D E C L A R A T I O N

I, R.J.McH. Clark, hereby declare that the dissertation entitled ' The geology of the Roodekraal Igneous Complex, Potchefstroom district' is my own unaided work. Neither the substance nor any part of this dissertation has been submitted in the past or is being or is to be submitted for a degree at any other university. Much of the information used was obtained while I was employed by Rio Tinto Exploration (Pty) Ltd.

R.J.McH. CLARK

12.10.1972

THE GEOLOGY OF THE ROODEKRAAL IGNEOUS COMPLEX, POTCHEFSTROOM DISTRICT

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ABSTRACT

The aims of the investigation dealt with in this dissertation may be divided broadly into two. The first is an attempt to determine the mineralogical and chemical composition, crystallisation history, structures and distribution of the rock types which make up the Roodekraal Igneous Complex. From this information, conclusions are drawn as to the probably genesis of the individual rock types, and the Roodekraal Igneous Complex as a whole. The second aim is to ascertain the precise nature of the zones of sulphide mineralization with regard to their structure and the mineralogy and paragenesis of the ore minerals and associated gangue minerals. Conclusions as to the probably source and nature of the solutions which formed the sulphide bodies are drawn from the above information.

An extensive drilling program and detailed field mapping were carried out between 1967 and 1971 to determine the distribution and structure of the rock types and the zones of sulphide mineralization. Microscopic examination of thin sections and polished sections, X-ray diffraction and other laboratory techniques were employed by the author to determine the mineralogy and petrology of the rock types, and the mineralogy and paragenesis of the ore minerals. Chemical analyses were made of a wide variety of rock types to determine their geochemistry. A sequence of samples of amygdaloidal andesite wall rocks taken at varying distances from a large sulphide body were analysed to determine what chemical changes the hydrothermal alteration has brought about.

The Roodekraal Igneous Complex, which is regarded as being approximately the same age as the Bushveld Igneous Complex, lies within sedimentary rocks of the Transvaal System, and was probably emplaced after the updoming of the Vredefort Ring Structure since the lava flows within the Roodekraal Igneous Complex are roughly horizontal. The author agrees with the sequence of emplacement for the rock types of the Complex as derived by Bisschoff (1950), which begins with amygdaloidal andesite followed by equigranular diorite, fine pyroxene diorite, coarse pyroxene diorite, dioritic-aplite, dolerite and syenite, and ends with syenite-porphyry. This sequence of emplacement has however been extended to include four previously undescribed rock types, namely massive andesite, pyroxene andesite, olivine gabbro and dioritic-pegmatite. The pyroxene andesite is the extrusive equivalent of the fine pyroxene diorite while the olivine gabbro was formed immediately after the emplacement of the coarse pyroxene diorite and shortly before the crystallisation of the dioritic-pegmatite. Pseudotachylite is present cutting all the rocks of the Complex except the syenite-porphyry and was thus introduced after the syenite and before the syenite-porphyry. The syenite-porphyry is not regarded by the author as being a component of the Roodekraal Igneous Complex proper and it is thought that this rock type was emplaced during Pilandsberg times.

The mafic rocks of the Roodekraal Igneous Complex may be divided into two groups. The first group, which includes the amygdaloidal andesite and equigranular diorite, has amphibole as the most abundant mafic mineral. The second group, which includes the pyroxene andesite, fine pyroxene diorite and coarse pyroxene diorite, generally has pyroxene as the dominant mafic mineral and invariably contains feldspar phenocrysts. In addition to the petrological differences between these two groups, 'Pearce diagrams' (Fig. xv (a) and (b)) demonstrate that these groups have separate differentiation trends. A geochemical study of the rock types of the Roodekraal Igneous Complex seems to indicate that their parent magma was tholeiitic. The fact that an earlier suite of igneous rocks with a tholeiitic composition is present in the Vredefort Ring Structure supports this conclusion.

The sulphide bodies are mainly localised along normal faults within the amygdaloidal andesite, and have apparently concentric zones of hydrothermal alteration around them. The most important process involved in the alteration has been the destruction of the original mafic minerals and the formation of biotite. The sulphide deposits are considered to be epithermal although both the pyrite and the pyrrhotite are regarded by the author as having been deposited at temperatures in excess of 400°C. A reversed zoning of the copper minerals is present in the mineralized zones, with the low temperature minerals in the centre and high temperature minerals further out. This zoning is similar to that present in ore bodies at the Artonvilla mine, in the Messina district, as described by Jacobsen (1967). The sulphides probably differentiated from a large hidden magma body beneath the Vredefort Ring Structure shortly after the widespread injection of pseudotachylite. The author concludes that although aqueous solutions brought about most of the hydrothermal alteration associated with the mineralized zones, the sulphides were transported in the volatilized state.

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CONTENTS

APPENDICES

ILLUSTRATIONS

I. INTRODUCTION

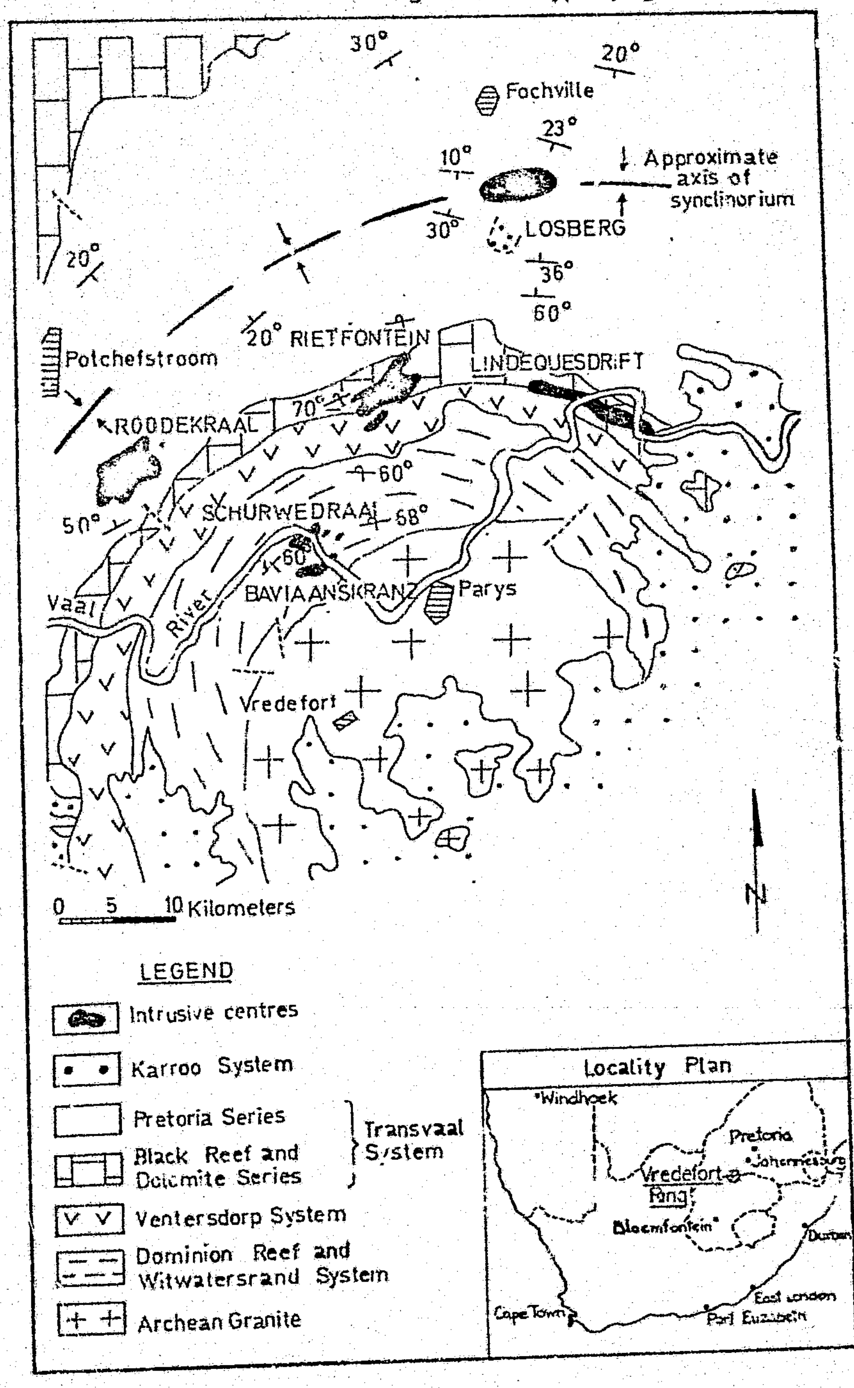
The group of volcanic and intrusive rocks that is the subject of this dissertation forms one of the largest centres of igneous activity present within the sedimentary collar of the Vredefort Ring Structure (Fig. 1). Due to the fact that the Complex is made up of both intrusive and extrusive rocks it is called the Roodekraal Igneous Complex which is in agreement with Bisschoff (1950) who calls it a 'Stollingsgesteente-Kompleks'.

The Roodekraal Igneous Complex is situated in the Potchefstroom district of the Transvaal. It lies eleven kilometres to the southeast of Potchefstroom on the Potchefstroom - Parys road between longtitude 27°8' and 27°12' west and latitude 26°47' and 26°50' south. It has an average altitude of 1 400 metres above mean sea level and a surface area of approximately thirteen square kilometres. The greater portion of the Complex is situated on the farm Roodekraal 37, small portions in the west are situated on Plessieskraal 43 and Prinsloos Rust 93.

The Complex is situated on the northwestern flank of the Vredefort Ring Structure and on the southern side of the Potchefstroom synclinorium of Transvaal System rocks. It lies within the Magaliesberg and Daspoort Stages of the Pretoria Series (Fig. 1).

Mellor (1907) gave a brief description of the most important rock types present in the Roodekraal Igneous Complex. This description was enlarged on by Willemse (see Nel et al., 1939). Mellor (1907) concluded that a porphyritic, diabasic rock was present in large proportion and was mainly composed of plagioclase and hornblende. He also concluded that the copper ores present in the amygdaloidal rocks were concentrated along a fissure or joint plane. Willemse (see Nel et al., 1939) stated that the porphyritic rock type contained, in addition to the minerals mentioned by Mellor (1907), monoclinic pyroxene, and concluded that the feldspar was mostly albite, together with anorthoclase and micro-perthite. He also noted the presence of a thin dike of syenite-porphyry in the extreme south of the Complex. Bisschoff (1950) produced a detailed study of the geology, structure and petrology of the Roodekraal Igneous Complex to which frequent reference will be made. He concluded that the Roodekraal Igneous Complex is post-Waterberg in age and that the structure within the Complex was caused by the intrusion of the coarse porphyritic rocks in the form of an assymmetrical laccolith which

Fig.1 Geological map showing location of the Roodekraal Igneous Complex within the Vredefort Ring Structure. (Modified after Abbott and Ferguson 1965, p.34, Fig.1)



bent the lavas upwards. With regard to mineralogy he decided that the only variety of feldspar present within the rock types of the Complex was plagioclase with a composition varying between the limits of $An_{0,5}$ and An_{37}, and that all the hornblende was an alteration product of the pyroxene. Further work of this author (Bisschoff 1970) makes mention of the dioritic rocks. Bisschoff (1972b) revised his previous conclusions as to the age and method of formation of the Roodekraal Igneous Complex and decided that it was probably emplaced at the same time as the Bushveld Igneous Complex, and that the andesite was extruded under shallow water into a basin formed by sediments of the Pretoria Series.

Copper mineralization has long been known to occur in the rocks of the Roodekraal Igneous Complex. The company employing the author, namely Rio Tinto Exploration (Pty.) Ltd., are reputed to be the seventh company to examine the economic potential of these copper deposits.

Detailed borehole logging on 135 diamond drill boreholes, and the compiling of geological sections from this information was carried out by the author between 1968 and 1971. The original geological mapping of the Complex was done between 1967 and 1969 on a scale 1 : 500 by means of a tape survey using a grid of lines stretching over the entire Complex. The lines were 200 feet (sixty one metres) apart and had pegs whose elevation above sea level was known at every 100 feet (thirty metres). These lines were established running northwest to southeast and various points along them co-ordinated using government trigonometrical beacons. The mapping was originally carried out by C. Marshall, M. du Toit, J. Duval and the author. It was then revised, additions made to it and compiled on a scale of 1 : 7 500 by the author.

Chemical analyses of thirty one different rock samples were carried out during 1969 and 1970, of these twenty one were done by the National Institute for Metallurgy as project K.26/70 and were presented in report number 1167. The remaining ten analyses were done by Gold Fields Laboratories (Pty) Ltd. The laboratory work undertaken by the author was carried out between April and December, 1971 at the University of the Witwatersrand.

The Roodekraal Igneous Complex forms an area of high relief above the surrounding Transvaal System sediments. Roodekraal - beacon No. 61 is the highest point of the Complex and has an elevation of 1 490,4 metres above mean sea level, and rises approximately 80 metres above the surrounding rocks of the Complex. The area in which the Roodekraal Complex is situated forms part of the 'Highveld' geomorphological province of King (1963). It is a post-African erosion surface, with well developed pediments. The Roodekraal Spruit, an intermittent stream which flows from northeast to southwest and is a tributory of the Mooi River, drains the area.

One of the most important problems involved in describing the geology of the Roodekraal Igneous Complex is the sub-division of the rocks into lithological units. The major sub-division of the rock types was made during field mapping, purely on a basis of texture. The rock types were divided into two groups, one group being equigranular, amygdaloidal and dark grey in colour and the other group being strongly porphyritic with a finer grained, almost black, groundmass. These two groups have been studied mineralogically and chemically to determine what differences exist between the groups other than the textural features.

In naming the various rock types at Roodekraal, the classification of rocks according to Streckeisen (1967) will be adhered to as far as possible.

It was attempted to decide at what stage in the formation of the Vredefort Ring Structure the Roodekraal Igneous Complex was emplaced and to this end the structure of the Complex is considered in detail.

With respect to the sulphide bodies, the zoning of the sulphide minerals, gangue minerals and the chemical components were studied in detail to ascertain under what conditions the sulphide minerals were emplaced. A comparison is made between these sulphide bodies and similar deposits at Artonvilla in the Messina district of Transvaal.

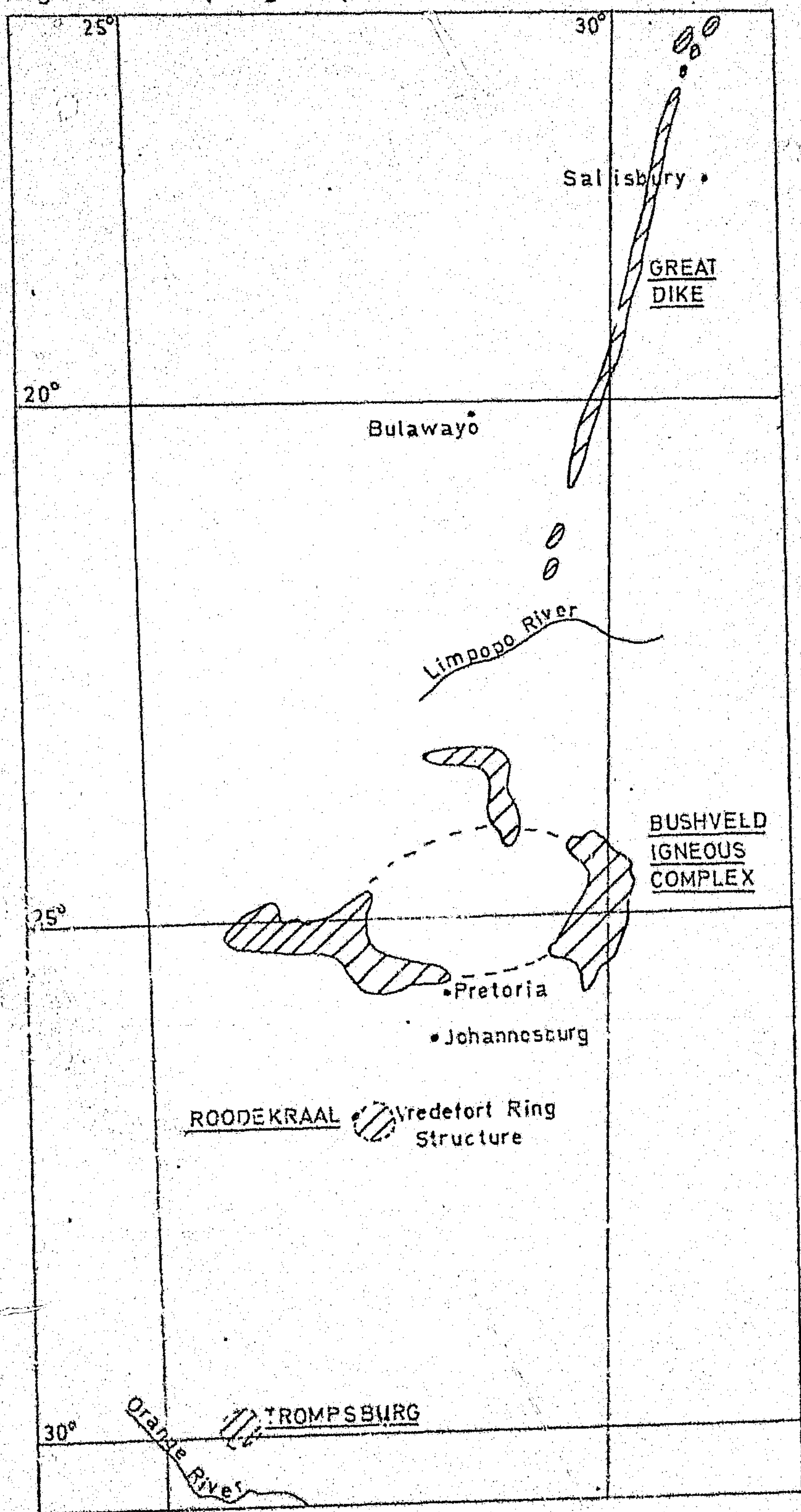
The dissertation is broadly divided into two sections, firstly all the factual data such as field relationships, mineralogy, petrology and geochemistry are presented and secondly the inferences and conclusions drawn from this data by the author are given.

II. REGIONAL GEOLOGY

As previously mentioned the Roodekraal Igneous Complex is intruded into the northwestern flank of the Vredefort Ring Structure. The rock types that it transgresses are Ongeluk volcanic rocks, Daspoort Quartzites and Shales, Magaliesberg Quartzites and Shales and a diabase sill. The contacts of the diabase and the Roodekraal Igneous Complex are soil covered and no good exposure is present, but it is known that the diabase has suffered the same deformation as the sedimentary horizons of the Vredefort Ring Structure. This can clearly be seen on Sheet 61 - Potchefstroom issued by the Department of Mines, Geological Survey, and it is thus presumed to be pre-deformation in origin.

The Vredefort Ring Structure, and hence the Roodekraal Igneous Complex, lies on a line of igneous activity stretching from the Great Dike of Rhodesia, through the Bushveld Igneous Complex and the Vredefort Ring Structure, finally ending in the Trompsburg Complex. The Great Dike of Rhodesia has been dated as 2 532 ± 30 million years old by Rb - Sr and K - Ar methods (Allsopp 1965), and the Bushveld Igneous Complex has been dated as 1 954 ± 30 million years by a Sr isotope method (Davies et al., 1970). Three of the centres of igneous activity within the Vredefort Ring Structure have been dated. An average of four determinations using a Rb - Sr method gives an approximate age of 2 040 million years (Nicolaysen et al., 1963) for the alkali granites and syenites at Schurwekraal while the same method gives an approximate age of 1 970 million years (Nicolaysen et al., 1963) for the basic granophyre ring dike which occurs near the centre of the Vredefort Ring Structure. The Losberg Intrusion has been dated by Sr isotope methods at 1 881 ± 282 million years by Davies et al. (1970). It follows that the average age of the centres of igneous activity within the Vredefort Ring Structure appears to be very nearly the same as the age of the Bushveld Igneous Complex. Rocks of the Trompsburg Complex have been dated as 1 372 ± 142 million years by a Sr isotope method (Davies et al., 1970). Thus it appears that the igneous rocks occurring along this lineament become progressively younger from north to south. This line of igneous activity is readily observed in Figure 2 which is modified after Hargraves (1970, Fig. 2, p. 256).

Fig.2 Map showing location of the Roodekraal Igneous Complex in relation to the Great Dike, the Bushveld Igneous Complex, the Vredefort Ring and the Trompsburg Complex.(modified after Hargraves 1970, p.256)



III. DETAILED GEOLOGY

A. Petrology of Individual Rock Types

1. Massive andesite

Macroscopic features

The massive andes te is pale grey, fine-grained and only occasionally contains phenocrysts and amygdales.

Microscopic features

The primary rock forming minerals present are plagioclase, common hornblende, uralite, augite, sphene, apatite and ore minerals. The plagioclase has a composition of An_{30} and is present as subhedral laths up to 0,8 millimetres long. The augite grains have a maximum diameter of 0,65 millimetres and may be twinned parallel to (100) while the sphene is present in rounded grains generally less than 0,10 millimetres in diameter.

Secondary minerals which were probably formed during the deuteric stage of alteration are calcite, quartz, actinolite and clino-zoisite. The calcite occurs in fissure fillings and interstitial grains in the groundmass. The quartz is present in anhedral grains up to 0,15 millimetres in width, or in cryptocrystalline masses which were formed later at low temperatures. Actinolite is in fine acicular crystals developed as an alteration product of augite and hornblende, and clino-zoisite is an alteration product of the feldspar.

Late-stage hydrothermal minerals are locally developed in abundance. These minerals include epidote which is present as aggregates, coating crystals of the primary rock forming minerals, and chlorite. Both these minerals are confined to zones of hydrothermal alteration.

A volumetric analysis of the mineral composition of the massive andesite is given in Table I.

TABLE I

Mineral composition by volume of the massive andesite

Mineral	Volumetric percentage
Plagioclase	72,4
Pyroxene	9,6
Amphibole	7,4
Ore minerals	7,2
Epidote	2,4
Sphene	1,0
Total	100,0

Augite grains are commonly concentrated in clusters within a groundmass of randomly orientated feldspar laths. The grains of sphene are poikilitically enclosed within crystals of plagioclase, hornblende and augite.

2. Amygdaloidal andesite

Macroscopic features

The amygdaloidal andesite is generally dark grey with a cryptocrystalline, microcrystalline or finely crystalline groundmass. The amygdales vary in size from microscopic to several centimetres in diameter, and are sometimes elongated in the horizontal plane, parallel to the direction of flow of the lava as indicated by flow lines and parallelism of feldspar crystals. Amygdales may have feldspar crystals aligned parallel to their edges (Plate II, 1). Within a single lava flow the amygdales become larger and more numerous towards the top and the grain size reaches a maximum in the centre of the lava flow. The individual lava flows are chilled along their contacts with adjacent flows, and are generally less than ten metres in thickness. A narrow zone of lava is present in square 2C, Plate XXIV which contains many irregularly shaped calcite amygdales and whorl like structures of cryptocrystalline quartz and hematite (Plate II, 2).

Microscopic features

The primary rock forming minerals present within amygdaloidal andesite are plagioclase, common hornblende, kaersutite, augite, magnetite, ilmenite and accessory amounts of apatite. The plagioclase has a wide range of composition from An_{24-32}, the size of the crystals ranging from microliths to phenocrysts 2,25 millimetres in length. The plagioclase grains are generally stubby and euhedral and only occasionally tabular parallel to (010), they are twinned according to the albite and more rarely according to the Carlsbad and pericline laws and may be zoned. Zoned crystals have a compositional range from An_{27} - An_{32}. The common hornblende and kaersutite occur in subhedral rectangular grains, which are generally under 0,50 millimetres in length. Both these amphiboles may be replaced by actinolite along their edges and cleavages. The augite grains are subhedral up to 0,80 millimetres in diameter and are invariably partially or completely replaced by uralite. Magnetite and ilmenite are present in abundance, with the ilmenite occuring in grains up to 0,60 millimetres in diameter while the magnetite grains, although more abundant, are smaller being up to 0,25 millimetres in diameter.

Deuteric-stage minerals are present in abundance and include albite, uralite, actinolite, quartz and sphene. Albite, with a composition of An_{0-9}, makes up the majority of the feldspar present in the rock. It is associated with the normal alteration products of feldspar such as sericite, cryptocrystalline quartz and epidote. The uralite is present as pseudomorphs after augite and is often partially replaced by needles of actinolite. Actinolite is present in fair proportion as an alteration product of the mafic minerals. The actinolite crystals are acicular or columnar up to 1,80 millimetres long and have been observed to cut completely across albite and quartz crystals. Quartz is present as colourless anhedral or euhedral grains and as crypto-crystalline masses. The anhedral grains which are generally inter-stitial to the other rock forming minerals and the euhedral grains which line the edges of fissures and amygdales, are regarded as being formed during the deuteric-stage although the cryptocrystalline aggregates were probably formed at a later stage. Sphene occurs as an alteration product of the uralite in subhedral grains aligned parallel to the cleavage of the amphibole, it also crystallises an an open space filling within the amygdales.

Late-stage hydrothermal minerals have developed in abundance in the vicinity of the sulphide bodies. The chief minerals developed are low temperature (ordered) albite, two varieties of mica namely olive-green to pale brown biotite and a green phyllosilicate, chlorite, epidote, hematite, goethite, the sulphide minerals and their alteration products and zeolite . Rutile and leucoxene were formed as supergene replacement products of the ilmenite.

The relative proportions of the various minerals present are summarised in Table II below.

TABLE II

Volumetric composition of the amygdaloidal andesite

Mineral	Volumetric percentage
Plagioclase	65,3
Ore minerals	10,0
Calcite	9,6
Biotite	8,1
Amphibole	4,4
Augite	1,2
Quartz	1,0
Chlorite	0,3
Zeolite	0,1
Total	100,0

Feldspar crystals comprise the majority of the rock and are generally randomly orientated giving the rock a 'felty texture'. Although the majority of the feldspar laths are the same size, a few phenocrysts are always present when the rock is examined under the microscope. On rare occasions the feldspar laths have a sub-parallel alignment in the direction of flow. The amphiboles and augite are present as smaller grains or clusters of grains situated between the feldspar laths, while quartz and calcite are commonly interstitial.

The amygdales have a clear cut and often repeated concentric sequence of mineral deposition within them. The order of occurrence of the minerals proceeding from the margin to the centre of the amygdales is as follows:-

Albite → sphene → actinolite → quartz → calcite → biotite → epidote → chlorite.

The actinolite in the amygdales is present as long acicular needles which often form a network within amygdales (Plates IX, 4 and XI, 4). Quartz occurs in euhedral crystals (Plate I, 2) which often rim the amygdales completely, and have their c-axes at high angles to the walls of the amygdales. Calcite of the amygdales is present in masses which are composed of a mosaic of interlocking anhedral crystals, and is only rarely present as euhedral grains. The epidote may replace the calcite of the amygdales, when it may occur as a fine-grained aggregate or as radiating masses of euhedral crystals with individual crystals up to 10 millimetres in length. Finally bright green chlorite with abnormal interference colours is present in the very centre of amygdales in the zones of late-stage hydrothermal alteration.

3. Volcanic agglomerate

Macroscopic features

The agglomerate consists of well rounded fragments of quartzite (Plate II, 3) and lava, together with separate mineral grains within a finely crystalline matrix of andesite. The amygdaloidal andesite of the matrix contains only a few small amygdales.

Microscopic features

Cracks within the quartz pebbles are filled with actinolite, calcite, and, in zones of hydrothermal alteration, ore minerals and chlorite.

4. Volcanic breccia

Macroscopic features

Two varieties of volcanic breccia are present. In one variety the lava has simply been fragmented and the fragments cemented by calcite (Plate II, 4). The fragments are usually large and angular and only a small proportion of the total volume of the rock is made up of calcite. More commonly however, the breccia is composed of fragments of coarse and fine andesite, individual mineral grains and fragments of grains, present within a fine-grained lava matrix (Plate III, 1). This variety of breccia, with a matrix of andesite, has rounded as well as angular fragments within it, and the matrix generally makes up at least 50 per cent of the volume of the rock.

Microscopic features

Hematite is abundant, occurring as a coating on rock and mineral fragments. Quartz and calcite are present between the fragments and may have replaced the fragments, especially feldspar grains, along their edges. Chlorite has replaced the calcite cement of the volcanic breccia. Individual rock fragments within breccia vary from microscopic size to several centimetres in diameter. The andesite of the matrix is microcrystalline to cryptocrystalline.

5. Equigranular diorite

Macroscopic features

The equigranular diorite is medium grey and contains a few amygdales. Although this rock type is as a whole fine-grained, irregularly shaped coarser grained patches are present within it. The coarser grained portions range in size from a few square millimetres to several square metres, have irregular shapes and are not arranged in a pattern or parallel to any geological contact.

Microscopic features

The primary rock forming minerals within the diorite include plagioclase, microperthite, augite, several varieties of amphibole, quartz, magnetite, ilmenite, apatite and sphene. The composition of the plagioclase varies between wide limits from An_{27} to An_{37}, and the size of the plagioclase crystals ranges from microliths to crystals of 5 millimetres in length. As in the case of the andesite, the plagioclase grains are stubby and euhedral and are only occasionally tabular parallel to (010), they are twinned according to the albite and more rarely the Carlsbad and pericline laws and may be zoned. The inclusions within the feldspar reflect this zonal arrangement. Augite is present in fair proportion as subhedral grains between 0,4 and 1,2 millimetres in width. Common hornblende and kaersutite are present in subhedral, rectangular grains between 0,20 and 0,60 millimetres in length. Arfvedsonite is present as 'coronas' around grains of kaersutite (Plate XV, 1). Since the arfvedsonite is in crystal continuity with the kaersutite, its formation probably represents a change to a more soda-rich composition in the solution from which the amphibole was formed. Quartz is present as a primary rock forming mineral in a portion of the diorite lying to the western end of the northern zone of equigranular diorite. The grains are less than 0,5 millimetres in diameter, anhedral and colourless and contain inclusions of apatite and actinolite. Magnetite and ilmenite are present in fair proportion as individual grains or in exsolution with one another. Sphene, in subhedral grains, and apatite, in short prisms, are present in accessory amounts.

Deuteric-stage minerals in the diorite include albite, uralite, actinolite, red-brown biotite, bowlingite, quartz and calcite. The albite is associated with the normal alteration products of the feldspar. Uralite is common and may be replaced along its cleavages by actinolite or sphene. Actinolite, in acicular or columnar crystals up to 1,0 millimetre long, is present as an alteration product of the other mafic minerals. Red-brown biotite is present in small grains replacing augite and amphibole. Olivine pseudomorphs are present within the diorite and were formed during the deuteric-stage. Calcite and quartz were the last deuteric-stage minerals to form, and are interstitial to the other rock forming minerals.

Olive-green to pale brown biotite, epidote, chlorite and replacement microperthites were formed by late-stage hydrothermal alteration associated with sulphide deposition. Other secondary minerals which were probably formed at lower temperatures include cryptocrystalline quartz, rutile and leucoxene.

The volumetric mineral composition of the equigranular diorite is given in Table III below.

TABLE III

Volumetric mineral composition of the equigranular diorite

Mineral	Volumetric percentage
Plagioclase	61,2
Amphibole	18,8
Pyroxene	10,6
Ore minerals	7,5
Biotite	1,3
Apatite	0,6
Total	100,0

The equigranular diorite is fine-grained to medium-grained and has a hypidiomorphic granular texture. The coarse-grained portions contain feldspar crystals up to 5 millimetres in length. The amygdales are composed of the same minerals arranged in the same sequence as in the amygdaloidal andesite.

6. Pyroxene andesite

Macroscopic features

This rock type is quite distinct in appearance from the amygdaloidal and massive andesite since it is darker and always contains an abundance of large feldspar phenocrysts and smaller pyroxene phenocrysts. It contains far less amygdales than the amygdaloidal andesite.

Microscopic features

Primary minerals present within the pyroxene andesite incl[illegible] plagioclase, augite, kaersutite, magnetite, ilmenite, apatite and sphene. The plagioclase is present in two generations as early formed tabular phenocrysts up to 18 millimetres in length and as microliths making up the fine-grained groundmass. The plagioclase has a composition of An_{28-34} and is twinned according to the albite and Carlsbad laws. The plagioclase phenocrysts are subhedral to euhedral. The augite phenocrysts are up to 2 millimetres in diameter, subhedral to euhedral and may be partially altered to uralite or actinolite. The kaersutite is only present in small grains of below 0,1 millimetres in length. Magnetite and ilmenite are present as accessory minerals together with apatite and sphene.

Minerals which were probably formed during the deuteric-stage of alteration include albite, uralite, actinolite, red-brown biotite, pseudomorphs after olivine, quartz and calcite. The albite was formed by alteration of the more Ca-rich plagioclase, and the uralite, actinolite and red-brown biotite as alteration products of the mafic minerals.

The pyroxene andesite as a whole has undergone very little late-stage hydrothermal alteration, it does however contain a little epidote, chlorite and olive-green to pale brown biotite. Rutile and leucoxene occur as alteration products of ilmenite.

The mineral composition of the pyroxene andesite is best summarised by means of Table IV below.

TABLE IV

Volumetric mineral composition of the pyroxene andesite

Mineral	Volumetric percentage
Plagioclase	70,9
Ore minerals	15,1
Pyroxene	4,5
Calcite	3,1
Amphibole	2,6
Biotite	1,5
Chlorite	1,5
Quartz	0,8
Total	100,0

The pyroxene andesite is strongly porphyritic containing plagioclase and augite phenocrysts set in a fine-grained groundmass. The amygdales contain the same minerals deposited in the same sequence as in the amygdaloidal andesite.

7. Fine-grained pyroxene diorite

Macroscopic features

The fine-grained pyroxene diorite is very similar in appearance to the pyroxene andesite. The chief differences between the two rock types being that the diorite has a coarser grained groundmass and does not contain amygdales.

Microscopic features

The fine pyroxene diorite has an almost identical mineralogy to the pyroxene andesite except that it contains no kaersutite, the difference between the two rock types being textural. The plagioclase is present in phenocrysts up to 20 millimetres in length and as smaller crystals within the groundmass. The composition of the plagioclase ranges from An_{30} to An_{33}. The augite occurs as euhedral phenocrysts averaging 2,60 millimetres in diameter and as smaller grains averaging 0,01 millimetres in diameter. The augite contains lamellae of orthopyroxene aligned parallel to (100). A small amount of green common hornblende is present.

Minerals formed by deuteric alteration are the same as in the pyroxene andesite, however the red-brown biotite is more abundant than in the pyroxene andesite and is present in grains up to 1,2 millimetres in length.

The fine pyroxene diorite has undergone very little late-stage hydrothermal alteration and only contains small amounts of epidote, chlorite and olive-green to pale brown biotite. Rutile and leucoxene occur as alteration products of ilmenite.

The mineral composition of the fine pyroxene diorite is given in Table V below.

TABLE V

Volumetric mineral composition of the fine pyroxene diorite

Mineral	Volumetric percentage
Plagioclase	71,4
Augite	9,8
Ore minerals	8,9
Amphibole	7,1
Biotite	2,0
Apatite	0,6
Olivine pseudomorphs	0,1
Calcite	0,1
Total	100,0

In common with the pyroxene andesite the fine pyroxene diorite is strongly porphyritic, the augite phenocrysts may be partially or completely poikilitically enclosed within the feldspar phenocrysts (Plate XIII, 4). The feldspar phenocrysts are often present in radiate clusters.

8. Coarse pyroxene diorite

Macroscopic features

The coarse pyroxene diorite is light grey and strikingly porphyritic, containing abundant feldspar phenocrysts up to 24 millimetres in length. This rock type always has a fresh appearance and is lighter in colour than the other intrusive rocks due to the greater abundance of feldspar phenocrysts. An unusual feature is the presence of large phenocrysts within narrow intrusions. The phenocrysts are frequently aligned parallel to the contacts of the intrusions.

Microscopic features

The composition of this rock type is very similar to that of the pyroxene andesite and the fine pyroxene diorite, having plagioclase, augite, magnetite, ilmenite, apatite and sphene as its primary constituents. The plagioclase is present in two generations both of which are larger than the corresponding plagioclase crystals in the fine pyroxene diorite, the phenocrysts have a length of 15 - 24 millimetres and the plagioclase of the groundmass has an average length of 2,5 millimetres. The plagioclase is twinned according to the albite, Carlsbad and pericline laws and may occasionally be zoned. A notable feature of the plagioclase is its almost constant composition of An_{32}. The augite also has a constant composition and occurs in grains averaging about 2,20 millimetres in diameter which may contain large inclusions of apatite and smaller inclusions of magnetite and ilmenite. Bisschoff (1950) observed brown amphibole occurring within the coarse pyroxene diorite which could possibly be kaersutite. As previously stated apatite is present in greater than accessory amounts, and occurs in euhedral columnar grains up to 5,0 millimetres in length.

The deuteric-stage minerals developed are the same as those in the fine pyroxene diorite. Uralite is the most abundant amphibole and replaces the augite mainly along cracks. The uralite is in turn replaced by actinolite. Red-brown biotite is present replacing augite and the amphiboles.

Hydrothermal alteration has only affected a very small proportion of the rocks where it has resulted in the formation of olive-green to pale brown biotite, epidote and chlorite. Minerals formed by the processes of supergene alteration are the same as in the other rock types of the pyroxene andesite/diorite suite.

The proportions of various minerals present are shown in Table VI.

TABLE VI

Comparison between volumetric mineral composition of the coarse pyroxene diorite as obtained by the writer and Bisschoff (1950, p. 20) and (1972b)

Mineral	Volumetric percentage	
	Writer	Bisschoff
Plagioclase	63,5	66,89
Pyroxene	19,3	10,34
Amphibole	8,2	8,24
Other alteration products	1,3	8,20
Ore minerals	7,1	3,90
Apatite	0,6	2,43
Totals	100,0	100,00

The differences between the volumetric analyses of the author and Bisschoff (1950) and (1972b) are attributed to the fact that the author used specimens from borehole cores and a wide variety of outcrops in his analysis while Bisschoff used specimens from only one outcrop, an exfoliation dome of coarse pyroxene diorite in square E 4 of Plate XXIV.

The plagioclase forms the majority of the coarse pyroxene diorite and the other minerals present are interstitial to the plagioclase.

9. Olivine gabbro

Macroscopic features

This rock type does not occur on outcrop and is only intersected in the two boreholes drilled on section 4 (Plate XXI). It occurs as a dark medium-grained, equigranular rock about thirty metres in thickness directly below a thick sill of coarse pyroxene diorite. The olivine gabbro has a gradational contact with the coarse pyroxene diorite above it, but a sharp contact with the equigranular diorite which underlies it.

Microscopic features

Within the olivine gabbro itself there is a rapid petrological variation with height above base. Thin sections were cut from samples taken at three different localities, which are marked by black dots (see Plate XXI) and each sample was shown to have a distinctly different petrology. Considering the petrology of these samples in order of increasing distance below the upper contact (see position of samples marked on Plate XXI) the following sequence is observed.

(i) The dominant mineral of the uppermost sample is plagioclase (composition An_{38-41}) present as about 45 per cent of the total volume of the rock, second in abundance is bronzite at about 40 per cent with a composition of En_{81}, next comes olivine with a composition of Fo_{81} making up 10 per cent of the volume, the remaining volume is made up of augite, kaersutite, red-brown biotite, magnetite and alteration products. The plagioclase was the last mineral to form and is present as an interstitial groundmass enclosing the other minerals. The bronzite is present as large anhedral grains with a length of up to 5,0 millimetres. The augite occurs as a few small grains with an approximate diameter of 0,70 millimetres. The olivine is present as rounded grains poikilitically enclosed within the pyroxene and plagioclase. The kaersutite and red-brown biotite occur mainly along the edges of the subhedral to euhedral magnetite grains and are primary minerals which crystallised from the residium.

(ii) In the specimen taken towards the middle of the olivine gabbro body, augite is by far the most abundant rock forming mineral making up about 80 per cent of the volume of the rock. The remaining volume is made up of interstitial plagioclase, olivine, subhedral or euhedral magnetite grains, which are concentrated in clusters, and red-brown biotite. The augite grains are small, being 0,10 - 0,20 millimetres in diameter, they are subhedral to euhedral, rounded and are poikilitically enclosed within the augite and plagioclase.

(iii) The lowermost sample is mainly composed of magnetite forming about 40 per cent of the rock by volume, augite is the next most abundant component making up about 30 per cent of the volume, olivine is present in fair abundance and the remainder of the rock is made up of small quantities of interstitial plagioclase, biotite and kaersutite.

The relationships between the samples are more easily appreciated in the form of a summary with the minerals arranged in order of decreasing abundance.

(i) Plagioclase + orthopyroxene + clinopyroxene + olivine + magnetite.

(ii) Clinopyroxene + plagioclase + magnetite + olivine.

(iii) Magnetite + clinopyroxene + olivine + plagioclase.

Thus it can be observed that :-

(a) There is a downward decrease in the amount of interstitial plagioclase present.

(b) Orthopyroxene is only present near the upper contact.

(c) A downward increase in the amount of olivine and magnetite present occurs.

(d) Augite reaches its greatest concentration near the centre of the body.

An average mineral composition was not determined for the olivine gabbro because due to the large variations in mineral composition an average would be meaningless in that it would not reflect the composition of any rock found in nature.

10. Dioritic-pegmatite and dioritic-aplite

Macroscopic features

The pegmatite and aplite are not present as pipe-like bodies and appear to be fissure fillings. The pegmatite veins do not contain xenoliths of the wall rock, and may have matching irregularities in the wall rocks on either side. The aplite may contain xenoliths of wall rock.

Microscopic features

Pegmatite

The pegmatite is composed essentially of plagioclase (composition An_{27-29}) and hornblende, with lesser amounts of interstitial quartz and calcite. Apatite and sphene occur in small amounts while biotite, a green phyllosilicate and actinolite are developed along the contacts with the wall rocks. Secondary minerals which are formed within the pegmatite are hematite and actinolite as alteration products of the hornblende.

The volumetric mineral composition of the pegmatite is given in Table VII below.

TABLE VII

Mineral composition by volume of the pegmatite

Mineral	Volumetric percentage
Plagioclase	73,8
Amphibole	16,7
Ore minerals	4,9
Quartz	3,2
Calcite	0,8
Other feldspar	0,3
Apatite	0,3
Total	100,0

The grain size of the various minerals is consistently large. The feldspar crystals are up to 25 millimetres in length, hornblende is present in anhedral grains with a maximum width of 1,[illegible] millimetres, actinolite crystals are smaller averaging 0,5 millimetres in length, while apatite and sphene are present in small grains about 0,2 millimetres in length. The pegmatite is unzoned except for a narrow rim, about 5,0 millimetres wide along its contacts with the wall rocks, which is finer grained and contains a concentration of red-brown biotite and actinolite. The plagioclase and primary hornblende may occur as an intergrowth (Plate XV, 2).

Aplite

The chief primary minerals present in the aplite are plagioclase (An_{30}), in grains generally less than 0,5 millimetres in length, and green amphibole. Augite, sphene, apatite and red-brown biotite are present in small amounts. Bisschoff (1950, p. 30) noted the presence of green amphibole around a core of brown amphibole, the amphiboles being in crystalline continuity with one another. Secondary minerals include quartz, calcite, epidote, olive-green to pale brown biotite and leucoxene.

The relative proportion of the constituent minerals in the aplite is given in Table VIII below.

TABLE VIII

Volumetric mineral composition of the aplite

Mineral	Volumetric percentage
Plagioclase	59,5
Amphibole	17,9
Augite	9,1
Ore minerals	8,1
Apatite	3,1
Biotite	2,3
Total	100,0

The aplite is composed in the main of randomly orientated laths of plagioclase under 0,5 millimetres in length, with subhedral grains of hornblende and augite occupying the areas between the feldspar laths. Xenoliths of wall rock are common and have been rounded by assimilation.

11. Dolerite

Macroscopic features

The dolerite is dark grey to black, fine-grained and equigranular.

Microscopic features

The main primary minerals are plagioclase and augite. The plagioclase occurs in phenocrysts up to 1,85 millimetres in length, but the average length of the plagioclase laths of the groundmass is 0,20 millimetres. The augite occurs in anhedral to subhedral grains with a maximum diameter of 0,50 millimetres and an average diameter of 0,08 millimetres. Magnetite is present in small anhedral grains. Secondary minerals include interstitial quartz and calcite and hydrothermal epidote and chlorite.

The volumetric composition of the dolerite dikes is given in Table IX.

TABLE IX

Volumetric analysis of the mineral composition of the dolerite dikes

Mineral	Volumetric percentage
Plagioclase	75,5
Pyroxene	13,7
Ore minerals	6,6
Chlorite	2,9
Epidote	1,0
Calcite	0,3
Total	100,0

The augite may be interstitial to the feldspar and may intrude it along cracks, or it may enclose it in a sub-ophitic texture. Within the interstitial areas aggregates of feldspar microliths occur together with epidote, chlorite and magnetite.

12. Rheomorphic veins

This rock type has the appearance and petrology of the amygdaloidal andesite except that it contains no amygdales.

13. Syenite dikes

Macroscopic features

On outcrop these dikes have a characteristic red colour which is absent when they are intersected at depth in boreholes. The dikes are always strongly porphyritic and have a fine-grained groundmass.

Microscopic features

The majority of the rock is composed of oligoclase (composition An_{28-30}) which is present in two generations, firstly as euhedral to subhedral feldspar phenocrysts with a length of up to 5,00 millimetres and secondly as smaller grains making up the groundmass with an average length of 0,40 millimetres. Quartz, which is present as a primary mineral, is interstitial and may form up to 10 per cent of the volume of the rock. Amphiboles which are present as small scattered grains within the groundmass are green hornblende and arfvedsonite. Red-brown biotite, apatite and magnetite are also present within the groundmass. Secondary minerals present include albite, actinolite, epidote, chlorite, olive-green to pale brown biotite and red-brown iron oxide.

The relative proportion of the various minerals present is given in Table X below.

TABLE X

Volumetric mineral composition of the syenite

Mineral	Volumetric percentage
Plagioclase	78,3
Ore minerals	7,7
Quartz	6,8
Calcite	3,3
Biotite	2,6
Chlorite	0,9
Apatite	0,2
Amphibole	0,2
Total	100,0

The euhedral plagioclase phenocrysts are randomly orientated within a groundmass composed mainly of a second generation of plagioclase. The quartz fills the irregularly shaped interstitial areas between the plagioclase crystals.

14. Pseudotachylite

Macroscopic features

This rock type is composed of a dark opaque very fine-grained groundmass which contains fragments of wall rocks and mineral grains. The rock and mineral fragments within the pseudotachylite are angular near the edges of veins, but rounded in the centre of the veins. The pseudotachylite may show a well developed flow structure, with flow lines passing around fragments of wall rock, and has sharp contacts with its host rocks.

Microscopic features

The dark opaque groundmass of pseudotachylite,when observed under the microscope, is seen to be completely structureless, while the rock and mineral fragments enclosed within the groundmass have undergone such intense shearing that they are in fact a mosaic of individual fragments. The enclosed fragments may often be elongated parallel to the flow lines within the pseudotachylite. The veins of pseudotachylite are almost invariably surrounded by a zone of microshearing. The larger shears may have fine aggregates of crushed rock distributed along them. The pseudotachylite is in places replaced by sulphide minerals.

15. Syenite-porphyry

Macroscopic features

This rock type is light grey, finely crystalline and contains an abundance of large reddish plagioclase phenocrysts and fragments of these plagioclase phenocrysts, which are randomly orientated.

Microscopic features

The primary rock forming minerals include oligoclase, barkevikite, hornblende, orthoclase and apatite. The oligoclase, which has a composition of An_{14-16}, is present in phenocrysts and fragments of phenocrysts up to 11 millimetres in length, but averaging 5 millimetres, and as small crystals forming the bulk of the groundmass. Barkevikite is present as phenocrysts up to 4,50 millimetres long and as smaller grains which appear to be fragments of original phenocrysts. Hornblende is present as a later formed mineral within the groundmass, it occurs in subhedral crystals averaging 0,25 millimetres in length. Orthoclase is present as anhedral grains in the interstitial areas between the abovementioned minerals. Small euhedral grains of apatite are commonly enclosed within plagioclase or barkevikite. Secondary minerals are rare because this rock type has undergone little alteration except for surface weathering. The main secondary mineral present is albite, together with minor amounts of quartz, epidote and chlorite.

Table XI below gives the proportions of the minerals present within the syenite-porphyry.

TABLE XI

Volumetric mineral composition of the syenite-porphyry

Mineral	Volumetric percentage
Plagioclase	79,9
Hornblende	11,7
Barkevikite	3,7
Ore minerals	1,7
Epidote	1,3
K - feldspar	1,1
Quartz	0,3
Chlorite	0,2
Apatite	0,1
Total	100,0

The phenocrysts have to a large extent been broken or cracked, and have the minerals of the groundmass filling the cracks. The barkevikite phenocrysts are often rounded and show alteration, generally involving darkening, along their edges.

16. Rock types surrounding the Roodekraal Igneous Complex

Macroscopic features

The Magaliesberg Quartzite is white while the Daspoort Quartzite is slightly darker in colour. Both varieties of quartzite display relic bedding planes which are usually 10 - 15 millimetres apart. The Daspoort Shale is dark brown and very fine-grained. The Ongeluk Volcanic rocks are brown and amygdaloidal, with the amygdales being mainly composed of quartz. The diabase is dark grey and medium-grained.

Microscopic features

Both varieties of quartzite are composed of grains varying in size from 0,06 to 1,0 millimetre in diameter. Quartz forms at least 90 per cent of the grains with most of the remainder being made up of orthoclase, microcline and myrmekite. Magnetite is present in small grains and chlorite and biotite occur around the edges of the larger grains. Bisschoff (1950, p. 35) also noted the occurrence of zircon. Where the quartzite occurs as xenoliths within the rocks of the Roodekraal Igneous Complex it shows every gradation between the original quartzite and a rock composed almost entirely of albite. The quartzite has a pronounced 'mosaic' texture with individual grains interlocking with their neighbours. Even where the quartzite has in the main been altered to albite, this texture is retained.

The Daspoort Shale is so fine-grained that the individual grains cannot be identified. Zeolite occurs along cracks within the shale.

The Ongeluk volcanic rocks are predominantly composed of feldspar, which has been intensely sericitized, together with small amounts of amphibole.

The diabase is composed essentially of plagioclase, monoclinic pyroxene and a little quartz, together with an abundance of secondary minerals including uralite, calcite and chlorite.

B. Geochemistry of the Individual Rock Types

Under this heading only the broad geochemistry of the rock types will be discussed. Specific aspects of the geochemistry will be considered in detail when the sequence of formation of the rock types at Roodekraal and the nature of the parental magma are dealt with under the section entitled 'Discussion of Results'.

The chemical analyses of the oxides and C.I.P.W. norms for most of the rock types present at Roodekraal are given in Appendix I. The average concentrations of the major elements for each rock type are given in Table XII and the concentrations of some of the minor elements, and useful ratios of these minor elements are presented in Table XIII.

TABLE XII

Average concentration of major oxides in weight per cent for the rock types of the Roodekraal Igneous Complex

Analyses used in calculating average	% Oxide / Rock Type	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O^-	H_2O^+	CO_2	TiO_2	P_2O_5	MnO	Total
RC 1	Massive andesite	51,49	12,91	1,27	8,64	3,48	10,43	6,25	0,44	0,25	0,83	0,71	1,97	0,78	0,19	99,64
RC 2 - 15	Amygdaloidal andesite	51,42	11,64	3,09	11,17	2,73	4,85	4,66	1,91	0,19	1,27	4,28	1,76	0,48	0,17	99,62
RC 16 & 17	Equigranular diorite	51,27	11,20	4,03	11,50	4,36	5,88	5,16	1,59	0,20	1,22	0,55	1,98	0,43	0,21	99,58
RC 18	Pyroxene andesite	49,65	11,64	6,30	8,46	4,53	6,28	4,31	1,79	0,14	1,24	2,69	1,80	0,47	0,19	99,49
RC 19 & 20	Fine pyroxene diorite	52,18	12,92	2,46	11,09	3,97	5,56	5,24	1,61	0,19	0,86	0,57	1,83	0,60	0,16	99,24
RC 21 & 22	Coarse pyroxene diorite	49,60	13,07	9,67	5,50	5,21	7,54	4,40	0,90	0,19	0,78	0,39	1,92	0,65	0,19	100,01
RC 23 & 25	Dioritic-pegmatite	55,29	16,67	Nil	7,29	2,38	6,27	7,20	0,34	0,15	1,50	n.a.	1,75	0,19	0,07	99,10
RC 24 & 26	Wall rock to dioritic-pegmatite	45,30	8,64	5,72	11,24	12,70	11,27	1,95	0,41	0,25	0,22	n.a.	1,77	0,26	0,16	99,89
RC 27	Dioritic-aplite	52,47	14,05	2,04	11,75	3,20	5,81	5,32	1,18	0,30	0,16	0,14	2,15	1,00	0,10	99,67
RC 28	Dolerite	47,01	14,56	3,52	9,76	5,05	9,79	2,70	1,88	0,44	2,43	0,08	2,13	0,38	0,10	99,83
RC 29 & 30	Syenite	61,81	15,26	0,96	6,37	0,28	2,20	5,84	3,06	0,18	2,10	1,82	0,32	0,08	0,30	100,58
RC 31	Syenite-porphyry	62,69	16,73	1,34	4,29	0,50	1,75	5,48	4,22	0,38	0,12	n.a.	0,40	0,14	0,10	99,14

n.a. = not analysed

TABLE XIII

Concentrations of some elements and ratios of elements in the rock types of the Roodekraal Igneous Complex

Rock Type	Mark of Sample	$\frac{Rb}{Sr}$	$\frac{K}{Sr}$	$\frac{K}{Rb}$	$\frac{Ca}{Sr}$	Rb ppm	Sr ppm
Massive andesite	RC 1	0,0438	4,4	112,1	98,9	33	753
Amygdaloidal andesite	RC 2	0,1536	56,2	365,5	76,1	61	397
Amygdaloidal andesite	RC 3	0,1468	37,6	256,2	9[illegible],4	48	327
Amygdaloidal andesite	RC 4	0,1621	50,0	308,5	99,5	59	364
Amygdaloidal andesite	RC 5	0,2847	67,3	236,3	111,1	80	281
Amygdaloidal andesite	RC 6	0,2544	61,1	240,3	112,0	72	283
Amygdaloidal andesite	RC 7	0,3253	54,2	166,7	141,4	81	249
Amygdaloidal andesite	RC 8	0,2051	59,7	291,4	100,5	81	395
Amygdaloidal andesite	RC 9	0,2312	43,9	189,9	90,7	89	385
Amygdaloidal andesite	RC 10	0,1262	17,7	140,4	135,4	52	412
Amygdaloidal andesite	RC 11	0,1883	44,4	236,1	110,2	61	324
Amygdaloidal andesite	RC 12	0,1965	37,0	188,1	91,5	67	341
Amygdaloidal andesite	RC 13	0,2472	59,4	240,3	135,4	67	271
Amygdaloidal andesite	RC 14	0,1012	30,3	300,0	58,4	44	435
Coarse crystalline amygdaloidal andesite	RC 15	0,2612	52,6	201,3	116,2	76	291
Equigranular diorite	RC 16	0,1134	35,3	302,6	153,0	39	334
Equigranular diorite	RC 17	0,1397	40,8	292,0	91,9	50	358
Pyroxene andesite	RC 18	0,1101	34,2	310,4	103,0	48	436
Fine pyroxene diorite	RC 19	0,1208	30,0	248,0	87,9	50	414
Fine pyroxene diorite	RC 20	0,0726	24,2	332,6	72,6	43	592 +
Coarse pyroxene diorite	RC 21	0,0493	14,3	291,2	60,4	34	690
Coarse pyroxene diorite	RC 22	0,0158	6,6	416,7	86,7	12	761 +
Dioritic-pegmatite	RC 23	0,0084	1,9	220,0	74,3	5	592 +
Wall rock to RC 23	RC 24	0,0984	23,6	240,0	185,0	25	254 +
Dioritic-pegmatite	RC 25	0,0074	6,8	920,0	67,3	5	676 +
Wall rock to RC 25	RC 26	0,0296	4	160,0	67,5	5	169 +
Dioritic-aplite	RC 27	0,0368	12,9	350,0	54,5	28	761 +
Dolerite	RC 28	0,1017	36,9	362,7	165,5	43	423 +
Syenite	RC 29	0,0895	41,0	458,1	22,4	62	693
Syenite	RC 30	0,5917	133,1	225,0	94,7	100	169 +
Syenite-porphyry	RC 31	0,7126	137,8	193,4	48,8	181	254 +

ppm – parts per million by weight

\+ – Analyst : Gold Fields Laboratories (Pty) Ltd. (Sr was determined in parts per ten thousand).

Remaining samples – Analyst : The National Institute for Metallurgy (Both Sr and Rb were determined in parts per million).

It should be borne in mind during the following discussion that all the rock types of the Roodekraal Igneous Complex except the olivine gabbro, syenite and syenite-porphyry have undergone extensive hydrothermal alteration. This alteration has probably resulted in the present chemical composition of the rock types being more alkaline than the original unaltered rock. A detailed discussion of the chemical changes taking place during hydrothermal alteration is presented under the section entitled 'Hydrothermal Alteration'.

1. Andesite

The chemical composition of the amygdaloidal andesite is almost identical to that of the massive andesite except for the distribution of the minor elements. In order to discuss the geochemistry of the andesite objectively the average of all the analyses for samples of andesite from Roodekraal, excluding the pyroxene andesite, will be compared with well known average compositions in Table XIV below.

TABLE XIV

Comparison between chemical analyses in weight per cent for Roodekraal andesite and some well known averages for andesite

Oxide	Average of fifteen analyses of andesite from Roodekraal *	Nockolds' (1954) average Tholeiitic andesite	Nockolds' (1954) average andesite	Daly's (1933) average andesite
SiO_2	51,43	51,43	54,20	59,59
Al_2O_3	11,72	13,05	17,17	17,31
Fe_2O_3	2,97	3,36	3,48	3,33
FeO	11,00	9,74	5,49	3,13
MgO	2,78	5,28	4,36	2,75
CaO	5,23	8,78	7,92	5,80
Na_2O	4,76	3,18	3,67	3,58
K_2O	1,81	1,04	1,11	2,04
H_2O-	0,20	-	-	1,26
H_2O+	1,24	0,87	0,87	-
CO_2	4,04	-	-	-
TiO_2	1,77	2,60	1,31	0,77
P_2O_5	0,50	0,48	0,28	0,26
MnO	0,18	0,19	0,15	0,18
SrO ppm	434	-	-	-
Rb_2O ppm	71	-	-	-
Totals	99,68	100,00	100,01	100,00

* - Average of analyses RC 1 - 15 (Appendix I).

ppm - parts per million.

It can be noted from the data presented in Table XIV that the andesites at Roodekraal has lower MgO, CaO, Al_2O_3 and SiO_2 contents and higher

Na_2O, K_2O, FeO and CO_2 contents than most varieties of andesite. It can thus be concluded that the andesite at Roodekraal is more alkaline than the world average. In the AFM diagram (Fig. i, Appendix II) the andesite has a proportionally higher iron content than the other rock types of the Complex. The (FeO + 0,8998Fe_2O_3) - MgO - TiO_2 ternary diagram (Fig. vi, Appendix II) also emphasises the high iron content of the andesite although the syenite and syenite-porphyry are enriched in iron relative to the andesite. Considering the (FeO + 0,8998Fe_2O_3 + TiO_2) - MgO - Al_2O_3 ternary diagram (Fig. vii, Appendix II), once again the andesite contains a high proportion of iron compared with the other rock types. From an examination of Table XII it is readily observed that the andesite contains more CO_2 than any other rock type in the Complex.

As far as the minor elements are concerned the massive andesite has a much lower Rb/Sr value than the amygdaloidal andesite

2. Equigranular diorite

The geochemistry of this rock type is best appreciated by referring to diagrams in Appendix II in which the ratios and functions of the various elements and oxides have been plotted. It can be observed that the equigranular diorite analyses occupy a similar position to the analyses of andesite in the AFM diagram (Fig. i, Appendix II) although the equigranular diorite contains less iron in comparison to alkalis and magnesium than the andesite. In the Na-K-Ca ternary diagram (Fig. v, Appendix II) the equigranular diorite shows K depletion relative to the andesite, while in the (FeO + 0,8998Fe_2O_3) - MgO - TiO_2 ternary diagram (Fig. vi, Appendix II) the equigranular diorite shows magnesium enrichment compared to the andesite.

As far as the distribution of the minor elements is concerned an examination of Table XIII (p. 28) and Figures xi, xii, xiii and xiv of Appendix II shows that the equigranular diorite has a very similar distribution of minor elements to the amygdaloidal andesite.

3. Pyroxene andesite

When the chemical composition of this rock type is compared graphically with the compositions of the other varieties of andesite present at Roodekraal, it is observed that the pyroxene andesite on average contains more calcium relative to the alkalis in the Na-K-Ca ternary diagram (Fig. v, Appendix II). The pyroxene andesite contains more magnesium relative to total iron plus titanium and aluminium than the other types of andesite (Fig. vii, Appendix II). It can be observed, from an examination of Table XIII (p. 28), that there is very little difference between the distribution of minor elements within the pyroxene andesite and the other types of andesite.

4. Fine pyroxene diorite

The analyses of the fine pyroxene diorite in Appendix I (RC 19 and RC 20) contain more silica than the analysis of the pyroxene andesite (RC 18). The fine pyroxene diorite contains relatively less iron compared to alkalis and magnesium than the pyroxene andesite (Fig. i, Appendix II). The relative proportions of all other chemical components, including the minor elements present in the fine pyroxene diorite, are similar to the proportions present within the pyroxene andesite, with the exception that more of the iron in the fine pyroxene diorite is in the lower oxidation state (Fig. viii, Appendix II).

5. Coarse pyroxene diorite

The variation of the major chemical components of the coarse pyroxene diorite is very similar to the variation present in the fine pyroxene diorite. When the variations of the minor elements in the above two rock types are compared it is observed that the coarse pyroxene diorite has lower Rb/Sr, K/Sr, Ca/Sr, K and Rb values and higher Sr contents than the fine pyroxene diorite and the pyroxene andesite (Figs. xi, xii and xiii, Appendix II) and Tables XII and XIII.

6. Dioritic-pegmatite and dioritic-aplite

To determine what exomorphic effects the pegmatite has had on its wall rocks the number of cations in the standard cell of the altered equigranular diorite wall rock to the pegmatite are compared with the number of cations in the unaltered equigranular diorite in Table XV. In Table XV, RC 16 is used as the unaltered equigranular diorite and RC 17 is omitted, this is because RC 16 is a channel sample of an unaltered equigranular diorite sill taken from a borehole core, while RC 17 is a sample taken from an outcrop of equigranular diorite which is much further from the area where the pegmatites have been sampled than RC 16.

TABLE XV

Comparison between the number of cations in the standard cells of the unaltered equigranular diorite and the wall rocks to the pegmatite veins

Cation	Number of cations in the standard cell of RC 16 i.e. the unaltered equigranular diorite	Number of cations in the standard cell of RC 24 i.e. the altered wall rock to pegmatite RC 23	Amount of cations required to convert the unaltered equigranular diorite into the altered wall rock to pegmatite RC 23	Number of cations in the standard cell of RC 26 i.e. the altered wall rock to pegmatite RC 25	Amount of cations required to convert the unaltered equigranular diorite into the altered wall rock to pegmatite RC 25
Si	48,78	48,97	+ 0,19	41,45	- 7,33
Al	11,64	12,82	+ 1,18	7,43	- 4,21
Fe^{3+}	3,12	0,05	- 3,07	8,83	+ 5,71
Fe^{2+}	10,44	10,33	- 0,11	8,35	- 2,09
Mg	8,49	18,83	+ 10,34	19,42	+ 10,93
Ca	7,61	6,83	- 0,78	17,70	+ 10,09
Na	8,48	5,82	- 2,66	1,58	- 6,90
K	1,80	0,90	- 0,90	0,14	- 1,66
H (hygroscopic)	1,13	2,26	+ 1,13	0,96	- 0,17
H (combined)	7,75	1,26	- 6,49	1,50	- 6,25
Ti	1,56	0,37	- 1,19	2,36	+ 0,80
P	0,34	0,27	- 0,07	0,17	- 0,17
Mn	0,19	0,10	- 0,09	0,15	- 0,04
Algebraic Totals	111,33	108,81	- 2,52	110,04	- 1,29

The most important chemical changes which have taken place are marked increases in the Mg contents of both wall rock samples, and marked increases in the Ca and Fe^{3+} contents of RC 26 when compared with the unaltered diorite. Both samples of wall rock have been depleted in Na, K, H, P and Mn, while RC 26 has been depleted to a large extent in Si. Generalising, there has been a decrease in alkalis and volatiles and an increase in femic constituents in the wall rocks of the pegmatite. This is what we would expect since most of the components which have been subtracted from the wall rock are those which have been enriched in the pegmatite. No exomorphic effects are observed around the aplites. When the distribution of the minor elements in the pegmatite and aplite is considered the most important feature is the extremely low Rb content and Rb/Sr values present in the pegmatite. This is probably produced by a lack of suitable host minerals for the rubidium.

To determine what changes in composition take place relative to height in the composite pegmatite - aplite veins a comparison is made in Table XVI between the average of the number of cations in the standard cells of dioritic-pegmatite veins occurring in the equigranular diorite, at some distance above the coarse pyroxene diorite, and the number of cations in the standard cell of an dioritic-aplite present within the coarse pyroxene diorite.

TABLE XVI

Comparison between the average number of cations in the standard cell of the dioritic-pegmatite and the number of cations in the standard cell of the dioritic-aplite

Cation	Average number of cations in standard cells of dioritic-pegmatite RC 23 and RC 25	Number of cations in standard cell of dioritic-aplite RC 27	Number of cations required to convert dioritic-aplite to dioritic-pegmatite
Si	51,35	50,65	+ 0,70
Al	18,26	15,95	+ 2,31
Fe^{3+}	0,00	1,49	- 1,49
Fe^{2+}	5,70	9,45	- 3,75
Mg	3,34	4,63	- 1,29
Ca	6,25	6,05	+ 0,20
Na	12,90	9,94	+ 2,96
K	0,42	1,44	- 1,02
H (hygroscopic)	0,94	1,94	- 1,00
H (combined)	9,20	1,02	+ 8,18
Ti	1,23	1,55	- 0,32
P	0,15	0,82	- 0,67
Mn	0,04	0,08	- 0,04
Algebraic Totals	109,78	105,01	+ 4,77

It can be observed from an examination of Table XVI that there is a striking decrease in the basic components Fe^{3+}, Fe^{2+}, Mg, Ti and Mn and also in K and P with increasing height. There is a strong increase in H and smaller increases in Na, Ca, Si and Al, with increasing height which is what one would expect from the great increase in the amount of plagioclase.

An interesting feature in the analyses of the pegmatite is the fact that neither contains any ferric iron, which is only possible if the hornblende is a member of the edenite-ferroedenite series of hornblende which contains no ferric iron. Since the edenite-ferroedenite series has a high silica content, and aluminium substitutes for silica in increasing amounts at elevated temperatures, the author feels that it must be a low temperature series of hornblende, which is what we would expect in a rock crystallised at low temperatures, such as a pegmatite.

7. Dolerite

The dolerite contains less SiO_2 than all other rock types except the wall rock immediately adjacent to a pegmatite vein. The MgO and CaO contents of the dolerite are higher, and the amount of alkalis present lower, than the proportions in the majority of the rock types analysed (Table XII). The dolerite, with the exception of the wall rock to the pegmatite vein has the highest Ca/Sr value of all the rock types analysed (Table XIII).

8. Syenite

The distribution of the major elements within this rock type is very similar to that of the syenite-porphyry (Table XII). Both these rock types contain more SiO_2 and less iron and TiO_2 than the other rock types of the Complex. It may be noted from Table XIII that both syenite and syenite-porphyry have higher Rb/Sr and Rb values than the other rock types, with the values for the syenite-porphyry being clearly higher than those for the syenite.

9. Syenite-porphyry

The geochemistry of this rock type has been compared with the syenite and other rock types of the Roodekraal Igneous Complex in the preceding sub-section. The geochemistry of the syenite-porphyry is compared to that of the syenite of the Pilandsberg dike swarm in Table XVII overleaf.

TABLE XVII

Comparison of chemical analyses in weight per cent for the syenite-porphyry and syenite of the Pilandsberg dike swarm

Constituent		Roodekraal syenite-porphyry RC 31	Pilandsberg syenite from Leeufontein, analyst Shand (1921)	Average of seven analyses of Pilandsberg syenite
SiO_2	%	62,69	60,24	54,83
TiO_2	%	0,40	0,94	1,09
Al_2O_3	%	16,73	18,54	15,24
Fe_2O_3	%	1,34	0,54	2,27
FeO	%	4,29	2,36	5,84
MgO	%	0,50	0,76	3,16
CaO	%	1,75	2,29	7,05
Na_2O	%	6,48	6,59	4,75
K_2O	%	4,22	5,44	2,42
P_2O_5	%	0,14	0,27	0,22
MnO	%	0,10	-	0,27
H_2O+	%	0,12	1,22	1,84
H_2O-	%	0,38		0,22
CO_2	%	n.a.	0,43	0,80
BaO	%	0,02	n.a.	n.a.
SrO	ppm	300	n.a.	n.a.
Rb_2O	ppm	198	n.a.	n.a.
F	%	n.a.	0,02	n.a.
SO_3	%	n.a.	0,04	n.a.
S	%	n.a.	0,07	n.a.
Rb/Sr		0,714	-	-
Totals		99,21	100,77	100,00

The average of seven analyses of Pilandsberg syenite are reproduced by permission of Dr. J. Ferguson (publication in preparation).

The Leeufontein analysis is of red syenite (umtekite type) and was published in Shand (1921, p. 241, No. F), the analyst being S.J. Shand. ppm = parts per million. n.a. = not analysed.

When the chemistry of the syenite-porphyry is compared with the average Pilandsberg syenite the main differences are that it has a lower content of basic oxides and a higher content of silica and alkalis. The geochemistry of the syenite-porphyry is, however, observed to correspond quite closely with that of a Pilandsberg syenite found at Leeufontein.

C. Mineralogy of the Rock Forming Minerals

1. Primary Rock Forming Minerals

Under this heading minerals which crystallised directly from the melt, before the residual fluids had brought about widespread alteration, will be considered.

a. Feldspar

The feldspar of the Complex is almost exclusively plagioclase, together with a small amount of potassium feldspar. The potassium feldspar is present within the syenite-porphyry, equigranular diorite and coarse pyroxene diorite.

(i) Plagioclase

The size of the plagioclase crystals vary greatly, from microliths present in the lavas, which are less than 0,01 millimetres in length, to crystals up to 25 millimetres long in the dioritic-pegmatite. The crystal shapes range from stubby euhedral grains to tabular grains flattened parallel to (010), plagioclase is also present as interstitial material in the olivine gabbro. The stubby euhedral grains are generally limited in their occurrence to the amygdaloidal andesite, equigranular diorite, syenite, syenite-porphyry, dioritic-pegmatite and the dioritic-aplite. The tabular crystals are largely confined to the coarse and fine pyroxene diorite and the pyroxene andesite. The plagioclase is generally twinned according to the albite law, although some Carlsbad and pericline twinning is present. In the unaltered plagioclase the albite twins have straight, regular twin lamellae, but where the plagioclase grains have undergone hydrothermal alteration the twin lamellae are irregular and lens shaped. Zoning is present in the plagioclase of all the rock types except the olivine gabbro, coarse pyroxene diorite, dolerite and dioritic-aplite.

The compositions obtained for the plagioclase generally compare well with the values derived by Bisschoff (1950, p. 10), see Table XVIII.