THE GEOLOGY OF CERTAIN IGNEOUS INTRUSIVE ROCKS IN THE FAR EAST RAND, TRANSVAAL, SOUTH AFRICA

BY

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THESIS SUBMITTED FOR THE M.Sc. DEGREE

UNIVERSITY OF THE WITWATERSRAND

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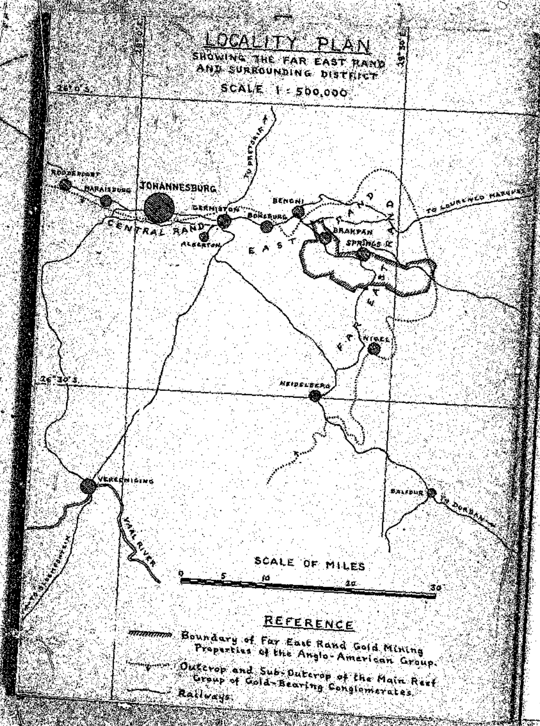
(References are denoted in the text by figures in parenthesis)



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I. INTRODUCTION

The Anglo-American Corporation of South Africa Ltd. controls five producing gold mines in the Far East Rand, namely, Brakpan Mines, Ltd., S.A. Land & Exploration Co. Ltd., (Sallies), Springs Mines, Ltd., Daggafontein Mines, Ltd. and East Daggafontein Mines, Ltd. These five adjacent mines occupy an east-west strip of ground, which will hereinafter be referred to as the Property, situated near the centre of the Far East Rand gold mining district. It is about 16 miles long, 64 square miles in area, and includes within its boundaries the towns of Brakpan and Springs. A plan of the Property, showing mine boundaries, shafts, boreholes and pre-Karroo geology, is shown in Plate I.

The land surface has an average elevation of 5300 feet above sea level. It is very gently undulating and featureless, being underlain for the most part by flat-lying sediments of the Karroo system. Outcrops are very scarce. Nearly everywhere there is a thick superficial layer of sub-soil and lateritic ironstone or alluvium.

The direction of drainage is from north to south. Most of the Property is drained by the Blesbok Spruit, which crosses the western part of East Daggafontein Mine, flowing southwards (Plate I). This stream follows an axis of very gentle post-Karroo up-warping and, with its tributaries, has eroded a wide strip of Karroo strata, exposing the underlying rocks. Over a large part of Daggafontein and East Daggafontein Mines the

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dolomite of the Transvaal System underlies superficial deposits. Rocks of the Black Reef Series and of the underlying Kimberley-Elsburg Series are exposed in the bed of a small stream which flows westwards into the Blesbok Spruit (Plate I).

In the southern corner of Sallies Mine, where the Transvaal System is missing, the Ventersdorp Amygdaloid and the uppermost Elsburg Reefs emerge locally from beneath thin Karroo strata.

Except in the two above mentioned localities, the older rocks are everywhere concealed beneath a Karroo covering.

II. GENERAL GEOLOGY

The general geology is illustrated in Plates I & II. The oldest formation penetrated by underground workings, shafts and boreholes is the Jeppestown Series, which is mostly argillaceous, though important gold-bearing conglomerates and quartzites occur locally. The Main Reef Leader, which is the most important economic formation, lies at the base of the Upper Witwatersrand System and rests directly upon the Jeppestown Series. Higher up in the System are the Kimberley Reefs, which are of growing importance as Main Reef Leader ore reserves diminish.

The Upper Witwatersrand System attains its maximum thickness of about 5200 feet in the south of Sallies and Springs Mines, where the Elsburg Series is overlain, without

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any angular unconformity, by the Ventersdorp Amygdaloid. The rocks of the Ventersdorp and Witwatersrand Systems were folded, faulted and eroded to a peneplane in pre-Transvaal times. The section in Plate II. shows how the Black Reef and dolomite of the Transvaal System overlap the entire succession of older rocks, from the Ventersdorp down to the Jeppestown Series.

The beds of the Transvaal System, in their turn, were folded and truncated by a peneplane in pre-Karroo times. The Black Reef Series, underlying the dolomite, is a patchy and economically unimportant formation, though in mines to the north of the Property it carries payable gold. The Transvaal beds are broadly synclinal in form, attaining a maximum thickness of a little over 1000 feet in the deepest portion of the syncline. They are absent in the west and in the extreme south-east of the Property.

The existing Karroo sediments are nowhere more than 400 feet thick. Their average thickness is much less. They were laid down on a post-Transvaal peneplane and have suffered no subsequent deformation except a very gentle warping. The beds belong to the Dwyka and Ecca Series. The upper divisions of the System are missing. An unknown thickness of Karroo strata has been removed during the post-Karroo to present day erosion cycle.

III. IGNEOUS INTRUSIONS

Exposed in underground workings in the Witwatersrand

/System

Witwatersrand/.

System and in shafts and surface boreholes penetrating the overlying formations, are a large number of igneous intrusive bodies, ranging in size from major dykes and sills hundreds of feet in thickness to minor intrusions a few inches to a few feet thick. Some of these rocks are fresh; others are completely decomposed, having suffered much stress-metamorphism since their emplacement.

Nearly all these intrusions fall naturally into five groups, which are summarised below in what is believed to be their order of increasing age. The rocks belonging to each group have structural and petrological features in common which distinguish them from those of other groups. Each group is believed to represent a separate and distinct phase of igneous activity.

(i) The Dolerites

The Dolerites are the youngest intrusives and penetrate all formations up to the Ecca Series. They are believed to be of Karroo age. The rock is nearly always fresh and has suffered little or no metamorphism since its emplacement. Five vertical dolerite dykes traverse the Property in a direction which varies from N.N.W. to W.N.W. They are not all regarded as truly contemporaneous. There are also at least two and possibly three sills which intrude the Transvaal dolomite and the Karroo strata and have been intersected by most shafts and boreholes on the Property.

/ (ii) The Syenites

Property./

(ii) The Syenites

Sills of a rock generally known as syenite are numerous in the Transvaal dolomite and have not been seen in any other formation. They are believed to be of Bushveld or post-Waterberg pre-Karroo age. The rock is generally in an altered condition but its primary features are always clearly recognisable. The term syenite is not strictly correct; most of the sills are tonalites. A few narrow inclined dykes which intrude the Witwatersrand beds are similar petrologically to the sills and are believed to be of the same age.

(iii) The Ilmenite Diabase

Ilmenite diabase is an altered basic rock, originally a dolerite, which intrudes the Witwatersrand strata in the form of irregular vertical dykes, trending roughly N.N.E., and occasional sills and narrow inclined dykes. It is not known to intrude beds of the Transvaal System and is believed to be of pre-Transvaal age. The rock is in a very altered condition but has certain distinctive petrological features by which it can generally be recognised.

(iv) The Norite-Granophyre

A very extensive sill with transgressive dyke phases, known to Ellis(5) as the "Van Dyk Granophyre", intrudes the Witwatersrand beds in Brakpan, Sallies

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Sallies/
and Springs Mines and persists over a large area to the south and west of the Property. It is nearly always composite, the sill phases consisting of a lower norite and an upper granophyre, both very altered. The contact between the two rock-types is sharp and not gradational. This intrusion is believed to be of Ventersdorp age. There is good evidence that it is older than the ilmenite diabase dykes.

(v) <u>The Quartz Diabase</u>

Quartz diabase is the oldest intrusive rock in the Property and the most common. It is an intensely altered quartz dolerite, sometimes so decomposed that its primary features are entirely obliterated. It is often known as "Ventersdorp" diabase. It is represented by the "Old Lady" (a complex dyke-sill body similar in structure to the norite-granophyre intrusion), the New State Areas Intrusion (a small outlying portion of the "Old Lady"), and a large number of simple dykes and sills of very widespread distribution in the Witwatersrand strata. The quartz diabase intrusions are known to be older than the Transvaal beds. They are believed to be of early Ventersdorp age and to have preceded the extrusion of the Ventersdorp lavas.

The rocks of each group are described in detail in the
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following pages, their modes of occurrence, petrological features, probable origin and age. Frequent reference is made to the published works of the late J. Ellis, who studied these same intrusive rocks in neighbouring mines outside the Property. The conclusions reached by the writer differ in some instances from those of Ellis.

The above five groups include every known intrusion in the Property except one; a dyke of quartz porphyry intruding the Witwatersrand beds in the northern part of Brakpan Mine. Little is known about this intrusion, which occurs in an old and largely mined-out area. It has been ignored. In East Daggafontein Mine there are several dyke-like bodies of a rock that has been called mylonite. These bodies resemble igneous intrusions but are believed to owe their origin to dynamic metamorphism of the Witwatersrand sediments. They are not described here.

/ IV. THE DOLERITES

IV. THE DOLERITES

1. THE DYKES

The five dolerite dykes traversing the Property, which are shown in plan at their intersections with the Main Reef Leader in Plates III & IV, are among the dykes described in a general way by Ellis(8) from observations made in neighbouring mines of the Union Corporation Group.

The principal trend of these dykes is roughly N.W.-S.E. A subordinate east-west trend is shown by dyke D (Plate IV) and by a few other dykes outside the Property. The fact that the dykes penetrate each other and do not usually end one against the other, suggests that they are not all contemporaneous, the earlier dykes having solidified before the later ones were intruded. Detailed microscopic examination bears this out. The dykes are similar petrologically but are not all identical. Dyke A is a typical fresh ophitic dolerite. Dykes B & C are much richer in iron-ore and some specimens of them might be more accurately described as gabbro rather than dolerite. Dykes D & E have not been examined, specimens not being obtainable.

These differences indicate the existence of at least two sets of dykes, one set represented by dyke A and the other by dykes B & C, essentially similar and belonging to the same igneous generation but not truly contemporaneous. It should be noted that dykes A & B are almost exactly parallel but

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belong to two different sets. Dyke D, which connects dykes B & C, belongs by inference to the same set, though its strike direction is very different. Dyke E might belong to either set or perhaps even to a third set.

Dyke A (the Modder East Dyke) cuts cleanly across the Far East Rand in a direction 32° W. of N. Its thickness varies from 200 feet to nearly 400 feet, averaging about 300 feet. Apart from occasional kinks at points where it intersects older diabase dykes (Plate III), its trace on the Main Reef Leader is very straight in plan and is not affected by the undulations of the reef. There can be little doubt that the dyke is essentially vertical. In East Daggafontein Mine the dyke's trace on the Kimberley Reef is not vertically above its trace on the Main Reef Leader, but is displaced some 300 to 400 feet to the north-east. This is probably due to the existence of kinks in a vertical section of the dyke, similar to those which interrupt its straightness in plan. These local changes in strike occur at points of intersection with diabase dykes. Similar local changes in the dip of the dyke, from vertical to inclined, might be expected to occur at stratigraphical discontinuities such as the contacts of the Kimberley Shale or the Bird Amygdaloid.

Dyke B (the Modder Dyke) is almost parallel to dyke A but different petrologically. Its average strike is 30° W. of N. In spite of their parallelism the two dykes are not regarded as contemporaneous. The Modder Dyke is practically vertical

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from near the surface, where it was encountered during the sinking of an old shaft now abandoned, down to Main Reef Leader level at a depth of nearly 4000 feet. Its thickness decreases southwards from about 130 feet in Brakpan Mine to 80 feet at the southern end of Springs Mine. Locally it splits into two parallel branches which re-unite. In the south of Springs Mine two very narrow inclined dolerite dykes, believed to be offshoots from the Modder Dyke, have been seen in the Bird Quartzite, nearly 2000 feet from the estimated position of the parent dyke.

Dyke C is somewhat irregular in strike, which is influenced locally by earlier structures and averages 50° W. of N. In East Daggafontein Mine the thickness of the dyke is between 30 feet and 100 feet. Its trace on the Kimberley Reef is nearly, but not quite, vertically above its position at Main Reef Leader level. Petrologically this dyke is identical to the Modder Dyke and different from the Modder East Dyke, which it intersects near the northern boundary of the Property. This intersection might show which dyke penetrates the other and hence establish the age relationship between the two sets of dykes. It is not however exposed to observation.

Dyke D is Ellis' "No. 4 Shaft Dyke". It is more variable in strike than the other dykes, the general trend being about 75° W. of N. Its thickness in Brakpan Mine is about 100 feet. At No. 4 Shaft Grootvlei Mine it is almost vertical from near

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the surface to a depth of 4000 feet (6).

Dyke E has a fairly uniform strike averaging 44° W. of N. Its thickness averages about 200 feet. Within the Property it has been intersected in only one underground developement end, now inaccessible. Nothing is known about its extension south-eastwards, where it traverses an undeveloped part of the Property.

The most important features common to all the dolerite dykes may be summarised as follows:-

(i) They are vertical or very steep and are continuous and unbroken both horizontally and vertically, having been traced over long horizontal distances and observed at levels from the Jeppestown Series upwards to near the present surface.

(ii) They are homogeneous in composition and are generally single bodies. Only the Modder Dyke is known to split into separate branches.

(iii) They do not displace the strata vertically. Their contacts with the wall rocks are sharp and chilled and are not sheared or brecciated. The only exception to this is the Modder East Dyke, which at one point displaces the reef vertically, and is very broken up near one wall.

(iv) Sills associated with the dykes are extensive and occur at a small depth below the present surface. They are generally confined to the Transvaal and Karroo

/strata

Karroo/

strata and seldom intrude the underlying Ventersdorp and Witwatersrand beds.

(v) The dykes intrude all formations up to the Ecca Series and are not intersected by any faults or intrusions of later age. They and the dolerite sills described below are the youngest known geological features in the Property.

2. THE SILLS

Sills of dolerite are of widespread distribution in the Far East Rand. The greater part of the Property is underlain by one or more sills, generally at a small depth below the surface. The deepest known occurrence is in No. 5 Shaft Springs Mine, at a depth of 750 feet.

The Green Sill, described by Ellis(6) as the lowest of a series of dolerite sills, shows a preference for the Transvaal dolomite as a host rock and is usually encountered a short distance below the base of the Karroo. It invades Karroo strata in areas where dolomite is absent (Plate V). Locally, where the dolomite has been exposed to surface erosion, the sill is found immediately below superficial deposits (Plate IV). In one borehole (D.M. 10) it is absent altogether, the dolomite being deeply eroded at this point.

The Green Sill is of considerable horizontal extent and has been traced throughout large areas to the north and south of the Property. Its extent in an eastward direction is

/unknown

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unknown. It is last seen, in Karroo strata, in boreholes on Vischkuil 12, (Plate I). When followed westwards its thickness decreases from over 100 feet in East Daggafontein to about 50 feet in Springs Mine and it disappears altogether before reaching the western boundary of the Property. In boreholes on Withok 7, south of Sallies Mine, thin dolerite sills, believed to be part of the Green Sill, were encountered in the dolomite and in the underlying Ventersdorp Amygdaloid. The Green Sill apparently splits up in this direction and invades pre-Transvaal strata.

On Sallies and Springs Mines there is a large outcrop of dolerite (the Sallies Outcrop) which occupies the highest ground on the Property (Plate IV). This is believed to be a remnant of another sill intruding Karroo strata at a higher level than the Green Sill. Other sills, believed to be part of the Green Sill, exist at depth immediately below it (Plate V).

The Green Sill in the dolomite is occasionally overlain by a rock, apparently intrusive, which consists very largely of magnetite and carries a little silver (Plate V). It is sporadic in distribution, having been observed in two widely separated boreholes (D.M.8 and E.D.14) but not in the intervening ones. In borehole E.D. 14 it is in contact with the Green Sill, which is chilled against it. In borehole D.M. 8 and in the J.V. Shaft, Springs Mine, it is separated from the Green Sill by a thin parting of dolomite. The age of this rock is unknown. Possibly it is a third sill of the same

/generation

same/

generation as the dolerites but of very different composition. On the other hand it may be of pre-Karroo age and in no way connected with the dolerites.

3. RELATION BETWEEN DYKES AND SILLS

There is no direct evidence of the age relationship between the dykes and the sills as intersections between them have not been observed. Neither is it possible to ascertain whether the dykes penetrate to the surface or stop short at the sills. Ellis(6) mentioned the existence of outcrops of the principal dykes, but none have been found on the Property. This may well be due to the susceptibility of the dolerite to weathering and the thickness of the subsoil; for example, where the Green Sill has been exposed to erosion (Plate IV) it is everywhere concealed beneath superficial deposits and is not visible on the surface.

The Modder Dyke was first encountered during the sinking of an old abandoned shaft. There are no records of this to show whether the dyke was found below the subsoil or below the Green Sill in the Karroo Strata (Plate V).

In any event the dykes are known to penetrate the formations in which the sills occur, and the obvious inference is that the sills are offshoots from the dykes. Ellis(6) believed that the Green Sill, which, unlike the dykes, is an olivine dolerite, must be associated with some other, olivine-bearing dyke. One such dyke occurs in Marievale Mine. This

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view is not accepted, for reasons discussed later. It is noticeable (Plate V) that the Green Sill is thickest in the neighbourhood of the Modder East Dyke and thins out and disappears westwards with increasing distance from the dyke. It is not apparently influenced by the presence of the Modder Dyke. The sill represented by the Sallies Outcrop, which is somewhat different petrologically from the Green Sill, occurs near the Modder Dyke and is not seen elsewhere. These facts suggest that the Green Sill was fed by the Modder East Dyke and that the Sallies Outcrop is a remnant of another sill fed by the Modder Dyke, the two dykes with their associated sills being similar in age but not contemporaneous. Microscopic examination of the rocks leads to the same conclusion.

4. PETROLOGY

(a) General

All the dolerites are tough, rather fine-grained, fresh-looking, holocrystalline rocks, dark grey to black in colour. Individual crystals can usually be distinguished with the naked eye but are seldom more than one or two millimetres in length. In very thin dykes and sills and near the margins of thick intrusions the rock has a finely-granular appearance, minute phenocrysts being visible in a dark, felsitic ground mass. At the immediate contact there is often a very thin selvedge of dark, stony tachylite.

In thin section the texture is ophitic or sub-ophitic, becoming fine-grained and porphyritic at the margins. The essential minerals common to all the dolerites are

/plagioclase

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plagioclase felspar and monoclinic pyroxene. Olivine is abundant in the Green Sill, inconspicuous in the Sallies Outcrop and very rare or absent in the dykes. Iron ores are abundant in the Modder Dyke, less common in the Modder East Dyke and inconspicuous in the Green Sill. Accessories are serpentine (replacing olivine), biotite, chlorite, quartz and occasional uralite, calcite and pyrite.

Essential Minerals

Plagioclase - tabular crystals, invariably twinned. Nearly always zoned, the central cores being more calcic than the outer shells. Composition varies from 75% An (bytownite) to 50% An (labradorite). Generally clear and fresh. Occasionally saussuritised.

Pyroxene - large crystals, prismatic or anhedral, enclosing other minerals. Prismatic cleavages conspicuous. Occasional simple twinning. Colourless to pale grey or brown. Non-pleochroic. Birefringence .025 - .028. Extinction angle c - axis : Z = 40° - 50°. Composition varies from diopside-augite to common augite. Nearly always fresh, occasionally altered to chlorite or uralite.

Olivine - small, cracked and somewhat corroded crystals. Colourless. Optically neutral. Composition: magnesian olivine with 12% FeO. Nearly always altered to serpentine along cracks. Occasionally replaced by biotite.

Iron ores - mostly magnetite. Well-formed crystals, anhedral grains, skeletal growths, laminae, fine grains and specks.

Accessories

Serpentine- Secondary after olivine. Pale green or brown. Massive or fibrous (chrysotile).

Biotite - fine flakes, nearly always in reaction relationship with pyroxene. Occasional pseudomorphs after olivine. Pleochroism

/strong

FIG. 1

Olivine Dolerite from the Green Sill, East Daggafontein Mine. Ordinary light, Magnification X16.
Plagioclase (clear)
Augite (pale grey)
Olivine, altered along cracks to serpentine (darker grey)

FIG. 2

Dolerite from Dyke A (Modder East), East Daggafontein Mine. Ordinary light. Magnification X22.
Plagioclase (clear)
Augite (pale grey)
Iron Ore (black)

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strong, X = yellow, $Y = Z$ = dark brown or green. Generally altered partially or completely to chlorite.

Chlorite - secondary after biotite or pyroxene. Massive, pale green, faintly pleochroic. Birefringence very low. Variety: penninite.

Quartz - minute clear pools and occasional micropegmatite, probably of primary origin. Occasional minute veinlets and cavity-fillings of secondary origin.

Uralite, Calcite,- secondary minerals, rare and local.

Pyrite - occasional disseminated grains in altered rock.

The differences in mineralogy and texture between the two major dykes (Modder East and Modder) and their similarities to their associated sills are pointed out in the descriptions below.

(b) The Modder East Dyke and the Green Sill

The Modder East Dyke and the Green Sill are identical in texture, which is typically ophitic (figs. I & 2). Small tabular plagioclase felspars are irregularly disposed within large anhedral crystals of pyroxene. The plagioclase is fresh and in the sill is strongly zoned, the central cores being bytownite of composition 75% An and the outermost shells labradorite of composition 60% An. In the dyke the plagioclase is labradorite with a smaller range of composition. The pyroxene is a pale diopside-augite extinguishing at $40^{\circ} - 45^{\circ}$. It is somewhat darker in the dyke than in the sill. Olivine, partly serpentinised, is abundant in the sill, and a few small crystals have been seen in specimens from the dyke at Kimberley

/Reef

Kimberley/

Reef level. Iron ore is not abundant and is more common in the dyke than in the sill. A very little biotite, partly altered to chlorite, is a frequent accessory and generally occurs in reaction relationship with augite. Occasionally it replaces olivine in the sill. Minute pools of quartz, assumed to be of primary origin are fairly common in the dyke and are not found in the sill.

In the marginal zones, near intrusive contacts, the grain of the rock is finer and the texture is porphyritic. Small well-shaped phenocrysts of pyroxene, plagioclase and olivine (in the sill) are embedded in a fine-grained ground mass of plagioclase microlites, augite granules and specks of iron ore. A marginal porphyritic texture is a feature common to all the dolerite intrusions.

Apart from the rarity of olivine in the Modder East Dyke, it is very similar in texture, mineralogy and freshness to the Green Sill. From the Main Reef Leader upwards to the Kimberley Reef, a vertical distance of about 1400 feet, the dyke changes slightly. Olivine appears in very small amounts, pyroxene becomes paler in colour and iron ores become less conspicuous. This suggests a gradual transition upwards in the dyke from a saturated rock with iron ore to an undersaturated magnesia-rich type identical with that of the Green Sill. There seems no reason why the sill should not be an offshoot from the dyke, the magma which arose first and spread out laterally in the dolomite being slightly different in composition from that

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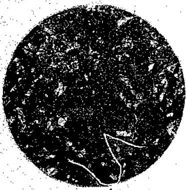

FIG. 3

Dolerite from Dyke B
(Modder), Springs Mine.

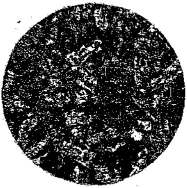

FIG. 4

Dolerite from Dyke C,
East Daggafontein Mine.

Ordinary light. Magnification X17.
Plagioclase (clear, showing cleavages)
Augite (pale grey)
Biotite and Chlorite (darker grey patches, indistinct)
Iron Ore (black)
Quartz (a few small clear pools)

FIG. 5

Dolerite from the Sallies Outcrop.
Ordinary light. Magnification X23.
Plagioclase (clear)
Augite (pale grey)
Iron Ore (black)
(No olivine in this specimen)

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which followed and solidified in the dyke fissure. On the other hand the undersaturated nature of the sill might be due to desilication of the magma by the dolomite. Borehole intersections show that the dolomite at the sill contacts is bleached and silicified. The slight difference in composition of the felspars and the pyroxenes of the sill, as compared with those of the dyke, might indicate absorption of lime and magnesia by the magma from the dolomite.

(vii) The Modder Dyke and the Sallies Outcrop

The Modder Dyke consists of a rather coarse-textured subophitic dolerite (fig. 3) with tabular plagioclase felspars, coarse prismatic crystals of augite, abundant iron ore and a little accessory biotite, chlorite and quartz. The plagioclase is labradorite of composition 60% - 65% An, slightly zoned and sometimes partly saussuritised. The augite is pale brown in colour and extinguishes at about 50° (common augite). Augite crystals are often fringed by reaction rims of biotite and chlorite. Magnetite is abundant, occuring as large well-formed crystals and as irregularly shaped masses intergrown with augite. A little interstitial quartz is common, sometimes in the form of micropegmatite. Locally , in narrow zones within the dyke, the dolerite is altered to epidiorite, with cloudy saussuritised plagioclase, uralite and chlorite replacing augite, minute secondary veinlets of chlorite, quartz and calcite and a little disseminated pyrite. There are no intrusive contacts between epidiorite and fresh dolerite, the one grades into the other. The

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this specimen)

The/ localisation within the dyke of these zones of alteration suggests that the agents were hot solutions derived from the magma itself and released in the closing stages of crystallisation of the rock, a process known as autometamorphism (1).

The Sallies Outcrop is a dolerite with very little olivine and coarse conspicuous iron ore. In this respect it resembles the Modder Dyke rather than the Modder East Dyke. The section shown in fig. 5 has a glomeroporphyritic structure (1), coarse crystals of labradorite being segregated into clots visible in hand specimen. This structure may however be local and not typical of the sill as a whole. The texture of the rock is ophitic. The pyroxene is a rather pale diopside-augite extinguishing at $40^{0} - 45^{0}$. Olivine is rare and occurs in very small crystals altered to green serpentine. Iron ores are coarse and conspicuous. No accessory quartz has been seen. This sill intrudes Karroo strata and does not transgress into the dolomite, which is perhaps the reason why it is much less undersaturated than the Green Sill.

Dyke C (fig. 4) is identical in every respect to the Modder Dyke and different from the Modder East Dyke, which intersects it near the northern boundary of the Property. The nature of this intersection is not known, but the dissimilarity of the two rocks at points not far from the intersection indicates that they are not contemporaneous.

/(d) <u>Contact Metamorphism</u>

(d) Contact Metamorphism

The contact metamorphic effects of the dolerite intrusions are unimportant and are confined to narrow zones close to the contacts. Such changes as have been observed are attributable to heat and the absorption by the wall-rocks of small quantities of magmatic fluid (injection metamorphism). Dolomite in contact with the Green Sill is bleached and silicified. Shale in contact with the dykes is slightly indurated. Biotite, chlorite, sericite and albite are sometimes developed in shale or quartzite close to dyke contacts. Chloritoid in shales of the Kimberley Series is resorbed and destroyed.

(e) Summary

Below is a summary of the main petrological differences between the two major dolerite dykes.

	The Modder East Dyke	The Modder Dyke
Texture	Typically ophitic	Sub-ophitic to gabbroic
Plagioclase Felspar	Labradorite Tabular crystals Moderately zoned Fresh	Labradorite Tabular crystals Weakly zoned Slightly saussuritised
Pyroxene	Diopside-augite Coarse anhedral crystals enclosing felspars Extinction c-axis:Z = 40° - 45° Fresh	Augite Coarse crystals, roughly prismatic, partly enclosing felspars Extinction c-axis:Z = 50° or more Occasionally uralitised
Iron ores	Subordinate Small grains	Abundant Coarse crystals and grains

cont'd

	The Modder East Dyke	The Modder Dyke
Accessories	Biotite, chlorite quartz (primary), very occasional olivine	Biotite, chlorite, quartz (primary & secondary), uralite, calcite, pyrite.

5. AGE AND ORIGIN

The dolerites are post-Ecca since they intrude sediments of the Ecca Series. Petrologically they possess all the features of Karroo dolerites as described by Du Toit (2). There can be little doubt that they are of Karroo age. It is interesting to note that certain dykes in the Far East Rand which were picked up by magnetometric survey (H. Gelletich - Beitr. ang. Geophysik, 1937, quoted by Du Toit (2)), can only have been these dolerite dykes, though at the time they were believed to be "Pilansberg" dykes of post-Waterberg pre-Karroo age. Their principal trend, which is about the same as that of the dykes which radiate from the Pilansberg volcanic centre, and the absence of outcrops in an area underlain by Karroo strata, no doubt gave the impression that they were pre-Karroo and belonged to the Pilansberg dyke system.

The fractures occupied by the dykes, according to Ellis(6), were opened and widened by the pressure of the magma itself overcoming the smallest compressive stress in the country rocks, which was horizontal and directed initially N.E. - S.W., at right-angles to the major dykes. In their straightness and continuity the major dykes are reminiscent of master-joints induced by warping in thick competent sediments, the east-west

/trending

east-west/
trending dykes representing a second set of joints not so well developed. The dolerites are the youngest structural features. They are not associated with any contemporaneous folding or faulting, but the major dykes coincide roughly with axes of very gentle up-warping, visible in the Karroo beds but not discernible in the older formations owing to the much more intense pre-Karroo folding (Plate V). This warping may have been responsibke, if not for the fractures themselves, for the inequality of the principal horizontal stresses which enabled straight vertical fractures to be opened up by the magma.

The sills are transgressive in character. They are not confined to the bedding-planes of any particular formation and are not found at any great depth below the present surface. They show a preference for the Transvaal Dolomite and the Karroo strata but are also known to intrude the underlying Ventersdorp and Witwatersrand beds. The controlling factor in their emplacement, according to Ellis (6), was depth below the surface at the time of their intrusion. Sills were emplaced at and above the deepest level at which the magma, forcing its way upwards under pressure, was able to lift the overlying strata. Below this critical level, which lay close to the present land surface, only dykes exist. Above it there are both dykes and numerous sills, most of which have been removed by subsequent erosion.

/ V. THE SYENITES

V. THE SYENITES

1. THE SILLS

Sills of intermediate and acid composition, generally known as syenite sills, are very numerous in the dolomite of the Transvaal System (Plate V). At least one sill is intersected by nearly every shaft and borehole penetrating the dolomite. The sills vary in thickness from a few feet to nearly 150 feet. They are lenticular in habit, follow closely the bedding-planes of the dolomite and are cut off by the erosion surface at the base of the Karroo strata (Plate V). They are clearly of pre-Karroo age and in no way related to the Karroo dolerite sills.

The table below shows the average relative thicknesses of syenite and dolomite between various levels above the base of the formation. It was compiled by averaging the results of a large number of shafts and boreholes.

	Height above base of dolomite:-					
	0-200'	200'-400'	400'-600'	600'-800'	800'-1000'	0-1000'
Average thickness of syenite	26	51	84	20	6	187
Average thickness of dolomite	174	149	116	180	194	813
Total thickness	200	200	200	200	200	1000

The table gives no indication of the thickness of any individual sill, which may be as much as 150 feet, but shows clearly that the relative proportions of syenite to dolomite is greatest in the zone between 200 feet and 600 feet above the base. The

/thickest

The/
thickest sills occur in this zone. At higher horizons sills are much less common. In the lowest zone, within 200 feet of the base, there are numerous sills but most of them are very thin.

In a thickness of 1000 feet of the dolomite formation, syenite sills amount, on an average, to 187 feet, or nearly 20% of the total. The source of this abundance of igneous material must lie outside the Property. Apart from a few insignificant dykes a few feet thick, there are no intrusions in the under-lying strata which could be the feeders of the sills in the dolomite.

Two distinct rock-types have been identified. These are known as green syenite and red syenite respectively. The former is the more abundant. It is common near the base of the dolomite in the form of very thin decomposed sills. At higher levels the rock is fresher and the sills are thicker, generally between 50 feet and 100 feet but sometimes over 100 feet. Only one sill of red syenite is known, but there may be more. In most shafts and boreholes the two types have not been distinguished from each other. The red syenite sill persists over a wide area and is nearly 100 feet thick in places. Sills of the green syenite are found both above and below it.

2. PETROLOGY

(a) The Green Syenite

The green syenite is a fine-grained dark coloured rock, which sometimes has a finely mottled appearance, ferro-magnesian

/minerals

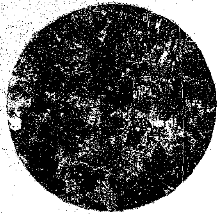

FIG. 6

Green Syenite Sill in Dolomite, Daggafontein Mine.
Ordinary light. Magnification X17.
Large crystal of andesine, partly albitised, on right (clear with pale grey patches).
Dark grey areas are mostly chlorite replacing pyroxene, and a little biotite and epidote.
Iron ore (black).
Quartz (clear). Large pool of quartz on extreme left, and minute pools and veinlets below centre.

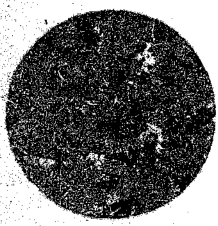

FIG. 7

Red Syenite Sill in Dolomite,
East Daggafontein Mine.
Ordinary light. Magnification X19.
Albite (pale grey)
Biotite and Chlorite (dark grey)
Quartz (clear)
Iron Ores (black specks)
(Note abundance of interstitial micropegmatite).

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minerals appearing very dark green and felspars white or reddish. In thin section it has a hypidiomorphic-granular texture. Plagioclase felspar and augite are present in approximately equal proportions but are never in ophitic relationship with each other. The most coarse-grained specimens are the freshest and are found only near the centres of thick sills. In thin sills and in the marginal regions of thick sills the rock is finer in grain, more altered and has a porphyritic texture. The contacts are chilled and rarely sheared.

In specimens which are comparatively fresh (fig. 6), the essential minerals are plagioclase felspar (andesine) and augite, with accessory iron ores, biotite, quartz, micropegmatite and apatite. Andesine occurs in thick tabular crystals, moderately zoned and partially or wholly albitised. Augite is coarse, tends to be euhedral and is partly altered to uralite and chlorite. Iron ores are sometimes conspicuous as well-formed crystals and anhedral grains. Biotite occurs as small flakes and shreds, generally in reaction relationship with augite. Quartz is present as small pools and sometimes as interstitial micropegmatite. Apatite in minute needles is a constant accessory.

The most conspicuous secondary change in the rock is the albitisation of primary plagioclase. Andesine crystals are invariably altered partially or completely to cloudy felspar with the composition of albite. Alteration begins at the

/crystal

the/ crystal margins and works inwards until the whole crystal is replaced by albite without any change in for . Patches of fresh clear andesine are often visible within areas of cloudy albite(fig. 6).

In thin sills and near the margins of thick sills the texture is finer. Phenocrysts of uralitised augite are embedded in a ground mass of minute uralite pseudomorphs, small grains of iron ore and fan-like clusters of thin lath-shaped plagioclase crystals, very cloudy and completely albitised. Biotite is altered to chlorite and ilmenite to leucoxene. Secondary epidote, quartz and calcite are common as disseminated grains and occasionally as encrusted crystals in cavities and minute veinlets in the rock.

Essential Minerals

Plagioclase - coarse thick tabular crystals. Aggregates of long fine laths. Composition: 35% - 40% An (andesine). Occasionally fresh, more often albitised.

Augite - stout columnar crystals. Fine granules. Pale brown to colourless, non-pleochroic. Birefringence about .028. Optical character: positive. Extinction angle, c-axis:Z = 35° - 40°. Composition: diopside - augite. Occasionally fresh, generally altered to uralite and chlorite.

Uralite - secondary after augite. Generally an essential mineral. Pseudomorphs after augite. Occasional ragged prismatic crystals and aggregates of fine needles. Pleochroism, X=Y= yellow-green, Z= green, occasionally brown. Birefringence about .027. Optical character: negative. Extinction angle, c-axis:Z = 13° - 18°. Composition: actinolite, some hornblende.

Accessories

Iron ores - mostly magnetite, some ilmenite. Crystals, grains, skeletal growths, laminae, specks, sometimes intergrown with augite.

Biotite - ragged flakes and small shreds generally in reaction relationship with augite. Pleochroism strong, X=yellow-green, Y=Z=dark green or brown. Partly or wholly altered to chlorite.

Chlorite - secondary. Pseudomorphs after augite, biotite, uralite. Scattered clots and fine disseminated scales. Occasional minute veinlets and cavity-fillings. Massive, pale green faintly pleochroic. Birefringence very low. Variety: penninite.

Quartz - water-clear pools and patches of micropegmatite, probably of primary origin. Minute veinlets and cavity-fillings of secondary origin.

Epidote - secondary. Small disseminated grains. Clusters of pointed columnar crystals in occasional cavities and veinlets. Pleochroism fairly strong, X=yellow, Y=brown, Z=green.

Calcite - secondary. Scattered rhombic crystals, fine aggregates, occasional veinlets and cavity-fillings. Common in very altered rock.

The essential primary constituents are andesine and augite, with accessory iron ores and quartz. The rosk is therefore an augite-tonalite and should not strictly be referred to as a syenite. The latter name however is in general use.

The primary minerals are in a much more advanced state of alteration than those of the Karroo dolerites, owing to the greater age of the rock and the fact that it has suffered a period of metamorphism in pre-Karroo times which the dolerites have missed. The sills have been subjected to the same deforming stresses as the dolomite and are folded with it. The alteration is typical of dynamic metamorphism of basic igneous rocks (1). The anorthite component of primary plagioclase has broken down to a dense microgranular mixture of secondary products (saussurite), with liberation of albite, which characteristically assumes the form of the original plagioclase crystals.

/Augite

crystals/
Augite is altered to uralite and chlorite, biotite to chlorite, and ilmenite to leucoxene. Secondary epidote, quartz and calcite occur as by-products of these metamorphic changes. The diabase dykes and sills in the Witwatersrand System, which are older than the syenites and have suffered stress-metamorphism in pre-Transvaal as well as in post-Transvaal times, are altered in a similar manner but to a greater extent.

It is possible that some mineralogical change in the green syenite was brought about by autometamorphism (1), *namely*, alteration of the rock by its own soda--andsilica-rich residual magma in the closing stages of crystallisation. The replacement of primary plagioclase by albite, for example, might be due to this cause rather than to subsequent stress-metamorphism of the solid rock. On the other hand albite is common in sheared diabase dykes and sills in the Witwatersrand System, in which it is almost certainly of stress-metamorphic origin.

(b) The Red Syenite

The red syenite is a fine-grained crystalline rock which derives its name from the reddish colour of the felspar of which it is very largely composed. In thin section it has a hypidiomorphic-granular texture. Albite is by far the most abundant mineral, amounting to about 90% of the total. Accessories are biotite, chlorite, quartz, micropegmatite and iron ores (fig. 7). The albite occurs in thick tabular crystals, closely packed together, slightly cloudy, and with scattered

/inclusions

scattered/

inclusions of biotite, chlorite and occasional iron ore. It is assumed to be of primary origin owing to its comparative freshness and the absence if any zoning or relics of original calcic plagioclase. Biotite is the chief accessory and is sometimes wholly altered to chlorite. Quartz is conspicuous and is mostly intergrown with felspar as micropegmatite. Iron ore occurs in small grains and isprobably primary, though some small specks disseminated in chlorite may be secondary.

Near the margins the texture is porphyritic, much of the albite occurring as well-shaped phenocrysts in a fine-grained ground mass of albite microlites, biotite, chlorite, iron ore, quartz and occasionally calcite, the latter possibly derived from the dolomite by assimilation.

Essential Minerals

Albite - thick tabular crystals closely packed, conspicuous simple and lamellar twinning. Composition: almost pure soda-felspar, not more than 5% An. Slightly cloudy, scattered inclusions.

Accessories

Biotite - small plates and aggregates of small flakes, occupying interstices between albite crystals. Pleochroism strong, X=yellow, Y=Z=dark green or brown. Partially or wholly altered to green chlorite.

Chlorite - secondary. Pseudomorphs after biotite. Small clots and fine disseminated scales. Pleochroism, pale green to dark green. Bi-refringence, small but distinct, interference colour masked by green body-colour. Variety: mostly clinochlore.

Quartz - some small water-clear pools. More often intergrown with cloudy felsp[illegible] as micro-pegmatite. Probably all of primary origin.

Iron ore - small grains and specks. Mostly primary but some maybe secondary.

The most noteable feature of therock is the abundance of albite and the absence of potash felspar. It is possible that a minute amount of orthoclase is present in the form of micropegmatite, but this could not be determined. If the albite is regarded as a plagioclase felspar with little or no lime, the rock is a biotite-tonalite. If on the other hand the albite ranks as alkali-felspar with no potash, the name syenite is correct. Since it is generally known as syenite, it is preferable to retain this name.

The effects of stress-metamorphism are much less marked than in the green syenite, owing to the different composition of the rock. There are no minerals, such as pyroxene, which break down readily under stress. Albite, a mineral stable under medium-grade stress-metamorphism, is slightly clouded but otherwise unaltered. Biotite is sometimes wholly altered to chlorite.

(c) <u>Contact Metamorphism</u>

The contact metamorphic effects of the syenite sills are not great. In narrow zones close to the sill contacts, the dolomite is recrystallised and new minerals are developed in it, through absorption of small quantities of magmatic fluid (injection metamorphism).

In one borehole intersection, the dolomite within a few inches of a thick green syenite sill is coarsely crystalline and packed with long acicular crystals of colourless tremolite.

/A few

tremolite/

A few feet from the contact the dolomite is finely crystaline and there are no metamorphic minerals.

3. THE DYKES

There are no dykes in the Property of sufficient thickness and extent to be the feeders of the sills in the dolomite. The ilmenite diabase dykes would be the obvious choice (Plate III), but there is strong evidence that these dykes are older than the sills. There are however several narrow inclined dykes intruding the Witwatersrand beds which in texture, mineral composition and alteration have features in common with both the green and the red syenite. For this reason alone they are called syenite dykes and are assumed to be of the same age as the sills.

In appearance thesyenite dykes are somewhat darker in colour, fresher looking and less sheared than the diabase dykes. In thin section their most conspicuous feature is an abundance of cloudy albite in aggregates of thin tabular crystals. Other minerals present are actinolite or hornblende, iron ores, quartz, a little biotite, chlorite, epidote, calcite and occasional pyrite. No pyroxene has been identified. The amphibole is generally acicular, resembling uralite derived from pyroxene. Sometimes it is wholly replaced by chlorite. Quartz is generally conspicuous and appears to be of both primary and secondary origin.

Syenite dykes intruding the Main Reef Leader are shown in Plate III. They are of limited horizontal extent and are

/seldom

are/

seldom more than a few feet thick. Their average strike is somewhat north of west and they dip to the south at angles between 35° and 60°. A thin and persistent sill of the same type has been seen a few feet above the Main Reef Leader in Springs Mine. In No. 5 Shaft Springs Mine, a narrow dyke very rich in albite intrudes the Kimberley Shale. In bore-hole S.A.L. 2, two similar dykes intrude a sill of norite which itself intrudes the Kimberley Shale. In the north of Springs Mine, a narrow inclined dyke rich in pyrite, believed to be a decomposed syenite, intersects the Kimberley Reef. In Geduld Prop.,Mines Ltd., north of the Property, a narrow dyke, somewhat similar to the syenites but with less felspar, intrudes the Black Reef Series, and is therefore post-Transvaal in age.

4. AGE

There is no proof that the green and red syenite sills are of the same age, but there seems little reason to doubt that they are essentially contemporaneous and were derived by differentiation from the same magma. The narrow dykes in the Witwatersrand System have features in common with both types of sill, suggesting that they were derived from the same igneous source. The age of the sills is post-dolomite and pre-Karroo. They could be connected with the Bushveld Igneous Complex or with the later, post-Waterberg, phase of dyke injection. Syenitic and dioritic sills in the dolomite are mentioned by Du Toit (2) as possible offshoots from dykes of post-Waterberg age. Dykes which might be the feeders of the sills do not exist in the Property.

VI. THE ILMENITE DIABASE

1. THE DYKES

Ilmenite diabase is an altered basic intrusive rock in which ilmenite is generally a conspicuous mineral. It is of wide-spread distribution in the Far East Rand and has been described by Ellis(6). It has been observed as dykes and sills intruded into Witwatersrand strata and into intrusions of Ventersdorp age(6), but has not been seen in the Transvaal System.

A number of ilmenite diabase dykes intersect the Main Reef Leader and are shown in Plate III. Their general trend is roughly N.E. - S.W. but their local strike is very variable. In thickness they vary from about 30 feet to over 100 feet. At their intersections with the Main Reef Leader the dykes are vertical or steeply-dipping. They do not displace the reef vertically to any great extent. Their contacts are chilled and are not often sheared.

A few of these dykes have been seen at Kimberley Reef level, roughly above their positions on the Main Reef Leader. Their behaviour at higher stratigraphic horizons is not known. Possibly they change to sills or alternations of dyke and sill. Shafts and boreholes have intersected a number of decomposed diabase sills and inclined dykes in the Kimberley-Elsburg strata, a few of which are identifiable as ilmenite diabase. In workings in the Kimberley Reef in Springs Mine, there are numerous

/narrow

numerous/

narrow decomposed sills and dykes which are classed provisionally as quartz diabase, but a few may be ilmenite diabase. In other mines ilmenite diabase intrusions have been observed as dykes alternating with sills(6).

A pair of thick dykes in Sallies and Brakpan Mines, which unite at intervals to form a single dyke (Plate III), are known at Main Reef Leader level in Geduld Prop. Mines Ltd., but have not been seen in Black Reef workings in the same mine, though the latter cover a wide area in which these dykes might be expected to occur. This cannot be regarded as conclusive evidence that the dykes are pre-Transvaal in age. Their continuity in a vertical direction has not been established. They may possibly change to sills in the Elsburg strata and fail to penetrate as high as the Black Reef horizon, or they may penetrate the latter at points far removed from their plan positions at Main Reef Leader level.

Like the Karroo dolerites, the ilmenite diabase dykes occupy fractures that are essentially vertical and were opened by a simple movement apart of the walls, but they lack the regularity and continuity of the dolerite dykes. The origin of the fractures is discussed later.

2. PETROLOGY

Ilmenite diabase is a tough, fine-grained rock, grey to greenish in colour, with a dull non-lustrous appearance, very different from the dark, lustrous, fresh-looking Karroo dolerites. Generally it cannot be distinguished from the

/older

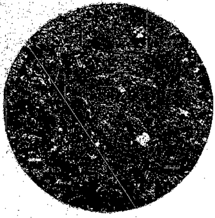

FIG. 8

Ilmenite Diabase Dyke, East Daggafontein Mine.
Ordinary light. Magnification X18.
"Shadows" of primary plagioclase felspars, replaced by chlorite, are visible near centre of field.
No trace of original pyroxene.
Ilmenite, partly altered to leucoxene (black).
Quartz (clear).

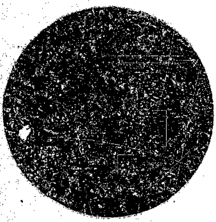

FIG. 9

Ilmenite Diabase Dyke, Daggafontein Mine. Ordinary light. Magnification X18.
No trace of original ophitic texture.
Uralitic hornblende (small pale bladed crystals)
Abundant chlorite (grey areas)
Remnants of primary ilmenite (dark patches with black specks)
A few minute pools of quartz (clear)

the/

older quartz diabase except by microscopic examination. The margins of dykes are fine-grained and occasionally sheared.

In thin section, typical ilmenite diabase has a palimpsest structure (I), the primary texture of the rock being largely obscured by alteration. The essential minerals are plagioclase felspar, uralite and ilmenite, with accessory chlorite, epidote, quartz, leucoxene, apatite and sometimes albite, calcite, talc and a little pyrite.

Plagioclase (andesine-labradorite) occurs as tabular crystals distributed in a manner suggesting an original ophitic texture (fig. 8). Fresh patches have been seen but are very rare. Generally the plagioclase is very decomposed and indistinct, being altered to a dense microgranular mass of secondary minerals or replaced by massive chlorite. Occasionally it is made over to albite, like the plagioclase of the green syenite sills.

Uralite occurs as ragged prismatic crystals or as aggregates of fine needles which frequently penetrate the felspars. It is green in colour and patchily altered to chlorite. Fragments of fresh augite, from which the uralite was derived, have been seen in specimens from other mines (6).

Ilmenite is generally conspicuous as large crystals and skeletal growths, partly altered to leucoxene or sometimes to sphene. Chlorite, epidote and quartz are invariably present. These minerals are of secondary origin, apart from a minute amount of quartz in the form of micropegmatite, which may be

/primary.

be/ primary. Apatite in minute rods and needles is a frequent accessory.

In parts of some dykes and particularly in thin sills, the rock is in a very altered condition and is difficult to recognise (fig. 9). The primary texture is entirely destroyed and relics of primary felspars are no longer visible. Uralite, chlorite, epidote, quartz, calcite and leucoxene are the essential constituents. A few fragments of primary ilmenite are generally preserved. Talc occurs in the form of minute tabular crystals and fine flakes, always in association with chlorite. Secondary albite is occasionally conspicuous as small scattered crystals crowded with fine inclusions of chlorite. Minute veinlets and amygdale-like cavities encrusted with chlorite, epidote, quartz, calcite and talc are fairly common and are characteristic.

At the margins of dykes a porphyritic texture is sometimes discernable, decomposed phenocrysts being embedded in a finely-granular or felsitic ground mass. When sheared the rock sometimes has a microscopic gneissose structure and shows "augen" of granular quartz, epidote and fragmented ilmenite, and long streaks and lenticles of chlorite, calcite, talc and leucoxene. Small euhedral porphyroblasts of albite are sometimes aligned transversely to the foliation, demonstrating the secondary origin of this mineral.

Essential Minerals

Plagioclase - tabular crystals, occasionally segregated into clots but more often scattered and unorientated. Approximate composition: 40% - 80% An.(andesine-labradorite). Hardly ever fresh. Nearly always replaced by chlorite, quartz, calcite, talc, epidote, albite or combinations of these minerals.

Augite - originally an essential primary mineral, now totally destroyed and replaced by uralite and chlorite.

Uralite - secondary after augite. Ragged prismatic crystals, acicular aggregates, fine scattered needles. Pleochroism, X=Y=pale green or yellow, Z=green to bluish green, occasionally brown. Birefringence .025 to .030. Extinction angle, c-axis:Z=15°-18°. Composition: mostly actinolite, some hornblende. Altered partly or wholly to chlorite.

Ilmenite - large well-formed crystals, anhedral grains, skeletal growths, long fine laminae, small grains and specks. Partly or wholly altered to white opaque leucoxene and occasional aggregates of brown sphene.

Accessories -

Chlorite - secondary. Pseudomorphs after plagioclase or uralite. Numerous scattered clots and fine scales. Common in cavities and veinlets in altered rock. Pleochroism: weak, pale yellows and greens. Birefringence very low, anomalous blue interference colours. Variety: penninite.

Epidote - secondary. Well-formed crystals, anhedral grains, granular aggregates, encrusted crystals in veinlets and cavities. Colourless to pale yellow-green. Faintly pleochroic.

Quartz - nearly all secondary. Pools, granular aggregates, cavity fillings, veinlets. A minute amount in the form of micropegmatite may be primary.

Albite - Secondary. Small well-shaped crystals, anhedral growths with indistinct outlines, occasional pseudomorphs after primary plagioclase. Conspicuous lamellar and chessboard twinning. Cloudy, full of fine inclusions of chlorite.

Calcite - secondary. Scattered rhombs, granular aggregates, cavity fillings, veinlets. Common in very decomposed and sheared rock.

Talc - secondary. Minute tablets, stellate groups, aggregates of fine flakes. Always enclosed in chlorite.

Pyrite - occasional small disseminated grains and crystals.

The rock was originally a dolerite somewhat similar to that of the Karroo Dykes but much older. There are marked differences in composition, texture and alteration between different dykes and between different parts of the same dyke. Some specimens of very altered ilmenite diabase are quite indistinguishable in thin section from the quartz diabase of the "Old Lady", an older rock. Some dykes have basic margins and acid centres. The margins are rich in uralite and chlorite with little or no trace of felspar. The centres are rich in albite (replacing primary felspar?) with little uralite or chlorite. It is unlikely that these dykes are composite, as one rock-type grades into the other.

Talc appears to be a diagnostic mineral, having been recognised only in the ilmenite diabase dykes. Ilmenite, leucoxene, epidote and green chlorite are generally more conspicuous than in the other intrusives. Micropegmatite is rare. It is more common in quartz diabase. In general the ilmenite diabase dykes are more altered than the syenite sills and slightly less altered than the quartz diabase intrusions.

A certain amount of injection metamorphism of shale and

/quartzite

and/

quartzite is visible within a few feet of the dyke contacts. The sediments are darkened in colour due to enrichment in fine chlorite. Sometimes there are scattered crystals of ilmenite altered to leucoxene. On the whole the contact metamorphic effects of the dykes are very slight.

3. ORIGIN AND RELATION TO OTHER STRUCTURES

The ilmenite diabase dykes are older than the Karroo dolerite dykes and younger than the quartz diabase intrusions. This is clear both from observed intersections between the dykes and from a study of the tear faults which displace the strata horizontally. The Witwatersrand strata are displaced by a number of tear faults, most of which strike roughly east-west (Plates III & VIII). Some have a right-handed and others a left-handed horizontal movement (the terms right-handed and left-handed are self-explanatory). It has been possible in most cases to estimate the direction and magnitude of the movement from the observed displacement on the faults of pay-shoots, axes of folding and dykes. Both sets of tear faults displace the quartz diabase dykes and probably the norite-granophyre dyke, though in the latter case the actual fault-dyke intersections have not been observed. Only the left-handed faults displace the ilmenite diabase dykes. The Karroo dolerite dykes are not displaced by any faults. The ages of these faults are not known, but the left-handed set is obviously younger than the right-handed set.

/Two

set/.

Two ilmenite diabase dykes show an apparent left-handed displacement on a right-handed tear fault,(the Vogels Tear Fault), which displaces the strata and the "Old Lady"dyke by about 3000 feet in the opposite direction (Plate III). Either the dykes chose to follow the pre-existing fault for some distance before resuming their original courses, or there was a reversal of movement on the fault at a later,post-ilmenite diabase, period. In either case the dykes would be younger than the original right-handed displacement. In the fault-plane itself there are traces of ilmenite diabase which could have been intruded into it or dragged along it.

The dykes are vertical and trend roughly N.E.- S.W. The axes of minor folding in the reef run N.W. - S.E., approximately at right-angles to the dykes. The angular relationship between the dykes, the fold axes and the right-handed tear faults can be explained by means of a strain ellipsoid orientated in plan such that one of its planes of no distortion (or maximum shearing stress) represents the right-handed tear faults (Plate VIII). The fold axes are aligned correctly in relation to the faults, that is, parallel to the long axis of the ellipsoid. The dykes are approximately parallel to the short axis. The regional stress most likely to give rise to this strain system would be an anti-clockwise shearing couple acting in a horizontal plane, the forces of the couple being directed parallel to the movement on the tear faults (Plate VIII). Ellis(4) explains

/the

explained/ the Grootvlei Tear Fault, which occurs to the north of the Property and belongs to the same set of right-handed tear faults, in a similar manner.

The fold axes are displaced by the faults. Hence the rocks first yielded to stress by folding, then by fracture and movement along planes of maximum shear (the tear faults) when the stress could no longer be absorbed by folding alone. The ilmenite diabase dykes are younger than the faults. It might be argued, from the angular relationship, that the dykes are tension fractures resulting from the same regional shearing stress. This is most unlikely because tensile stress could not be transmitted through ground already broken up by tear faults. Any further adjustment would be by movement on the tear faults already in existence.

It is more likely that the dykes were intruded at a period when the bulk of the regional stress had been relieved and what remained was insufficient to cause further movement on the tear faults. The fractures were opened and widened by the pressure of the intruding magma itself, acting against the smallest stress in the country rocks, which was compressive, not tensile. This is in accordance with the views of Ellis(6). The irregularity of the dykes and the occasional alternations of dyke and sill show that there were no great differences in the magnitudes of the principal stresses at the time of intrusion, though in general the smallest stress, at right-angles to the plane of /the of/

the fractures, was horizontal and directed roughly N.W. - S.E.

To account for the displacement of the earlier structures by tear faults with a left-handed movement, a reversal of the regional stress is necessary and is consistent with the observed facts. There have obviously been at least two periods of earth movement, in which the directions of the regional stresses were different. The strata are folded in two directions at right-angles, namely, about a major synclinal axis running roughly N.E. - S.W. (Plate VIII , and about minor axes running N.W. - S.E. A renewal of the regional stress which caused the major syncline (believed to be of earlier date than the minor folds) could account for most of the left-handed tear faults, and possibly some reversal of movement on the older right-handed faults.

4. AGE

The ilmenite diabase dykes are intermediate in age between the Karroo dolerites and the quartz diabase intrusions. In their general state of alteration they are comparable with the quartz diabase, which is pre-Transvaal, rather than with the syenites, which are post-Transvaal. They have not been seen to intrude beds of the Transvaal System and may be older than the latter. Intersections with the syenite dykes are not exposed.

If it were possible to date the tear faults, this would

/date

would/ date the ilmenite diabase dykes. The minor N.W. - S.E. folding associated with the right-handed tear faulting has affected the Ventersdorp lavas and, to a much smaller extent, the Transvaal beds, suggesting a post-Transvaal age for the faults and the dykes. On the other hand the latter may be pre-Transvaal and may have preceeded some of the folding.

On the whole the indications are that the ilmenite diabase dykes are post-Ventersdorp and pre-Transvaal in age, belonging to the period of earth movement which followed the extrusion of the Ventersdorp lavas and preceeded the deposition of the Transvaal beds. The left-handed tear faults, which represent entirely different stress conditions, belong by inference to a later, post-Transvaal, period of earth movement.

/VII. THE NORITE-GRANOPHYRE

VII THE NORITE - GRANOPHYRE

1. THE DYKES AND SILLS

A large and complex intrusion, essentially of sill form but with transgressive dyke phases, intrudes the Witwatersrand beds in Brakpan, Sallies and Springs Mines and persists over a large area to the south and west of the Property. This is the "Van Dyk Granophyre" described by Ellis(5). It is shown in plan in Plate VI and in section in Plate VII. Although generally known as granophyre it is made up of two very different rock types, an acid granophyre and a basic norite.

In Van Dyk Mine and in the extreme west of Brakpan Mine this intrusion transgresses the Main-Bird Series in the form of a thick dyke striking north-south (Plate VI). This dyke connects two sill phases, one in the Jeppestown Series on the west side, the other in the Kimberley Shale or the Bird Series on the east side (Plate VII). Another dyke phase transgressing the Elsburg beds has been intersected in No. 4 Shaft Springs Mine (Plate VII). This dyke evidently marks the eastern limit of the upper sill phase. The sill ends along a line running roughly N.W. - S.E. (Plate VI). No other sill or dyke phases have been seen to the east of this line except in Marievale Mine, where a sill of norite and another of granophyre (not the "Marievale Granophyre") occur in the Jeppestown Series(5).

The upper sill phase of the intrusion attains a maximum known thickness of 540 feet in the Kimberley Shale. It consists /of consists/ of an upper granophyre and a lower norite, the two parts being about equal in thickness. The contact between the two rock types is sharp, the norite being chilled against the granophyre. Thin basic sills, probably offshoots from the main norite sill, intrude the overlying granophyre. In No. 7 Shaft Springs Mine, the two types are not in contact but are separated by about 50 feet of quartzite of the Bird Series. The dyke in the Elsburg Series intersected in No. 4 Shaft Springs Mine consists of very altered granophyre. A thin sill of granophyre, possibly underlain by norite, occurs below it in the Kimberley Shale (Plate VII).

The dyke which transgresses the Main-Bird Series in Brakpan and Van Dyk Mines displaces the strata vertically by about 300 feet, the beds on the east side being thrown down. The dyke is between 100 and 300 feet thick, strikes north-south and dips steeply to the west. Its contacts are somewhat irregular and frequently dip locally in the opposite direction. The dyke consists mainly of norite. The granophyric phase is intermittent and occurs near the western (hanging wall) contact. One thick dyke of granophyre, apparently an offshoot from the main dyke, branches off on the east side, striking roughly east-west. Its extent is unknown. In the Jeppestown Shale on the west side of the main dyke there are numerous narrow intrusions of both norite and granophyre, striking and dipping in many different directions. Small bodies of granophyre have been seen which appear to be

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be/ completely enclosed by shale. Further to the west, in Van Dyke Mine, the intrusion has been observed as a thick sill deep in the Jeppestown Series (5).

It is clear from the shape of the intrusion and its effect on the strata, that the fractures into which magma was intruded were opened and widened chiefly by vertical movement apart of the walls. The beds below the intrusion have dropped relative to those above it. The mechanics of this type of intrusion have been worked out by Ellis(5). The fracturing of the rocks in this manner and the injection of magma into the fractures are explained as due to subsidence under gravity of large blocks of Witwatersrand strata, through weakening or melting of the underlying Basement Complex, or some other deep-seated cause.

There was evidently some distortion and local sagging of the beds during subsidence, since the thickness of the sill phase is in places nearly twice the vertical displacement of the strata on the dyke. For simple subsidence the sill should be of a constant thickness equal to the vertical displacement. Ellis(5) preferred a different explanation for this. He maintained that there was no sagging of the strata, the anomalous thickness of the sill being due to metamorphic re-constitution of shale, which was changed into granophyre.

The norite-granophyre intrusion is similar in structure to the "Old Lady" quartz diabase intrusion (Plate VII), but thicker and of wider horizontal extent. Its full extent and

/shape

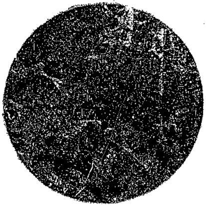

FIG. 10

Fresh Norite from Sill in the Kimberley Shale, Sallies Mine. Ordinary light. Magnification X19.
Enstatite, partly serpentinised (long prismatic crystals)
Diopside (twinned crystal above centre of field, and another on the extreme right)
Anorthite (pale interstitial masses, fractured and veined)

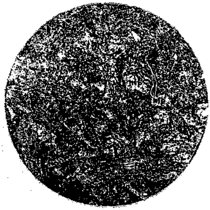

FIG. 11

Norite from Sill in Kimberley Shale, Sallies Mine.
Ordinary light. Magnification X17.
Enstatite altered to serpentine and uralite.
Anorthite decomposed.
Patches of interstitial micro-pegmatite (mp).

and/

shape are not known. The fact that sills of norite and granophyre in the Jeppestown Series are known in Marievale Mine, far to the east (5), suggests that the intrusion as a whole may originally have been a dome-shaped body similar to the "Old Lady", now modified by folding and faulting and with its uppermost sill phases removed by erosion.

2. PETROLOGY

(a) The Norite

The norite is a tough, greenish-grey rock, occasionally coarse-grained, with crystals up to half aninch in length. It is similar in general appearance to the diabases but coarser in grain.

In thin section the rock has an almost panidiomorphic texture when fresh (fig. 10), the essential minerals being enstatite, and diopside, in coarse euhedral crystals, with a little interstitial plagioclase felspar (bytownite to anorthite) and a minute amount of quartz and micropegmatite. There is no iron ore. The proportion of plagioclase to pyroxene is low and the rock approaches pyroxenite in composition.

Fresh norite is very rare and confined to the central portions of thick norite bodies. Generally the rock can be described as serpentine-amphibolite, with no primary minerals except quartz (fig. 11). The pyroxenes, being non-aluminous magnesia-rich types, are altered to acicular or fibrous uralite (tremolite-actinolite) and massive or foliated serpentine.

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Chlorite is rare. Plagioclase is decomposed and generally unrecognisable. Occasionally there is a little calcite.

<u>Essential Minerals</u>

Enstatite - well-formed prismatic crystals, slightly rounded. Colourless, non-pleochroic. Bi-refringence about .012. Extinction: parallel to c-axis. Optical character: neutral or negative. Composition: ferrif-erous enstatite, 10% - 15% FeO. Nearly always altered to uralite and serpentine.

Diopside - well-formed crystals and corroded forms. Sometimes coarsely intergrown with enstatite. Occasionally simple twinning. Colourless to very pale green, non-pleochroic. Bi-refringence .027 - .030. Optical character: positive, with rather small axial angle. Extinction angle, c-axis:Z = 30° - 40°. Nearly always altered to uralite and serpentine.

Uralite - secondary. Roughly pseudomorphous after pyroxene. Aggregates of long needles and fine fibres intergrown with serpentine. Colourless to very pale green. Pleochroism very weak or absent. Birefringence .025 - .030. Extinction angle, c-axis:Z = 15° - 18°. Composition: tremolite-actinolite.

Serpentine - secondary. Massive or finely-foliated. Intergrown with uralite. Colour: very pale yellow green, pleochroism very weak. Bi-refringence about .011. Variety: antigorite.

<u>Accessories</u>

Plagioclase - optically continuous interstitial areas showing lamellar twinning. Composit-ion: bytownite to anorthite. Nearly always decomposed.

Quartz - occasional minute clear pools, and patches of micropegmatite.

In its advanced state of alteration the norite is comparable with the diabase dykes and sills in the Witwatersrand strata, rather than the syenite sills in the dolomite. Its age is believed to be pre-Transvaal.

/(b) <u>The Granophyre</u>

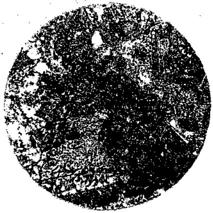

FIG. 12

Granophyre from *Sill in the Kimberley Shale*, Sallies Mine. Ordinary light. Magnification X16.
Quartz (clear)
Felspar (dark grey, rectangular outlines)
Hornblende and Chlorite (grey, outlines dotted)
Ilmenite (skeletal, black)
(Note abundance of coarse and fine micropegmatite).

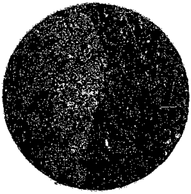

FIG. 13

Contact of Granophyre (right) with Quartzite (left). Brakpan *Mine*. Ordinary light. Magnification X15.
The granophyre is *fine-grained* and rich in hornblende.
The quartzite is recrystallised, contains shreds of hornblende and has patches of granophyric texture.
The contact in this example is *sharp*.

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(b) <u>The Granophyre</u>

The granophyre is a dull grey crystalline rock, somewhat
lighter in colour than the norite but similar in grain-size.
In thin section it has a granitic texture and composition (fig.
12.), the minerals being felspar (assumed to be orthoclase),
quartz (much of which is intergrown with felspar as micropegma-
tite), hornblende, ilmenite, chlorite, sericite, leucoxene and
occasionally calcite, epidote and a little pyrite.

Felspar and quartz occur both individually and in inter-
growth with each other as micropegmatite. Individual felspar
crystals are generally rectangular in section and clouded with
fine sericite. Simple twinning is occasionally visible but
no lamellar twinning. The optical properties are indetermin-
able but the felspar is assumed to be orthoclase by its rect-
angular outlines, small extinction angles and opaque, cloudy
nature. Often the crystals are optically continuous with
surrounding areas of felspar intergrown with quartz.

Quartz occurs individually as clear pools with very
irregular outlines, always optically continuous with the
quartz in adjacent areas of micropegmatite. The intergrowth,
which is here referred to as micropegmatite, implying that it
is of primary origin, is very variable in texture, ranging from
a coarse interfingering type to a very fine vermicular or
fibrous type resembling secondary myrmekite. Sometimes it is
typically micrographic and shows wedge-shaped areas of clear
quartz disposed in a regular pattern within cloudy felspar.

Hornblende occurs as elongated prismatic crystals rather
/raggedly

rather/
raggedly terminated and sometimes distorted. Ilmenite is fairly common as large crystals and skeletal growths partly altered to leucoxene. Chlorite is common and sometimes replaces hornblende. A little calcite is occasionally associated with chlorite. Epidote is very uncommon but has been seen replacing felspars in a few specimens from one bore-hole. Its presence is difficult to explain and may be purely local.

<u>Essential Minerals</u>

Orthoclase - tabular crystals, rectangular in section. Also intergrown with quartz as micropegmatite. Never fresh. Clouded with fine sericite. Occasional inclusions of chlorite and finely granular quartz.

Quartz - some individual pools. Mostly intergrown with felspar as micropegmatite. Clear, few inclusions.

Hornblende - prismatic crystals, raggedly terminated. Occasional simple twinning. Pleochroism, X=Y=pale green or yellow, Z=green, occasionally brown. Birefringence .022 - .025. Extinction angle, c-axis:Z=15° - 17°. Composition: common hornblende. Sometimes replaced partly or wholly by chlorite.

<u>Accessories</u>

Ilmenite - crystals and skeletal growths, partly to altered to leucoxene.

Chlorite - patches replacing hornblende. Scattered clots and fine scales. Massive, pale green, faintly pleochroic. Birefringence generally low. Optical character: positive. Variety: mostly penninite, some clinochlore.

Calcite - occasional grains associated with chlorite.

Pyrite - small disseminated grains.

Epidote - generally absent. Replaces felspars in a few specimens.

The granophyre has the texture and composition of an altered hornblende granite with much primary micropegmatite. Ellis(5) however regarded it not as an igneous intrusive but as a syntectic rock, derived from shale or quartzite by recrystallisation in the solid state. According to his view, the felspar, quartz and hornblende are not magmatic minerals, but grew in the solid state at the expense of sericite and chlorite, which crystallised at an early stage in the formation of the rock and not later as products of its alteration. The micropegmatite, according to Ellis, did not arise through simultaneous crystallisation of quartz and felspar from a magma, but represents an intermediate stage in the growth of separate quartz and felspar crystals from an intimate mixture of fine quartz and sericite. On petrological grounds there is little to choose between the two theories of origin. On other grounds however the balance of evidence seems to favour an igneous intrusive origin. This is discussed later.

(c) <u>Contact Metamorphism</u>

The norite sill shows a chilled contact with granophyre above and with shale or quartzite below. The sediments below the norite are thermally altered with little recrystallisation. There is little change in the granophyre near the norite contact except perhaps a slight increase in the amount of hornblende.

The contact between the granophyre below and shale or quartzite above is gradational and is often indistinguishable /underground indistinguishable/ underground or in hand-specimen. There is a gradual change from shale to granophyre through a transitional rock which first shows chlorite, sericite, granular quartz, ilmenite, and leucoxene, and finally shreds of hornblende, embryo felspar and traces of micropegmatite, passing by degrees into true granophyre. The change from quartzite to granophyre is more rapid. In the transitional zone the quartzite is re-crystallised, loses its sedimentary characteristics and acquires a granophyric texture (fig. 13). These contacts are not typical of an intrusive rock and are regarded by Ellis as evidence that the granophyre itself is recrystallised shale or quartzite.

3. ORIGIN OF THE GRANOPHYRE

In the opinion of the writer, both the norite and the granophyre are intrusive igneous rocks. Ellis(5) on the other hand regarded the norite as an intrusive and the granophyre as a syntectic rock, namely, shale or quartzite re-crystallised in the solid state by heated emanations arising from the norite, or by heat and rock stresses. Ellis' arguments in favour of his theory are recapitulated briefly below, followed by criticisms.

(i) The thickness of the norite sill in the Kimberley shale is between 250 and 320 feet, about equal to the vertical displacement of the strata on the dyke, which is 300 feet. The granophyre overlying the norite is /220 to 320 feet

norite is/
220 to 320 feet thick. This points to the norite being a simple intrusion filling the space left by subsidence of the beds, and the granophyre being a syntectic rock produced from shale by some action of the norite.

Shaft and borehole intersections in the Property confirm that the combined thickness of the norite and granophyre sills is generally, but not always, greater than 300 feet.

In three intersections the sill thicknesses in feet are as follows:-

	No. 7 Shaft Springs Mine	Borehole S.A.L.1.	Borehole S.A.L.2.
Granophyre	30	220	310
Norite	170	290	230

In other intersections the norite and granophyre have not been distinguished from each other.

These data, though scanty, give no strong reasons for supposing that both rocks are not intrusive. There seems no reason why the beds under the intrusion, deprived of their solid support at great depth, should not have bent and sagged as well as subsiding in bulk, making the sill thickness greater than the vertical displacement on the dyke. Ellis objected to this on the grounds that the beds above the intrusion, having no solid support, would be more likely to sag than those below it, making the sill thinner, not thicker. On the other hand the fact that a sill exists at all shows that the pressure of the magma, at that depth below the surface, was sufficient to support the weight of the overlying rocks. This was not the
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case at great depth, otherwise there would have been no subsidence of the beds. Thus the rocks below the sill were free to sag while those above it were not.

(ii) Comparing two boreholes (not named), one of which intersects the sill in the Kimberley Shale while the other does not, the thickness of shale plus granophyre in the one is equal to the thickness of shale in the other. Hence the granophyre does not displace the shale but replaces it.

In the table below, two boreholes which intersect the sill in the Kimberley Shale are compared with the nearest shafts and boreholes in which the sill is either absent or does not intrude the Kimberley Shale. Other intersections of the sill in the Kimberley Shale exist, but records of them are incomplete.

	Thickness in feet of:-			
Shaft or Borehole	Norite	Granophyre	Kimb.Shale	Shale plus Granophyre
Borehole S.A.L. 1.	290	220	430	650
Borehole S.A.L. 2.	230	310	410	720
No.4 Shaft Van Dyk Mine	-	-	300	-
Borehole R.C. 3.	-	-	360	-
No.4 Shaft Brakpan Mine	-	-	420	-
No.8 Shaft Springs Mine	-	-	410	-
No.7 Shaft Springs Mine	-	-	380	-
No.5 Shaft Springs Mine	-	-	300	-

The above figures do not support Ellis' conclusions. The thickness of the Kimberley Shale, though somewhat irregular, does not seem to be affected by the presence of the sill. If the granophyre is a syntectic rock, the shale in the first two boreholes should be thinned by an amount equal to the thickness of the granophyre. No such thinning is apparent.

(iii) The granophyre is typically developed in shale. It is not so common when the immediate cover is quartzite. Shales would be more prone to this type of alteration because their constituents are in a fine state of division and include alkali- and alumina- bearing minerals.

There are not enough intersections in the Property to show whether granophyre is less common in quartzite than in shale. Two shaft intersections show the sill intruding the Bird quartzite formation, below the Kimberley Shale. In both cases granophyre is present as well as norite. In No. 7 Shaft Springs Mine there is a 30-foot sill of granophyre overlain by quartzite and separated by 50 feet of quartzite from an underlying sill of norite 170 feet thick. In No. 5 Shaft Springs Mine there is a sill [illegible] feet thick, overlain and underlain by quartzite. The upper part is granophyre and the lower part norite, but the individual thicknesses of the two phases are not known. The thickness of the Bird quartzite in these two shafts, compared with its thickness in neighbouring shafts and boreholes, is as follows:-

Shaft or Borehole	Thickness of Bird Quartzite (feet).
No. 7 Shaft Springs Mine	370
" 5 " " "	255
" 1 " " "	250
" 3 " " "	240
" 6 " " "	210
No. 4 Shaft Brakpan Mine	310
Borehole S.A.L. 1.	275
Borehole S.A.L. 2.	280

No definite conclusions can be drawn from these figures, as the thickness of the Bird quartzite formation is very irregular. There is, however, no definite evidence of thinning in the first two shafts to suggest that part of the quartzite has been replaced by granophyre.

(iv) In the sill phases granophyre occurs above norite, never below it. For a composite intrusion the relative positions of the two rocks might be expected to alternate.

The granophyre has no chilled contacts typical of an intrusive rock. The norite shows a chilled contact with the granophyre and there are thin basic sills within the granophyre, also showing chilled contacts. This indicates that the intrusion has not differentiated in place, producing an upper granophyre and a lower norite.

The third possibility, that the granophyre is altered shale or quartzite, fits the facts best.

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The sediments below the norite are thermally alteied but have not become granophyric. Hence it appears that whatever promoted the formation of granophyre rose and did not descend, unless the change was promoted solely by heat and rock stresses, which would be greater over the intrusion than under it.

It is true that the distribution of the two rocks is not typical of a composite intrusion, for granophyre is not found below norite. On the other hand they do not invariably occur together. Dykes and sills of granophyre without norite have been seen in Nos. 4 & 7 Shafts Springs Mine, and in the Main-Bird and Jeppestown Series in Brakpan Mine. Xenoliths of re-crystallised quartzite have been found in granophyre dykes. Such occurences suggest a composite intrusion or a differentiated one. They are difficult to reconcile with a syntectic origin for the granophyre.

The contact of the granophyre with shale or quartzite is seldom sharp which for an intrusive rock is unusual, though quartz veins intruding the reefs and quartzites of the Witwatersrand System frequently have ill-defined gradational contacts. This shows that metamorphism of the sediments in contact with the granophyre, by heat, magmatic fluids, or both, produced a marginal rock resembling the granophyre itself. It does not prove that the granophyre as a whole is recrystallised shale or quartzite. A parallel case is that of the Roolberg

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Rooiberg/
quartzites and felsites overlying the Red Granite in parts of the Bushveld. These rocks have in places been converted, through regenerated or introduced felspar, into rocks almost or quite indistinguishable from granite (2).

A super-heated magma of acid composition, such as would crystallise to a granophyre, would be far more likely to effect these metamorphic changes in the sediments than a basic magma (the norite) which, as its chilled margins show, did not possess superheat. The metamorphic effects of basic intrusions on strata of the Witwatersrand System are generally insignificant. There seems no reason why in this instance emanations from the norite sill, or heat and rock stresses associated with it, should have been so powerful as to transform a great thickness of sedimentary rock into granophyre.

Ellis, in advocating a syntectic origin for the granophyre, implied that the norite intruded the sediments as a magma and solidified at its margins before the overlying rocks were changed, by emanations from the norite or by heat and rock stresses, into granophyre. He did not explain why the upper chilled crust of the norite sill, which must have been subjected to the same influences as the overlying rocks, was not similarly recrystallised. In a later paper(7) dealing with an occurrence of syntectic granophyre in Marievale Mine, (a different body having no known connection with the norite-granophyre here described), Ellis stated that diabase dykes intruding sediments which were later recrystallised to granophyre, were themselves

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themselves/
changed to a granophyre similar to that produced from the sediments, but richer in hornblende. There is no sign here of any such recrystallisation, either in the thin sills which intrude the granophyre or in the upper chilled crust of the main norite sill.

On the whole the evidence seems to favour the bulk of the granophyre being an intrusive igneous rock, though some marginal granophyre may possibly represent shale or quartzite recrystallised in the solid state (syntexis) or assimilated by the acid magma. If the process was assimilation there should be xenoliths of country rock within the granophyre. Such xenoliths are known to exist. The amount of shale or quartzite recrystallised or assimilated cannot have been great, as there is no appreciable thinning of the sedimentary formations which the granophyre intrudes. This does not by any means imply that large bodies of granophyre cannot arise by a process of pure syntexis: for example, the Marievale Granophyre referred to above has been shown by Ellis(7) to be a syntectic rock unconnected with any igneous intrusion.

The question remains whether the norite-granophyre intrusion is composite or differentiated. That the intrusion differentiated in place, producing an upper granophyre and a lower norite, seems unlikely because the two rocks do not grade into each other, but the possibility should not be discounted. The association of an upper acid with a lower basic rock is a common one. The simplest explanation of these occurrences is

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that the intrusion differentiated in place.

The chilling of the norite against the granophyre and the absence of any metamorphism of the former by the latter, suggests that the intrusion is composite, the norite being the younger rock. This however introduces complications, since it necessitates two separate periods of subsidence and igneous injection. Granitic magma must have arisen first and filled the fractures when they were first opened. With renewed sinking of the strata, involving the reopening of existing fractures and the opening of new ones, noritic magma arose and filled the space beneath the already consolidated granophyre. The existence of thin basic sills within the granophyre (unless these belong to a later generation than the norite) lends support to this view. The fact that norite is always found below granophyre and never above it, must be accepted as fortuitous if the intrusion is regarded as composite. For a differentiated intrusion these positions are correct.

In any event the norite and the granophyre are closely associated. It seems likely that the two magmas arose from the same deep-seated source, either independently or as a parent magma which differentiated after it was intruded. If the intrusion is composite, differentiation may have taken place at depth in a subterranean resevoir, in which case the upper acid fraction might have been squeezed upwards into the fractures earlier than the lower basic fraction. On the other

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other/ hand the acid magma may have originated through melting at great depth of sediments similar in composition to the shales of the Upper Witwatersrand System. This might explain the similarity of the granophyre which crystallised from a fluid magma to that produced by recrystallisation of shale in the solid state.

4. AGE

Ellis believed this intrusion to be of the same age as the Bushveld Igneous Complex (5). The association of a lower norite with an upper granophyre certainly suggests the Bushveld Complex, especially as it would be impossible to distinguish the norite from some specimens of norite or pyroxenite from the Complex (5). The granophyre too is a similar rock to that which occurs in the Bushveld as part of the Rooiberg Series and again as the marginal phase of the Red Granite (2). There are however the following objections to a Bushveld age:-

(i) If the intrusion is post-Transvaal, the dyke in No. 4 Shaft Springs Mine might be expected to change to another sill at the base of the dolomite or within it, these being very favourable horizons for sill formation. No such sill has been seen. Either the intrusion penetrated the dolomite as a dyke and not as a sill, which seems unlikely, or it is pre-Transvaal, as suggested in Plate VII.

(ii) The intrusion is structurally similar to the

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"Old Lady" and resulted from the same type of stress, namely, internal tension due to subterranean subsidence (5). The "Old Lady" is known to be pre-Transvaal and its peculiar structure is probably due to special conditions prevailing during the Ventersdorp Period, when the existence at great depth of a vast quantity of fluid magma caused the overlying beds to subside in bulk (3). It would be more logical therefore to assign a similar age to the norite-granophyre, rather than to assume a recurrence of identical conditions at a later geological period, in which there was no volcanic activity on the same scale as in the Ventersdorp.

(iii) The norite-granophyre dyke in Brakpan Mine is intersected by two tear faults, one right-handed and the other left-handed (Plate III). It appears in plan to be displaced by both faults, though the actual fault-dyke intersections have not been observed. This indicates that it is older than the ilmenite diabase dykes, which are believed to be pre-Transvaal.

On the evidence available a pre-Transvaal age is preferred. The norite-granophyre is probably younger than the "Old Lady", though similar in origin. In both intrusions the magma was forced upwards under pressure and probably did not reach the surface, therefore intrusion took place either before or after, but not during, the extrusion of the Ventersdorp lavas (3).

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lavas (3)./
The "Old Lady", which does not penetrate higher than the lower Kimberley beds, is believed to be older than the lavas. The norite-granophyre intrusion covers a wider area and penetrates to a much higher stratigraphic horizon. Possibly the uppermost sill phases, which now no longer exist, intruded the lavas themselves. Hence in all probability the norite-granophyre is of late or post-Ventersdorp age, younger than the lavas.

/ VIII THE QUARTZ DIABASE

VIII THE QUARTZ DIABASE

1. THE DYKES AND SILLS

(a) General

Quartz diabase, often known as "Ventersdorp" diabase, is the most common intrusive rock in the Witwatersrand System. It is very altered quartz dolerite, older than the ilmenite diabase, but similar to it in many respects. Sometimes the two rocks are indistinguishable.

Quartz diabase intrusions include the "Old Lady" (Plates III & VI), the New State Areas Intrusion (an outlying portion of the "Old Lady"), and a large number of simple dykes and sills too numerous to show on a small-scale plan. All these intrusions are believed to be of the same age, though sometimes, especially in thin dykes and sills, the rock is sheared and completely decomposed, making identification impossible.

(b) The "Old Lady" and the New State Areas Intrusion

The "Old Lady", known to Ellis (3) as the "Marievale Quartz Dolerite Intrusion", is shown in plan in Plates III & VI and in section in Plate VII. It is a sill with transgressive dyke phases, having the shape of a stepped dome considerably elongated in a N.W. - S.E. direction. The principal dyke phase, which has been traced for a long distance in Main Reef Leader workings in several mines, describes a very erratic course and encloses an area in which the strata have subsided vertically a distance of about 250 feet. The sill phase which

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overlies the sunken strata enclosed by the dyke is equal in thickness to the vertical displacement. It is generally found immediately below or immediately above the Bird Amygdaloid (Plate VII). In Marievale Mine it penetrates locally as high as the Kimberley Shale (ℰ). Outside the ring formed by the dyke, a lower sill phase in the Jeppestown Series, a short distance below the Main Reef Leader, has been observed in several places. It is of smaller horizontal extent than the upper sill. The extent of the intrusion in depth is unknown. Probably its behaviour in the lower Witwatersrand System is similar, namely, sill phases alternating with dyke# phases, the area enclosed becoming greater with increasing depth.

The dyke phase, which transgresses and displaces the lower Main-Bird strata, is continuous except for short stretches where it is represented by faults devoid of any igneous rock (Plates III & VI). Near the southern boundary of the Property the dyke splits into two branches, which are displaced horizontally by later tear faults (Plate VI). One branch, represented by a fault, continues southwards across Vogelstruisbult into Marievale Mine, where the dyke reappears. The other branch, also represented by a fault, dies out when followed southwards. In the undeveloped area of East Daggafontein Mine and to the south-east of it, the approximate position of the dyke is inferred from the presence or absence of the sill phase in surface boreholes (Plate VI). The closure of the ring is complete except in the

/area

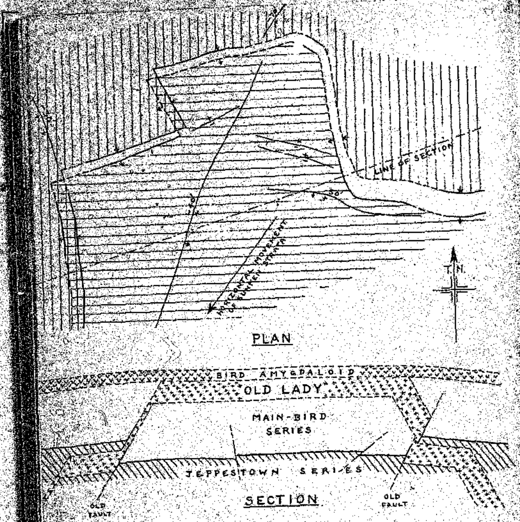

FIG. 14.

PLAN AND CONJECTURAL SECTION OF THE NORTHERN CORNER OF THE "OLD LADY", SHOWING VERTICAL AND HORIZONTAL DISPLACEMENT OF THE STRATA.

SCALE 1 : 10,000

Main Reef Leader enclosed by the "Old Lady" and thrown down 250 feet

Main Reef Leader outside the "Old Lady".
(Arrows show direction of dip of "Old Lady" dyke)

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