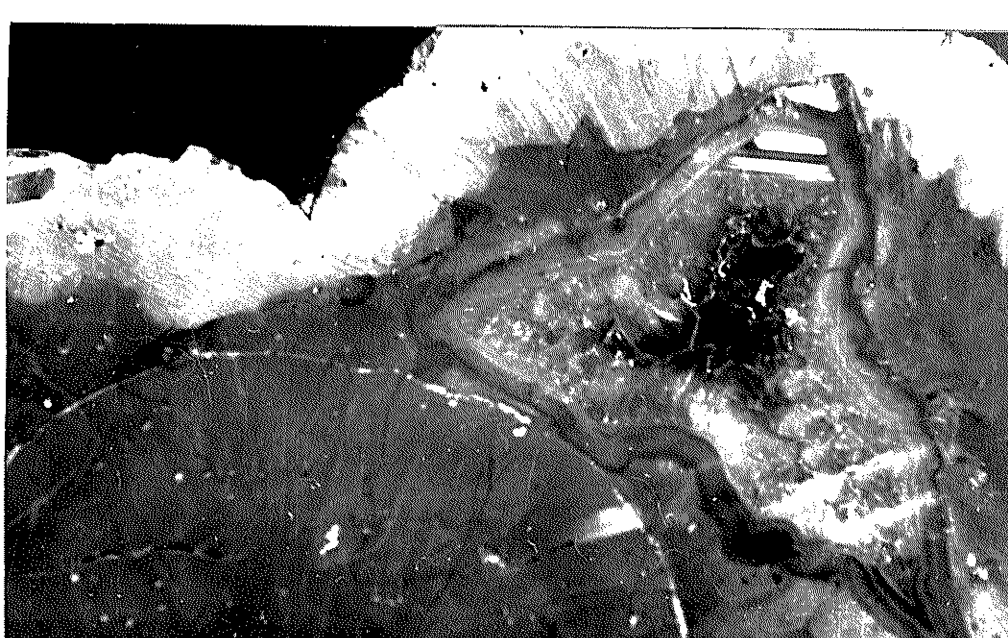


PLATE XXVIII.

(a) Exterior of thunder egg showing flattening and an extreme example of the botryoidal surface. Scale in cm.

(b) Agate in thunder egg. Interior part of thunder egg shown in plate XXVII(b).





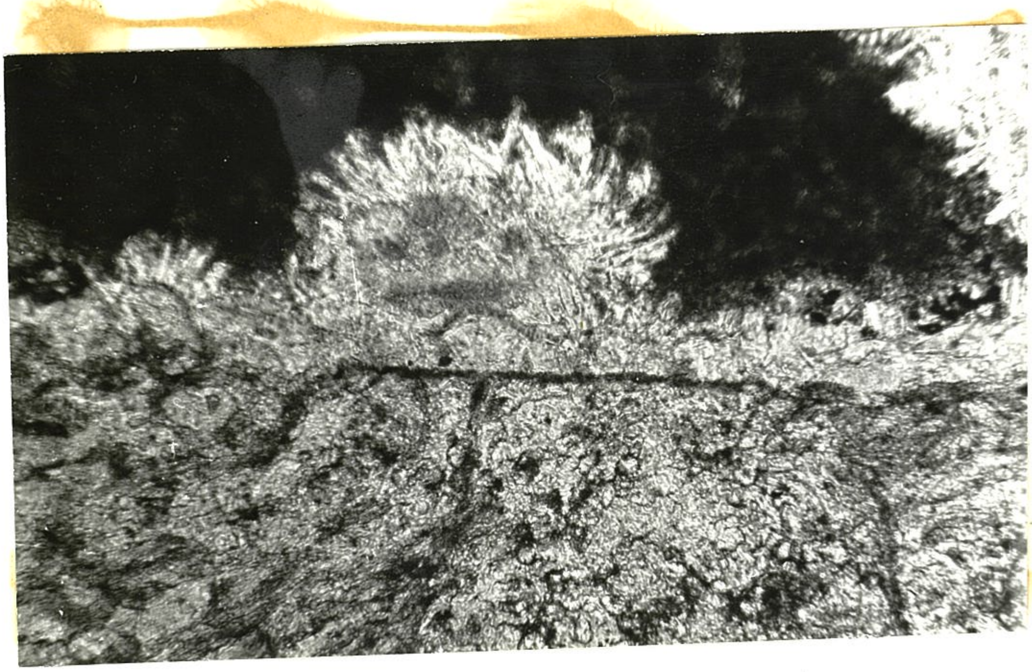
2 CM.

PLATE XXIX.

(a) Photomicrograph of a lump of glass in a massive ignimbrite.

(b) Photomicrograph of devitrified glass shards in massive ignimbrite.

glass



1 MM.

1 MM.

PLATE XXX.

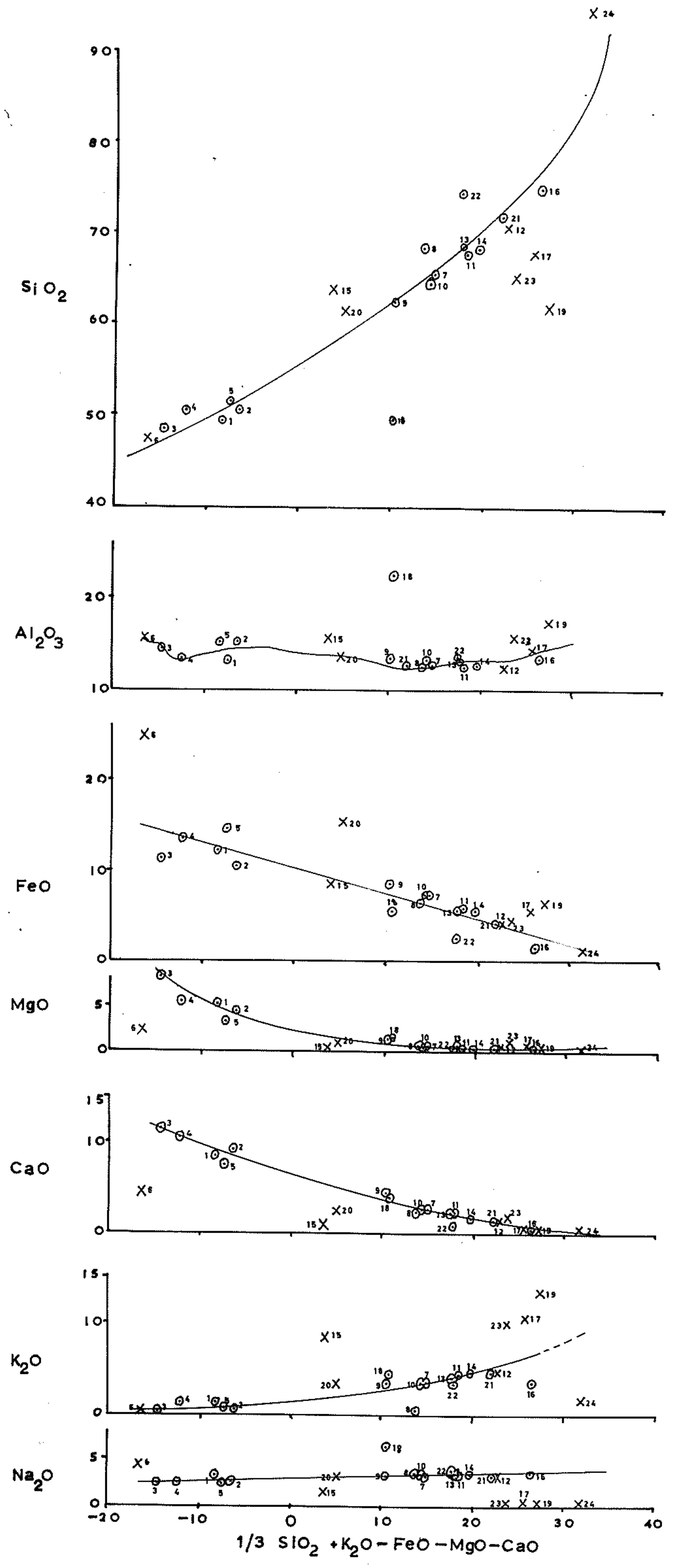
(a) Agglomerate just west of the Lebombo Mountains near the Umsunduzi River.

(b) Conglomerate in western foothills, in the Umsunduzi River bed.

PLATE XXX

PLATE XXXI.

Variation diagram of the percentage of the variable major oxides against percentage 1/3 $SiO_2 + K_2O - FeO - MgO - CaO$. The number of the points correspond to those given in appendix 1 circles represent chemical analyses and crosses represent chemical compositions calculated from weight percentage which is in turn calculated from the results of a point count.



SiO_2
Al_2O_3
FeO
MgO
CaO
K_2O
Na_2O
1/3 SiO_2 + K_2O − FeO − MgO − CaO

PLATE XXXII.

Clinopyroxene-

~~Clino~~-orthopyroxene inversion curve in relation to the temperature of the magma.

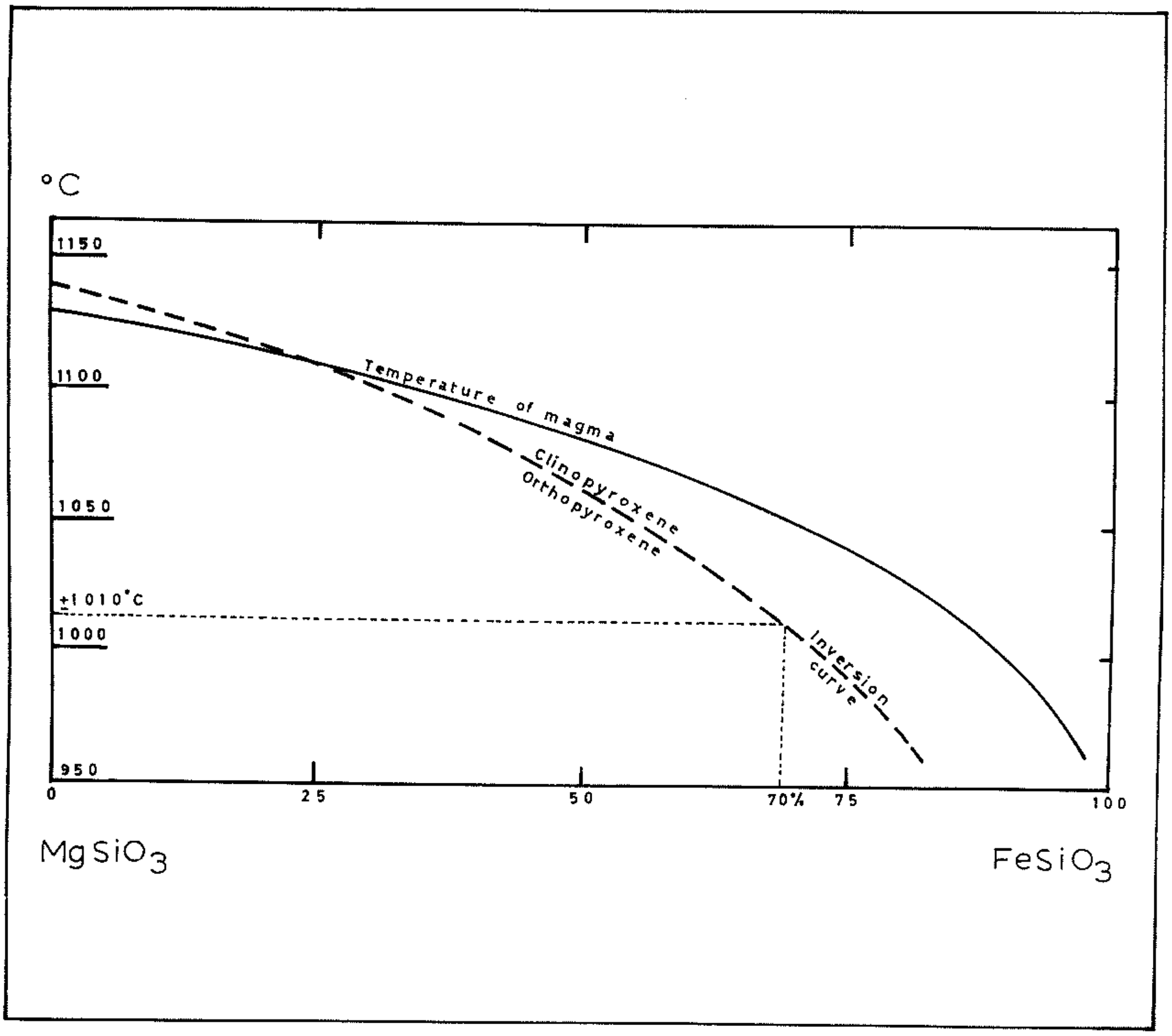

°C
1150
1100
1050
±1010°C
1000
950
0
25
50
70%
75
100
Temperature of magma
Clinopyroxene
Orthopyroxene
Inversion curve
MgSiO3
FeSiO3

PLATE XXXIII.

Tuff bed showing sharp upper contact of tuff on the new road to Jozini Dam.

PLATE XXXIII