THE GEOLOGY OF AN AREA NORTHWEST OF PRETORIA.

by

M. v. R. STEYN.

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THE GEOLOGY OF AN AREA NORTHWEST OF PRETORIA.

ABSTRACT.

The conclusion is upheld that the two zones of quartzite xenoliths in the area represent detached fragments of the Magaliesberg horizon separated from the floor of the Bushveld Igneous Complex by the intrusion of the latter.

Rocks which occupy a similar stratigraphical position in the Bushveld Igneous Complex to the leptites from the present area, have been described from elsewhere by Vermaas (1949, p. 60) and others. In most cases these rocks are described as being undoubtedly of sedimentary origin, as remnants of the original bedding planes serve to indicate. The writer could find no evidence of any sedimentary structures in the leptites from the area under discussion. These sediments are nevertheless considered to have originated from argillaceous rather than arenaceous sediments.

Only part of the normal zonal succession of the gabbroidal rocks of the Bushveld Igneous Complex is present in the area surveyed, namely the Critical, Main and Upper Zones. The Critical Zone which is represented by various types of layered rocks, exhibits a chill phase at its base and is noticeably thinner than is normally the case. This zone, furthermore, does not contain either the Chromitite Horizons nor the Merensky Reef in this area. The Main Zone is characterized by a uniformity of rock-types except near the top of the pseudostratigraphical succession where spotted norite and mottled anorthosite make their appearance.

Three main bands of magnetic iron ore are present in the Upper Zone, namely the Upper, Middle and Lower Bands. This zone also exhibits a granitic phase in its uppermost horizons. Field evidence indicates that the dunite occurrences, which are all situated stratigraphically in the lower part of the Main Zone below the Pyramid Hills Horizon, are transgressive structures. They are also considered to represent a final, pegmatitic phase in the

Bushveld Igneous

activity. Relatively small bodies of gossan and of iron ore indicated on the map, are associated with several of the dunites.

The suggestion is advanced that the Granophyre attained its present position by intrusion. A similar mode of emplacement, namely that of intrusion, is envisaged for the red Bushveld Granite in the area, which forms an isolated occurrence surrounded on all sides by gabbro, on the horizon of the Lower Iron Ore Band.

In conclusion, evidence is given of contemporaneous deformation within the Ecca Grit.

I. INTRODUCTION.

The country represented on the map Plate I covers a surface area of about 58 square miles lying between 25° 32' and 25° 39' South Latitude and 27° 58' and 28° 06' East Longitude. The greater part of the area falls within the confines of the Pretoria district, except for two farms in the south-west, namely Krelingspost 66 and Hoekfontein 67, which are in the Brits district.

The area covered by the map is readily accessible by means of two good highways and many subsidiary farm roads. The former are the main roads to Brits and Hebron. Part of the road to Hebron is tarred. Many of the subsidiary roads are impassable during the summer months, owing to the fact that the surface soil is the well-known heavy black turf which originates from the weathering of gabbro.

The main railway-line to Rustenburg traverses the southern part of the area.

In mapping use was made of aerial photographs kindly supplied by the Union Geological Survey, on a scale of roughly 1:20,000. Outcrop mapping was carried out on these photographs and the information thus obtained was transferred on to a base map to the scale of 1:25,000. The field work was carried out during the months of June, October and November 1952.

For the identification of minerals, refractive index determinations were often carried out. Where necessary all three refractive indices n'_α n_β and n'_γ of biaxial minerals were determined, n'_α and n'_γ being assumed to be the lowest and highest values respectively in a grain mount. In addition to the indices of refraction the universal stage was also used in the determination of the plagioclase feldspars, pyroxenes and olivine.

A. <u>Previous Work.</u>

Although geological work in the Bushveld Igneous Complex was done on a regional basis prior to 1898, the earliest reference to the geology of the area northwest of Pretoria specifically, is contained in a publication by Henderson (1898). Inter alia he describes diallage norites from the Zwartkoppies Range (at that time referred to as Zwaartkoppies).

The fact is emphasized by him that rocks of the Range belong to the Norite family. It is of interest to note that the principal ferromagnesian constituent was recorded at that time as strongly pleochroic hypersthene, whereas rocks containing this mineral are now known to be subordinate to the bronzite-bearing ones.

In the Annual Report of the Geological Survey of Transvaal, Kynaston (1904, p. 73) records the presence of a band of pyroxenite on Klipfontein 482 associated with segregations of magnetite and occasional occurrences of ferruginous opal.

This occurrence is regarded in the present investigation as an hortonolite dunite body. Kynaston further mentions that the pyroxenite on Klipfontein 482 is a nearly black, coarsely crystalline rock, consisting almost entirely of large crystals of enstatite, together with a little brown hornblende, secondary green hornblende and magnetite. Reference is also made to magnetite bands north of the Koppies which were traced in the norite along the northern parts of the farms Onderstepoort 496, The Pyramids 370 and Klipfontein 482.

The/4................

The same author also noticed the difference between the bands of magnetite and the segregations of iron ore associated with the above-mentioned 'pyroxenite', in which connection he states that .... "they (the magnetite bands) are clearly defined from the surrounding norite, in this way differing in mode of occurrence from the zone of magnetite, observed in association with pyroxenite on the southern portion of Klipfontein, where the iron ore occurs in irregular lumps and masses".

Reference is made to the area under discussion and the general geological features are given in the Explanation of Sheet 1, Pretoria (Lombaard, B.V. and Krige, L.J, 1929, p. 22).

Nel (1939, p. 51) gives a brief description of the gabbro immediately overlying the diabase in this area and Boshoff (1939, p. 9) describes the rocks along a traverse across the Upper Zone of the Bushveld Complex in the vicinity of Hebron.

B. Acknowledgements.

I should like to express my gratitude towards my parents and my twin brother for the great interest shown in the work and for financial assistance; to Professor J. Willemse of the Pretoria University under whose guidance the work was done; to Dr. H. J. Nel and Mr. G. M. Koen for taking some of the photomicrographs; to the Union Geological Survey for the loan of aerial photographs and to Mrs. and the late Mr. W.R.F. Teichmann and Mr. C.T.P. Eksteen and their families for their hospitality during my stay in the field.

II. PHYSIOGRAPHY.

A. Surface features.

The area consists roughly of a southern, relatively flat-lying portion and a northern, slightly more elevated portion, the former composed mainly of basic rocks of the Bushveld Complex and the latter of granophyre and to a lesser extent of Ecca grit.

A/.................

Plate 2.

The Zwartkoppies viewed from the Granophyre ridges in the North. The dip-slopes of the Magaliesberg Range can be seen in the background.

A line of hills, the so-called Zwartkoppies, extends across the flatter part from east to west and forms a "backbone"-like feature to the area. These hills rise up to 550 feet above the general level of the plains. The southern boundary of the area is formed by a zone of quartzite (herein referred to as the Southern Zone of Quartzite Xenoliths), lying from two to three miles north of the Magaliesberg Range. In the south-western corner of the area this zone of xenoliths forms a prominent ridge and two smaller hills.

Altitudes in the area vary from 4618 feet at the trigonometrical beacon on Krelingspost 66 in the south-eastern portion of the area, to less than 3900 feet in the Sand Spruit on the Northern boundary of the map.

An instructive view may be obtained of the surrounding country from the Krelingspost trigonometrical beacon. To the south, stretching in an east-west direction to beyond the confines of the map, are the dip-slopes of the Magaliesberg Range, separated by a zone of diabase from the vantage point. Along the strike of the gabbro to the west, a view is obtained of the Hex River valley dotted with gabbro and norite koppies, followed to the north by part of the very level Springbok Flats. Dimly discernable on the horizon are part of the southernmost edge of the Palala Plateau and in the foreground the granophyre ridges and Zwartkoppies Range. A view towards the east shows the Pyramids followed in the distance by hills composed of rocks belonging to the Waterberg System and the Premier Mine on the horizon.

B. <u>Drainage</u>.

The drainage of the area is accomplished by means of several more or less north-flowing streams, which are non-perennial.

From east to west they are the Tlale, Sand and Kaffers-kraal Spruits. The first-mentioned afterwards joins the Aapies

River/.............

River and the Sand and Kafferskraal Spruits unite in the northern part of the area to become the Sand River which in turn joins the Pienaars River several miles to the north of the area.

The Sand Spruit is dry for the greater part of the year barring the summer months, during which period it may carry considerable volumes of water, usually causing several of the smaller roadways to become impassable.

The spruits transgress the general strike of the rocks and have relatively straight courses, though they may locally contain small meanders. Cutting through the Southern Zone of Quartzite xenoliths, through the Zwartkoppies Range and through the granophyre area in turn and forming a small "poort" in the latter, the spruits have contributed towards the unevenness of the topography.

Several subsidiary drainage courses are normally dry as they serve only for stormwater after rains. The drainage system appears to be superimposed, having been initiated on the Karroo System now represented by isolated outliers.

Only one spring is known from the area, namely that on the central part of Klipfontein 482, several hundred yards south of the homestead and in close proximity to the Sand Spruit. It apparently originates as a result of the underground damming effect of a dolerite dyke cutting through the gabbro country rock.

The mean annual rainfall is approximately the same as that of the immediate vicinity of Pretoria, namely about 25 inches per annum. The climate, especially in the northern parts, is hot during the summer months.

Considerable quantities of maize are grown on certain farms in the area, for example on Klipfontein 482, which also produces tobacco, fruit and vegetables. The soil, as a rule, is very fertile.

Along the drainage courses black turf soil predominates and contains calcareous nodules ranging from mere specks up to

lumps/..........

Plate 3.

A Wildesoring on Wildebeest-hoek 20.

Plate 4.

A Cluster of Naboom on Middel-water 589.

lumps an inch in diameter.

Lombaard (1934, p. 50) points out that the black soil on gabbro from the Lydenburg district, has undergone noteable changes compared with the fresh rock, though the soil is still similar to the rock in several respects. He mentions that relative to the molecular sum of Al_2O_3, Fe_2O_3, $Mg\ O$, $Ca\ O$, Na_2O and K_2O, little change has taken place in silica, iron, magnesia and potash; there has been a loss of soda, phosphorus and lime, a rise in alumina and a large increase in water.

Van der Merwe (1940, p. 74), in connection with the black and red soils originating from the gabbro, states that this rock "on decomposition under prevailing climatic conditions, invariably produces a black clay irrespective of the situation, except where intermixing of the weathered product with coarser material, derived from other sources, takes place or in the vicinity of magnetite bands, occurring in the norite formation. Under these circumstances the resultant soils are red or chocolate in colour, leached and deficient in carbonate of lime. For instance, in the initial stage of soil formation from norite, the shallow soil is opened mechanically by rock fragments and the soil material has a reddish brown tint".

The problem of the origin of the black soil characteristic of a large part of the area is almost certainly clay-mineralogical in character and therefore beyond the scope of the present investigation.

C. Vegetation.

The unspoilt parts of the area are commonly covered with various species of acacia, which show preference for the drainage courses. Types such as the Wag-'n-bietjie (A. caffra) and Soetdoring (A. Karroo) are relatively well-represented whereas trees such as the Wildesering (Burkea africana) and Boekenhout (Faurea Saligna) are somehwat less widespread. Clusters of Naboom species

(Euphorbia/..................

(Euphorbia Ingens) are present usually in sheltered positions among the quartzite ridges in the southern part of the area, as well as rare specimens of the well-known Kiepersol. Specimens of the Karee (Rhus lancea) have a scattered distribution and the grasses constitute mostly "sweet" veld.

III. GEOLOGICAL FORMATIONS.

The geological formations present in the area are arranged in descending order of age in the following table:

TERTIARY AND RECENT DEPOSITS		....	(Sand (Gravel (Silt
KARROO SYSTEM	(Ecca Series	....	(Grit
BUSHVELD IGNEOUS COMPLEX	(Quartz-bearing rocks	....	(Granite (Granophyre
	(Olivine-bearing rocks	......	(Dunite
	(Gabbroidal rocks	....	(Gabbro and Norite (Hybrid rocks
TRANSVAAL SYSTEM	(Pretoria (Series	(Magaliesberg (Stage	(Leptite (Quartzite

IV. GENERAL GEOLOGY.

The geology of the area can readily be described by reference to two zones of quartzite xenoliths, a Northern one and a Southern one. In between these two zones occur the gabbroidal and olivine-bearing rocks of the Bushveld Igneous Complex.

Only part of the typical zonal succession of the Complex is represented in the present area. The only zones which can definitely be deliniated are the Upper and Main Zones.* This discrepancy in the zonal development as compared to other areas of the Bushveld Igneous Complex, is caused by the absence of the Merensky Reef and all the Chromitite horizons. It should be emphasized here that

the/..............

* The boundary between these two zones is marked by the Lower Magnetic Iron Ore band. The reasons for this division are discussed in Chapter VI No.B2(b), p. 46.

the position of the former horizon as indicated on the accompanying map, is inferred.

The Critical Zone in this area is only approximately recogniseable as that part towards the base of the Main Zone which contains the greatest variation of layered rocks. It would then be bordered towards the south by the Southern Zone of Quartzite Xenoliths. Beyond the Southern Zone of Quartzite Xenoliths diabasic rocks occur and as these have been studied in detail by Nel (1940), they have not been re-investigated.

Lying mostly to the north of the Northern Zone of Quartzite Xenoliths and separated from it for the greater part by a zone of leptite, is a strip of country occupied by granophyre.

Pseudostratification in the gabbroidal rocks is usually marked from the Zwartkoppies Range, that is about the middle of the Main Zone upwards, and is generally less well-developed below this horizon.

Dunite and allied rock-types are present as pipelike occurrences, two large and six smaller ones. These pipelike bodies have a linear distribution and are aligned roughly along the lower part of the Main Zone.

A small outcrop of Red Bushveld Granite occurs on the same horizon as the Lower band of magnetic iron ore, immediately to the east of a small tributary of the Kafferskraal Spruit on Sjambok Zyn Kraal 52.

The only geological formation younger than the Bushveld Complex, is part of the Ecca Series of which several relatively small occurrences are represented.

V. THE TRANSVAAL SYSTEM.

The only member of the Transvaal System which is represented in the area surveyed, is the Pretoria Series and that as two zones of quartzite xenoliths, a Northern one and a Southern one and a zone of leptite just to the north of the Northern zone of Quart-

zite/....................

zite Xenoliths. These rocks, originally of sedimentary origin, presumably represent portions of the Magaliesberg Stage quartzite.

A. Southern Zone of Quartzite Xenoliths.

This zone outcrops almost continuously, close to the southern boundary of the area and extends from east to west across the farms Hartebeesthoek 524, Strydfontein 630 and 606, Wildebeesthoek 611 and 20, Kafferskraal 323, Middelwater 589 and Vissershoek 45, as well as the southern portions of Uitvalgrond 584 and Krelingspost 66.

The quartzite has an average dip of 36° to the north and has been subjected to transverse faulting on the central part of Hartebeesthoek 524. Here the rocks show conderable jointing and have a coarsely crystalline texture, being typical of the Doornpoort type (Hall, 1932, p. 413). The surface width of individual quartzite outcrops in the Southern zone of xenoliths, varies from approximately 210 feet near the trigonometrical beacon on Hartebeesthoek 524 to approximately 850 feet on the south-western part of Uitvalgrond 584.

On the south-eastern part of the latter farm bands of poorly cemented quartz grains resembling sandstone, alternate with the characteristic coarse, recrystallized quartzite. The former vary in thickness from about ½" to a zone of 20 yards in surface width. This sandy quartzite has a reddish brown colour due to iron-staining. The coarse quartzite on the other hand, has a greyish white colour.

The two types can thus readily be distinguished from one another even from some distance, due to their differences in colour and texture.

Under the microscope the typical coarsely crystalline quartzite presents an interlocking mosaic of quartz grains and scattered wisps of sericite mica.

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Plate 6.

Jointed Quartzite on Hartebeesthoek 524.

Plate 5.

Quartzite Xenolith dipping towards the right i.e. north, on Vissershoek 45.

According to Harker(1950,p.67),any slight original impurity in the sandstone betrays itself by the formation of some new mineral,in this case mica,scattered through the quartz mosaic. The presence of muscovite in the quartzite may therefore be taken as an indication that more volatile constituents,as well as water,were present and consequently facilitated recrystallization of the original sandstone. The resulting phenomenon is an alternation of quartzite and sandstone bands.

On Hartebeesthoek 524 joints in the quartzite are common and developed to such an extent that it is almost impossible to distinguish the true dip (see plate 5). In this locality the quartzite has a pinkish to light purple colour and on weathering yields a rusty surface. Two joint systems are well-developed, one trending due east and dipping almost vertically and another striking north north-east and dipping approximately 76° towards the east. The mode of weathering of these outcrops is extremely irregular giving rise to jagged surfaces.

In the western part of the area the Southern Quartzite Zone splits up and forms two parallel ridges which stand out prominently.

The origin of this zone of quartzite xenoliths appears to be adequately explained by Hall and du Toit (1923, p. 74), in which connection they state that "there is little doubt that these detached quartzites are fragments of the Magaliesberg horizon torn off the floor of the Bushveld Complex as a result of the intrusion of the latter". The divergence of the outcrops in the western part is likewise caused by the wedging effect of the magma, resulting also in the formation of hybrid rocks.

The cause of the unpronounced surface features of the eastern outcrops, lies in the fact that the quartzite is extremely jointed and in parts not very effectively recrystallized. The rock is also very brittle.

In/......................

In thin section a specimen of quartzite from the easterly outcrops is entirely composed of interlocking, anhedral quartz grains ranging in size from 0.45 mm. to 2.3 mm. in many cases surrounded by a very thin film of turbid material. The quartz grains exhibit cracks and sinuous joints which pass through the grains, as well as minute inclusions which are often arranged in parallel rows. The inclusions commonly consist of chloritic and sericitic material. Both minerals also form veinlets up to 0.04 mm. wide, extending through individual quartz grains. As a rule the quartz exhibits wavy extinction.

B. <u>The Northern Zone of Quartzite Xenoliths</u>.

The Northern Zone of quartzite xenoliths extends more or less along the gabbro-granophyre junction and consists of four separate outcrops of quartzite aligned in an approximately east-west direction. This zone of xenoliths is very much less continuous than the southern one and is present only as scattered outcrops forming small knolls as for example on the farms Kruisfontein 164 and on the northern part of Sjambok Zyn Kraal 52.

The most westerly outcrop of quartzite is in a somewhat jointed condition, a fact which renders the determination of the exact thickness difficult. The surface width of the latter is about 150 yards. On a part of the quartzite which is less disturbed than the rest of the outcrop, the dip is 47° to the north. This outcrop is overlain by leptite.

On the western part of Kruisfontein 164 a second quartzite outcrop has a surface width of approximately 180 yards and varies in colour from greyish-white to pink and shades of brown. Shear planes and joints are present on the northern part of the outcrop and in some cases impart an almost brecciated appearance to the rock. A striking feature of the rocks from this locality is the abundance of mica flakes and staining in various shades of brown, pink and green and also the presence of irregular "nests" of radially or

diversely/.............

diversely orientated, slender tourmaline needles.

In thin section the quartzite consists of interlocking quartz grains with an average diameter of approximately 0.55 mm. Muscovite mica, when present, is interstitial and has an average largest dimension of 0.93 mm.

Quartzite, with the same characteristic appearance as the above-mentioned outcrop, occurs about 400 yards east of the latter. In this case the surface width is only approximately 30 yards.

A prominent ridge of quartzite is present on the central part of Kruisfontein 164, and dips to the north at an angle of 36°. The surface outcrop-width is about 80 yards, which means that this quartzite has a thickness of approximately 144 feet. The eastern part of the outcrop is traversed by a transverse fault.

C. Leptite.

1. Field observations.

Leptite forms a topographically prominent east-west trending ridge, which rises abruptly from the turf flats in the northern part of the area. The most prominent outcrops are situated along the common boundary between Sjambok Zyn Kraal 52 and Kameelfontein 51, where the rocks exhibit a characteristic mode of weathering into jointed, approximately rectangular blocks rarely attaining and not observed to exceed, $\frac{1}{\;}$ square foot in cross-section.

In its most typical development the leptite is a fine-grained, very compact, dark rock on a fresh surface and weathers to a brown or straw-brown colour. Minute feldspar porphyroblasts are sparsely scattered through the leptite and it is a common occurrence for a specimen not to contain a single visible porphyroblast.

In the Sand Spruit, immediately above its junction with the Kafferskraal Spruit, the leptite has a brick-red colour and contains a fine-grained, partially decomposed, somewhat ochreous inclusion measuring approximately 8 feet by 3 feet. The latter is less weather resistant than the leptite and may represent a remnant

of/..................

of shale, as angular, clastic quartz grains embedded in a limonitic groundmass can easily be distinguished in thin sections of this rock.

In this locality anastomosing granitic veinlets up to 2½ feet long and up to 1" thick are intrusive into the reddish leptite, and also exhibit a brickred colour similar to that of the surrounding leptite. These granitic veinlets contain pegmatitic portions in which red feldspar, quartz and biotite together occupy an area of not more than 5 square inches. These minerals can readily be distinguished without the aid of a lens.

A small northwest-southeast striking depression at the eastern extremity of the outcrop of leptite is caused by a weathered dolerite dyke. Kuschke (1950, p. 15) has also recorded leptite from approximately the same horizon in the Brits area.

2. Petrography

The leptite is characterized by a remarkable homogeneity throughout and bears a strong resemblance to felsite. Microscopically the rock consists of rather rounded grains of quartz and feldspar of very similar grain-size, varying from 0.02 mm. to 0.24 mm. in cross-section with an average of approximately 0.07 mm.

TABLE I: MODAL COMPOSITION OF TYPICAL LEPTITE FROM HALF-A-MILE WEST OF THE SAND SPRUIT ON KAMEELFONTEIN 51.

Mineral	Modal Composition
Plagioclase	32
Quartz	49
Hornblende	19
Ore	Accessory

In the calculation of the mode given in Table 1, the S.G. of the feldspar was taken as 2.62.

Measurement/...................

Measurement of the maximum extinction angle by means of the Universal Stage, carried out on the unaltered parts of feldspar porphyroblasts proved the latter to be albite.

According to Kuschke (1950, p. 16), microcline is the dominant feldspar in leptites from the Brits area. The feldspar, constituting the matrix of the leptite under consideration is plagioclase according to etching tests (Gabriel and Cox, 1929, p. 290.) It is turbid in virtually all cases and this fact, together with the relatively minute dimensions of the grains, renders determination by ordinary optical methods impossible.

With regard to the porphyroblasts of albite, Harker (1950, p. 243) states in connection with sediments rich in clastic grains of sodic feldspar, that the "recrystallization gives rise to pellucid grains of untwinned albite, with a strong tendency to prophyroblastic development, and usually enclosing numerous granules of magnetite". Pleochroic green hornblende is present as minute, feathery individuals similar in grain-size to the quartz, and together with the magnetite dust, in all probability accounts for the dark colour of the rock.

Macroscopically the leptite bears a remarkable resemblance to felsite, and although field observations sometimes suggest this to be the case, microscopical study of the leptite reveals inter alia, that the latter contains too high a proportion of quartz to be mistaken for felsite. As the available time did permit a chemical analysis of the rock to be made, other methods had to be sought whereby a comparison could be drawn between the quartz content of the leptite and felsite. Accordingly, the modal composition of leptite was compared with the norm of felsite (Lombaard, 1933, p. 151) in Table II. Hornblende and ore, naturally, do not enter into the discussion.

Table II/.............

TABLE II: QUARTZ TO FELDSPAR RATIOS OF LEPTITE AND FELSITE.

	A. Mode	B. Norm
Feldspar	32	64.05
Quartz	49	26.40
Quartz: Feldspar	1.5 : 1	0.4:1

A. Leptite, from Sjambok Zyn Kraal 52.

B. Felsite from Springfontein No. 351, Pretoria District, quoted from Lombaard (1933, p. 151).

As is evident from TABLE II, leptite has an appreciably higher quartz to feldspar ratio than the felsite, namely 1.5 to 1 and 0.4 to 1, respectively. It is thus obvious that the leptite contains proportionately almost four times as much quartz as the felsite and consequently the possibility of regarding the former rock as a felsite, is excluded.

3. Geological Relationship.

Granitic rocks of the Upper Zone are intrusive into the leptite and consequently the latter is often found as inclusions in the granite, especially in the area along the Sand and Kaffers-kraal Spruits, near their junction with one another.

The granite thus clearly postdates leptite in this area.

Although leptite and quartzite, the latter belonging to the Northern Zone of Xenoliths, frequently outcrop in close proximity to one another (the junction as a rule being readily traceable in the field), the actual contact is never exposed. At one of these points, namely immediately to the south of Hebron, the two rock-types concerned outcrop to within a yard of one another and the impression gained is not one of a gradual transition from quartzite to leptite, but rather one of a comparatively rapid passage from one rock to the other.

It/..........

It appears reasonable to assume therefore, that the leptite does not represent a straightforward feldspathized quartzite, in which case a gradual transition of quartzite to leptite is to be expected, but much rather a metamorphosed shaly rock, which had originally possessed a sharp contact towards the quartzite (sandstone).

It must, however, be emphasized that in thin section, many of the quartz grains constituting the quartzite are replaced by microperthite. Minute ablong to rounded areas of quartz which have escaped feldspathization, are completely enveloped by microperthite, frequently in a manner recalling granophyric intergrowth.

At the eastern extremity of the leptite occurrence, the outcrop terminates abruptly against granophyre and the junction is covered by an overburden of talus and soil.

VI. THE BUSHVELD IGNEOUS COMPLEX.

The rocks of the Bushveld Igneous Complex may conveniently be divided into three groups according to the quartz and olivine content of the respective rock-types. In addition there are hybrid rocks. The various groups, arranged in descending order of age, are:-

D. Quartz-bearing Rocks . . . . (2. Granite; 1. Granophyre.

C. Olivine-bearing Rocks . . . . (Dunite.

B. Gabbroidal Rocks . . . . (Gabbro and Norite.

A. Hybrid Rocks.

A. Hybrid Rocks.

1. Field Observations.

On the northern part of Middelwater 589 an outcrop of hybrid rock occupies an area of approximately 400 yards by 110 yards. Along the northern boundary of the outcrop, the rock grades into

quartzite/........

Plate 7.

Streaky appearance of quartzite on Middelwater 589. The dip of the "streaks" is to the ~~left~~ right i.e. north.

Plate 8.

Streaky appearance of the hybrid rock disturbed as a result of partial mobilization.

quartzite and along the southern boundary into diabase, in such a manner that no sharp contact can be distinguished between the rocks concerned.

The quartzite into which the hybrid rock grades has a streaky appearance due to the selective weathering of certain layers (Plate 7), resulting in small, roughly parallel ridges on the surface of the rock. The latter tends to weather into spheroidal blocks rather resembling weathered igneous rocks. The streakiness in the quartzite conforms to the dip of the Southern Zone of Quartzite Xenoliths i.e. approximately 36° to the north.

2. Petrography.

The hybrid rock is medium-grained, leucocratic to mesotype on a fresh surface.

TABLE III: VOLUME COMPOSITION OF HYBRID ROCK FROM MIDDELWATER 589.

Mineral.	% Comp.
Plagioclase	39%
Quartz	31%
Orthopyroxene	24%
Clinopyroxene	1%
Ore	3%
Biotite	2%

The most abundant mineral is saussuritized feldspar which is present as much clouded, well-defined, oval to elongated grains of average length 0.27 mm. Anhedral grains of bronzite ($2V_{\alpha} = 61^{\circ}$) have an average longest dimension of 1.2 mm. The quartz grains enclose orthopyroxene poikiloblastically and have an average longest dimension of 0.04 mm.

Accessories are monoclinic pyroxene, biotite, hornblende and small grains of zoisite showing an anomalous blue colour.

A/................

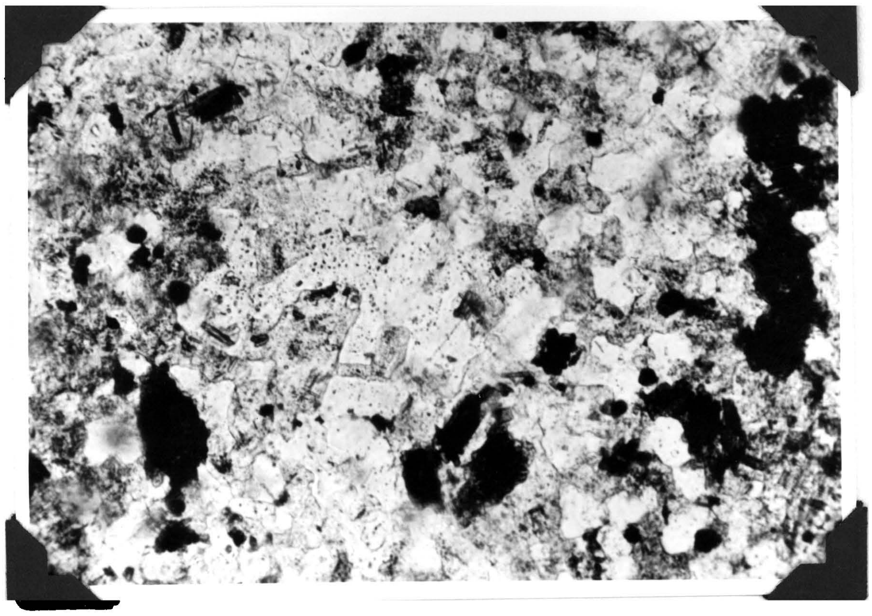

Plate 9.

Leptite showing quartz (white), feldspar (grey), hornblende (large dark areas) and ore (smaller rounded grains).

Ordinary light X 30

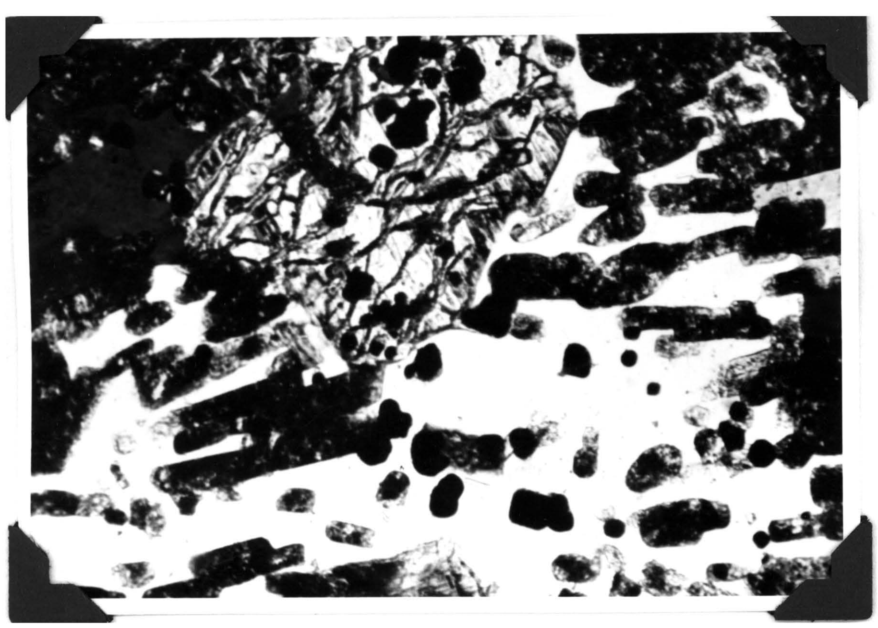

Plate 10.

Hybrid rock showing quartz (white), rhombic pyroxene (upper centre), altered feldspar (elongated grains) and ore (black rounded grains).

Crossed nicols X 30

A higher concentration of micaceous minerals and pyroboles in certain zones of the quartzite causes the macroscopically visible streaky appearance illustrated in plates 8 and 7.

The micaceous minerals also show a planar arrangement which, according to Harker (1950, p. 153), indicates that "there has been a great compression of the rock in the direction perpendicular to the cleavage planes". In the case under consideration the structure of the quartzite did not reach the stage of well-developed cleavage planes. Billings (1950, p. 218), in connection with bedding cleavage, states that "this type of deformation may be due to the upward pressure of magma more or less perpendicular to the bedding".

The latter explanation appears to be a close approximation to the actual conditions which existed in this case and which resulted in the planar structure of the quartzite on Middelwater 589. The upward pressure perpendicular to the bedding planes would presumably have been caused by the intrusion of diabase which outcrops immediately south of the hybrid rock.

B. Gabbroidal Rocks.

1. Gabbro and Norite.

(a) Mineral Composition.

The common gabbro is a medium to coarse-grained, leucocratic to mesotype rock, exhibiting a greyish to greyish-black colour on fresh surfaces, depending on the proportion of salic to mafic elements in the rock, which in most cases implies the proportion of feldspar to rhombic and monoclinic pyroxenes respectively.

The gabbroidal group in this area includes besides gabbro and norite also mottled anorthosites and spotted anorthosites. The mineralogical composition of rocks belonging to the gabbroic group of the Bushveld Igneous Complex is given in Table IV (p.25), which represents data on a profile extending from the Critical Zone up to the Upper Zone. This profile extends across parts of the farms Strydfontein 630 and Klipfontein 482 as indicated on the accompa-

TABLE IV. DATA ON THE ROCKS OF THE KLIPFONTEIN PROFILE.

No.	Horizontal distance in yards from Southern Quartzite Zone.	Percentage by Volume.						Pr-Val.	Rhombic Pyroxenes.			Zonal name according to Niggli.
		Plagioclase.	Rhombic Pyroxene.	Monoclinic Pyroxene.	Quartz.	Biotite.	Ore.		$n'\alpha$ $\pm .002$	$n'\gamma$ $\pm .002$	$2V_\alpha$	
M 32c	6300	85	6	8	1	A	-	.42				Leuco-gabbro
M 32b	6300	80	15	3	2	A	-	.44			54°	Leuco-norite
M 32a	6300	85	5	9	1	A	-	.36				Leuco-gabbro
M 31c	5500	77	12	11	-	-	-	.52			52°	Leuco-norite
M 31b	5500	72	14	14	-	-	A	.50				Leuco-norite
M 31a	5500	73	15	12	A*	-	A	.55				Leuco-norite
M 30	4900	74	15	10	1	-	A	.60			51°	Leuco-norite
M 29	3100	80	5	13	1	1	-	.28			51°	Leuco-gabbro
M 49	2200	69	15	14	3	A	A	.50	1.695	1.708	50°	Leuco-norite
M 51	2000	53	23	20	3	1	A	.53	1.696	1.707	55°	-Norite
		INFERRED POSITION OF MERENSKY REEF.										
M 52	1750	65	8	22	4	2	A	.24	1.691	1.703	54°	Leuco-gabbro
M 53	1580	61	7	28	2	2	A	.20	1.692	1.706	59°	Leuco-gabbro
M 55	1120	67	13	14	5	1	A	.48	1.702	1.714	50°	Leuco-gabbro
M 56	930	78	5	13	2	2	A	.28	1.697	1.709	53°	Leuco-gabbro
M 57	700	43	30	21	4	A	-	.58	1.693	1.707	55°	Norite
M 27	580	60	30	8	2	A	A	.79	1.677	1.692	73°	Leuco-norite

nying map, and is conveniently referred to as the "Klipfontein Profile".

The feldspar content of the most common rocks of the gabbroidal group averages 70% by volume, and ranges from 43% to 85% by volume.

Rhombic and monoclinic pyroxenes average 13 and 14% by volume respectively, of the gabbroidal rocks.

Accessories are quartz, which is sometimes present in quantities up to 5*% by volume, biotite and ore. Biotite and ore together rarely exceed 2% by volume and as a rule are present in much smaller quantities or entirely absent.

(i) Feldspar.

The classification adopted for plagioclase feldspars in this treatise is that proposed by Kennedy (1947, p. 561) and the percentages of anorthite are by weight.

Accordingly, the polysinthetically twinned plagioclase feldspars of the gabbroidal rocks in the area, range from andesine (ab_{55} an_{45}) through labrodorite (ab_{50} an_{50} - ab_{30} an_{70}) to bytownite (ab_{30} an_{80}), falling for the greater part within the labradorite field. Little or no zoning was observed and only one case of a bent feldspar grain, namely that in a specimen (M 30) collected several hundred yards west of the homestead on Klipfontein 482. The zonally built feldspar grain encountered in the same thin section (M 30), proved to have the mantle (ab_{42} an_{58}) richer in albite than the core (ab_{36} An_{64}). Fresh feldspar grains are the rule.

Microstructures resembling a very finely developed form of micropegmatite, are present within certain plagioclase feldspar grains and although these "intergrowths" never attain any degree

of/..............

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* This high value is usually found in the vicinity of quartzite xenoliths and is probably largely due to contamination of the gabbro by the quartzite.

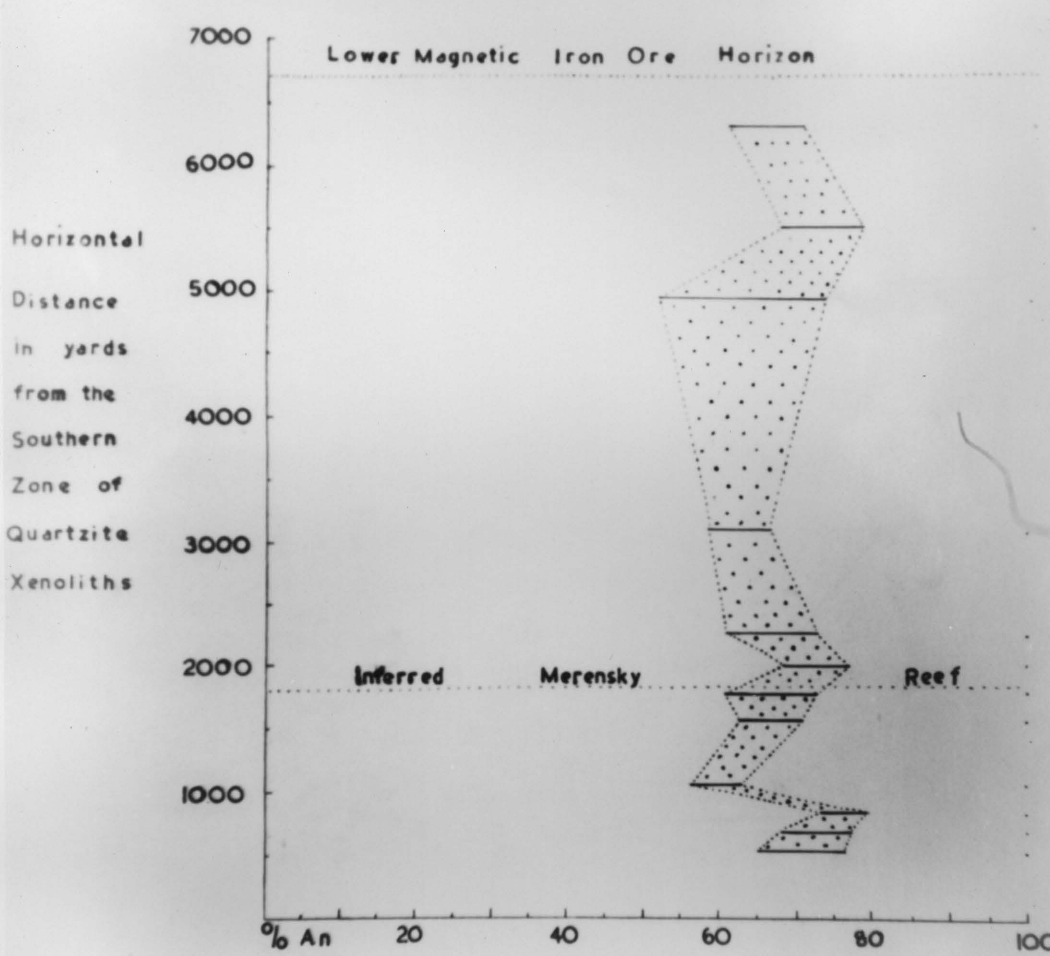

FIG. 1
VARIATION IN ANORTHITE CONTENT OF ROCKS
OF THE KLIPFONTEIN PROFILE

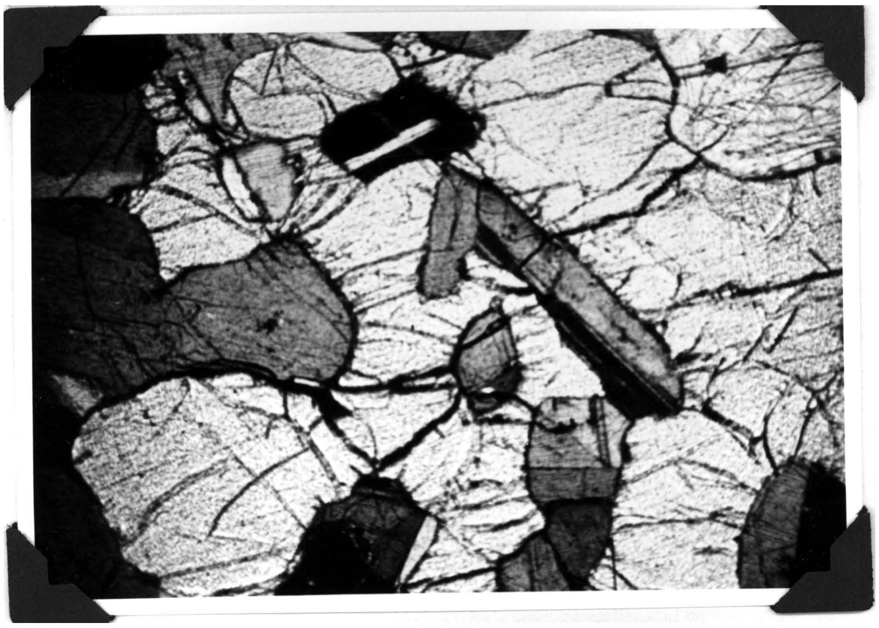

Plate 11.

Norite, showing rhombic pyroxene (center) partially penetrated by Plagioclase laths resulting in a sub-ophitic texture.

Crossed Nicols X 30.

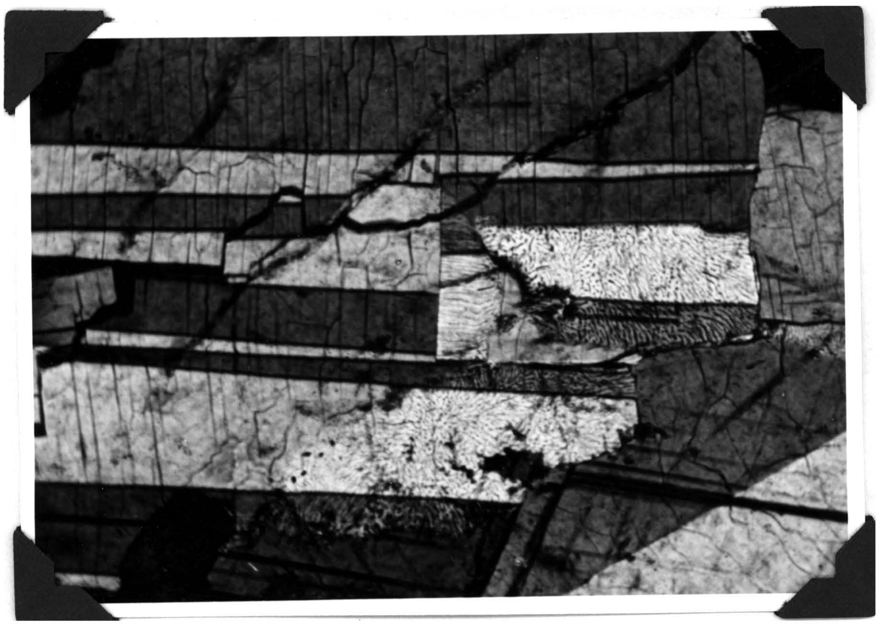

Plate 12.

Plagioclase showing "intergrowths", which have no visible relation to twinning.

Crossed Nicols. X 30.

of prominence, they attain their best development in the Pyramid Hills Horizon. The phenomenon is illustrated in plate 12 and is of too minute a character to permit determination by ordinary optical methods. Steyn (1950, p. 13) recorded similar structures from the vicinity of Magnet Heights. In his specimens the structures were better developed and it was spectroscopically determined that the "intergrowths" contained no quartz and appeared to consist of two plagioclase components differing in anorthite content. No system seems to govern the distribution of these microstructures, a fact which is obvious from the following considerations:-

(a) a feldspar grain may show "intergrowths" on any part of it or along the edges only,

(b) a grain of feldspar may lie adjacent to others showing no such structures and

(c) the phenomenon does not bear any apparent relationship to the twinning planes and does not disturb the twinning of individuals in any obvious manner.

Perusal of fig. 1 (p. 37) reveals an oscillatory variation in the anorthite content of the plagioclase feldspars of rocks belonging to the gabbroidal group. This oscillatory variation is especially marked in the Critical Zone.

The writer agrees with Kuschke (1939, p. 77) in this connection, who, in his treatment of the Critical Zone in the Lydenburg area, states that this oscillatory variation is due to separate heaves of magma differing somewhat from one another in composition.

Except for their presence in the upper horizons of the Upper Zone, alkali feldspars are completely absent from the gabbroidal rocks of the Main and Critical Zones.

(ii)/.................

(ii) Pyroxenes.

Both rhombic and monoclinic pyroxenes are present in the gabbroidal rocks of the Bushveld Igneous Complex in the area under discussion. Fig. 2 (p.31) is a graphic representation of the relative abundance of the respective pyroxenes by volume, at varying pseudostratigraphical heights, in rocks of the Klipfontein Profile.

In the lower 400 feet of the Critical Zone there is a marked predominance of rhombic over monoclinic pyroxene whereas the remainder of this Zone is characterized by a rapid oscillatory variation in the mineralogical composition of the rocks. In contrast to the Critical Zone, mineralogical variation in the Main Zone is of a much less rapid character and generally more uniform.

(α) Rhombic Pyroxenes.

The classification here adopted for the rhombic pyroxenes is that proposed by Poldevaart (1950, p. 1067), which is similar to the decimal classification employed for other 'continuous' series of solid solutions such as the olivines and plagioclase feldspars. As a rule rhombic pyroxenes from the area under discussion are characterized by irregular cracks which extend across the grains, apart from the more common prismatic cleavages.

Two conventional crystallographic orientations of rhombic pyroxenes exist at present, namely those of Dana (1909, p.344) and of Groth (Niggli, 1926, p. 273). The difference between the two is that the a- and b-axes are interchanged. According to the orientation of Groth (see fig. 4) the true acute angle (88°) between (110) and $(1\bar{1}0)$ is bisected by the trace of the a-axis, whereas this trace bisects the true obtuse angle (92°) in the case of the orientation of Dana.

The differences are also in evidence from the following considerations:-

Groth/..............

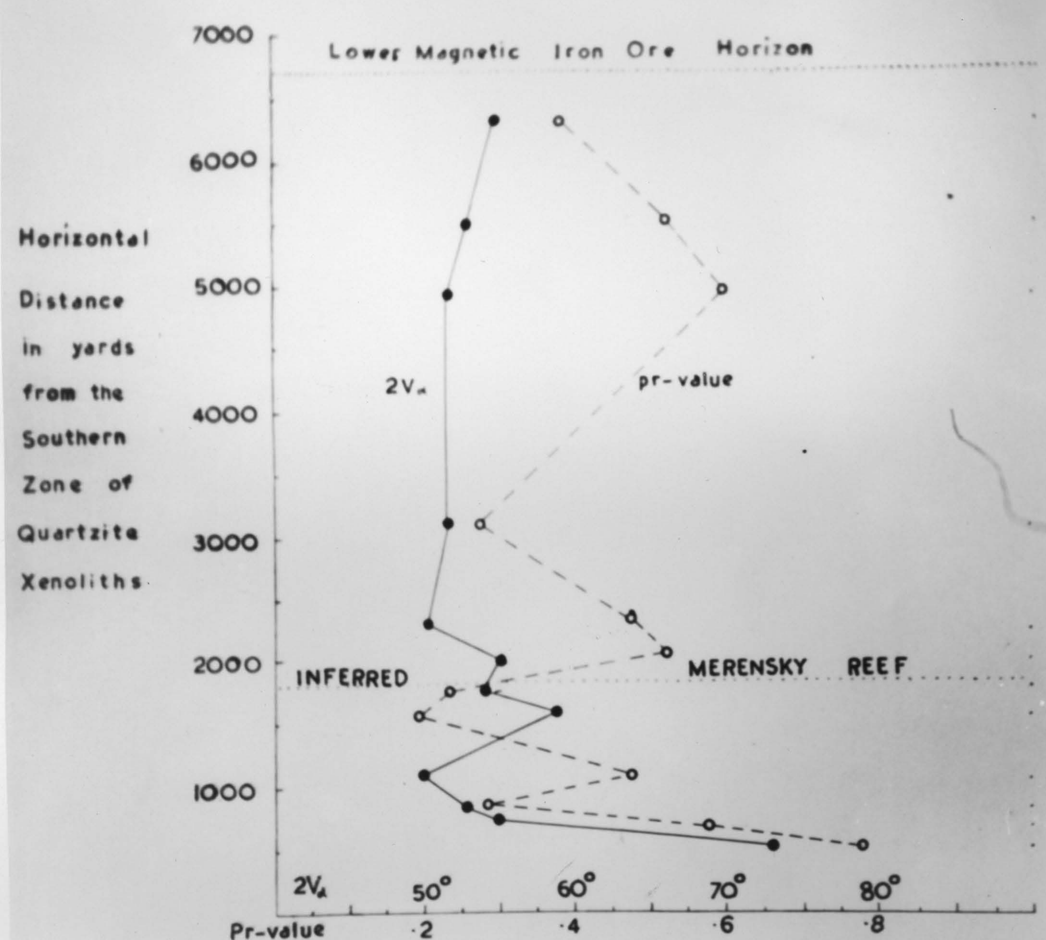

FIG. 2

VARIATION OF 2Vα OF RHOMBIC PYROXENES & Pr-VALUES OF ROCKS OF THE KLIPFONTEIN PROFILE

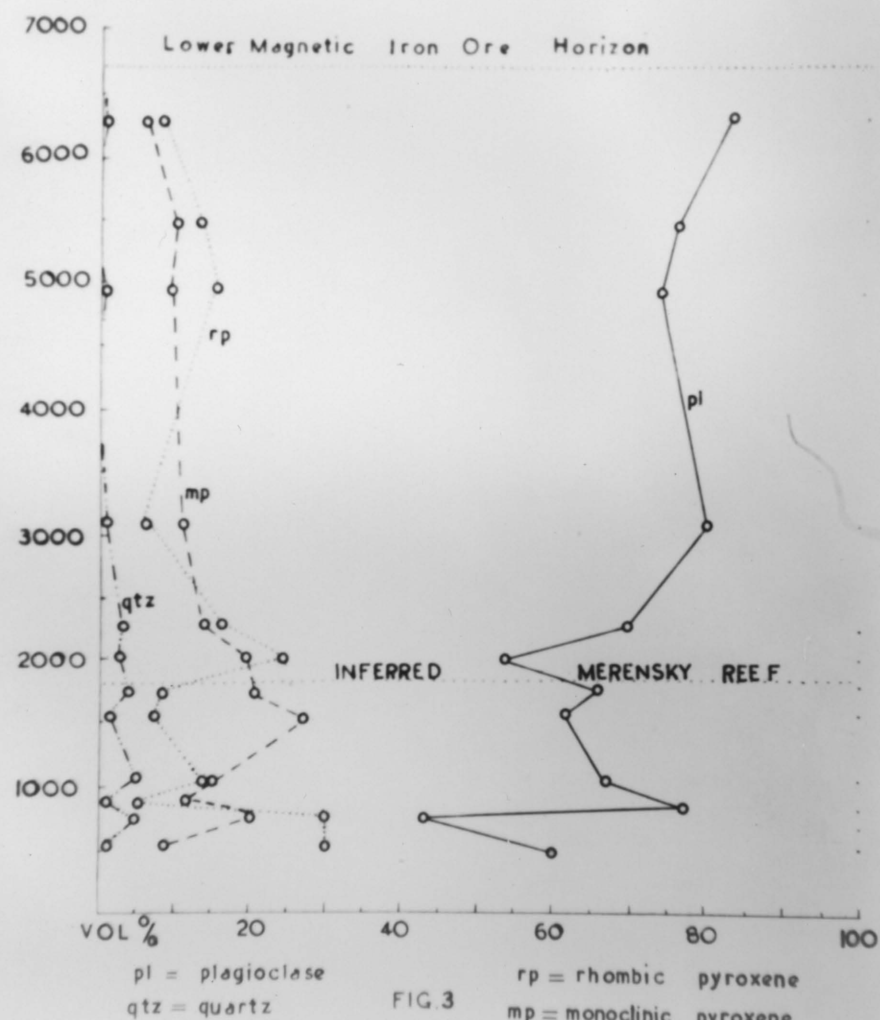

FIG. 3

QUANTITATIVE MINERALOGICAL COMPOSITION OF ROCKS OF THE KLIPFONTEIN PROFILE

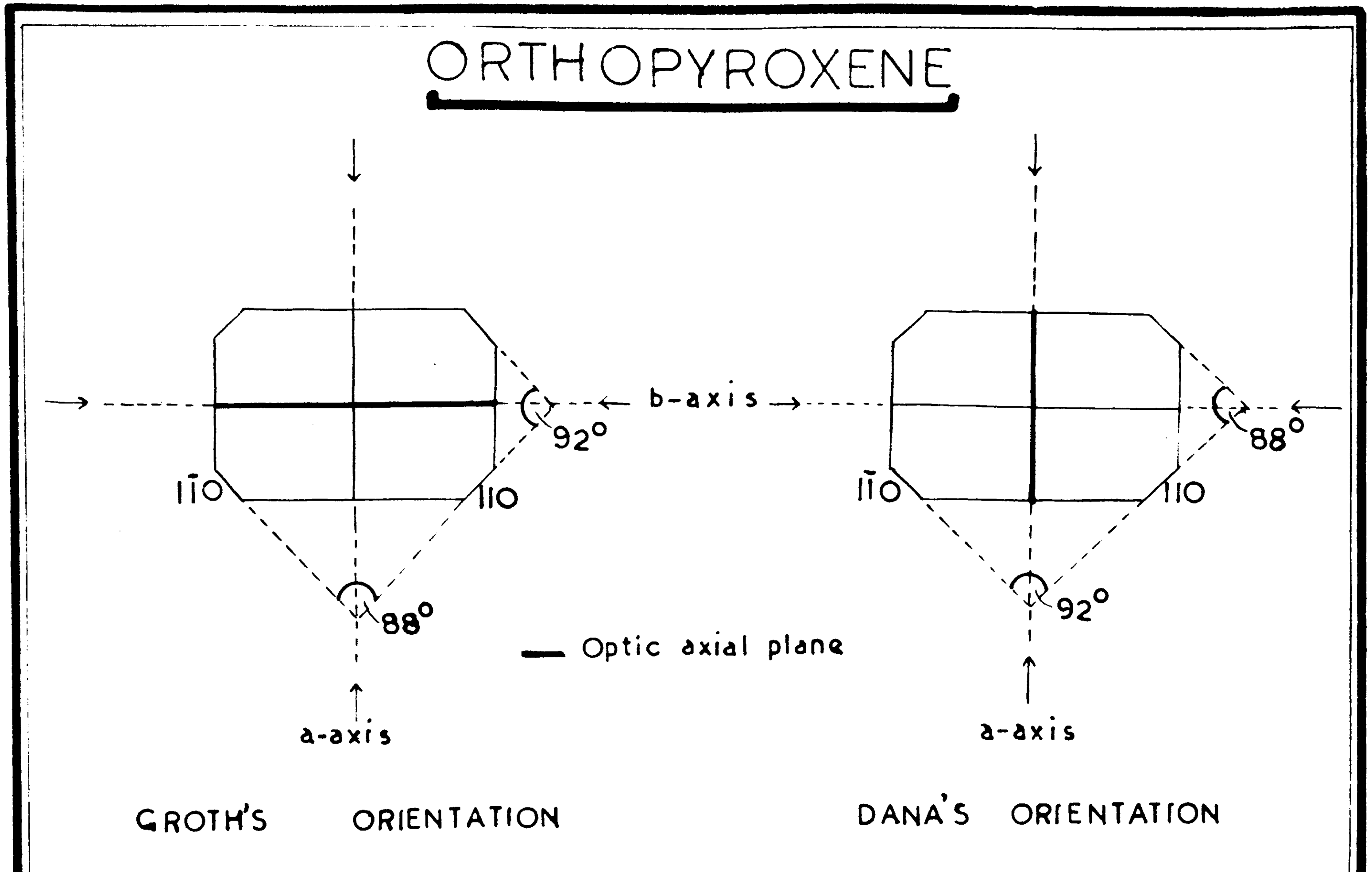

FIG. 4

M. v. R. Steyn

GROTH.	DANA.
a:b:c = 1.031 : 1 : 0.5880	a:b:c = 0.970 : 1 : 0.571
i.e. $c<b<a$	i.e. $c<a<b$

The unit cell dimensions of rhombic pyroxenes is as follows:-

$$a_o = 18.2\ A^o$$
$$b_o = 8.86\ A^o$$
$$c_o = 5.20\ A^o$$

i.e. $c<b<a$

From this the axial ratio is deduced, namely

$$a:b:c = 2.055 : 1 : 0.5885$$

This ratio corresponds closely to that of Groth, with the exception of the a-axes. The difference in the respective values of the latter was caused originally by the incorrect assumption of the unit face of the rhombic pyroxene. It is thus evident from the above, that the orientation of Groth is the more correct one to adopt, a fact which is adhered to in petrographical descriptions given in this treatise. Consequently, the optic axial plane of the rhombic pyroxenes is parallel to (100).

The well-known lamellar structure (plate 13), present in the rhombic pyroxenes, has previously been encountered by practically all who have examined the gabbroidal rocks of the Bushveld Igneous Complex, inter alia Kuschke (1939, p. 61), Vermaas (1949, p. 30), Lombaard (1934, p. 20), Nel (1939, p. 46) and Steyn (1950, p. 15).

This phenomenon is clearly visible only in sections cut normal to the axial plane. The lamellae often do not extend right up to the crystal edges but pinch out before reaching it. In this way a peripheral zone with feeble or without any lamellation is developed, a fact previously noted by Nel (1939, p. 46). A specimen from the northern part of Strydfontein 630 contains an orthopyroxene grain in which the lamellae are slightly bent.

The /...........

Plate 13.

Lamellar structure in orthopyroxene (center of field), surrounded by plagioclase.

Crossed nicols. X 30

Plate 14.

Core of Rhombic pyroxene surrounded by mantle of Monoclinic pyroxene.

Crossed nicols. X 30.

The optic axial angle ($2V\alpha$), is readily determined on sections in which lamellar structure is present, provided the lamellae are vertically orientated. The section is merely rotated in a horizontal plane until the striations are parallel to the north-south cross-hair, whereby the optic axial plane becomes parallel to the plane of rotation of the K-drum of the Universal Stage and the optic axial angle can be determined by rotating this drum.

(ii) Monoclinic pyroxene.

Diallage, exhibiting the (100) parting, is usually present. Simple twins on (100) often show the characteristic herring-bone structure. The optic axial plane is always parallel to (010) and the mineral sometimes shows a faint green pleochroism. The optic axial angle ($2V\gamma$) of this pyroxene varies from 54° to 63° and the extinction angle γ/c from 38° to 49°. These properties indicate a composition of approximately Wo_{42} En_{36} Fs_{22}, (Wager and Deer, 1939, p.241) although the axial angle of the pyroxene is somewhat high.

The mineral maintains an average of 17% by volume in the gabbroidal rocks of the Main and Critical Zones and never exceeds 28 per cent by volume. Monoclinic pyroxene is sometimes found as a mantle surrounding a core of rhombic pyroxene, in the manner indicated by plate 14.

(iii) Accessories.

Uralite is a common accessory and pyroxenes are met with in all stages of uralitization. This is especially marked in the vicinity of the dunite bodies. Quartz is interstitial and locally present in quantities up to 5% by volume, though its somewhat high value is only encountered in close proximity to the Southern Zone of Quartzite Xenoliths and, no doubt, due largely to contamination by the latter. Biotite is present interstitially in small but variable quantities in the gabbroidal rocks of the Bushveld Igneous Complex. This mineral varies in relative quantities from zero to 2% by volume, although the average is less than 0.75% by volume. As a rule ore does not exceed 0.5% by volume of the rocks examined and is usually present in much smaller amounts or entirely absent.

2. THE DISTRIBUTION OF THE PETROGRAPHICAL ZONES OF THE BUSHVELD IGNEOUS COMPLEX.

The gabbroidal rocks of the Bushveld Igneous Complex occupy an east-west striking belt of country averaging 5 miles in surface width and gradually increasing in width towards the west. The dip of pseudo-stratification, where determineable has an average value of 17° to the north, thus conforming in general direction to the dip of the Southern Zone of Quartzite Xenoliths and also to that of the Magaliesberg quartzite situated beyond the southern boundary of the area surveyed.

(a) Critical Zone.

In view of the fact that the rocks situated to the south of the Southern Zone of Quartzite Xenoliths are diabasic (Nel 1939, p. 39), the only possible position of the base of the Critical Zone is immediately to the north of this quartzite zone.

(i) Chill Zone.

In this area the base of the Critical Zone is formed by a fine-grained, melanocratic rock, representing a chilled variety of gabbro. The latter can be traced to the north of and along almost the entire strike of the Southern Quartzite Zone. Owing to lack of suitable outcrops neither the exact surface width nor the precise relationship of the chilled rock to the underlying quartzite could be determined. No veining of the quartzite by the chilled gabbro was noticed and the surface width of the latter is approximately 500 feet or slightly more as on the western part of Hartebeesthoek 524. Small quartzite remnants having maximum dimensions about 1" x 3" are often present as inclusions in the fine-grained rock and usually stand out in relief on a

weathered/.............

weathered surface. Small black specks of magnetite, which vary from approximately 0.5 - 4 mm. in diameter show a similar marked relief.

In thin section the rock is beautifully fresh and composed of polysinthetically twinned plagioclase, pyroxene and scattered blebs of magnetite. The plagioclase varies in length from 0.21 mm. to 1.37 mm., averaging about 0.6 mm. The composition is labrodorite (Ab_{36} An_{64}) and the mineral is often poikilitically enclosed by pyroxene, giving rise to an ophitic texture. The pyroxene is predominantly monoclinic, has an average diameter of 0.6 mm. and the following optical properties:-

$$2V_{\gamma} = 62^{\circ}$$
$$\gamma/c = 48^{\circ}$$
$$n'_{\alpha} = 1.693 \pm .002$$
$$n_{\beta} = 1.699 \pm .002$$
$$n'_{\gamma} = 1.720 \pm .002.$$

The mineral is thus a member of the diopside-hedenbergite series (Winchell 1951, p. 410), with the composition of Di_{45}, though the axial angle 2V and the extinction angle γ/c are both somewhat high. Salite structure is common and "herringbone" twins occasionally present. Larger hypersthene* individuals of average diameter 2.1 mm. and showing the characteristic pink pleochroism, are less common than monoclinic pyroxenes. In certain cases, as for example near the western boundary of Hartebeesthoek 524, biotite, exhibiting a marked brown pleochroism is invariably associated with the ore.

The rock of which two chemical analyses are given in Table V, may be described as a fine-grained hypersthene gabbro.

* The mineralogical properties of the hypersthene occurring in the chilled gabbro, have already been dealt with by Nel, (1940, p. 59).

Table V/...................

TABLE V.

	I.	II.	III.	IV.
SiO_2	51.54	50.30	52.70	49.70
TiO_2	0.34	2.15	0.15	0.25
Al_2O_3	18.67	15.02	21.05	23.20
Cr_2O_3	-	-	-	0.07
Fe_2O_3	0.28	2.63	0.50	0.92
FeO	9.04	8.64	5.80	4.02
MnO	0.47	0.17	-	0.09
MgO	6.84	7.43	4.20	5.46
CaO	10.95	10.49	12.60	12.32
Na_2O	1.58	2.02	2.10	2.43
K_2O	0.14	0.28	0.30	0.89
P_2O_5	0.09	0.16	0.20	0.08
CO_2	-	-	-	0.20
H_2O^+	0.34	0.33	0.05	0.68
H_2O^-	0.03	-	-	0.10 + Sulphides 0.06
	100.22	99.60	100.10	100.50

I. Norite, chilled floor phase; Zilikaatsnek 79.
Analyst: C. J. Liebenberg.
Quoted from Nel, 1939, p. 53.

II. Norite, chilled floor phase, one mile south of Sjambok Siding.
Analyst: E. G. Radley.
Quoted from Hall, 1932, p. 727.

III. Norite, Bon Accord Quarry, north of Pretoria.
Analyst: H. G. Weall
Quoted from Hall, 1932, p. 304.

IV. Fine-grained footwall Norite, Zwartfontein North, Potgietersrust district.
Analyst: L. Möser.
Quoted from Hall, 1932, p.304.

For/..................

For the purpose of comparison two more chemical analyses are given, namely one of the common Pyramid norite and another of a fine-grained footwall norite from the Potgietersrust district. The Analyses of chilled norite (Nos. I, II and IV, Table V), show a high degree of uniformity and are also similar to that of the Bon Accord norite (No. III, Table V). The main points of difference are the slight variations which occur in the iron and magnesia contents of the various rocks.

Field relationships of the chilled basal portion of the Critical Zone and its close resemblance chemically to the Pyramid norite, suggest that the chilled gabbro represents a rapidly cooled and consequently less differentiated phase of the original magma, as previously suggested by Hall (1932, p. 310).

(ii) Main Occurrence of the Critical Zone.

(a) Field observations.

As a rule outcrops are scarce in the Critical Zone and where present rarely protrude above the surrounding grassveld. The pseudostratification dips at angles varying from 15° to 20° to the north. Outcrops are fresh as a rule, though in some cases the zone of weathering extends downwards for about 25 feet as for example in a railway cutting on the southern part of Klipfontein 482.

Just above the chill zone, quartz grains occur as small protrusions on weathered surfaces of the medium-grained gabbroic rocks. A specimen of the latter from Strydfontein 606 contains, in addition to quartz, a bleb of sulphide and a grain of biotite both approximately 1.5 mm. in diameter.

Rhythmical layering, in which alternating leucocratic and melanocratic bands are present, occur on the southern part of Klipfontein 482. In the bed of the Sand Spruit on Strydfontein 606, various differentiated rock-types are present (see plate 15). The nomenclature used in describing these rocks is essentially similar to that defined by Hall (1929, p. 299), in his memoir on the Bushveld Igneous Complex.

The/............

Plate 15.

Anorthositic Norite overlying norite in the Sand Spruit on Strydfontein 606.

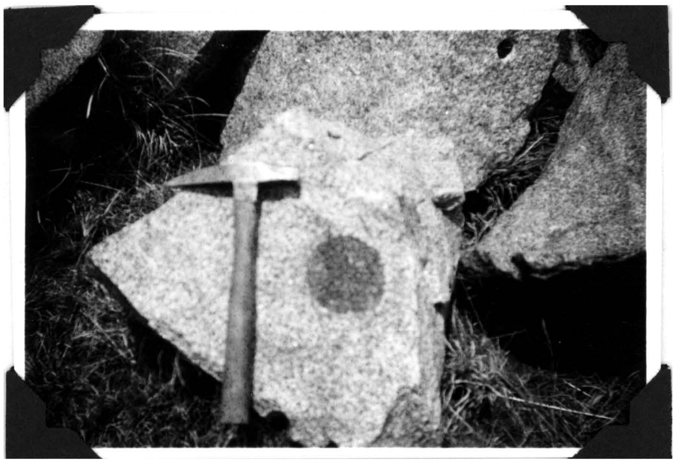

Plate 16.

Circular pyroxenitic segregation in norite on Strydfontein 630.

The succession, in assending pseudostratigraphical sequence, is therefore evengrained, spotted norite overlain by an anorthositic layer containing scattered pyroxene 'clots'. This is followed by mottled anorthosite and coarser spotted norite. The former is described by Hall as ....."a variety that is characterized by relatively large, irregular clusters of pyroxene crystals scattered more or less at random. On a fresh fracture the clusters show broken outlines and are indicated by darker, shadowy areas of such dimensions that two or at most three would in general fall within the limit of a handspecimen".

Wells (1952, p. 923), after a detailed petrographical study of the mottled anorthosite, states that the dark clots might represent either cognate xenoliths of a pyroxenitic rock or pockets of residua trapped in a plagioclase crystal mush.

The spotted norite is defined by Hall as ...."those varieties of norite in which the ferromagnesian element (rhombic pyroxene) is distributed more or less uniformly in the form of dark grey, rounded crystals throughout the rock, in sharp contrast to the intervening light-coloured, feldspathic areas. The diameter of pyroxene grains ranges for the most part between 1 and 5 mm., but is fairly constant for a given rock, while the distance across the feldspathic portions separating two neighbouring grains of pyroxene is as a rule several times that of the diameter of such grains".

The outcropsin the Sand Spruit consist solely of waterworn and exfoliated boulders and owing to their irregular and scattered distribution the determination of thicknesses of the various layers is rendered difficult and in most cases impossible. The majority of the layers appear to be several yards thick. Immediately south of Hornsnek siding the spotted norite contains a limited number of perfectly circular segregations of rhombic pyroxene varying from 2" to 6" in diameter (see plate 16). Lenses of fine-grained, pyroxenitic material several square feet in extent are also present in this vicinity and may represent

xenoliths/.......

xenoliths of pre-existing pyroxenite.

(5) Microscopical Features.

The mineralogical variation of the rocks belonging to the Critical Zone is given in Table V, specimens M 52 to M 57 and M 27.

In thin section the spotted norite is composed of interlocking, subhedral plagioclase feldspar grains and anhedrous of hypersthene. Monoclinic pyroxene is scarce and the texture of the rock is ophitic to subophitic. The mineralogical variation of both feldspars and pyroxenes is of an oscillatory nature (see figs. 2 and 3).

The feldspar is invariably polysinthetically twinned plagioclase, unaltered as a rule and without any zonal structure. The latter has an average value of 61% by volume of the rocks of the Critical Zone and varies in anorthite content from Ab_{47} An_{53} to Ab_{26} An_{74} i.e. from Labradorite to Bytownite. The variation in the anorthite content of different grains in the same thin section rarely exceeds 15% and is much less as a rule. Labradorite from spotted norite occurring on Strydfontein 630 has the following refractive indices:

$$n'_\alpha = 1.562 \pm .003$$

$$n_\beta = 1.564 \pm .002$$

$$n'_\gamma = 1.568 \pm .003$$

These indices indicate a composition of Ab_{37} An_{63} or Labradorite.

The rhombic pyroxene constitutes an average of 16% by volume of the rocks of the Critical Zone. The optic axial angle $2V_\alpha$ varies from 68° to 50°, corresponding to an FeO-content of 25% and 35% (molec.) respectively. In only one instance was an unusually high axial angle $2V_\alpha$ obtained, namely 72°.

The monoclinic pyroxene maintains an average of 17% by volume of the rocks of the Critical Zone and is diallage as a rule, as previously stated in the introductory paragraph to this

chapter/.........

chapter. The modal variation of the monoclinic pyroxene, like that of rhombic pyroxene, shows an oscillatory variation in the Critical Zone.

In order of abundance the accessory minerals are biotite, quartz and ore. Biotite and quartz do not exceed 2 and 5% by volume respectively of any rock in the Critical Zone.

(iii) Chromitite Horizons.

With regard to the chromitite bands in the Lydenburg area, Kuschke (1939, p. 26), was able to determine that only in the case of the Main Group do the petrographical characters of the associated rocks in any way afford an indication as to the position of the group. As no outcrops of any of the chromitite horizons could be located in the area surveyed, the abovementioned method was resorted to in an attempt to locate the probable position of at least the Main Group. Kuschke was able to demonstrate that the axial angle $2V_\alpha$ of the rhombic pyroxenes always exceeds 80° above the Main Group, whereas below it the value of $2V_\alpha$ seldom if ever exceeds 80° and is generally lower.

If the axial angle be accepted as a criterion, the possibility of this chromitite group being present in the area is ruled out, as the highest value obtained for an axial angle is 76°.

(iv) Merensky Reef.

Although outcrops in the Critical Zone are not exceptionally plentiful in this area, they are nevertheless sufficiently present to furnush a fairly complete if discontinuous section through this Zone. Efforts to locate the Merensky Reef in the area investigated met with little success and petrogaphical evidence did not assist materially in locating the position of the Reef.

Kuschke (1939, p. 73) found that the axial angles ($2V_\alpha$) of the rhombic pyroxenes below the Merensky Reef in the Lydenburg district varied from 73° to 75°, while above the Reef the axial

angles/.........

angles ($2V_\alpha$) were usually lower, namely 70° to 72°.

Schmidt (1952, p. 242) recorded axial angles ($2V_\alpha$) of 78° to 79° for pyroxenes in the rocks immediately below the Merensky Reef in the Rustenburg area. Above the Reef he did not measure axial angles of less than 70°.

In only one instance does the axial angle ($2V_\alpha$) of pyroxenes in the gabbroidal rocks in the area under discussion exceed 70° namely in a specimen (M 27) collected from Strydfontein 630. The possibility of the Merensky Reef occupying this position is unlikely as practically all outcrops of differentiated rocktypes occur above this horizon. It is therefore not possible to decide on the presence of the Merensky Reef from the axial angles ($2V_\alpha$) of rhombic pyroxenes in the rocks either overlying or underlying the Reef (if it does exist) in this area.

The upper limit of the Critical Zone (and base of the Main Zone) was consequently taken to be the point at which the layered rocks cease to be abundant. This point coincides fairly closely with the base of the anorthositic gabbro which as a rule forms the hanging wall of the Merensky Reef (Wagner, 1929, p. 126). Consequently the boundary between the Critical and Main Zones as indicated on the map is only an inferred one.

The mineralogical variation of rocks of the Critical Zone is of the characteristic oscillatory type as figures 2 and 3 serve to indicate, and the general trend agrees with that obtained by Nel (1940, p. 59) which covers only the lower part of the present traverse. The difference between the axial angles ($2V_\alpha$) of rhombic pyroxenes of the uppermost specimen of Nel and the corresponding specimen of the author is probably caused by the fact that lamellar structure and intergrowths in the rhombic pyroxenes of the Critical Zone render accurate determinations of axial angles ($2V_\alpha$) difficult. The axial angles for rocks of the lower part of the traverse were also deduced from the refractive indices (n'_α and n'_γ) of the rhombic pyroxenes (Polderaart 1950,

p. 1067). The latter method was considered to be more accurate and was consequently utilized in the compilation of the variation diagram fig. 2.

As a rule the difference between the measured axial angles ($2V_\alpha$) and deduced axial angles did not exceed 4° and in only one instance was a value of 7° recorded.

(b) Main Zone.

(i) Field observations.

The Main Zone varies in surface width from a little more than 3 miles in the Eastern part of the map to approximately $3\frac{1}{2}$ miles in the West. The Zwartkoppies are formed by rocks belonging to the Main Zone and lie more or less in its center. The country lying between the Zwartkoppies and the granophyre ridges is practically devoid of outcrops, as a result of which this part is best suited for agricultural purposes. In an old quarry situated approximately in the center of Klipfontein 482, rhythmical layering is present in the gabbro as a result of the alternation of bands up to four feet thick which contain a higher or lower proportion of light to dark silicates. The banding conforms in dip to the general pseudostratification of the gabbroic rocks of the area.

Sporadic outcrops of a thin band of pyroxenite occur on Klipfontein 482, as for example the small outcrop some 45 feet in surface width, situated approximately 400 yards south-east of the trigonometrical beacon on that farm and indicated on the map. A pyroxenite band is also present at the same horizon several miles to the east of the area under consideration and is situated stratigraphically immediately below the Pyramid Hills gabbro*. In the area covered by the accompanying map the pyroxenite does not resemble the common type which characterizes the Bushveld Igneous Complex, to a very great extent. On a weathered surface diversely orientated laths of pyroxene up to 1.5 inches in length may readily be distinguished. The nature of the outcrops are such that the

* Personal communication by Dr. H. N. Visser.

genetic relationship of the pyroxenite to the surrounding gabbro could not be established but presumably the pyroxenite band conforms in pseudo-dip to the pseudostratification of the surrounding gabbroidal rocks i.e. approximately 18° to the north. The pyroxenite presumably originated through crystal settling though no direct evidence of this is present. The pseudostratification, which is of the same character as that described by Van den Berg (1946, p. 175 et seq.), is well displayed in a quarry on Klipfontein 482.

Macroscopically, rocks belonging to the Main Zone are characteristically uniform except for the upper horizons below the Lower Magnetic Iron Ore Horizon, at which point mottled anorthosite and spotted norite make their appearance.

On a weathered surface the spotted norite exhibits a pitted appearance due to the more rapid decomposition of the hypersthene grains. The mottled anorthosite is identical to that of the Critical Zone and occurs as lens-shaped bands having thicknesses of several feet. Circular depressions 1 to 1.5 inches in diameter on weathered surfaces are due to the inferior weather-resisting properties of the pyroxene clusters.

In the past there has been some difference of opinion with regard to the position occupied by the bands of magnetic iron ore i.e. whether they belong to the Main or to the Upper Zone. Hall (1932, p. 276) sets the boundary between the Main and Upper Zones at the Lower Magnetic Iron Ore Horizon and other investigators (e.g. Steyn, 1950, p. 46) regard the Lower (Main) Group of Magnetic Iron Ore Bands at least, as belonging to the Main Zone. In this case the appearance of fayalite is regarded as indicating the lower margin of the Upper Zone.

In this treatise it is suggested that the Lower Iron Ore Horizon be taken as the boundary between the Main and the Upper Zones as originally proposed by Hall (op. cit.). Being the most persistent horizon, it forms a useful criterion in the field for the demarcation of the Main and the Upper Zones, whereas a division between the two zones based solely on petrographical characters of the

rocks /

rocks, such as the somewhat erratic appearance of olivine for example, would not always be of much value in the field.

The occurrences of Magnetic Iron Ore will thus be discussed under the Upper Zone.

(ii) Petrography.

The mineralogical composition of rocks representing inter alia a profile across the Main Zone, is given in Table IV (p. 25). specimens M 49 to M 32. The pr.-value, that is the ration of orthopyroxene to the sum of ortho-pyroxene and clino-pyroxene is also given in the table and graphically represented in fig. 2 and 3 (pp. 31 and 32).

The spotted appearance of the spotted norite, which directly underlies the Lower Magnetic Iron Ore Horizon, is due to evenly distributed hypersthene anhedrons with an average longest dimension of 6.1 mm. situated in a feldspathic groundmass. Diallage is scarce. The volume composition of the spotted norite (M 19) from Klipfontein 482, is given in Table VI, (p.48) together with that of the mottled anorthosite (M 18) from the same farm.

In the case of the mottled anorthosite the section was cut through only one of the pyroxene clusters, as it is not possible to obtain more than this number within the same slide.

TABLE VI: COMPOSITION OF SPOTTED NORITE AND MOTTLED ANORTHOSITE FROM KLIPFONTEIN 482.

% by Volume of.	Spotted Norite.	Mottled Anorthosite.
Labradorite	77	70
Rhombic pyroxene	22	2
Monoclinic pyroxene	1	28
Quartz	Accessory	Accessory
Hornblende	-	Accessory

Both/............

Both monoclinic and rhombic pyroxenes are present in the pyroxenite on Klipfontein 482, and that in the ratio of one to five respectively. Lamellar structure as well as exsolution bands of monoclinic pyroxene are characteristic of the rhombic pyroxene. The feldspar of the pyroxenite is of the same average composition as that of the gabbro namely Ab_{30} An_{70} or Labradorite-Bytwonite and constitutes only 5% of the rock by volume.

TABLE VII: COMPOSITION OF PYROXENITE FROM KLIPFONTEIN 482.

Mineral.	Percentage by Volume.
Labradorite	5
Rhombic pyroxene	74
Monoclinic pyroxene	14
Uralite	7
Ore	Accessory
Biotite	-

The rhombic pyroxene has the following properties:-

$$2V_{\alpha} = 62^{\circ}$$

$$n'_{\alpha} = 1.693 \pm .003.$$

$$n_{\beta} = 1.702 \pm .003$$

$$n'_{\gamma} = 1.706 \pm .003$$

? ferrosilite ? mol prop

This indicates an FeO-content of 28% by weight (Poldevaart, 1950, p. 1076).

The feldspar of the gabbroidal rocks forming the greater part of the Main Zone is labradorite varying in anorthite-content from An_{53} to An_{70} and is invariably polysinthetically twinned. The variation in anorthite content is illustrated in fig. 1 (p.27) Labradorite maintains an average volumetric percentage of 67 in the Main Zone and the average length of feldspar grains is approximately 1.84 mm.

Rhombic/..................

Rhombic pyroxene is less abundant in the Main Zone than in the Critical Zone as reflected by the respective average volumetric percentages of the two zones namely 11% and 16%. Axial angles 2V of the rhombic pyroxenes vary from 54° to 51° and thus correspond to an FeO-content of 40% (mol.) and 45% (mol.) respectively (op. cit.).

Monoclinic pyroxene is diallage as a rule, which maintains an average of 11% by volume of the rocks of the Main Zone. With regard to the pyroxene clusters in the mottled anorthosite, this mineral is markedly interstitial, resulting in a true sub-ophitic texture. Often a "core" of rhombic pyroxene is completely enveloped by monoclinic pyroxene, corresponding to the so-called "coronophitic texture" as described by Wells (1952, p. 919), in which clinopyroxene is related to bronzite in a manner recalling corona structure. With reference to the exsolution growths of monoclinic pyroxene in rhombic pyroxene, an extract from a publication by Hess (1941, p. 580 et. seq.) may be worthy of mention.

"In the writer's opinion there is strong evidence to indicate that the hypersthene with orientated plates is pigeonite which has by slow cooling inverted to orthopyroxene". Furthermore he states (page 582) that "it appears that those pigeonites in hypabyssal rocks which crystallized at a temperature very slightly above the inversion temperature have a much greater tendency to invert to hypersthene with oriented inclusions of augite, than do those more iron-rich pigeonites which probably crystallized farther above the inversion temperature."

(c) Upper Zone.

(i) Field Observations.

The Upper Zone varies in surface width from approximately $1\frac{1}{2}$ miles in the eastern part of the area to about $2\frac{1}{2}$ miles in the west. At both the eastern and western extremities of the area the junction with granophyre is covered by a soil overburden which renders an accurate determination of the thickness difficult.

Outcrops/

Outcrops are poor and as a rule confined to the uppermost horizons of this zone. In contrast to the underlying Main Zone, the Upper Zone is characterized by a greater variation of rock-types which are in ascending pseudostratigraphical order gabbro, diorite and alkali-granite.

Outcrops of gabbro are scarce and as a rule the greater part of the Upper Zone is covered by an overburden of black turf. The gabbro, within which the three magnetic iron ore horizons are situated, constitutes approximately 91% of the Upper Zone by volume

Three bands of magnetic iron ore, namely the Lower, Middle and Upper Bands are present, together with several less persistent and lenticular bands. The three Main Bands are subject to some variation in thickness namely from a little more than one foot to approximately 40 feet.

The Lower Band which outcrops most consistently, can be traced intermittently throughout the entire area and extends from the eastern boundary of Klipfontein 482 in a westerly direction to beyond Sjambok Zyn Kraal 52, at which point it attains the greatest thickness namely 40 feet, as calculated from it's surface outcrop and an angle of dip of 25 degrees. Grains of magnetite are abundantly present in the gabbro over a horizontal distance of about 100 feet below the Lower Band and the ore content of the gabbro increases with proximity to the iron ore horizon.

On the central part of Sjambok Zyn Kraal 52 this band has been disturbed, probably by the local intrusion of Bushveld Granite. Two detached masses of magnetic iron ore, approximately 300 feet and 25 feet respectively in length, conform in strike to the Lower Magnetic Iron Ore Horizon but are situated at a slightly lower stratigraphical horizon than the latter. These two detached masses of iron ore clearly have no lateral persistence and terminate abruptly along their strike against the surrounding gabbro. On the western part of Sjambok Zyn Kraal 52 a remnant of gabbro is completely enveloped in iron ore of the Lower Horizon.

No/...................

No contacts are visible and the remnant which contains much magnetite, has a brown colour which on closer examination proves to be [illegible] feldspar.

On the north-eastern part of Klipfontein 482, the Lower Iron Ore Horizon shows a horizontal displacement of some 800 feet, which in all probability also affects the Upper Band as indicated on the accompanying map.

The Middle Magnetic Iron Ore Horizon is less persistent than the Lower one and extends from Syferfontein 310 in the western part of the area to the eastern part of Sjambok Zyn Kraal 52, at a stratigraphical height of approximately 2000 feet above the Lower Iron Ore Band.

The Upper Magnetic Iron Ore Band is the least persistent of the three Horizons at the surface and sporadically outcrops in the eastern part of the area. On Kruisfontein 164 this Horizon is partially covered by grit belonging to the Ecca Series. The Upper Iron Ore Horizon differs somewhat in appearance from the more common type of ore, owing to the fact that the former is partially decomposed to ochreous, limonitic material which envelopes relatively solid grains of magnetite. On Kruisfontein 164 a limonitic band 2 to 3 feet thick has a slight lateral persistence within the Main (Upper) Band. Because of the somewhat disturbed condition of the Upper Band it was not possible to determine the dip with certainty. An indication of strike-faulting within the Upper Band is afforded by slickensides which dip steeply to the north. This movement may possibly be related to the previously mentioned faulting which affected the Lower Iron Ore Horizon.

The only outcrop of diorite of which the author is aware, is situated in the Sand Spruit immediately south of Hebron. At this locality granophyre is intrusive into the diorite (plate 22).

Outcrops of alkali-granite, representing the uppermost horizons of the Upper Zone, occur to the south and south-west of Hebron and are mostly situated close to, and in certain cases adja-

cent/.........

cent to the granophyre. This granite occupies a comparatively continuous strip of country but is also present as isolated outcrops entirely surrounded by leptite. On the greater part of Kruisfontein 164 neither leptite nor granite is represented and the granophyre is directly in contact with gabbro; this contact is not exposed due to an overburden of soil.

The intrusive relationship of granite to leptite is exposed at various localities such as the lower reaches of the Sand Spruit before the junction of the latter with the Kafferskraal Spruit. In this vicinity inclusions of leptite up to several feet in diameter are present in granite of the Upper Zone and the former is also veined by the latter. On a weathered surface the granite has a pitted appearance due to the inferior weather resisting properties of feldspar as compared to hornblende.

(ii) Petrography.

TABLE VIII. MINERALOGICAL COMPOSITION OF ROCKS BELONGING TO THE UPPER ZONE.

Distance in yards from Upper Band of Magnetic Iron Ore.	330	1060	1358	1622
Specimen No. on map.	M99	M82	M81	M84
Rock names after Niggli	Leuco-gabbro	Diorite	Alkali-granite	Alkali-granite
Microperthite	-	-	9	42
Albite	-	-	32	8
Andesine	-	56	-	-
Labradorite	64	-	-	-
Quartz	Accessory	7	16	20
Hornblende	-	28	39	27
Monoclinic pyroxene	28	2	2	-
Micropegmatite	-	-	-	3
Ore	5	4	1	Accessory
Biotite	-	2	1	-
Apatite	1	1	Accessory	
Rhombic pyroxene	2	-	-	-

A detailed description of the Upper Zone of the Bushveld Igneous Complex in this area has been given by Boshoff (1939, p. 9). Consequently only comparatively brief mention will be made of these rocks in the present treatise.

The gabbro of the Upper Zone is a medium-grained, leucocratic to mesotype rock on a fresh surface and the main constituents are easily distinguishable without the aid of a lens as feldspar and pyroxene. In Table VIII the composition of the rock, which is a leuco-gabbro (Niggli, 1931, p.312), is given together with the compositions of other specimens from the Upper Zone.

Anhedral to subhedral plagioclase grains vary in composition from An_{45} to An_{64}, that is Andesine to Labradorite and measure 1.85 mm. X0.42 mm. on the average. Diallage is the predominating dark mineral and is present as anhedrons of average cross-section 1.13 mm. The ratio of monoclinic to rhombic pyroxene in the gabbro of the Upper Zone is 14:1, which is a marked increase of the former over the latter as compared with gabbro from the Main Zone for example. In order of abundance the accessories are ore and apatite.

In thin section the diorite exhibits alteration, the most marked of which is the sericitization of the feldspars. Where determineable the latter have the composition Ab_{54} An_{46} i.e. Andesine, and occupy 56% of the rock by volume. Irregular sericite clusters are often enveloped by green hornblende and chlorite. The former exhibits a marked pleochroism from dark-brown to olive-green and is frequently partially altered to ore. Apatite, the most abundant accessory, varies from euhedral hexagons of average diameter 0.09 mm. to tabular crystals and slender needles up to 0.77 mm. in length. Quartz is interstitial.

The alkali-granite is an even-grained, mesotype to leucocratic rock which owes its distinctive pinkish to orange-coloured appearance on a fresh surface to the abundance of flesh-coloured feldspar in strong contrast to the dark-green hornblende. In parts

there/...............

there is a strong resemblance to syenitic types and where feldspar and hornblende are present in approximately equal proportions, the rock becomes evenly mottled pink and dark-green.

In thin section the majority of the feldspars are completely altered to sericite and can only be distinguished with difficulty; other grains have an altered core and comparatively fresh mantle and as a rule the clouded condition of the feldspar grains prevents determination of their zonal structure. Tabular grains of microperthite of average size 1.9 X 0.8 mm. constitute a maximum of 42% of the granite by volume. "Free" plagioclase is more common in the lower than upper horizons of the alkali-granites, namely 56% as against 8% by volume (TABLE VIII). The anorthite content of this mineral varies between An_2 and An_6. Hornblende is the most abundant dark silicate and averages 32%. This mineral, which has an average length of approximately 0.86 mm., in many cases replaces monoclinic pyroxene.

Part of the hornblende appears to be primary and exhibits a brownish-green colour and part of it has a secondary origin, in which case the mineral is fibrous. The primary hornblende has the following properties:

$$2V_{\alpha} = 67^{\circ}$$
$$\gamma/c = 12^{\circ}$$

Pleochroism α or X = straw-brown.
β or Y = olive-green.
γ or Z = dark-green.

Absorption formula is $\gamma > \beta > \alpha$

A prominent increase in the quartz-content of the rocks takes place with rise in pseudo-stratigraphical height namely from 7% to 20% by volume. Micropegmatite increases from isolated, poorly defined intergrowths at lower horizons, to 3% by volume of the granite in the uppermost horizons. Monoclinic pyroxene was not noticed in the uppermost horizons, whereas this mineral is

very/...............

Plate 17.

Intrusion Breccia showing angular quartzite fragments (white).

very often altered and in various stages of uralitization, in the lower horizons of the Upper Zone. Biotite, apatite and ore are accessories. Biotite is almost invariably associated with hornblende usually as incomplete kelyphitic rims around the latter.

In the area under discussion variations in the Upper Zone of the Bushveld Igneous Complex and especially in the uppermost horizons of this zone are much more rapid than in lower horizons of the Complex. Although exposures are not particularly suitable, it appears that a transition between rocks of the Upper Zone and the granophyre, is non-existent. In several cases the two rock-types are adjacent to one another in the field, yet each rock retains its general lithological characteristics up to the point of junction.

(iii) Intrusion Breccia.

Approximately half a mile to the south of Hebron an intrusion breccia forms an outcrop of not more than 60 square yards in surface extent and consists of angular to subangular fragments of quartzite varying in size from mere specks to blocks of approximately 18 inches diameter (see plate 17). The latter are conspicuous on a weathered surface due to their superior weather resisting properties, and are firmly cemented together by a mixture of mobilized quartzite and granitic material. The outcrop of breccia is situated on the northern side of a quartzite remnant approximately at the junction of the latter with alkali-granite of the Upper Zone.

Along the southern extremity of the breccia, the quartzite adjacent to it is feldspathized and, impregnated with hornblende, the latter locally to such an extent as to impart an amphibolitic appearance to the rock. The granitic rocks furthermore, are unusually coarse-grained in the vicinity of their junction with the breccia. The transition of one rocktype into the other is gradual and in all cases accomplished within a matter of three yards.

Microscopical/.................

Photograph is missing from the physical copy

Microscopical examination in thin section reveals that the fragments within the breccia consist of interlocking quartz grains, partly or wholly feldspathized. The latter are invariably clouded and in many cases an unaltered core of quartz is completely enveloped by feldspar. Pleochroic green hornblende frequently accompanies the feldspathized quartz grains. The groundmass of the breccia is composed of an irregular mixture of feldspar, hornblende and quartz.

C. OLIVINE-BEARING ROCKS.

1. Dunite bodies.

(a) Field Observations.

In the area covered by the map, eight dunite bodies are present, which range in size from several yards in diameter on the central part of Uitvalgrond 584, to approximately 700 yards on the southern part of Klipfontein 482. Owing to better exposures of the larger occurrences, more information could be collected about them than about the comparatively small bodies. As far as could be ascertained none of the olivine-bearing bodies bears a concordant relationship to the gabbro and the dunite invariably intrudes the country rock transgressively.

In all cases the dunite occurrences, which are numbered 1 to 8 on the accompanying map, are roughly circular or oval in cross-section at the surface and the designation "pipelike" for these intrusions therefore appears to be fully justified. A characteristic feature of the latter is the fact that their presence is frequently recognisable in the scenery by irregular oval to circular patches almost bare of vegetation excepting a very thin covering of grass, in conspicuous contrast to the surrounding bush-clad ground.

Association with dunite bodies are occurrences of magnetic iron ore, which outcrop as small knolls. The ore weathers to a shiny black surface, exhibits a dull black colour on fresh sur-

faces/.................

Plate 18.

Boulders of gossan from a prospecting pit on Klipfontein 482.

faces and is situated in close proximity to the dunite intrusions, though actual contacts are not exposed. In all cases the area occupied by these knolls does not exceed approximately 120 square yards. Irregularly distributed ochreous, opaline gossans measuring up to 35 feet in surface diameter, are associated with occurrences Nos. 3 and 6.*

A quarry has been constructed along part of the southern extremity of dunite no. 5 on Klipfontein 482, exposing part of the contact between it and the surrounding gabbro country rock (see fig. 5, p.63). This contact is highly irregular though well-defined. The surrounding gabbro is not very brittle. The irregularity of the contact does not bear any relationship to the decomposed state of the gabbro and the condition of the latter is due merely to disintegration as a result of weathering. Furthermore, the dunite is not directly in contact with gabbro but separated from it by a zone of decomposed olivine-gabbro pegmatite, veins of which extend into the surrounding gabbro. In the vicinity of the dunite bodies the gabbro is frequently impregnated with olivine resulting in the formation of an olivine gabbro.

The eastern part of the above-mentioned quarry contains bluish-black hornblendite segregations which vary from two inches to approximately one yard in diameter, and have no visible connection with one another. Along the northern extremity of the quarry numerous gossan veins composed of a yellowish, opaline ochreous substance, range in thickness from half and inch to two inches. These veins strike roughly in a north-south direction and vary in dip from 40° to 50° to the east.

(b) Petrography.

Macroscopically the dunite is a melanocratic, phanerocrystalline and very heavy rock, possessing an uneven fracture and black, shiny lustre on a fresh surface. The rock has a tendency to split along limonite-coated joints when struck with a hammer. Weathered surfaces are coarsely pitted and dull and

* The numbers refer to designations on the accompanying map.

stained with iron oxide. The dunite is fresh as a rule except on the northern part of occurrence No. 3 on Klipfontein 482, in which case it shows serpentinization on part of the outcrop.

In thin section the dunite consists of interlocking highly birefringent grains of olivine varying in diameter from 0.46 mm. to 3.68 mm. The composition of the olivine constituting the largest bodies is given in Table IX, as well as that of the olivine gabbro associated with two of the intrusions. The mineralogical compositions of olivine are according to Poldervaart (1950, p. 1067) after Deer and Wager.

TABLE IX. COMPOSITION AND PROPERTIES OF OLIVINE FROM HORTONOLITE-DUNITE OCCURRENCES.

Ref.No. on map.	3		5		7
Rock-type	Dunite	Olivine-gabbro	Dunite	Olivine-gabbro	Dunite
$2V_\alpha$ of olivine	71°	74°	74°	75°	72°
Composition (Mol.%).	$Fo_{52}Fa_{48}$	$Fo_{46}Fa_{54}$	$Fo_{46}Fa_{54}$	$Fo_{44}Fa_{56}$	$Fo_{50}Fa_{50}$
Mineralogical name	Hortonolite	Hyalosiderite	Hyalosiderite	Hyalosiderite	Hortonolite
* n'_α	I.742 ∓.004	-	I.746 ∓ .003		I.756 ∓.004
n'_β	I.755 ∓.004	-	I.760 ∓ .003		I.772 ∓.004
n'_γ	-	-	-		-
Appr.diam. of olivine body.	550'		2100'		1800'

The feldspathic dunite associated with some of the intrusions was in too advanced a state of weathering to permit microscopical examination thereof.

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* An unaccountable difference occurs between the composition of the olivine as deduced from the axial angles and that as deduced from the refractive indices.

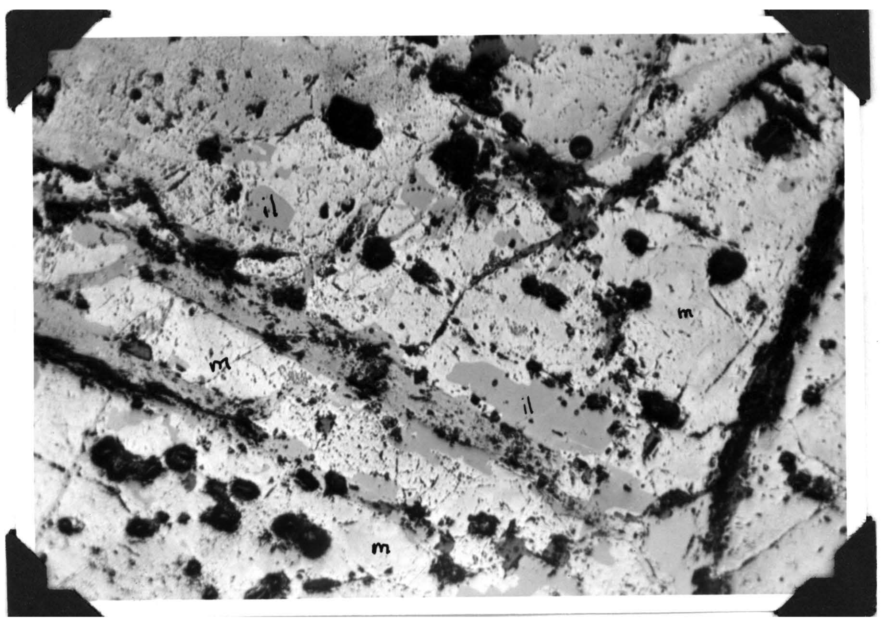

Plate 19.

Ilmenite (il) occurring as blebs and lamellae within maghemite (m).

Crossed nicols. X 30.

The olivine-gabbro associated with the dunite has following mineralogical composition.

TABLE X. COMPOSITION OF OLIVINE-GABBRO ASSOCIATED WITH THE DUNITE. (No. 7)

Mineral	% by Volume.
Labradorite	57
Olivine	25
Monoclinic pyroxene	17
Rhombic pyroxene	-
Hornblende	1
Ore	Accessory.

The Hornblende, which is an accessory, has the following optical properties:-

$$2V_{\alpha} = 72^{\circ}$$
$$\gamma/c = 18^{\circ}$$
$$n'_{\alpha} = 1.668 \pm .002$$
$$n_{\beta} = 1.670 \pm .003$$
$$n'_{\gamma} = 1.672 \pm .002$$

IRON ORE ASSOCIATED WITH THE DUNITE.

In a polished section of magnetic iron ore which outcrops in close proximity to dunite No. 5 on Klipfontein 482, and which also forms part of this transgressive intrusion, small patches of ilmenite are entirely surrounded by maghemite. In certain cases small remnants and embayments of maghemite are present in the ilmenite blebs. The blebs of ilmenite, when arbitrarily arranged, give the impression of relicts due to replacement but the fact that they are often aligned in certain directions obviously corresponding to crystallographic directions in the maghemite, suggests that they are also due to exsolution (Plate 19).

2. Origin of the Dunite.

It has long been known that the dunites and their associated rocks bear a discordant relationship to the pseudostratified members of the gabbro-norite group of the Bushveld Igneous Complex (Wagner 1929, p. 86) and the present area is no exception.

The possibility exists that the dunite represents a final pegmatitic phase of the gabbroidal magma, as previously envisaged by Wagner (1929, p. 87). The mode of occurrence of the olivine in the olivine-gabbro favours this viewpoint, as the former is invariably interstitial and the last mineral to have crystallized. The relatively coarse-grained nature of the dunites and their associated rocks including the gabbro-pegmatite, indicates fugitive constituents and similarly favours a late-phase pegmatitic origin for these bodies.

Bateman (1951, p. 422) offers a solution with regard to the precise mode of intrusion of these pipelike bodies. He enviseages a socalled "late gravitative liquid accumulation" of dunitic composition, which, in the case under consideration, would have become subjected to pressure and would have "squirted" elsewhere into the country rock, thus forming transgressive pipelike structures.

D. QUARTZ-BEARING ROCKS.

1. Granophyre.

(a) Field Observations.

The Granophyre occupies a stretch of country along the northern part of the area and covers part or all of the farms Boekenhoutfontein 81, Kruisfontein 164, Kameelfontein 51 and a small area in the north-eastern corner of Sjambok Zyn Kraal 52. Along its southern extremity the granophyre, which forms a topographically prominent, reddish, bushclad rise, is bounded by ridges of leptite and alkali-granite, the latter belonging to the Upper Zone of the Bushveld Igneous Complex. The less ele-

vated/.......

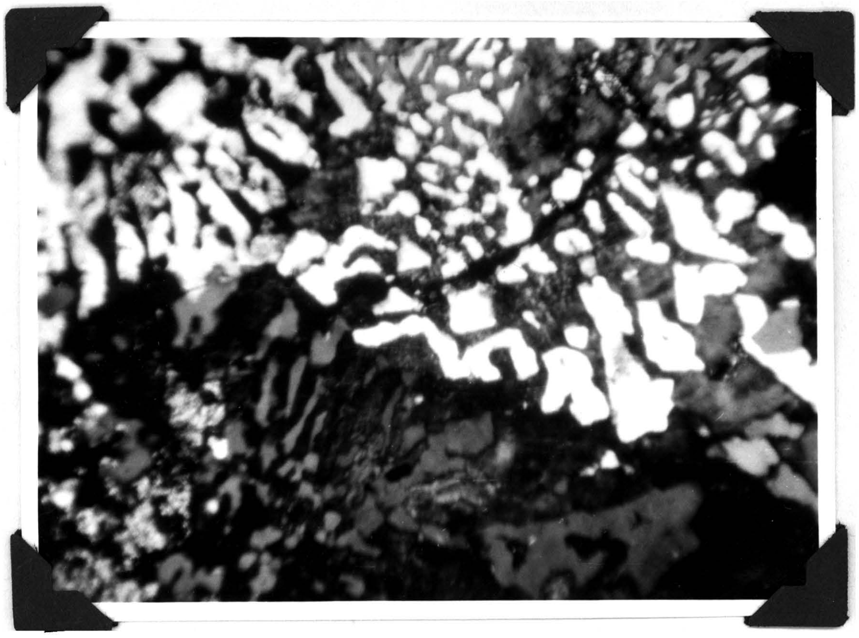

Plate 20.

Granophyre showing rodlike quartz grains (white), intergrown with feldspar (dark).

X Nicols. X 30.

Plate 21.

Granophyre, showing the resemblance of the quartz grains (white) to cuneiform characters.

X Nicols. X 30.

vated areas of granophyre are as a rule overlain by several inches of ferricrete or "ouklip".

Immediately below the ford through the Sand Spruit, to the west of Hebron, granophyre is admirably exposed in the bed of the Spruit. Close examination reveals that the quartz has been leached out of the rock, leaving only minute cavities which are frequently filled with limonitic material. In many cases small, elongated cavities radiate from a central point, no doubt representing the positions previously occupied by quartz of the granophyric intergrowths.

This phenomenon is in all probability caused by the fact that water passing over the granophyre may acquire an alkalinity from the overlying and surrounding turf soil which carries an abundance of calcareous nodules and as a result of this alkalinity quartz will readily go into solution and be leached out.

Scattered outcrops of granophyre are situated on the northern part of Sjambok Zyn Kraal 52, to the south of the leptite ridges and have no visible connection with the main body of granophyre. Vertical shear planes striking approximately northwest are present in the most westerly of these outcrops.

(b) Petrography.

Macroscopically the granophyre is a fine-grained, compact reddish rock almost devoid of dark minerals. Outcrops are frequently jointed and cause the rock to be split up into approximately cubical units, several cubic inches in volume.

Microscopically the rock is composed entirely of granophyric intergrowths of quartz and feldspar which is predominantly microperthite. Two types of intergrowths may be distinguished; one in which the quartz forms rodlike individuals radiating from a central area and another in which quartz resembles cuneiform characters (see plates 20 and 21). The intergrowths, which can frequently be distinguished in a handspecimen without the aid of a lens, have an average cross-section of 0.76 mm. In isola-

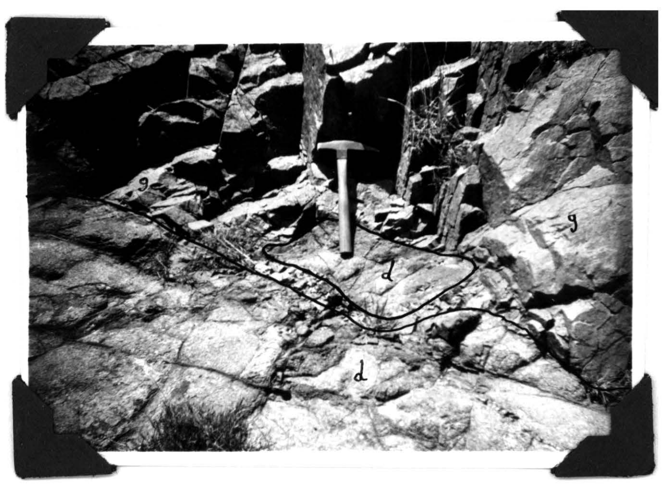

Plate 22.

Contact between granophyre (g) and diorite (d), showing inclusion of diorite in granophyre on Sjambok Zyn Kraal 52.

ted cases the quartz and feldspar are not intergrown.

Dark minerals are hornblende and less commonly biotite which may exhibit alteration; zircon and ore are scarce accessories.

Kuschke (1950, p. 35) could detect no preferred orientation of either quartz or feldspar in the granophyre of the Brits area, some miles to the west of the area under discussion.

(c) Relationships to the Surrounding Rocks.

Although contacts between granophyre and other rocks are not commonly exposed, several localities exist at which these relationships may be observed.

In the Sand Spruit immediately south of Hebron, diorite belonging to the Upper Zone of the Bushveld Igneous Complex, is intruded by granophyre. Veins of the latter extend into the diorite and a remnant of it is enclosed by granophyre (see plate 22). In Hebron itself, granophyre encloses a small remnant of alkali-granite of the Upper Zone, though both rocks are in too advanced a state of weathering for the relationship to be definitely established. Immediately to the west of Hebron a granophyre veinlet was noticed in alkali-granite of the Upper Zone. At it's junction with leptite in this vicinity, the granophyre assumes a fine-grained character reminiscent of a chill phase. This is microscopically apparent as micropegmatite of an unusually fine-grained nature.

The emplacement of granophyre thus in all probability postdates the gabbroidal rocks of the Bushveld Igneous Complex in this area, or alternatively the granophyre must at least have been in a state of plasticity at one stage during its history.

2. Granite.

(a) Field Observations.

The only outcrop of Bushveld Granite in the area surveyed, is a small occurrence less than 100 yards in diameter, on the central part of Sjambok Zyn Kraal 52. Solid outcrops occupy a rela-

tively/........

tively small portion of the total surface, and are situated on approximately the same horizon as the Lower Magnetic Iron Ore Horizon, thus corresponding closely, presumably coincidentally, to the stratigraphical position of the Magnet Heights Granite in the Lydenburg district.

(b) Petrography.

Macroscopically the granite is a flesh-coloured rock when fresh, weathering to a rough, straw-brown surface on which small protrusions indicate the positions occupied by quartz grains. All the chief constituents of the rock may be recognised in a handspecimen, namely pink feldspar, quartz and a dark mineral which as a rule is hornblende. The granite is a fine-grained, equigranular rock of average grain-size 0.6 mm. and of homogeneous texture throughout.

Microperthite is the predominating feldspar, in which the two components often show several stages of separation. Relatively large plagioclase components on which determinations could be carried out, indicated a composition of albite-oligoclase ($Ab_{89} An_{11}$ - Ab_{98}-An_2). Orthoclase is less common and as a rule cloudy due to incipient alteration. Areas occupied by quartz exhibit a mosaic of interlocking grains approximately 1.18 mm. in diameter. Hornblende is a scarce accessory.

At the southern extremity of the outcrop of granite, a small quartzite outcrop approximately 3 feet in length is present, though this may possibly represent an erratic boulder. No contact between granite and the surrounding gabbro country rock is exposed and very little information can be gained with regard to the relationship of the granite to the gabbro.

By analogy with other parts of the Bushveld Igneous Complex, the granite in this area in all probability attained its present stratigraphical position by intrusion. The comparatively fine-grained character of the rock moreover, seems to support such a conclusion.

VII/............

VII. THE KARROO SYSTEM.

A. Ecca Series.

1. Field Observations.

In the northern part of the area an outcrop of grit belonging to the Ecca Series occurs along the southeastern portion of Kruisfontein 164 and extends eastwards for several miles to beyond the area covered by the map. Besides this occurrence, two very much smaller outcrops are present in the south-western corner of Kruisfontein 164 and the vicinity of the southern boundary of Kameelfontein 51. Topographically the grit does not form an unusually pronounced feature. The largest outcrop occupies an east-west stretch of gradually rising ground which culminates in the granophyre ridges and thus covers the granophyre-gabbro contact. An accurate determination of the thickness of the grit is rendered difficult by poor outcrops, though it appears to be of the order of tens of feet rather than hundreds of feet. The most westerly outcrop of grit is situated approximately 1½ miles to the west of Hebron, around the trigonometrical beacon on Kameelfontein 51, at which point it overlies leptite unconformably. The cementing material is highly ferruginous and locally developed pebbly washes contain rounded boulders up to seven inches in diameter. Thin intercalated lenses of shale have a maximum thickness of approximately 1". In the case of an outcrop situated on the southwestern part of Kruisfontein 164, the cementing material is ochreous and imparts a strawbrown colour to the rock.

Almost a mile to the east of the abovementioned outcrop, the largest occurrence of grit occupies part of a ridge on Kruisfontein 164 from where it extends eastwards to beyond the area covered by the accompanying map. In this vicinity the outcrop partially covers the Upper Band of Magnetic Iron Ore. Ferruginous concretions varying in largest dimension from 4" to 1" are scattered through the grit and the latter also exhibits evidence

of/..............

Plate 23.

Contemporaneous deformation in Karroo grit. Hammer handle aligned along the fold axis.

Plate 24.

Vertical section of a fold on Kruisfontein 164.

of contemporaneous deformation. The dip of the grit in this locality is 26° to the north and it includes ferruginous, argillaceous bands up to 3" thick which contain only a small proportion of quartz grains. The argillaceous bands are incompetent the more competent quartzose bands and the latter are consequently less disturbed than the argillaceous layers which exhibit evidence of slumping.

According to Twenhofel (1939, p. 531), material deposited higher up on a slope tends to move towards the lower parts and this leads to the formation of asymmetrical or overturned, more or less closed folds. The axial planes in most cases dip into the slope. This is the case in the area under consideration where the somewhat localized and imperfect folds are slightly overturned towards the north and thus dip towards (into) the originally sloping surface of deposition. As would be expected, the fold axes are aligned at right angles to the dip of the sediments namely approximately east-west (plate 23).

A limited amount of brecciation has occurred within the grit, indicating that the sediment was already partially consolidated when the movement commenced.

The nature of the grit in the vicinity suggests that the movement was arrested in the initial stages of deformation, as indicated by:-

(i) the localized and incomplete nature of the folds;

(ii) almost vertical disposition of the fold axes;

(iii) absence of complete slumping or any other major dislocations in the sedimentary structures.

2. Microscopical features.

Under the microscope the grit consists of angular, clastic quartz grains varying in largest dimension from 0.08 mm. to 2.68 mm., averaging approximately 0.24 mm. In many cases quartz grains are traversed by irregular limonite-filled cracks and in rare instances the grains contain, besides rows of minute

inclusions/.........

inclusions, microscopically small wisps of muscovite and biotite.

3. Relationship to Older Formations.

The Ecca grit represents the youngest geological formation in the area surveyed and rests unconformably upon rocks of the Bushveld Igneous Complex. Indications are that a much greater area was previously covered by grit than is the case at present, owing to the fact that remnants of these rocks are found at localities several miles distant from existing outcrops of grit. When followed towards the east, beyond the area covered by the map, coal seams make their appearance in the formation. The latter can thus be assigned to the Middle Ecca or Coal Measure Series with reasonable certainty.

VIII. DYKES.

A. Field Observations.

Four dykes of doleritic composition are known in the area. The longest of these extends in a northwesterly direction across Klipfontein 482 and a shorter one extends from gabbro of the Upper Zone of the Bushveld Igneous Complex into leptite, in a northwesterly direction, to the south-east of Hebron. Due south of Hebron a third dyke contains scattered segregations of sulphide.

The largest of the dykes is covered for the greater part by soil, and as far as the writer is aware, exhibits only one intrusive contact namely that with gabbro, situated approximately one hundred yards due south of the homestead on Klipfontein 482. At this point the dyke, which is approximately 25 yards wide, gives rise to a small spring, which issues from a point along its southern contact. Veins from the dyke extend into the surrounding gabbro and are chilled to a fine-grained basaltic rock.

B. Petrography.

Near the abovementioned contact the dolerite is somewhat altered and a thin section from this vicinity shows the feldspars to be almost completely sericitized and the pyroxenes to be al-

tered/..........

Plate 25.

Dolerite showing diversely orientated plagioclase laths (white) partly penetrating pyroxenes (grey and black) on Sjambok Zyn Kraal 52.

X Nicols. X 30.

tered to serpentinous material, chlorite and ore. Quartz is present as an accessory. As a rule, however, the rock is beautifully fresh and has a sub-ophitic texture (plate 25).

Feldspar is present as subhedral grains of average length 1.4 mm. and corresponding in composition to Labradorite $Ab_{40}An_{60}$. Anhedral grains of monoclinic pyroxene usually exhibit wavy extinction and have the following properties indicating augite:

$$2V_{\gamma} = 52^{\circ}$$
$$\gamma/c = 42^{\circ}$$

Rhombic pyroxene is scarce and quartz, chlorite and ore are accessories.

With regard to the age of the dykes, nothing definite can be stated beyond the fact that they are all of post-Bushveld Igneous Complex age and may possibly also be of post-Karroo age.

IX. STRUCTURE OF THE AREA.

The structure of the area is a comparatively simple one. Quartzite belonging to the Southern Zone of xenoliths varies in dip from 36° to 45° to the north and the pseudostratification of the overlying gabbroidal rocks of the Bushveld Igneous Complex indicates a similar direction of dip. Transverse faults of small displacement are present at various localities in the area as for example on Hartebeesthoek 524 in which case quartzite of the Southern Zone of Xenoliths is affected. The Upper and Lower Magnetic Iron Ore Bands are similarly affected on the north-eastern part of Klipfontein 482. Evidence of relative movement within the gabbro itself may be witnessed in the form of shear zones at a number of localities in the area.

The unusually large gap between the Pyramids and Zwartkoppies Ranges, which occupy identical pseudostratigraphical horizons in the gabbroidal rocks, derives an explanation from the fact that the intervening rocks do not as a rule show the characteristic spheroidal mode of weathering to any great extent, but

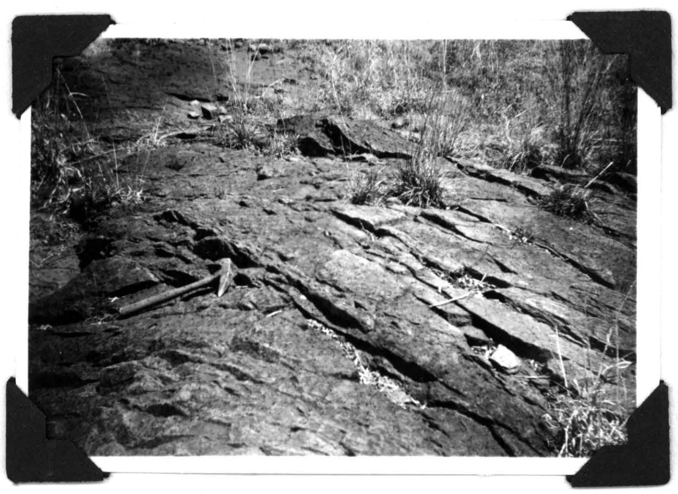

Plate 26.

Jointed gabbro on Klipfontein 482. The joints strike approximately north-south.

are rather intensely jointed. The joints are most frequently aligned in a north-south direction. Similar conditions exist in the gabbro further to the west on Klipfontein 482 (plate 26).

On the north-western part of Uitvalgrond 584, a shear zone forms a small "nek" in the Zwartkoppies Range. In this vicinity the gabbro is disturbed over an area of approximately 150' x 50' feet and bears a resemblance to brecciated rock.

The dunite bodies , as previously stated, transgressively intrude [illegible] the Bushveld Gabbro. Leptite and granophyre form a roof to the gabbroidal rocks which dip beneath the leptite and granophyre as is generally the case in the Bushveld Igneous Complex.

The Ecca grit overlies all rocks belonging to the Bushveld Igneous Complex.

Considered areally the map covers part of the Southern Central Sector of the Bushveld Igneous Complex.

X. ECONOMIC CONSIDERATIONS.

The economically important ore deposits associated with the Bushveld gabbro namely the chromitite and platinum-bearing horizons, are not represented in this area as previously noted. The reason for their absence may be sought in the marked thinning out of the Critical zone and the gabbroidal rocks in general as compared to other areas in which these two horizons are present. Although several of the gossan occurrences associated with the dunite bodies have been subjected to a limited amount of prospecting in the past, none of the bodies have proved to be of any economic value.

The magnetic iron ore bands are of little economic importance at present. On the south-western part of Sjambok Zyn Kraal 52, part of the Lower Magnetic Iron Ore Band is quarried for use as roadmetal.

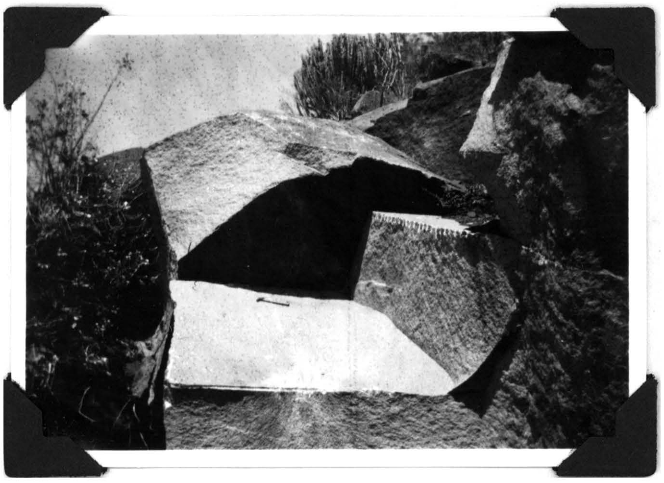

Plate 27.

Plane of pseudostratification of gabbro on Klipfontein 482. The hammer lies on this plane, which dips towards the observer i.e. North, at approximately 18°.

Blocks of gabbro for monumental and other purposes are quarried on the central part of Klipfontein 482 and previously also a little further to the east on the same farm. The gabbro is broken by the well-known method of employing the three mutually perpendicular planes of pseudostratification and splitting the rock accordingly (see plate 27). Stone from the quarry at present operating on Klipfontein 482 has a dark colour and takes an excellent polish.

Various types of rock, highly decomposed as a rule, are employed as roadmetal. These include weathered gabbro and gabbro pegmatite from the quarry on the southern part of Klipfontein 482, decomposed gabbro from Uitvalgrond 584 and quartzite from Hartebeesthoek 524 and Kruisfontein 164. Both the quartzite occurrences are especially suitable for use as roadmetal owing to the fact that the outcrops are highly jointed and the rock consequently requires no further crushing.

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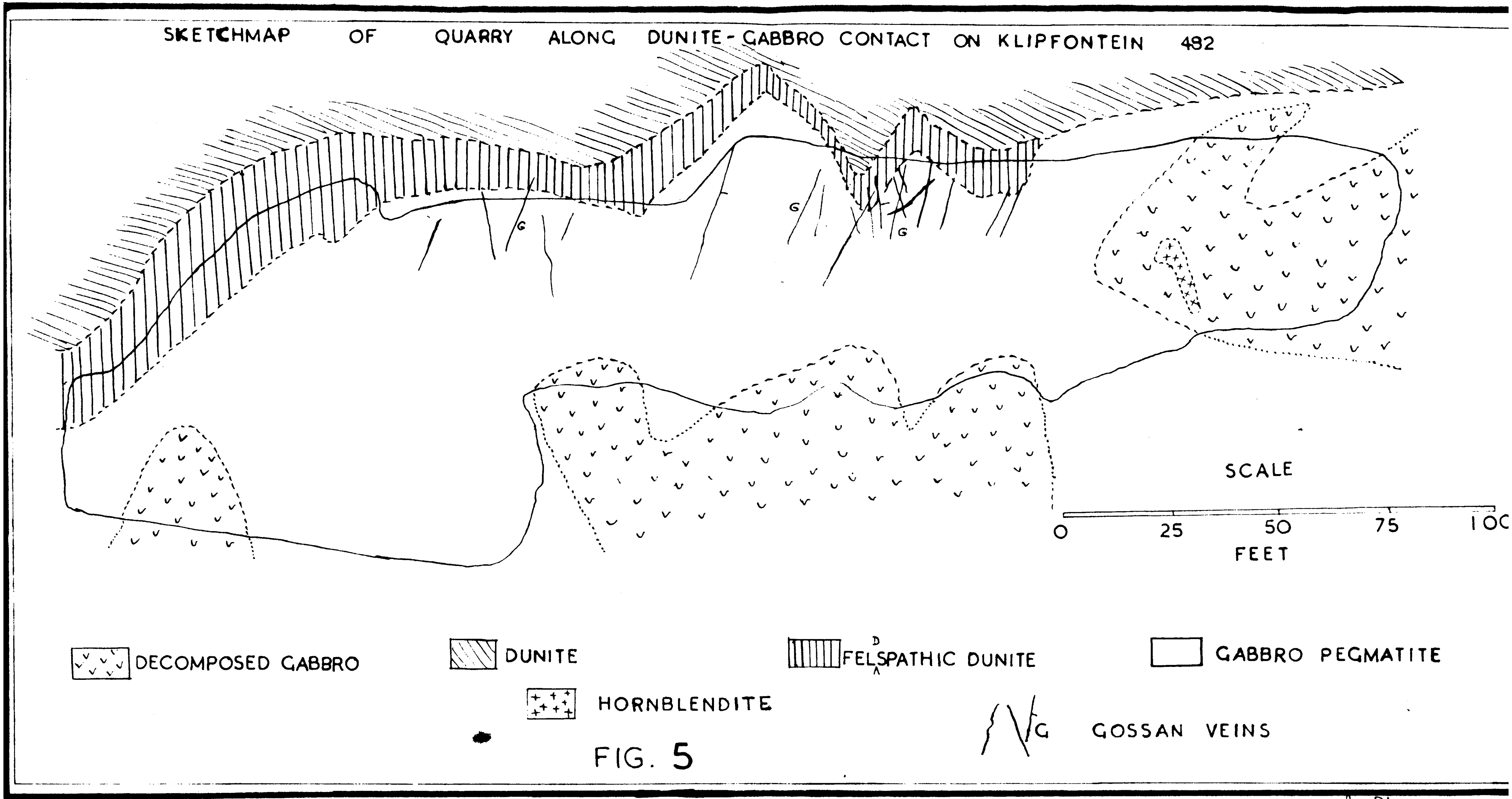

FIG. 5

M. v. R. Steyn