

The Geology and the Structure of the Area in the  
Vicinity of Magnet Heights, Eastern Transvaal,  
with special reference to  
the Magnetic Iron Ore

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Frontispiece - A spectacular outcrop of the  
Main Seam in Sekhukhuneland.

TABLE OF CONTENTS

	<u>Page</u>
<u>ABSTRACT</u>	
<u>CHAPTER I</u>	
INTRODUCTION : General .....	1
Previous Work .....	4
<u>CHAPTER II</u>	
TOPOGRAPHY AND DRAINAGE .....	6
<u>CHAPTER III</u>	
GEOLOGY : General .....	8
(i) Xenoliths in the Mafic Rocks	12
(ii) The Roof Rocks .....	13
(iii) Magnetitite Seams and Plugs.	17
(iv) Anorthosite .....	18
(v) Pyroxenite .....	19
(vi) Gabbro and Troctolite .....	19
(vii) Granite .....	19
(viii) Diabase, Dolerite and other Minor Intrusives .....	23
(ix) Recent Deposits .....	24
<u>CHAPTER IV</u>	
GEOLOGICAL STRUCTURE .....	24
(1) Faulting .....	24
(2) Folding .....	28
<u>CHAPTER V</u>	
MINERALOGY .....	30
(1) General .....	30
(2) Textures and Order of Crystallisation .....	34
(3) Exsolution, Replacement and Intergrowth Phenomena .....	39
(4) Mineralogy of the Magnetitite	41
<u>CHAPTER VI</u>	
INDIVIDUAL PETROGRAPHIC UNITS .....	57
(1) The Magnetitite Seams .....	57
(2) The Magnetitite Plugs .....	77
(3) The Chemical Composition of the Magnetic Iron Ore .....	80
(4) Layered Mafic Rocks .....	82
<u>CHAPTER VII</u>	
PETROGENESIS .....	93
(1) Paragenesis of Ilmenite, Ulvite and Spinel in Magnetite .....	93
(2) Petrogenesis of the mono- mineralic rocks in the Upper Portion of the Layered Rocks of the Bushveld Complex .....	101

ABSTRACT

The area investigated at Magnet Heights covers ten miles of strike of the uppermost six thousand feet of the layered mafic rocks of the Bushveld Complex. A fall of a thousand feet southwards from the Magnet Heights trading store has caused the almost complete "stripping off" of the soil cover to produce excellent rock exposures; a situation unique in this zone of the Bushveld Complex.

Monomineralic layered rocks identified are magnetitite, anorthosite and pyroxenite. The remaining layered rocks are predominantly gabbroic. In mapping, the Main Magnetitite Seam was taken as a datum line relative to which four lower seams and 21 upper seams were numbered and mapped. Each of these seams can be recognised by noting its  $V_2O_5$  content, its thickness and its field relationships. Anorthosite is more common than magnetitite and is often intimately associated with the latter rock. For example, the Main Seam is underlain with a sharp contact by five feet of pure anorthosite and grades upwards into magnetite anorthosite. Most of the seams are gradational upwards with a sharp lower contact, some are gradational upwards and downwards, and Seam No. 13 has a sharp upper contact and is transitional downwards into gabbro. Pyroxenite is the rarest monomineralic rock and only two bands were identified. The Magnet Heights granite is a large dyke which was mechanically intruded into rigid gabbro.

Using mainly the magnetitite seams as markers, numerous faults and an anticline were identified in the course of mapping. Strike-faults with throws of up to one hundred feet have produced repeated outcrops of the Main Seam on Magnet Heights 346. KS. On Steelpoortdrift 365. KT, small oblique faults have frequently dislocated the Main Seam. The Steelpoort Fault, which displaces the Main Seam laterally for a distance of five-and-a-half miles, was calculated to have a throw of about five thousand feet. The Sekhukhune Fault bordering the western side of the Lulu

./ . . . . .

(Abstract) cont. ....

Mountains is considered to have a similar throw. This fault system on Magnet Heights 846. KS might be interpreted as a type of graben. The presence of an anticline in the northern portion of the area explains the absence there of outcrops of the Main Seam.

Generally, in the gabbroic rocks plagioclase and magnetite crystallised before olivine and pyroxene. Pyroxene occasionally was concentrated to form pyroxenite, but olivine has not been concentrated to produce harzburgite or dunite. The magnetite, during cooling, exsolved ulvite and/or ilmenite and finally spinel. Some of the ulvite was later oxidised to secondary ilmenite. Large ilmenite crystals, which are frequently twinned, and <sup>which</sup> contain exsolved magnetite lamellae were precipitated presumably directly from the magma.

When magnetite crystals began to separate sufficiently early, it is postulated that magnetite <sup>was</sup> concentrated by magmatic sedimentation into a monomineralic crystal layer on what, at that time, constituted the floor of the magma chamber. Thus the lowest seam could have resulted. The Main Seam is composite. Its feldspathic centre is probably due to a temporarily decreased rate of magnetite deposition. Magma, charged with magnetite and plagioclase crystals, is suggested to have made its way under the influence of gravity and magmatic currents which may have existed, to the floor of the magma chamber and there to have deposited a layer of magnetite crystals succeeded by an overlying layer of slowly settling plagioclase laths, thus producing the <sup>ns</sup> traditional top of the Main Seam.

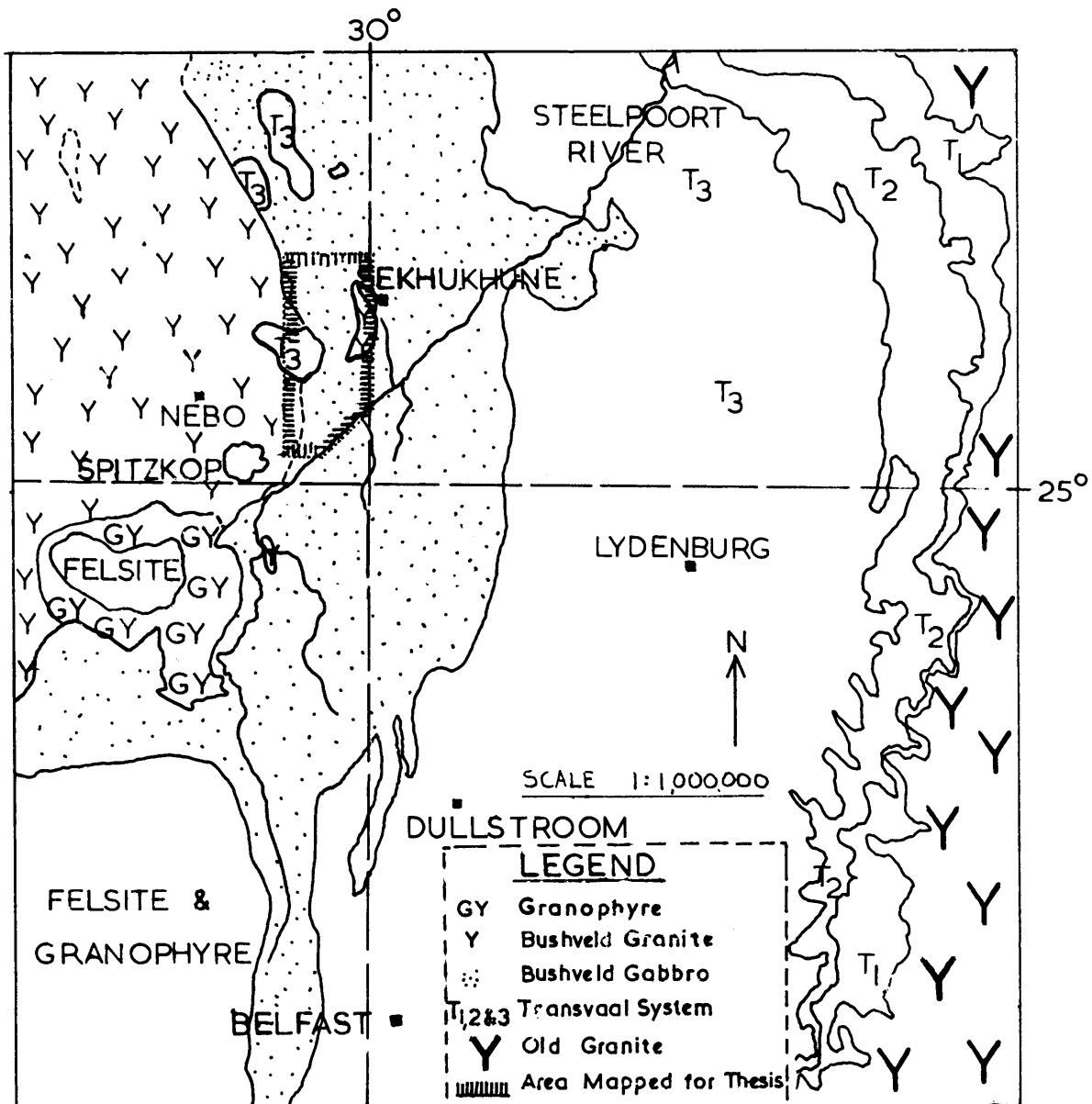
The rhythmic occurrence of the magnetite <sup>is</sup> seams in the column may have been due to intermittent precipitation of magnetite by the magma or, rather improbably, <sup>is</sup> the periodic convective overturn of the magma. In the rare event of the magma having contained a sufficient concentration of pyroxene crystals, a pyroxenite band was formed.

The magnetite and, to a lesser extent the plagioclase crystal layers, are suggested to have been converted to monomineralic rocks by diffusion.

(Abstract) cont. ....

The magnetite plugs are possibly late pegmatoid bodies which were formed in the nearly solid gabbro and were intruded upwards, probably not more than a thousand feet from their site of segregating.

FIG. 1. LOCALITY MAP OF AREA INVESTIGATED



# C H A P T E R I

## INTRODUCTION.

"The Magnetite Bands and their associated rocks make a series of outcrops which are not only instructive as a most striking instance of the intimate association of rocks of extreme acid and basic composition, but offer a display most probably unique for its impressive grandeur.

This locality is incomparably the finest demonstration of the Principal Magnetite Horizon available anywhere in the Lopolith." (Hall 1932, p.342/343).

This quotation from Hall is taken to introduce the reader to the most spectacular part of the locality mapped for this Thesis. This area consists of approximately ninety square miles of the eastern portion of the Bushveld Igneous Complex. The rocks in this area include the uppermost six thousand feet of the Bushveld gabbro and associated magnetite rich seams and anorthosites, the Magnet Heights granite and a part of the roof including the Signal Hill quartzite.

Mapping and prospecting by the author and two other geologists, Mr. R. Jacob and Mr. K. McQuillin, on behalf of the Anglo-American Corporation of South Africa Limited, was carried out on the farms Magnet Heights 846. KS, Ironstone 847. KS and Steelpoortdrift 365. KT. Further work carried out independently by the writer covered the remainder of these farms and part, or all, of Goedgemeende 815. KS, Avontuur 814. KS, Duizend Annex 816. KS, Schoonoord 326. KT, Diamond 848. KS, 'Groblers Vrede 844. KS, Droogehoek 882. KS, Driehoek 883. KS, Aapjesboom 884. KS, Steelpoort Park 366. KT and De Hoop 886. KS.

In the employment of the Anglo-American Corporation, the

writer spent three months in the field in 1962, and his co-workers two months each. The prospecting work entailed cutting parallel survey lines at five hundred feet intervals, normal to the strike of the iron-ore seams. Pits were sunk at three hundred feet intervals on these lines to determine ore grade and reserves. Where seams were too hard to be pitted they were drilled with a small petrol-driven Atlas Copco jumper drill. This work was done with the help of a large gang of Africans and could not have been completed by an individual in less than six months.

Initially the area was mapped using a plane table and a telescopic alidade on a scale of 1 : 5,000 with an almost exclusive bias in favour of magnetic iron ore. The various seams and plugs were sampled to determine their  $V_2O_5$  content and some comprehensive assays were also made by the Central Metallurgical Laboratory of the Anglo American Corporation.

Magnet Heights was subsequently revisited by the writer on several occasions and mapping was done on aerial photographs on scales of 1 : 17,000 and 1 : 36,000. More attention was then paid to rocks other than the economically important magnetic iron-ore. By using various marker bands, of which the magnetic iron-ore seams are the most important, an interpretation of the structure was made.

The total area mapped is about fifteen miles from north to south and about six miles from east to west. The mapping was carried out in the following manner: -

by plane table with a telescopic alidade

10 square miles 1 : 5,000

on aerial photographs

30 square miles 1 : 17,000

The general map (No. I) was compiled from the detailed maps and from the aerial photographs, all converted to a scale of 1 : 20,000. Some inevitable distortion resulted from

using photographs, especially in such mountainous areas, without carrying out the necessary corrections. Compromises were necessary, but it is considered that the final position of the geology is reasonably accurate with no point deviating more than one thousand feet from its true position.

Four maps accompany this treatise:

- No. I - A regional map on a scale of....1 : 20,000
- No. II - A detailed map of the magnetic iron ore seams on the south of Magnet Heights 846.KS on a scale of....1 : 5,000
- No. III - A detailed map on a scale of 1 : 5,000 of the magnetic iron ore seams in the vicinity of the Magnet Heights River on Magnet Heights 846.KS and Ironstone 847.KS
- No. IV - Two east-west, scale.....1 : 10,000 sections across Magnet Heights 846.KS and Ironstone 847.KS constructed from the surveyed lines, three east-west sections on a scale of.....1 : 20,000 deduced from the No. I map and two stratigraphical columns compiled from the two 1 : 10,000 sections

The petrographical study was carried out in the Department of Geology at the University of Pretoria.

The purpose of the work was to try and determine the genesis of the magnetic iron ore seams and the accompanying monomineralic rocks.

My sincere thanks are due to the following:

The Anglo American Corporation of South Africa Limited for allowing me to use much official information.

Messrs. K. McQuillin and R. Jacob who also worked in the area.

The Staff of Kier's Store at Magnet Heights for accommodating me during my fieldwork.

The Bantu Affairs Department for allowing me to enter and work in a Native Reserve.

Mr. D.N. Hall for critically reading the manuscript.

Professor J. Willemsse and other members of the Staff of the Geology Department of the University of Pretoria, who assisted in various ways.

Other Geologists who have offered suggestions and comments and with whom I have discussed my work.

Clivetti (Africa (pty.) Limited) for the loan of a typewriter.

My wife for typing the thesis.

The Government Printers for permission to trace Fig. 1 off the Regional Geological Map of South Africa.

#### PREVIOUS WORK

Little previous detailed mapping has been carried out in this particular area.

In 1908 Hall mapped the area on a small scale. He concluded that there is no strike faulting and that the thick iron ore seam in the Magnet Heights River was part of a second and lower series of seams under the Main Seam which overlooks the river (Hall 1932, p. 344). Apart from the Main Seam he mapped only the uppermost seams which outcrop on the eastern slope of Signal Hill.

Hall regarded the roof rocks north-west of Sekhukhune as granite and terminated the Magnet Heights granite east of the Magnet Heights River.

In 1922 members of the Shaler Expedition found two places on the eastern side of the Magnet Heights granite where the granite is intrusive into the gabbro (Hall 1932, p.366

Lombaard (1934) made the following relevant observations on the magnetite-rich zone of the Bushveld Complex: -  
"there appears to be a hiatus between the Bushveld granite and the underlying norite at Tautesberg" (p. 10 and 11).  
"Alkali feldspars are absent except in the upper norite". (p. 18). He postulated that the magnetic iron ore seams are the result of differentiation of separate intrusions aided by crystal settling within each individual intrusion (p. 32 / 33).

In 1943 C.M. Schweltnus and J. Willemse carried out a general investigation of the titaniferous vanadiferous iron ores of the Bushveld Complex. They found that  $V_2O_5$  ranges from 0 to 1.5% in the different seams and that the Main Seam has the most  $V_2O_5$ ,  $TiO_2$ , according to them, ranges from 2% to 24%, the least being in the Main Seam and there is thus an antipathetic relationship between Ti and V. No mineral was detected to account for the  $V_2O_5$  which, therefore, is probably accommodated in the magnetite lattice.

Strauss (1946, p. 35-50) investigated magnetite of the Bushveld Complex. Most of his work was done on material from what is now designated as Seam No. 21, where it outcrops on the road to Jane Furse Hospital. What he seems to have described are various weathering phenomena. The "grey mineral" is probably maghemite and the "pink-brown mineral" unaltered primary magnetite.

Strauss & Truter (1949) wrote a paper on the minor alkaline intrusives south-east of the Magnet Heights Store. They confined themselves entirely to this petrographic assemblage, mapping only incidentally a couple of magnetite seams.

Steyn (1950) worked in the Magnet Heights area for his M.Sc. Thesis. He recorded that olivine appears fourteen hundred feet above the Main Seam and used this position where olivine reappears as a division between the Main Zone and the upper zone. He interpreted the quartzite and metamorphic rocks on Schoonoord 326. KT as xenoliths in the Magnet Heights granite.

C H A P T E R II

TOPOGRAPHY AND DRAINAGE

There are three distinct erosion surfaces in the area (Fig. 6) -

- (a) the plateau composed of roof rocks 5,000 feet above sea level
- (b) the plain north of Magnet Heights 4,000 feet above sea level
- (c) the sloping floor of the Steelpoort Valley 3,500 - 2,200 feet above sea level

Striking features which do not conform with this pattern are: -

- ( i) the Lulu Mountains rising eastwards to Thama Koosh (6343 feet)
- ( ii) the Magnet Heights granite (5,500 feet)
- (iii) the Signal Hill quartzite (5,700 feet)

The Signal Hill quartzite and the Magnet Heights granite each form prominent features which dominate their surroundings. The roof of quartzite, leptite, diabase and granite caps a steep escarpment rising from the plain north of Magnet Heights and from the sloping floor of the Steelpoort Valley.

The Magnet Heights Store lies on the watershed between the Olifants- and the Steelpoort Rivers. Northwards the ground falls very gently and is drained by a choked river system. This plain, north of Magnet Heights, will be called "The Flats" and, as it is largely covered with soil, mapping the solid geology is rather difficult.

From Signal Hill and the westerly escarpment of roof rocks, the rivers drain westwards and ultimately northwards to the Olifants River. Southwards from Magnet Heights, a fall of 1,300 feet over eight miles has led to the "stripping off"

of most of the soil cover to provide almost complete rock outcrop. The best exposure is in the first three miles on the farms Magnet Heights 846.KS and Ironstone 847.KS, where there is a fall of 1,000 feet. The gabbro and interstratified magnetic iron ore seams have been strongly eroded leaving the harder bands, which are troctolite, magnetic iron ore and certain gabbro bands, as escarpments (Sections C D and E F ).

The jointed gabbro weathers spheroidically (Fig. 5) and yields a deep red soil. The anorthosite alters near the surface to kaolin and the seams of magnetic iron ore break into slabs, the size of which is related to and characteristic of the parent seam (Table I). Troctolite produces unbroken sheets (Fig. 4).

The Main Seam is particularly resistant to erosion because, even when it has been broken into slabs by disintegration along joints, these slabs remain more or less in situ as a litter of blocks. Weathered gabbro tends to disappear from under the magnetite rock, which then slumps downwards as broken pavement. (Fig. 7).

Xenoliths are harder than the country rock and protrude upwards as isolated knolls. The granite disintegrates along its joints into large boulders and hills of granite have a jagged profile.

On Magnet Heights 846.KS streams in places follow the strike faults. For example, the Magnet Heights River rises in, and flows for about two miles southwards along the biggest of these faults. Northwards across "The Flats" the faults do not give rise to any topographical features. The Sekhukhune Fault has given rise to a deep V-shaped valley towards the south, but north of Sekhukhune it is bordered to the east by the Main Zone gabbro rising to Thama Koosh. The Steelpoort River meets the Steelpoort Fault on the south of De Hoop 886.KS and north-eastwards, the river runs in the vicinity of this Fault.

The vegetation of the area was probably originally bushveld,

but now much of it has been cut away. The trees on the granite do not seem to differ from those on the gabbro. The strike faults on Magnet Heights 846.3S and the westerly contact of the Magnet Heights granite are marked by a line of bigger and greener trees, which are visible from the road.

### C H A P T E R III

#### GEOLOGY

##### GENERAL

As mentioned in the introduction, the area of ninety square miles mapped for this thesis covers the uppermost six thousand feet of the mafic portion of the Bushveld Complex and about ten miles of strike. As the total thickness of the mafic portion is about thirty thousand feet (Du Toit, p. 123), this uppermost six thousand feet represents about one fifth of the total column. Taking the total area of the Complex as about twenty thousand square miles, the area mapped by the writer is about half a per cent of the area of the entire Bushveld Complex.



Fig. 2 View looking northwards from Mpupa Store. Prominent scarps are troctolite. T1, is troctolite 1,200 feet and T2, is troctolite 2,200 feet above the Main Seam.

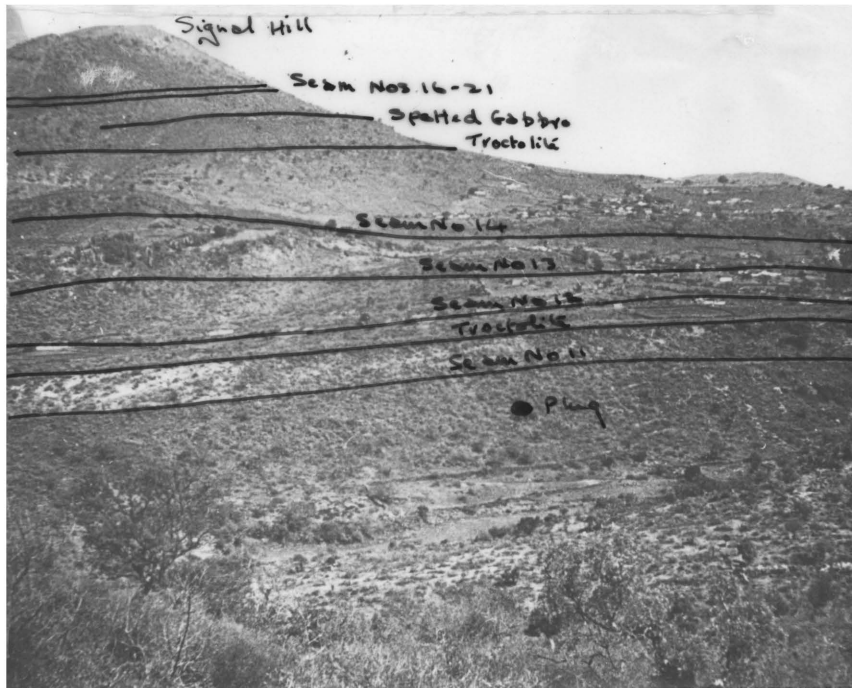


Fig. 3 View looking westwards towards Signal Hill from the plug below Seam No. 8 on Magnet Heights 848.XS.



Fig. 4 Characteristic unjointed troctolite above Seam No. 11 on Magnet Heights 846. YS.

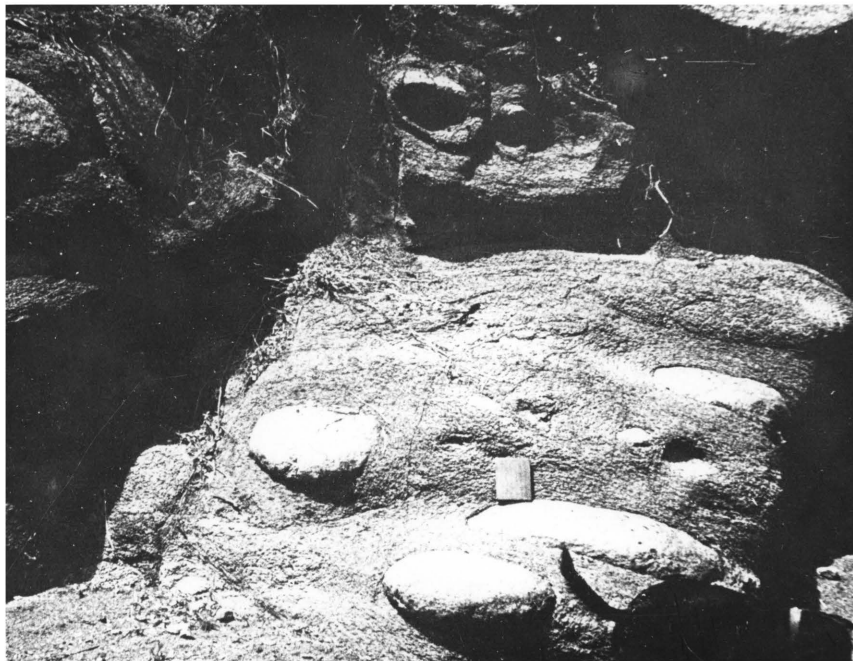


Fig. 5 Spheroidal weathering of gabbro below Seam No. 8 on Magnet Heights 846. YS.

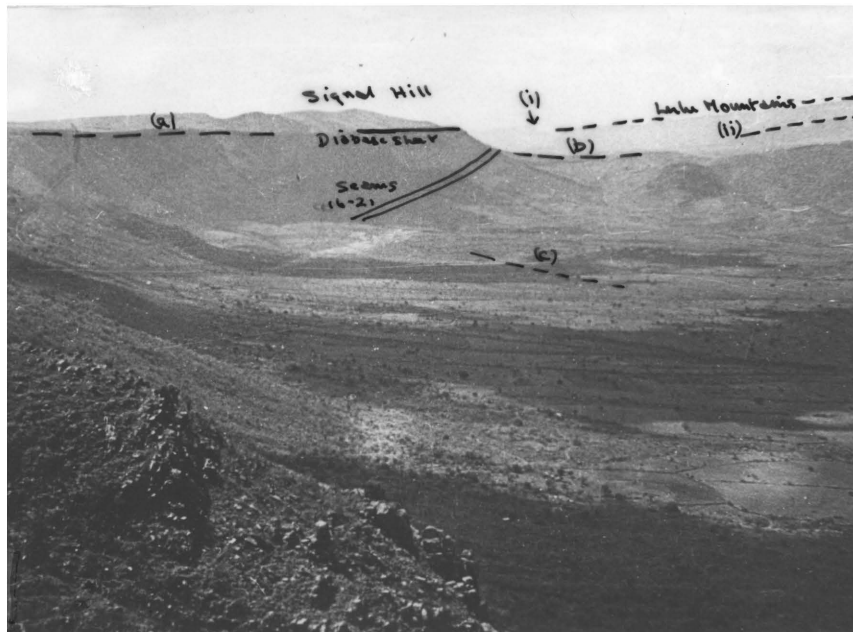


Fig. 6 View looking northwards from the Bushveld granite on De Hoop 386.KS

- (a) Plateau of roof rocks 5,500 feet above sea-level
- (b) The Plain north of Magnet Heights  
4,000 feet above sea-level
- (c) The sloping floor of the Steelpoort Valley  
3,500 - 2,800 feet above sea-level
- ( i ) Thama Koosh 6,343 feet above sea-level
- ( ii ) Magnet Heights granite 5,500 feet above sea-level.

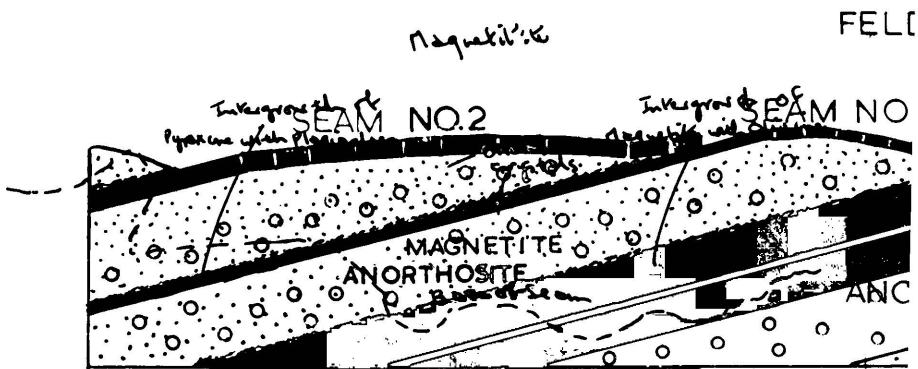


FIG. 7. GENERALISED SECTION OF THE SLUMPING  
Anorthosite  
THROUGH ELIMINATION OF WEATH

rocks of the gabbro suite in the portion of the Bushveld Complex in the vicinity of Magnet Heights include diorite, gabbro, hypersthene gabbro, hyperite, norite and troctolite. Monomineralic rocks are magnetitite, \* anorthosite and pyroxenite. Magnetitite makes up 1½% and anorthosite 2½% of the topmost 6,000 feet of mafic rocks. The locality of occurrence of the various rock types is stated relative to the magnetitite seams and the Main Seam; for example, troctolite below the No. 8 Seam and 1,200 feet above the Main Seam.

Hornfelsic, quartzose and calcareous xenoliths from a few feet to half a mile in length are quite common in the gabbro.

The Roof is composed of quartzite, leptite, hornfels and a post-Bushveld diabase sheet. The metamorphic components of the Roof are intruded by the Main Bushveld granite which is also locally in direct contact with the gabbro.

The salic rocks include Main Bushveld granite, the Magnet Heights granite, minor granite bodies and an assemblage of pegmatite dykes and quartz veins

Rocks intruded later than the granite include diabase sheets, dolerite dykes and sills, and a suite of minor alkaline intrusives of Spitzkop age.

Part of the area has been covered by a recently deposited blanket of calcrete, gravel, red clay and black turf (Fig.10)

The various rock units will now be considered individually: -

(1) Xenoliths in the Mafic Rocks

These fall into three categories: -

- (a) Quartzose xenoliths
- (b) Hornfelsic xenoliths
- (c) Calcareous xenoliths

As no laboratory work was done on them, they will not be discussed at length. All the xenoliths can have been derived from rocks of

/ 13 ....

\*In the same way as the designation 'chromitite' is commonly used for a rock rich in chromite, the term 'magnetitite' is here applied to designate a rock rich in magnetite. As magnetite often grades into anorthosite, the following further classification is proposed: -

predominantly magnetite	-	MAGNETITITE
magnetite >	plagioclase-	FELDSPATHIC MAGNETITITE
plagioclase >	magnetite -	MAGNETITE ANORTHO-SITE
predominantly plagioclase-		ANORTHO-SITE

the Pretoria series. They tend to be elongated along the strike of the layered rocks and the biggest xenoliths occur near the Roof.

(a) Quartzose Xenoliths

In the gabbro above the Seam No. 21 and below the Signal Hill quartzite are about twenty quartzite xenoliths. None is large, the average size being about fifty feet long and ten feet thick. They are considered to be fragments of the quartzite roof incorporated in the uppermost gabbro. A few hundred yards south-west of the trading store on Droogehoek 832.KS, a flagstone xenolith dips conformably westwards with the gabbro.

(b) Hornfelsic xenoliths are less common but larger than the quartzose types. They are not conspicuously attenuated. Some of the hornfels appears to be amygdaloidal (Fig. 8) but the white spots could be of metamorphic origin.

The most accessible xenolith is that east of the river in the southern portion of Magnet Heights 846.VS. It seems to be a lens lying between the Upper Seam No. 2 and 3. It is composed of pseudo-amygdaloidal hornfels (Fig. 8), hornfels showing remnants of current bedding, <sup>a</sup>flinty fine-grained variety and <sup>a</sup>pale grey quartzite.

An interesting small xenolith is exposed in the Magnet Heights River in the southern portion of Magnet Heights 846. KS (Fig. 9). Upper Seam No. 1, which lies directly above <sup>it</sup> is not distorted or attenuated.

A xenolith shown on Map No. I on the farm Ironstone 847.KS interrupts Seam No. 21 for about a thousand feet.

(c) A small banded calcareous xenolith outcrops on Ironstone 847.KS near the horizon of Seam No. 8

(ii) The Roof Rocks

Apart from the granite which will be described separately, the roof rocks consist of quartzite, leucite and thin bands of cordierite hornfels.



Fig. 8 A xenolith of pseudo-amygdaloidal hornfels in the southern portion of Magnet Heights 846.KS.

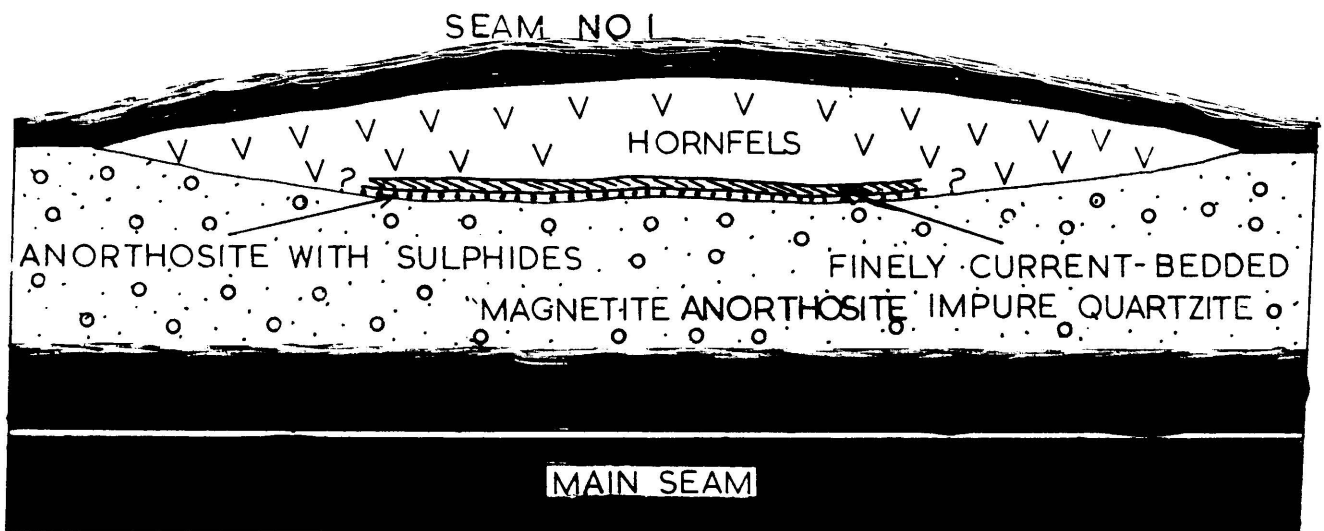


FIG. 9. HORNFELSIC XENOLITH IN THE MAGNET HEIGHTS RIVER. SOUTHERN PORTION OF MAGNET HEIGHTS 846-KS.

SCALE 1:100

In the southern scarp above De Hoop 886.KS a narrow band of leptite intervenes locally between the gabbro and the overlying Main Bushveld granite. On Ironstone 847.KS, Magnet Heights 846.KS and Schoonoord 326.KT, the roof is composed of dislocated blocks of quartzite and leptite.

The leptite in the area is a fine-grained purple-pink or olive-coloured rock. On Ironstone 847. KS it is interbedded with quartzite. Most of the leptite occurs in the vicinity of Sekhukhune where it is associated with coarse white quartzite and a little cordierite hornfels.

The quartzite is the most conspicuous roof rock because of its whiteness and resistance to erosion. The most striking of these features is Signal Hill rising to nearly six thousand feet above sea-level and commanding a wonderful view of a large part of the eastern Bushveld. Here the quartzite is up to four hundred feet thick and rests unconformably on the underlying gabbro (Fig. 11). The rock is white and granular containing some pink and white feldspar, which comprises up to twenty percent of the whole rock. The Signal Hill quartzite forms a basin, the sides of which dip inwards at about twenty degrees. On the southern rim of this basin there is a pronounced joint direction dipping outwards at about seventy degrees. The quartzite does not extend laterally from this basin and northwards is replaced as roof by a diabase sheet which thins out southwards against Signal Hill.

At the north end of the Magnet Heights granite lie shattered slabs of quartzite which are tilted at different angles and overturned in places. Here, as elsewhere, the quartzite shows current bedding and ripple marking. Originally, this quartzite may have been connected with the quartzite of Signal Hill.

North-west of Sekhukhune a large hill of almost vertically orientated quartzite is mainly white, but contains some red and green bands. The quartzite within about ten feet of the gabbro weathers more readily than the same rock further away from the gabbro.

Cordierite hornfels is dark grey, fine grained and shows thin contorted bedding. It is presumably derived from shale and occurs on Schoonoord 326.KT in lenses up to thirty feet thick, between the gabbro and the overlying quartzite.



Fig. 10 Recent deposits completely obscuring rocks on Aapjesboom 324.KC. This view is from the Roof on Broogehoek 882.KC looking towards the Steelpoort bridge.

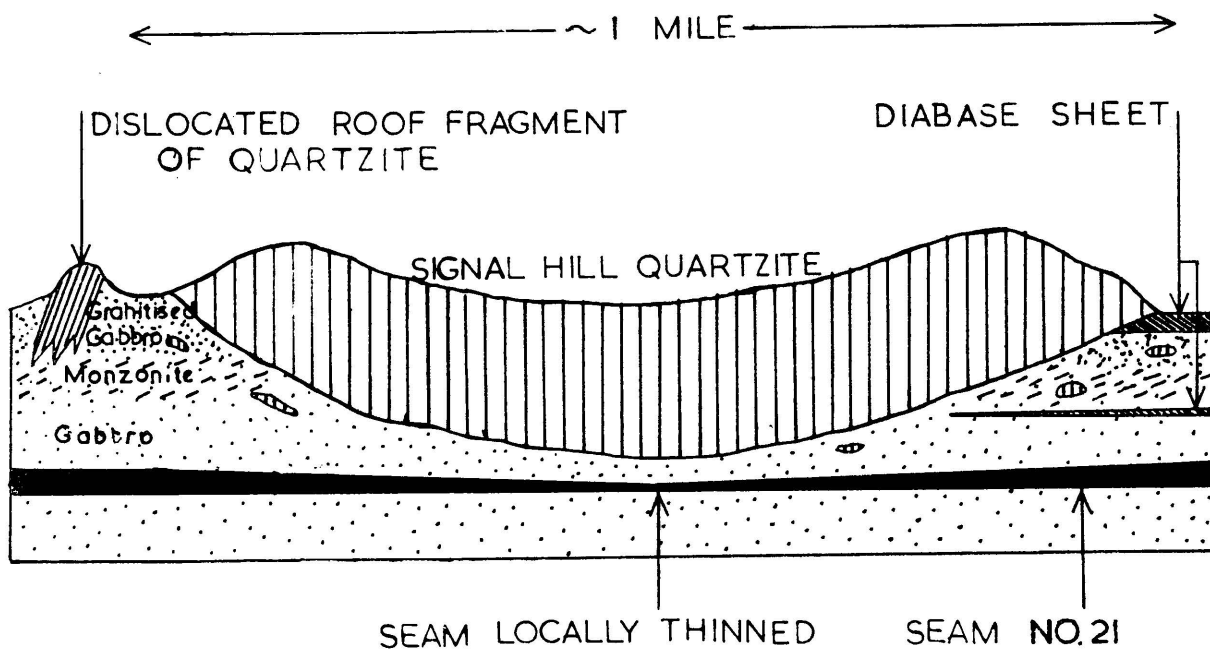


FIG. 11  
NORTH-SOUTH DIAGRAMMATIC SECTION (NOT TO SCALE)  
ACROSS THE SIGNAL HILL QUARTZITE AND UNDERLYING MAFIC ROCKS

(iii) Magnetitite Seams and Plugs

Thirty-one magnetitite seams have been mapped in the area. Four are below the Main Magnetitite seam and these will be numbered one to four lower seams in ascending order of occurrence. The Main Magnetitite Seam will be taken as a datum line and the seams above it will be numbered one to twenty-one, counting from the Main Seam. Certain of these upper seams are composite, as probably is the Main Seam itself. The Seam No. 6 consists of three closely spaced magnetitite seams and Seam Nos. 7, 12 and 14 are composed of two adjacent magnetitite bands. These seams have been considered as a single seam for convenience in field mapping. Gabbroic rocks, other monomineralic rocks, plugs and xenoliths will be located by stating their position in the stratigraphical column relative to the Main Seam and by naming the nearest magnetitite seam.

The magnetitite seams divide into four natural divisions on a basis of their  $V_2O_5$  content and their grouping in the stratigraphical column (Map IV).

Sub-zone D: 0.3% $V_2O_5$	Upper Seam Nos. 16 - 21
Sub-zone C: 0.6% $V_2O_5$	Upper Seam Nos. 2 - 15
Sub-zone B: 1.5% $V_2O_5$	Main Seam & Upper Seam Nos. 1 - 7
Sub-zone A: 2.0% $V_2O_5$	Lower Seam Nos. 1 - 4

Magnetitite seams overlying anorthosite have knife-edge lower contacts (Figs 44 and 49), whereas those above gabbro tend to be transitional at the base. Magnetitite is generally transitional upwards into magnetite anorthosite, but a notable exception is Seam No. 13, which is overlain with a sharp contact by a thick anorthosite, and which grades downwards into gabbro (Fig. 57). Xenolithic lenses of anorthosite, and in a few places of gabbro, up to eighteen inches long and parallel to the tops and bottoms of the seams, are to be found in the magnetitite. The

main field features of the various seams have been incorporated in Table I. (p.55)

About fifteen transgressive magnetitite plugs have been mapped. They are usually monomineralic apart from containing a small percentage of sulphides, but one large plug on Magnet Heights 346.KS, below ~~the~~ Seam No. 8, is composed of a broken ring of magnetitite. The plugs seem to be intrusive into the country rock, into which they rarely have sent small offshoots.

The plugs are transgressive bodies of magnetitite cutting vertically through the gabbro. They are approximately circular or elliptical in plan. One dyke-like body of magnetitite, about three hundred feet long and twenty feet wide, was encountered on Steelpoortdrift 365.KT. The majority of plugs outcrop below the horizon of the Main Magnetitite Seam and the largest plugs occur below the horizon of the lowest magnetitite seam. Due to their superior hardness, plugs generally stand out in the landscape as conspicuous features.

(IV) Anorthosite is generally mottled in appearance, the mottles being poikilitic pyroxene crystals (Fig. 62, Slide 63). Some of the anorthosite is conspicuously banded (Fig. 63), and the thickness of the various layers ranges from six inches to about forty feet. The topmost portions of some of the anorthosite bands (e.g. the one below the Main Seam and that above ~~the~~ Seam No. 15) contain sulphides. The anorthosite bands which have been mapped in the field are those which are leucocratic (Fig. 44) and which contrast with the gabbro. Overlying most of the magnetitite seams ~~is~~ magnetite anorthosite. It is rather dark (Fig. 49) and has not been separately mapped in the field.

On the road, about half-a-mile south of the Magnet Heights Store, is an isolated outcrop of anorthosite which is either an inclusion or a plug, as there is no anorthosite band near or at that particular horizon.

- (V) Pyroxenite. About twenty feet below Seam No. 6 is a melanocratic band composed of about eighty percent pyroxene (orthorhombic in excess of monoclinic) and twenty percent plagioclase. The pyroxene content is sufficiently high to justify calling this rock pyroxenite. A similar rock exists about ten feet above ~~the~~ Seam No. 11. It has a sharp basal contact and grades upwards into gabbro.
- (VI) Gabbro and Troctolite. An estimated 96% of the rock sequence is gabbroic or troctolic. The harder, prominent layers, which form scarps (Fig. 4, Map IV), have been mapped individually. In the field, the two varieties distinguished are merely troctolite and gabbro, which includes also hypersthene gabbro, hyperite and norite. There is a great deal of variation in the texture and composition of the gabbro due to variation in grain-size and relative proportions of the four minerals present which are plagioclase, pyroxene, magnetite and olivine. The layered rocks sometimes show cross bedding (e.g. the troctolite below the Seam No. 15) and this is considered to be due to flow in the partly consolidated magma. The topmost fifty feet of the gabbro has been contaminated by roof material and in two thin sections examined (Nos. 54 and 55) the gabbro has been hybridised. This material seems to be the diorite described by previous workers. Weathered gabbro produces a substantial cover of fertile red soil. Troctolite, because it is relatively unjointed, weathers less readily than gabbro. The individual gabbroic and monomineralic layers, bands and seams will be described in Chapter six.
- (VII) Granite. The granite in hand-sample is pink, coarse-

grained, equigranular and composed mostly of quartz, feldspar and hornblende. It weathers to a yellow-brown rock. There is very little pegmatite in the granite.

The Main Bushveld Granite was mapped only in the south-west of the area on De Hoop 336.KS and Droogehoek 332.KS. It lies above the leptite locally, and elsewhere is directly against the gabbro. The writer believes that the basal part of the granite is fine-grained and that it becomes coarser upwards from the gabbro. No contact of this granite with the leptite was seen in the field and the Roof in this area, as elsewhere, deserves a much closer investigation.

If one reconstructs the profile of the Bushveld Complex, the Main Bushveld granite may originally have overlain the diabase sheets and the Signal Hill quartzite and may even have been in contact with the vertically intruded Magnet Heights granite.

The Magnet Heights granite is identical in appearance to the Main Bushveld granite and its most northerly outcrop is on the farm Magnet Heights 346.KS, after which it was named. Thirteen thousand feet southwards in the vicinity of the Trigonometrical Survey beacon No. 57, it reaches its maximum width of about six thousand feet. A very instructive cross-section of the granite is exposed in the Magnet Heights River. A spotted dyke is intruded along the western contact of the granite (Fig. 13). Contained entirely within the granite is a more or less flat-lying leptite xenolith which is a few hundred feet wide and over a mile long. The Magnet Heights granite is a large dyke which appears to have been mechanically intruded into rigid gabbro.

Near the contact of the Magnet Heights granite, in the Magnet Heights River, are xenoliths about one foot in diameter. These occur only within/about one hundred feet of the margin of the granite, which otherwise

seems uncontaminated. In a few places and then locally, the granite is hornblende-free, medium-grained and leucocratic but these variations are strictly local and there remains the image of a coarse uniform granite.

The Diamond granite underlies the highest point of the road from Magnet Heights to Sekhukhune. It may join the Magnet Heights granite, but it was not observed to do so, as the intervening area is covered with deep sand derived from granite. It is nevertheless considered to be an offshoot dyke of the Magnet Heights granite. It stops about half-a-mile north of the road and about a quarter of a mile to the north-east begins another granite body of the same thickness and extending northwards for about four thousand feet. It is concluded that these two granites belong to the same mass offset by a fault, an assumption which presupposes either that, if it is a normal fault, the granite dyke is not vertical or that alternatively, the fault is a tear fault. Generally, this granite resembles the typical Bushveld granite - and for that matter the Magnet Heights granite - but locally it is very red in colour, fine-grained or graphic. There is a considerable amount of vein quartz along the western contact of the occurrence, which suggests the presence of a fault.

Throughout the area are occasional small granite dykes.

They are not finer-grained than the Main granite and it is remarkable that such small bodies, one foot to three feet wide, are so coarse-grained and without marginal chilling.

A considerable amount of pegmatite outcrops in the gabbro between the Magnet Heights granite and Signal Hill. The pegmatite is composed of quartz and feldspar, and an increasing amount of hornblende towards



Fig. 12 Fine-grained Main Bushveld granite showing pronounced columnar structure and capping the roof escarpment above the gabbro on De Hoop 886.KS.

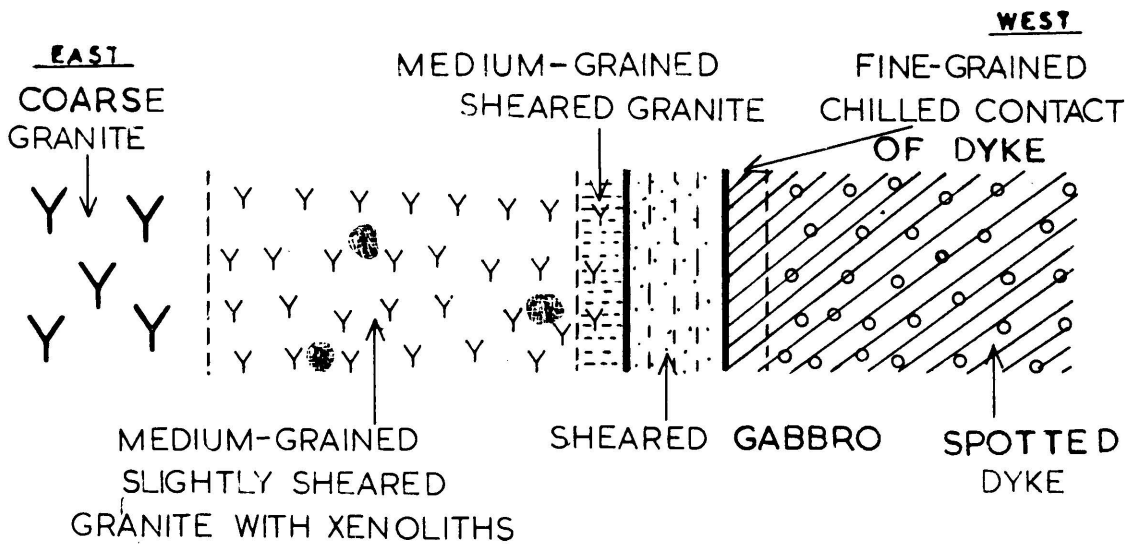


FIG 13. THE WESTERN CONTACT OF THE MAGNET HEIGHTS GRANITE IN THE RIVER ON IRONSTONE SCALE 1:50

the Roof. The pegmatites generally do not trend more than  $45^{\circ}$  from a north-south direction. As there is virtually no pegmatite in the granite and much in the gabbro, the pegmatite is likely to be contemporaneous with or older than the granite. Lombaard (1934, p.8) has suggested that the pegmatite is a residual acid differentiate of the gabbro:

(VIII) Diabase, Dolerite and Other Minor Intrusives

As no laboratory work was done on these rocks, no proper criteria were established to distinguish dolerite and diabase. Consequently, the name diabase is used to designate the mafic sheets up to two hundred feet thick in and near the Roof. Dolerite is the name given to the smaller dykes and sills mapped elsewhere in the area.

North of Signal Hill, a diabase sheet one hundred to two hundred feet thick directly overlies the gabbro. About ten feet of the margin of the sheet is fine-grained, the rest having a medium-grained texture. This sheet thins out southwards against the Signal Hill quartzite (Fig. 11).

Numerous dolerite dykes and sills occur in the gabbro, especially along fault-planes. The dykes generally have a north-south trend and are sometimes amygdaloidal. The thickness of the dykes and sills is indicated on the geological maps.

Detailed work has been done by Strauss & Truter (1950, p.169-193) in the vicinity of the Magnet Heights Store on a suite of minor intrusives related to the Spitzkop Alkaline Series. The information on the map of Strauss & Truter has merely been incorporated in map No. II accompanying this thesis. The writer has not definitely identified any other alkaline rocks in the area though certain dykes of unknown composition were encountered and these are

recorded on the maps as dykes of unknown composition.

(IX) Recent Deposits

Most of the 'Flats' north of the Magnet Heights Store is covered by primary soil a few feet thick, or a thick blanket of turf, calcrete, and transported red sand and soil. Nevertheless, the 'Flats' yields a considerable amount of geological information which can be derived from the observation of float material.

The river draining northwards from Sekhukhune is completely choked with black soil and calcrete. The greatest accumulation of recently deposited material, however, is found on Aapjesboom 884. KS (Fig. 10) where there is more than fifty feet of sand, gravel and boulder beds, calcrete and clay obscuring the underlying rocks on most of the farm. North-west of the Steelpoort River all the magnetitite seams are buried and re-emerge only towards the south on De Hoop 886. KS. The deposit on Aapjesboom 886. KS represents a typical piedmont deposit.

C H A P T E R IV

GEOLOGICAL STRUCTURE

The structure of the Magnet Heights are is more complicated than was assumed by previous workers but is, nevertheless, relatively simple. The layering in the gabbro strikes north-south, with a regional dip to the west, of  $14^{\circ}$ . This figure was decided upon after about a hundred dip readings had been taken. There is both faulting and folding in the area.

(1) Faulting

The throw of the faults ranges from a few feet to more

than five thousand feet. Most of the displacement suggests normal faulting but some horizontal movement may also have operated. The following faults have been identified: -

- (a) The Sekhukhune Fault
- (b) The Steelpoort Fault
- (c) The Magnet Heights Fault System comprising several small faults.

(a) The Sekhukhune Fault borders the western margin of the Lulu mountains and trends southwards in a deep V-shaped valley to join the Steelpoort Fault about two miles north-east of the Steelpoort bridge. The throw of this fault is four thousand ~~feet~~ to seven thousand feet as movement has brought gabbro of the Lulu mountains in the east from below the Main Seam to above the level of Seam No.21 west of the fault (Profile AB, Map IV). This implies a throw of greater than four thousand feet which is the interval between the Main Seam and Seam No. 21. It is the opinion of the writer that the maximum throw of the fault is not more than seven thousand feet, but the throw can only be determined accurately when the stratigraphy of the gabbro of the Lulu mountains is known.

The relationship of the Sekhukhune Fault to the Steelpoort Fault has not been studied nor has been the occurrence of the former, north of Sekhukhune.

(b) The Steelpoort Fault, which is the southern limit of the area mapped, displaces the Main Seam a distance of five and a half miles, with the down-thrown side to the north-west. If it is a normal fault, the throw is about five thousand feet. The Steelpoort Fault is an oblique fault, trending at about  $25^{\circ}$  to the strike of the gabbro. More work would have to be done along the length of the fault to determine if there is lateral movement. The fault is exposed where it crosses the Steel-

poort River on the boundary between De Hoop 886.KS and Aapjesboom 884.KS. A wide dolerite dyke has been intruded along the fault zone.

- (c) The Magnet Heights Fault System. The most obvious member of this group of faults is that followed by the Magnet Heights River on Magnet Heights 846. KS. Southwards this fault becomes oblique to the strike of the gabbro cutting off, in turn, the Main Seam and Upper Seam Nos.1 - 7. East of the river are two smaller strike faults with throws of fifty to one hundred feet, (Profile CD and Fig. 14). The fault passing through the Chief's Kraal on Magnet Heights 846.KS has a throw increasing from about three hundred feet at the Kraal to about 2,000 feet in the north-west corner of ~~the~~ Schoonoord 326.KT (Profile AB). In the north this fault either swings to the north-east, as drawn on the map, or continues northwards and is met by another fault with a north-east trend. The structure in the north of the area will become clear when mapping is continued in that direction. There are less important oblique faults on Magnet Heights 846.KS and these are shown on the map. There is no evidence of faulting between the road on Magnet Heights 846. KS and Signal Hill.

An oblique fault, which dislocates the Diamond Granite, is inferred on Magnet Heights 846.KS and Schoonoord 326.KT.

On Ironstone 847.KS and Steelpoortdrift 365.KT sections constructed from the map strongly suggest the existence of a fault with a downthrow to the north-west about eight hundred feet on the line of the Magnet Heights granite (Fig. 14). The gabbro hill just south of Sekhukhune may be a wedge between the intersection of this fault and the Sekhukhune Fault. If this Magnet Heights granite fault continues to the south-west, it has

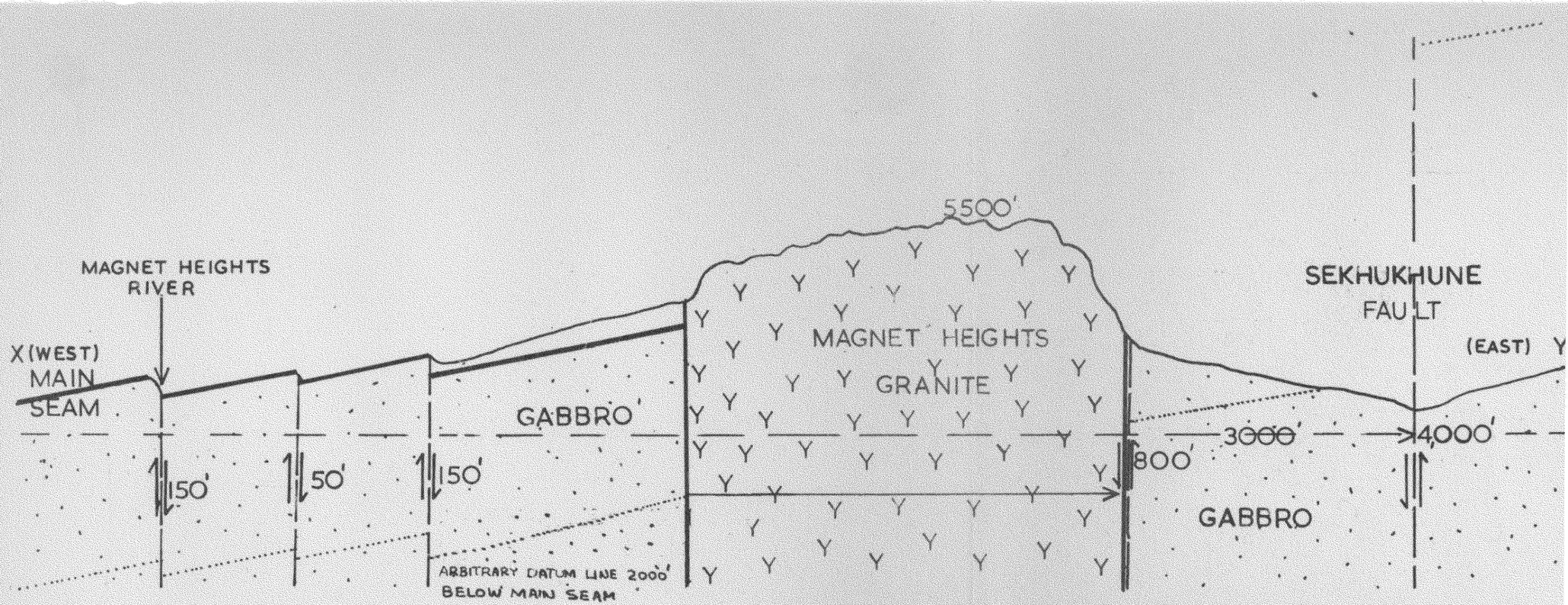


FIG 14. PROFILE ALONG X-Y ON THE REGIONAL MAP INDICATING THE RELATIVE MOVEMENTS OF THE VARIOUS FAULTS



Fig. 15 Minor fault dislocating Upper Seam No. 1 in the Magnet Heights River near the boundary between Magnet Heights 846. KS and Ironstone 847. KS.

a small throw as there is no observable disturbance of the rock succession on De Hoop 306. KS.

South of the Magnet Heights granite and trending north-south are at least ten small faults with throws from a few feet to about one hundred feet. In the Magnet Heights River, where it cuts through the Main Seam outcrop on Steelpoortdrift 365. XT, there is a zone of minor faults, with a north-south strike. The trends of the faults south of the Magnet Heights granite were inferred from examination of the drainage pattern, observed fault directions in the Magnet Heights River, displacement of markers and study of the aerial photographs.

A number of small faults such as the one photographed (Fig. 15), are to be seen in the area. The profile in Fig. 14 might be interpreted as demonstrating ~~and~~ type of graben structure, though the down-faulting in the west is very slight compared to that in the east.

## (2) Folding

Folding is known in the Bushveld Complex, but has not previously been recorded in this area. The absence of the Main Seam on the 'Flats' north of Magnet Heights was tacitly explained by assuming that it is buried beneath soil, and the metamorphic rocks west of Sekhukhune, which are in actual fact roof rocks, were assumed to be xenoliths in the gabbro below the Main Seam, or in the Magnet Heights granite. Evidence of the existence of an anticlinal fold is: -

- (a) Seam No. 6 dips at  $10^{\circ}$  eastwards in the river south of the Chief's Kraal on Magnet Heights 346. KS.
- (b) Seam No. 21 dips east at  $10^{\circ}$  to  $15^{\circ}$  near the north end of the Magnet Heights granite, a fact confirmed by pitting.
- (c) Twenty-four magnetometer traverses across the 'Flats' suggest that the Main Seam is not buried under soil.

- (d) In the north of the area on Goedgemeende 815.XS, Seam No. 21 dips to the east at  $10^{\circ}$  to  $15^{\circ}$ .
- (e) Roof rocks west of Sekhukhune dip eastwards at about  $10^{\circ}$

As the Magnet Heights granite cuts obliquely across the strike of the layering in the gabbro, each of the upper seams must terminate in turn against the granite, but northwards, from the outcrop of Seam No. 6 near the Chief's Kraal, there is no exposure and the next seams visible are Seams No. 17 and 21 near the north end of the granite. Where exposures are poor, it is possible to determine the dip direction of Seam No. 21 by noting on which side of the outcrop of the Seam No. 17 and the spotted gabbro are to be found.

The reason why the Main Seam does not outcrop on the 'Flats' is now clear: - it is folded back down in the core of a faulted anticline before reaching the surface (Profile AB). As the fold axis, striking at about  $165^{\circ}$ , is oblique to the strike ( $002^{\circ}$ ) of the layering in the gabbro, the Main Seam will ultimately reappear, as it does in fact on Malek's Kraal, about twenty miles to the north.

North of Sekhukhune Seam No. 21 outcrops twice. This may be due to the presence of a strike fault or of a small syncline (Fig. 16).

There is a small pitching syncline shown on Map III in the south of Magnet Heights 846. XS. The fold axis is east - west and it pitches with the regional dip to the west.

C H A P T E R V

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MINERALOGY

(1) GENERAL

In the field <sup>a</sup> careful search was made to obtain the freshest magnetitite available. Thirty-five polished sections were prepared of magnetitite and fifty thin sections cut of feldspathetic magnetitite, anorthosite, pyroxenite, troctolite and gabbroic rocks.

The polished sections were examined under reflected light using magnifications from X100 to X2000. Where possible, statistical counts were made to determine the mineral percentages in the slides and polished sections. The figures which appear in Tables III and V were extrapolated from about five separate counts made on different portions of the sections. It was not possible to determine microscopically the percentage of large ilmenite grains in the ore, as the magnification of the ore microscope is too large. Consequently, slabs were polished, etched with HF vapour or heat-treated (acetylene torch), and the percentage of ilmenite present was calculated.

In sampling the silicate rocks, there was a definite tendency to take specimens of the harder bands. Work carried out on the silicate rocks was confined to observation of textures and calculation of the relative percentages present of the various silicate and ore minerals. The fabric of the rock sections was examined in an attempt to determine the order of crystallisation, mindful of the remark by Turner & Veerhoogen (1960, p. 62): -

"Most petrographers to some extent interpret the criteria of idiomorphism and grain size to suit personal prejudices as to the sequence of crystallisation."

Plagioclase is the main constituent of the silicate rocks and usually comprises 60% to 70% of the rocks examined. It generally forms subhedral laths about five to ten millimetres long. There is also fine plagioclase in the groundmass of the rocks.

Plagioclase is also the predominant silicate contained in the magnetitite. In seams with transitional upper margins the magnetite <sup>decreases</sup> with a corresponding increase in feldspar content but without any change in the amounts present of other minerals. Even in the purest magnetitite of the Main Seam there are occasional trapped feldspar crystals. Above the Main Seam the rock contains 85% of feldspar and 10% of magnetite but only 5% of other minerals (Slide 41).

The plagioclase content at a particular horizon in a seam is constant.

Magnetite is present in all the rocks examined and generally constitutes about 4% of the gabbros. As mentioned previously, magnetite and plagioclase are intimately associated in magnetitite. The Main Seam grades upwards from magnetitite through feldspathic magnetitite into magnetite anorthosite. In Seam No. 6, which has a transitional basal contact over a distance of one inch, the number and size of the magnetite crystals increase upwards until the rock is predominantly magnetitite (Fig. 19, Slide 15).

Pyroxene is the commonest ferro-magnesian mineral in the silicate rocks. Orthopyroxene is generally less abundant than clinopyroxene. Only one rock, 150 feet above the Main Seam, was identified as norite (Slide 48).

The seams rarely contain much pyroxene. Seam Nos. 6, 7 and 11, however, each contain about 5% of late crystallising and accordingly interstitial but discrete grains of pyroxene. The silicate clusters in the Main Seam are poikilitic orthopyroxene crystals, enclosing magnetite (Fig. 51, Slide 5). This is an interesting parallel to the mottled anorthosite in which each mottle is usually a poikilitic pyroxene crystal enclosing plagioclase laths (Fig. 68). Seam No. 13 contains poikilitic pyroxene crystals incorporating small idiomorphic magnetite crystals about one millimetre in size (Fig. 61).

Olivine in places partially or completely takes the place of pyroxene as the ferro-magnesian constituent of the rocks. There is a part of the column extending for about 1,200 feet above the Main Seam, in which very little olivine was observed. Six slides examined from this part of the column contained no olivine, though there is a little in Upper Seam No. 4.

A chain of subhedral olivine crystals occurs one millimetre above the base of the Main Seam (Fig. 5C, Slide 3). Olivine only becomes an important constituent of the magnetite in Seam Nos. 9 to 12. Its presence in the seams of sub-zone C correspond with the occurrence also in sub-zone C of prominent troctolite sheets (Map IV).

Biotite appears about one hundred feet below the Main Seam and was not recorded below this point in the sequence. Apart from small idiomorphic crystals in magnetite and plagioclase, the biotite occurs in larger blades, which often protrude into these two minerals. It constitutes 1% to 2% of most of the slides but in one rock (gabbro 4,200 feet, Slide 52) near the Roof, biotite forms 4% of the gabbro. Biotite is present in all the seams above and including the Main Seam.

A striking change in appearance in the biotite occurs approximately 1,500 feet above the Main Seam. Below this point it is pale brown and weakly pleochroic while, higher up, it becomes increasingly dark and pleochroic. Towards the Roof, the crystals become larger. Biotite is concentrated at the basal contacts of some of the seams (e.g. Seam No. 11).

Apatite occurs only within two thousand feet of the Roof. It is always idiomorphic and originally was thought by the author to have crystallised early (Fig. 74). However, according to Turner & Verhoogen (1960, p. 63) :

"Idiomorphism seems, too, a doubtful criterion of early crystallisation in the case of certain consistently idiomorphic accessories such as apatite which, from their content of "volatile" components ( $P_2O_5$ , OH, Cl) are unlikely to have crystallised before the main crop of anhydrous silicates. Originally, by replacement, is more likely here.

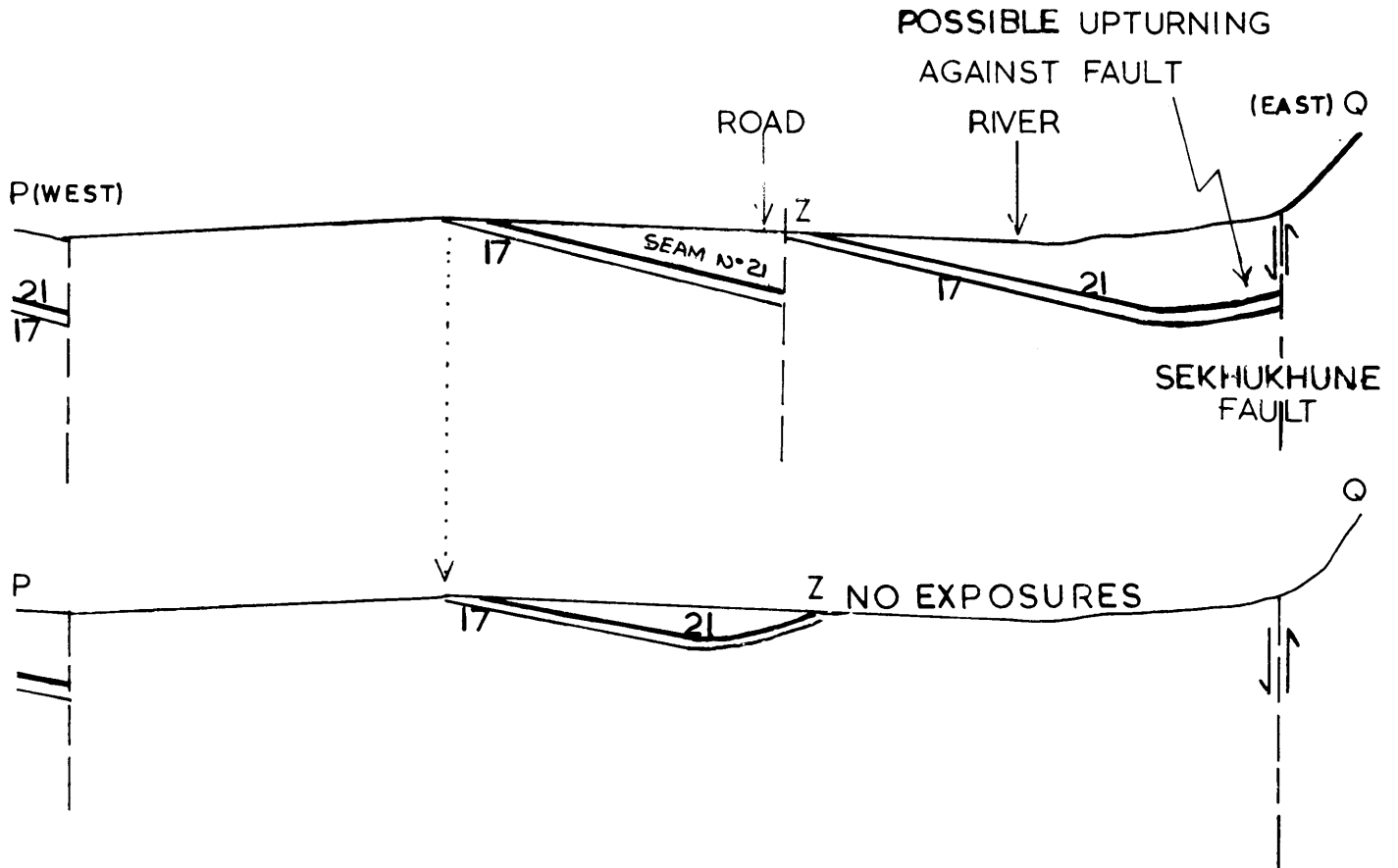
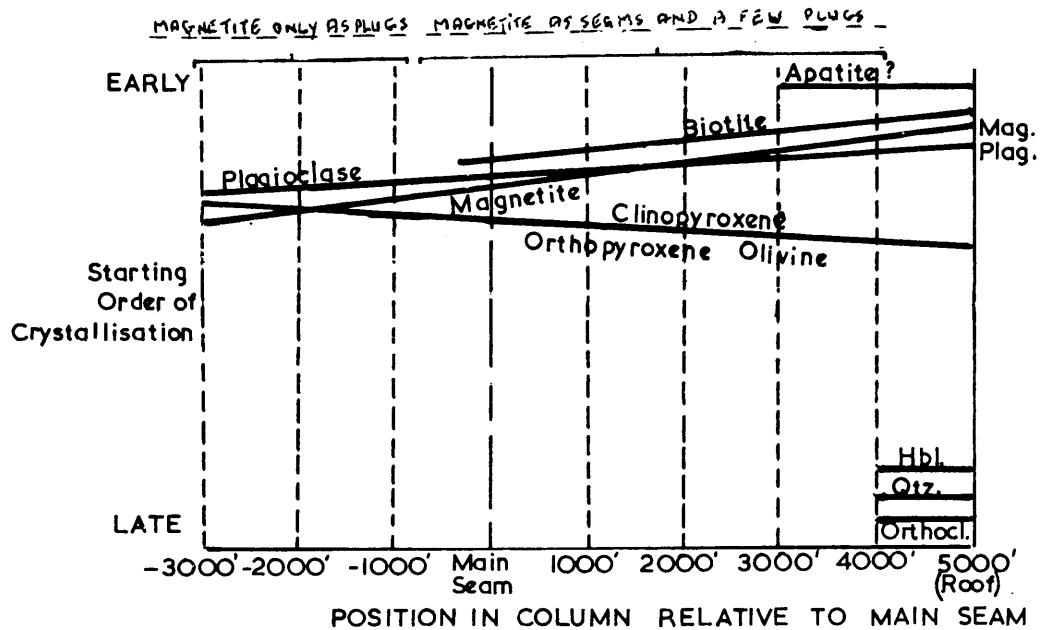


FIG 16. TWO POSSIBLE INTERPRETATIONS OF THE OUTCROP OF SEAM NUMBER 21 AT Z ON MAP NO 1.

FIG 17 ORDER OF CRYSTALLISATION OF THE MINERALS AT DIFFERENT ELEVATIONS IN THE GEOLOGICAL COLUMN



Hornblende appears as a primary mineral only within about eight hundred feet of the Roof. Granitised rocks near the Roof contain abundant hornblende. Hornblende is virtually absent in the seams.

Quartz occurs only very near the Roof in clear irregular grains in the rock. It is considered to have been introduced during the process of granitisation.

Orthoclase Feldspar accompanies quartz near the Roof and ~~is~~ <sup>could</sup> ~~thought to~~ have been formed by granitisation of the gabbro.

## (2) TEXTURES AND ORDER OF CRYSTALLISATION

Plagioclase, in few places, contains inclusion of biotite, magnetite and apatite. It occurs as subhedral laths and generally crystallised early. There is one case in which feldspar did not crystallise as early as pyroxene and that is in the pyroxenite about four hundred feet above the Main Seam where plagioclase encloses early-crystallised pyroxene crystals. The anorthosites contain about 95% plagioclase, about 80% of which occurs in large laths and the rest consists of small interstitial crystals (Fig. 66).

In the magnetite seams plagioclase crystals are two to five millimetres in length. In seams lower in the sequence, the laths tend to be idiomorphic but higher in the column, are generally subhedral.

The impression obtained from examination of all the seams is that feldspar was one of the first minerals to crystallise in the magma.

Magnetite includes small idiomorphic biotite crystals throughout the sequence (Fig. 23) and apatite towards the top of the column (Fig. 75). In the hyperite xenolith in Seam No. 11, magnetite includes small plagioclase crystals. In the gabbroic rocks large magnetite crystals appear to be interstitial, but smaller crystals tend to be idiomorphic, being occasionally included in plagioclase and frequently in pyroxene and olivine.



Fig. 18 Magnetite (white) lying interstitially between plagioclase laths (black). A little pyroxene (grey) has partly replaced magnetite and anorthosite. Magnetite anorthosite above Upper Seam No.1. Slide 42. Negative photograph, X 7.

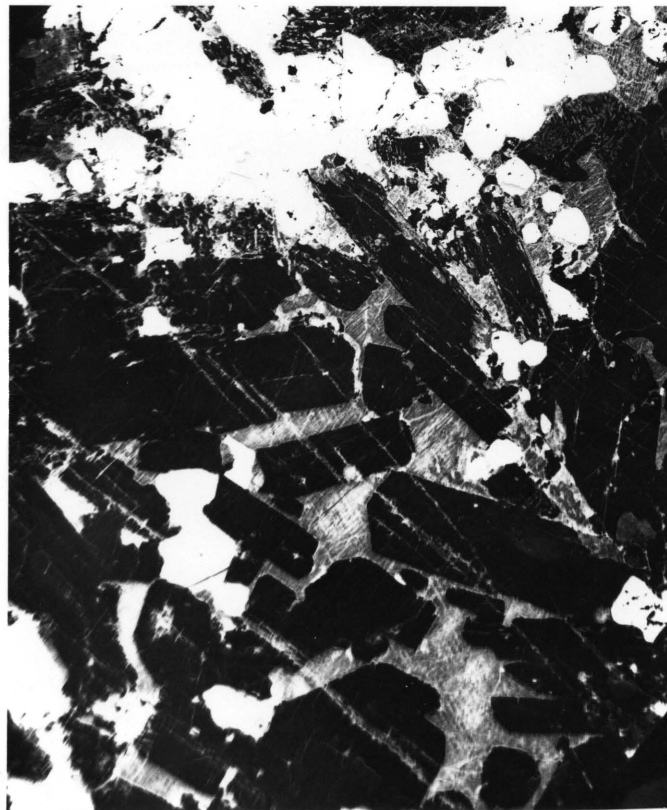


Fig. 19 Euhedral magnetite (white) and plagioclase (black) are included in pyroxene (grey). The seam develops upwards with progressive increase in the concentration of magnetite crystals. Base of middle unit of Seam No. 6. Slide 15. Negative photograph, X 7.

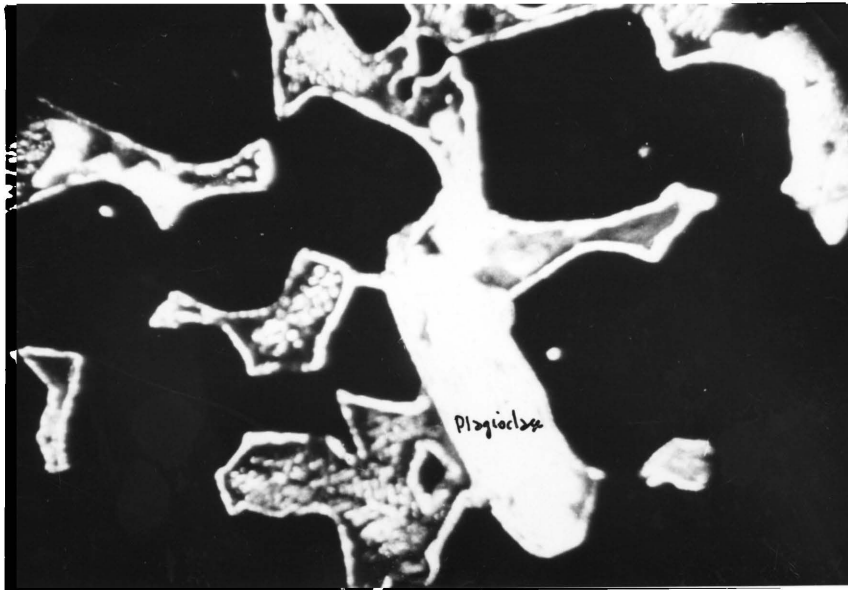


Fig. 20 Idiomorphic magnetite crystals (black) included in poikilitic orthopyroxene (cross-hatched). Plagioclase in the photograph is subhedral. Upper Seam No. 7. Slide 18. Crossed Nicols, X7.



Fig. 21 Plagioclase laths (black) enclosed in magnetite (white). A little interstitial biotite and the orthopyroxene rim occurring between plagioclase and magnetite, is grey. Top of Seam No. 11. Slide 23. Negative photograph X 5.

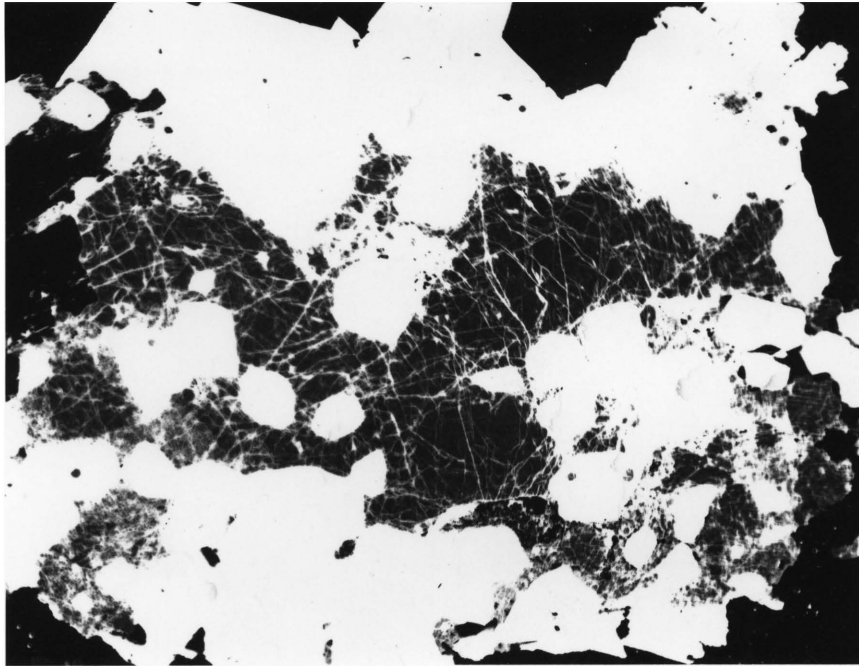


Fig. 22 Euhedral magnetite crystals (white) included in poikilitic olivine (black). Lower unit of Seam No. 12. Slide 24. Negative photograph, X 7.

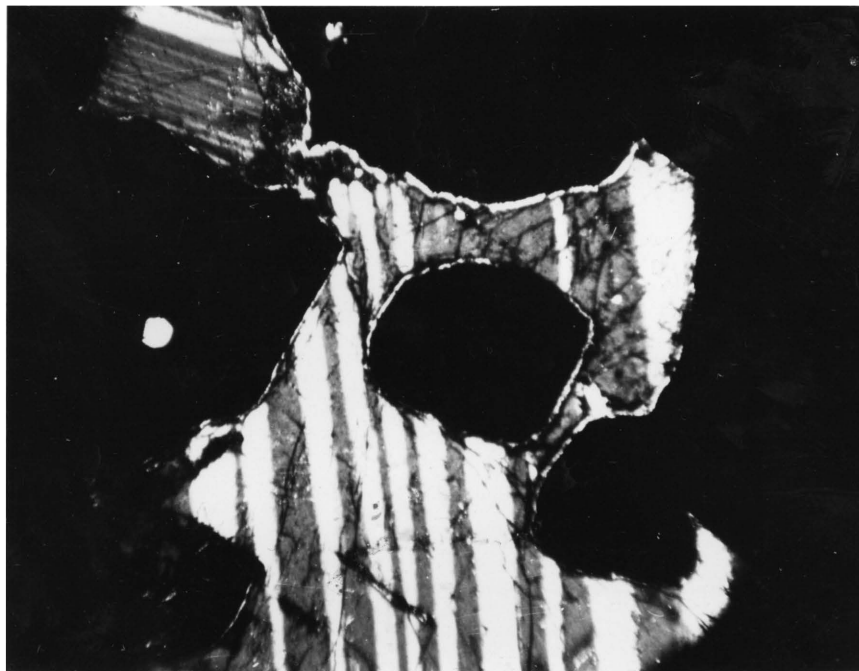


Fig. 23 Subhedral magnetite crystals included in plagioclase. The small white crystal in the magnetite is biotite. The white rim between magnetite and plagioclase is orthopyroxene. Lower unit of Seam No. 12. Slide 24. Crossed nicols, X 30.

In the magnetite orthosite (Fig. 18) the magnetite appears to be interstitial to the plagioclase but there are some contradictory occurrences of subhedral or euhedral magnetite crystals enclosed in plagioclase laths. There is much evidence that magnetite had a long period of crystallisation. Locally, curved interfaces between magnetite and feldspar crystals probably indicate simultaneous crystallisation of these two minerals (Wells, 1952<sup>pp 13-14</sup>). The impression obtained from examining all the thin sections is that plagioclase and magnetite began to crystallise before pyroxene and olivine. Only in the later stages of their development did growing plagioclase and magnetite interfere with each other. Upwards in the sequence the growing magnetite crystals interfere increasingly with the crystallisation of the plagioclase laths (e.g. compare Fig. 21 and Fig. 27) though in the hyperite xenolith (Slide 22) in Seam No. 11, magnetite includes plagioclase. Within the poikilitic orthopyroxene crystals in the Main Seam, the magnetite has poor crystal form (Fig. 51, Slide 5) and is interpreted as having grown simultaneously with the poikilitic pyroxene crystals in which it is enveloped. It is possible that the pyroxene has partially replaced the magnetite. In all the seams magnetite crystallised before pyroxene and olivine but magnetite continued to crystallise for a long period, overlapping both these minerals and occasionally forming an intergrowth with them.

Pyroxene Some sections show magnetite and feldspar crystals enclosed in later pyroxene (Figs. 19 and 20). However, in the pyroxene above the Main Seam (Slide 45) pyroxene crystallised early.

Olivine crystallised simultaneously with plagioclase in the troctolites (Fig. 72, Slides 40, 46, and 50) but when present in minor quantities in a rock, it appears to have crystallised late.

Apatite is always idiomorphic but, as mentioned, this idiomorphism may not be a result of early crystallisation.

Some Biotite crystallised early, <sup>and</sup> ~~as~~ is included in magnetite and occasionally in plagioclase. Most of it, however, crystallised interstitially as subhedral blades which frequently penetrate magnetite and feldspar crystals.

The generalised order in which the various minerals started to crystallise is: - (a) plagioclase, (b) magnetite, biotite, apatite?, (c) pyroxene and olivine, (d) hornblende . The order in which minerals started to crystallise at different levels in the column is shown in Fig. 17.

(3) Exsolution other than in magnetite, replacement and intergrowth phenomena

A rim often occurs between plagioclase and magnetite (Figs. 20 and 23) and in most cases this rim is thought to be orthopyroxene. Discrete magnetite crystals in silicates are attacked by the silicates and are often partially destroyed (Figs. 58 and 59). Biotite, in places, is locally replaced by hornblende. Olivine and pyroxene are separately intergrown with magnetite (Figs. 24 and 25). This is partly due to replacement but it is the opinion of the writer that this intergrowth may signify a eutectic crystallisation. Residual pyroxene frequently has partially replaced plagioclase and biotite. Some replacement of magnetite in the seams by pyroxene did take place, but it is considered to have been of minor importance.

Orthopyroxene has usually exsolved clinopyroxene (Fig. 70, Slide 22) and the reverse also occurs but is less common. Near the Roof clinopyroxene has sometimes exsolved magnetite (Fig. 76). Also near the roof, hornblende has replaced pyroxene in fresh rock and is concluded to be a late magmatic mineral (Fig. 75). It forms a periphery round and locally has completely replaced pyroxene and possibly biotite. Quartz and orthoclase near the Roof are thought to have been introduced into the rock by the process of granitisation.

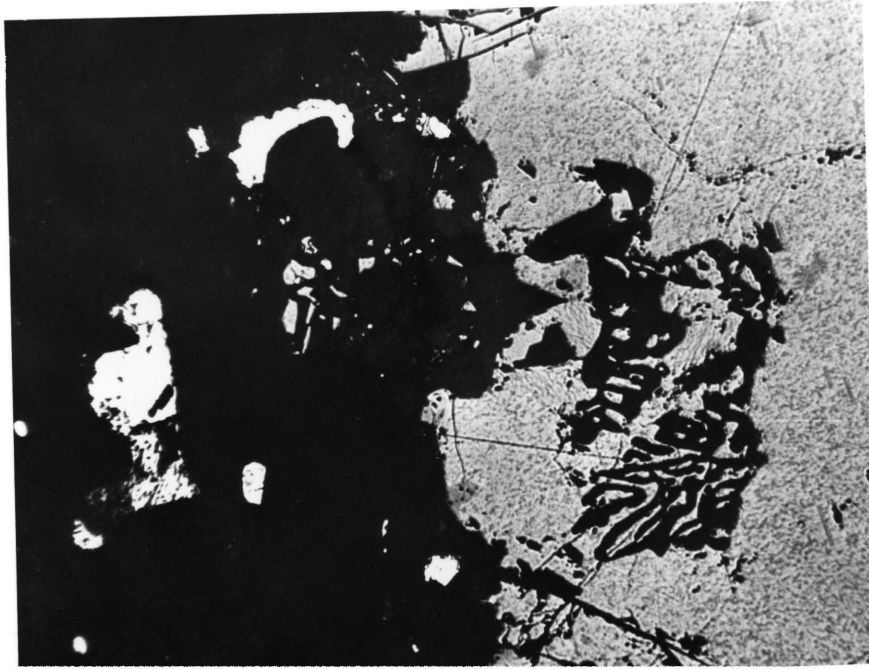


Fig. 24 Intergrowth of magnetite (grey) and gangue mineral (black) considered to be olivine. The white minerals are sulphides in plagioclase. Lower Seam No. 3. Section 2. Oil immersion, X 100.



Fig. 25 Intergrowth of pyroxene (black) and magnetite (white). Middle unit of Seam No. 6. Section 15. Oil immersion, X 100.

(4) Mineralogy of the Magnetitite

The following minerals were distinguished: -

- (i) Magnetite
- (ii) Ilmenite
- (iii) Ulvite
- (iv) Spinel (Hercynite or Pleonaste near to  $FeAl_2O_4$  in composition)
- (v) Martite
- (iv) Maghemite
- (vii) Sulphides

(i) Magnetite. Discrete idiomorphic crystals are one to two millimetres in size (Specimen 26) and in coarse-grained magnetitite grains as big as ten millimetres (Fig. 47, Specimen 5). These large crystals are tightly interlocking with a very thin irregular pyroxene, olivine or spinel film separating the grains. The Main Seam is composed of closely interlocking crystals whereas the uppermost seams are more friable being made up of smaller, less tightly bound crystals. These latter seams consequently weather more easily.

Magnetite crystals enveloped in gangue in the xenolith in Seam No. 11 (Fig. 56) in the underlying anorthosite have been corroded leaving only a skeletal structure of ilmenite (Figs. 53 and 59). This is thought to be due to magmatic action rather than to weathering, and the replacing mineral is probably pyroxene.

Vein and fissure fillings of uniform magnetite, occurring in weathered rock (Fig. 42), are considered to be secondary because of their interstitial position. This is not the same conclusion as that of van Rensburg (1962, p 62/63, Photo II,) who considers this type of magnetite to be an unaltered primary type.

Magnetite weathers to <sup>maghemite</sup> ~~martite~~ (Fig. 43) and, to a small extent, to <sup>martite</sup> ~~ilmenite~~.

(ii) Ilmenite is present in all the polished sections. It

occurs in the following forms: -

- (a) Discrete ilmenite grains up to 5 mm. long (Figs. 26 and 27)
- (b) Large lamellae .01 mm. thick (Fig. 32)
- (c) Small lamellae .005 mm. thick (Figs. 34 and 35)
- (d) Very fine anhedral ilmenite grains

(a) Discrete ilmenite grains are subhedral or anhedral.

They grow to a considerable size (Fig. 27) and are often twinned. Ilmenite crystals lie between magnetite crystals and often are adjacent to gangue, which may be present. Where a grain of ilmenite is in contact with gangue and magnetite it tends to be anhedral against the former and subhedral against the latter (Section 41 and 42). This may be due to partial replacement of the ilmenite by gangue. There is slender evidence that coarse ilmenite grains are later than the magnetite as they, very occasionally, include magnetite grains (Basal unit of Seam No. 12, Section 24) and plagioclase and chalcopyrite (middle unit of Seam No. 6, Section 15). In the section of Seam No. 11, a euhedral spinel crystal is enclosed in a large ilmenite grain. Constituents of spinel have migrated from the surrounding magnetite into the periphery of ilmenite crystals (Fig. 35). Ilmenite crystals have exsolved magnetite lamellae (Fig. 28) and these lamellae were seen with only one trend in each ilmenite crystal. This magnetite, which is younger than the ilmenite twinning, is partly altered and is interrupted by sheets of spinel (Fig. 29).

- (b) Large ilmenite lamellae (Fig. 32) occur locally in some of the fresh magnetite and in none of these seams are these large lamellae uniformly distributed. They contain spinel blebs in their margins. It is possible that these large lamellae are capable of segregating out of the magnetite, leaving the spinel they contained, behind in the magnetite, as irregular lamellae. This would explain the occurrence of irregular spinel lamellae orientated parallel to the (III) plane of the magnetite. (Fig. 39). According to Edwards (1954, p.77) during slow cooling, ilmenite lamellae may diffuse out of the magnetite to form interstitial grains.

- (c) Small ilmenite lamellae occur in the lowest one foot of the Main Seam and in the plug below Seam No.11. They lie in the (III) plane of the magnetite (Figs. 31, 34 and 35) and they appear to be truncated and sometimes offset by plates of spinel, which are inferred to be younger.

These small lamellae show maximum extinction in the  $45^{\circ}$  position under polarised light. According to Ramdohr (1953, p.82) ilmenite, which forms through the oxidation of ulvite, has oblique extinction whereas primary exsolved ilmenite has straight extinction. Therefore, according to Ramdohr, this fine ilmenite was produced by oxidation of ulvite. Evidence possibly corroborating this hypothesis is the fact that this fine ilmenite and ulvite are antipathetic. Nevertheless, it is the writer's opinion that they may have exsolved directly from the magnetite, because the lamellae, though small, are well developed and evenly distributed throughout the magnetite grains.

- (d) Fine irregular ilmenite. In all the magnetite examined fine-grained ilmenite, which is antipathetic to ulvite, occurs in and near fissures. Locally lamellae have begun to develop (Fig. 33). This ilmenite is thought by the writer to have possibly been produced by oxidation of ulvite, as it occurs only in the vicinity of fissures, which would have permitted the increase of oxidising agents.

- (3) Ulvite has been exsolved on the (100) plane of the magnetite (Figs. 36 and 37). The resulting texture has been referred to as 'cloth-texture' by Vincent & Phillips (1954, p. 4). The exsolved ulvite constitutes about one third of the area of the magnetite crystals in most of the polished sections. Exceptionally, there is no ulvite in the rock, its place being taken by fine ilmenite lamellae. The size of the ulvite compartments

/ 4. ....

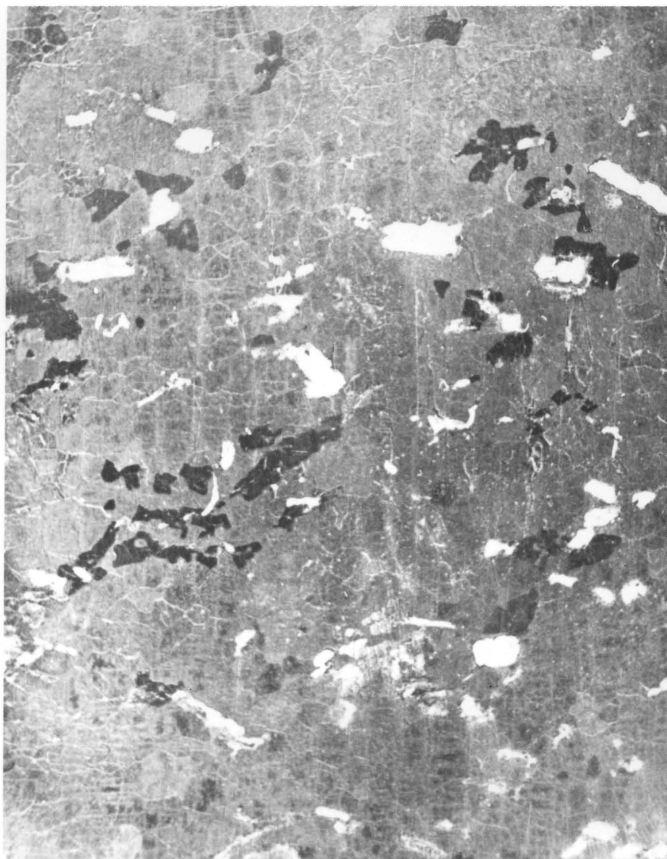


Fig. 26 Fabric of feldspathic magnetite composed of plagioclase (white), ilmenite (black) and magnetite (grey). Upper Seam No 4, Section 14. Polished slab, etched with HF vapour, X24.

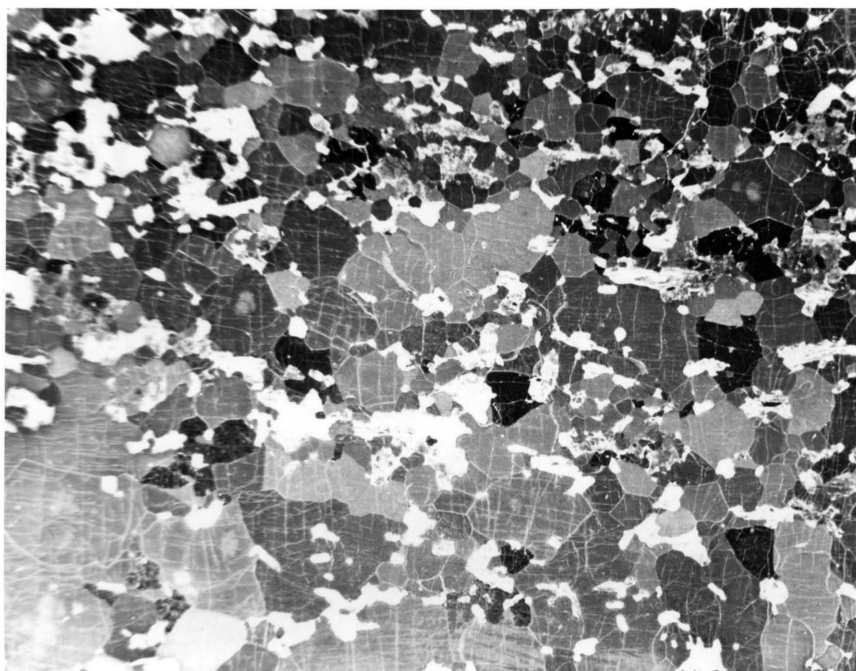


Fig. 27 Textural relationship of silicates, plagioclase and olivine (white), magnetite (various shades of grey) and ilmenite (black). Upper unit of Seam No 12, Section 25, polished slab, etched with HF vapour, X 3.

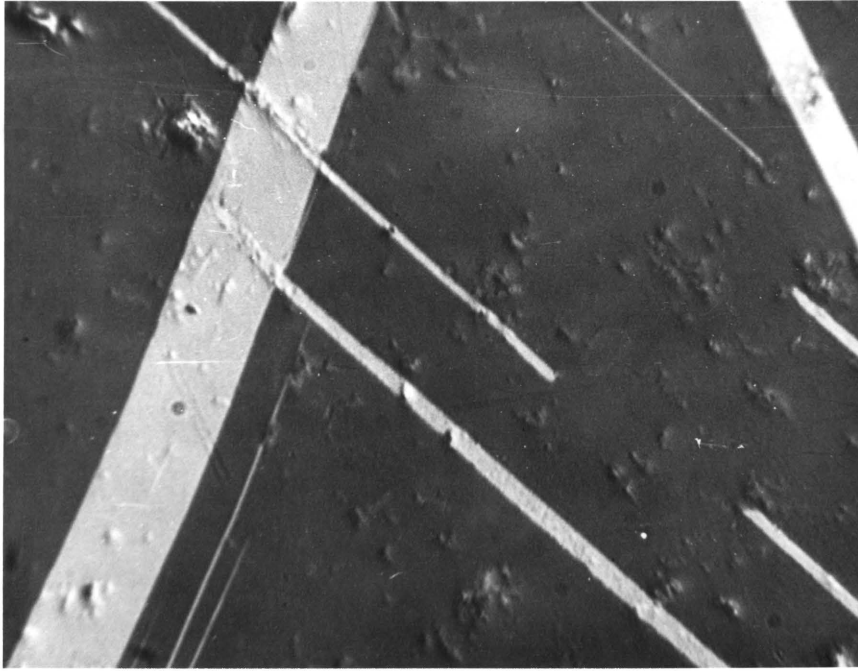


Fig. 28 Large twinned ilmenite grain. Exsolved lamellae of magnetite (narrow and white) in twinned ilmenite (light and dark). The lamellae are inferred to be later than the twinning of the ilmenite. Upper unit of Seam No. 12, Section 25. <sup>Partly obscured</sup> Crossed Nicols, X 360.



Fig. 29 Spinel (black), occupying part of the plane of a magnetite lamella (white) exsolved by ilmenite (grey). Upper Seam No. 2, Section 11, Cil immersion, X 500.

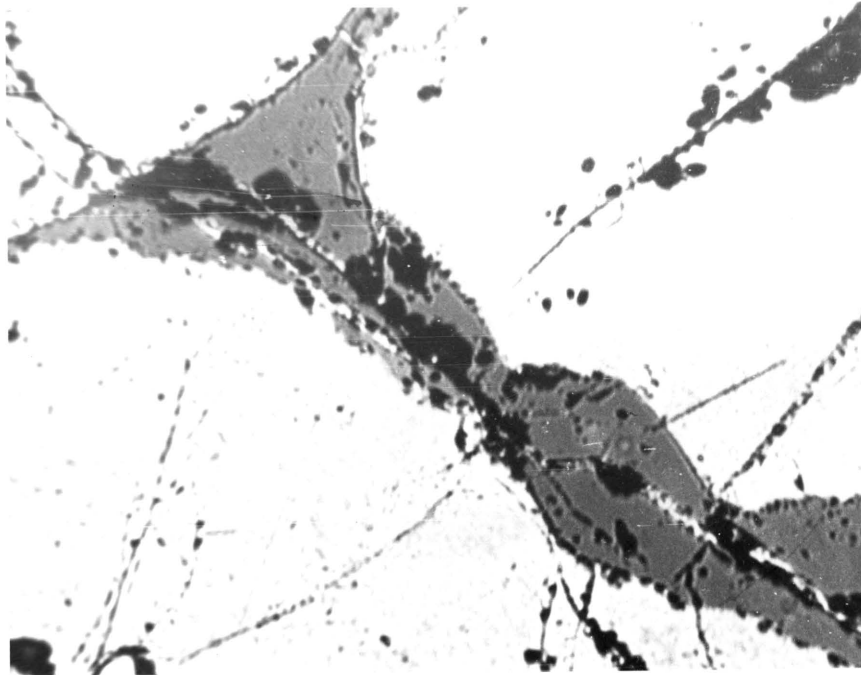


Fig. 30 Interstitial ilmenite (dark) between magnetite grains (pale). Lower unit of Seam No. 12, Section 24. Oil immersion. X 100.

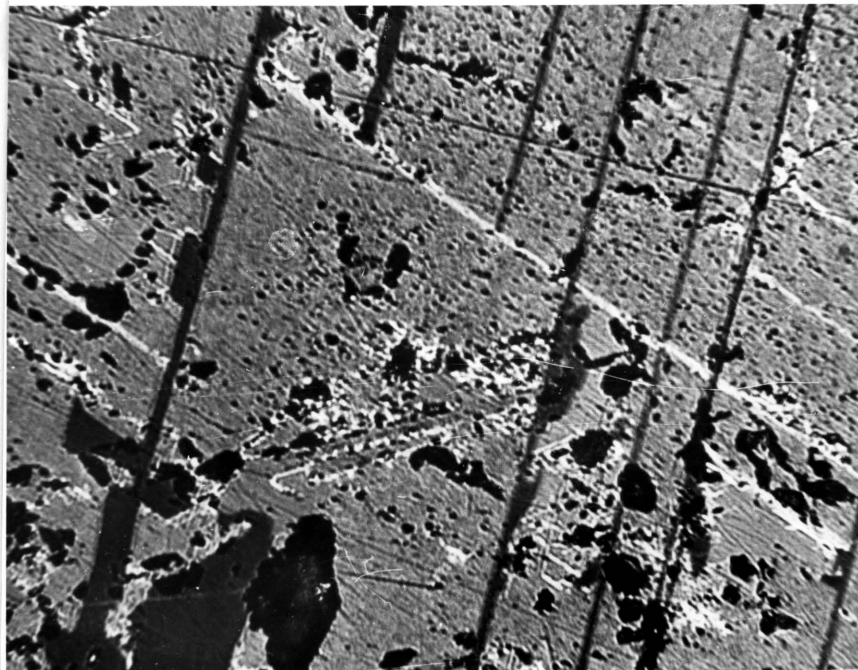


Fig. 31 Slightly irregular ilmenite lamellae (dark and light), exhibiting oblique extinction, in magnetite (grey). Plug below Seam No. 11 on Magnet Heights 846. KS. Section 34, Crossed Nicols, X 100.

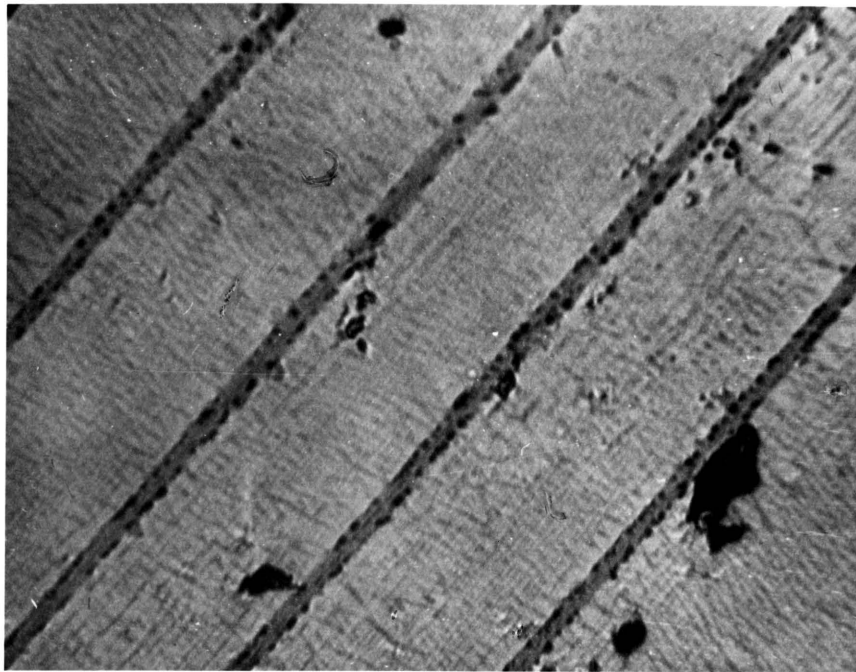


Fig. 32 Primary ilmenite lamellae (dark grey) containing specks of spinel (black) in magnetite (grey). The darker network in the magnetite is ulvite, which is evenly distributed. Lower Unit of Seam No. 12, Section 24, Oil immersion, X 200.

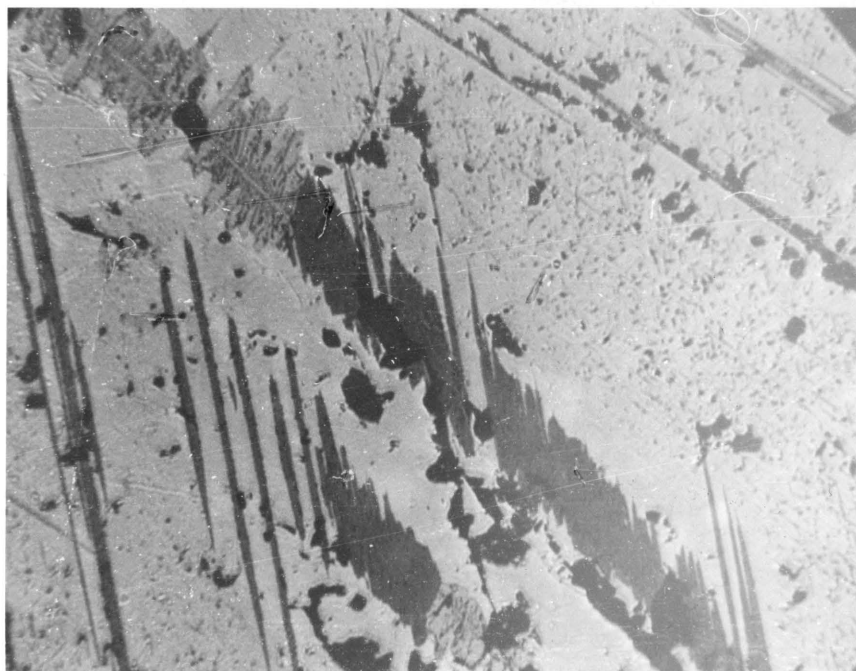


Fig. 33 Ilmenite produced by oxidation of, or exsolved instead of, ulvite which is absent in the vicinity of the ilmenite. Basal unit of the Main Seam. Section 5. X 100.

is about .005 mm.

- (4) Spinel has ~~been~~ <sup>from</sup> exsolved ~~by~~ magnetite as plates. Ramdohr (1953, p. 58) has described spinel from Magnet Heights as pleonaste. These plates have a length twenty to thirty times their width and range from 0.01 to 0.1 mm. in length. Constituents of spinel have migrated from magnetite, near ilmenite, into the margin of the ilmenite (Fig. 35). Plates have also segregated into discrete grains in some of the magnetite. This process can be observed in various stages of completion (Fig. 38) and sometimes the grains contain a core of chalcopyrite (Fig. 39).

Irregular spinel lamellae lie in the (111) plane of the magnetite (Fig. 39, parallel to ilmenite lamellae, and it is considered that the spinel may originally have migrated into ilmenite lamellae which, in turn, later diffused out of the magnetite crystal leaving the spinel behind. Discrete spinel grains are common where plates are rare and vice versa (Figs. 39 and 40). These grains are resistant to weathering, as they occur in strongly weathered magnetite, implying that they are not pyroxene, olivine or plagioclase. Ramdohr (1952, p. 635) states that "commonly spinel grains are coarse, rounded and, in some cases, branched".

There is probably a decrease in exsolved spinel plates from Seam No. 11 upwards. The ulvite forms box-like frames around spinel (Fig. 37) and in the uppermost seams, though there are no spinel plates, there are ulvite boxes implying that spinel plates were present originally, but that they have subsequently migrated elsewhere (Sections 27 to 31).

Where magnetite is completely surrounded by gangue it tends to be without its spinels. For example, the magnetite in the magnetite anorthosite, above the Main Seam, contains ulvite boxes but no spinel. The uppermost seams have interstitial gangue. This may be why they have lost their spinel plates; but the purer seams

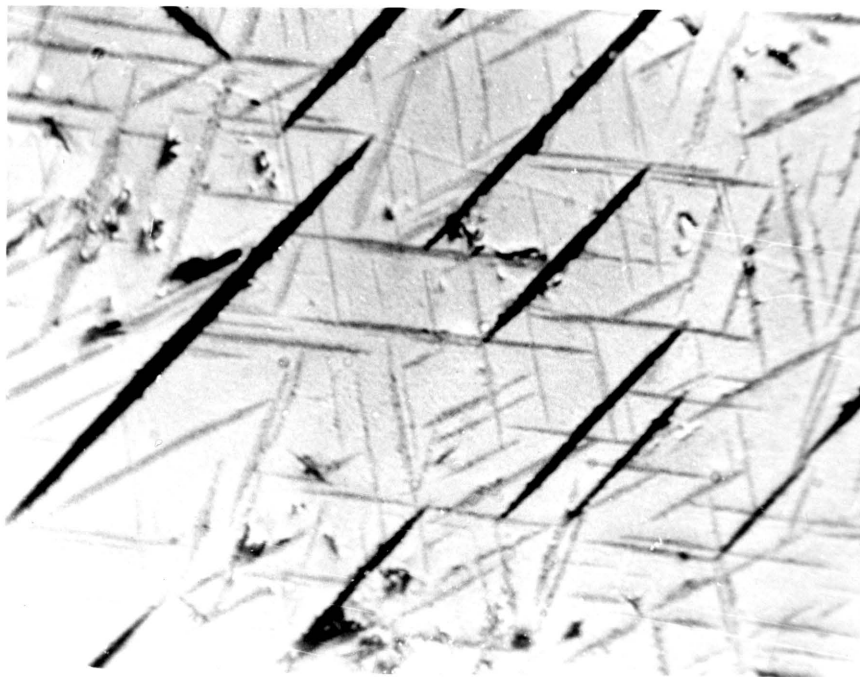


Fig. 34 Small ilmenite lamellae (dark grey) in magnetite (light grey). Exsolved spinel plates (black) are inferred to be younger than the ilmenite which they appear to truncate. Basal Portion of Main Seam. Section 3. Oil Immersion, X 500.



Fig. 35 Small ilmenite lamellae (dark grey) exsolved on the (111) plane of magnetite (pale grey). Flack spinel plates lie in the (100) plane of magnetite. A large ilmenite crystal in the left of the picture has collected spinel (black) from the adjacent magnetite. Basal Portion of the Main Seam. Section 3. Oil immersion, X 500.

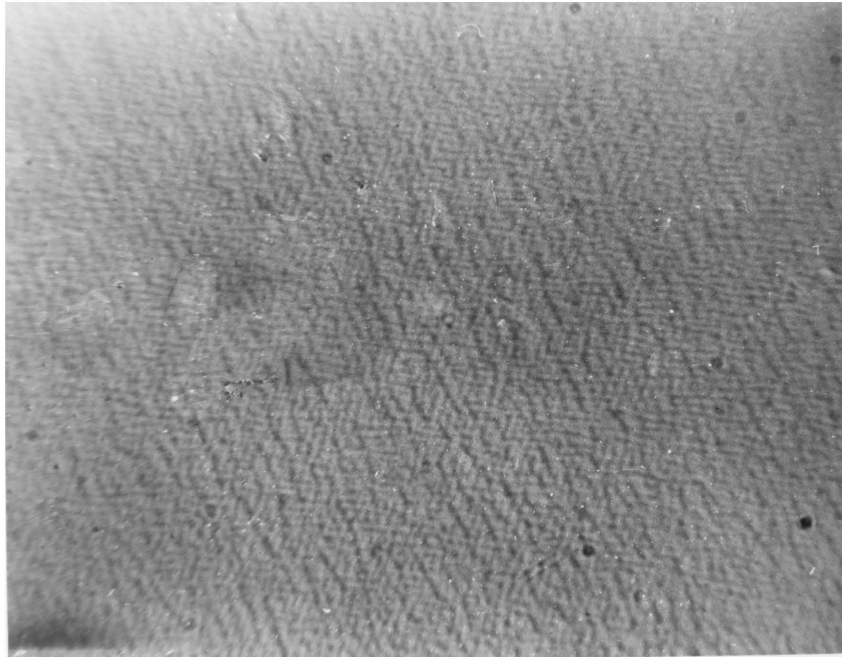


Fig. 36 Fine network of ulvite (grey) in magnetite.  
Lower Seam No. 3. Section 2. Oil immersion,  
X 340.

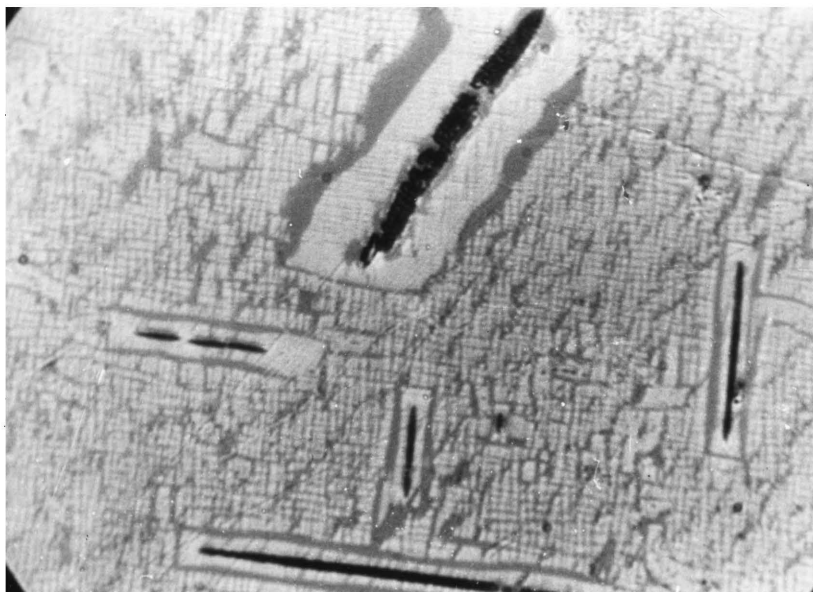


Fig. 37 Ulvite (grey) forming a network in magnetite  
(pale) around spinel (black). Fine ulvite  
also occurs inside the boxes. Lower Seam No.3.  
Section 2. Oil immersion, X 1,000.

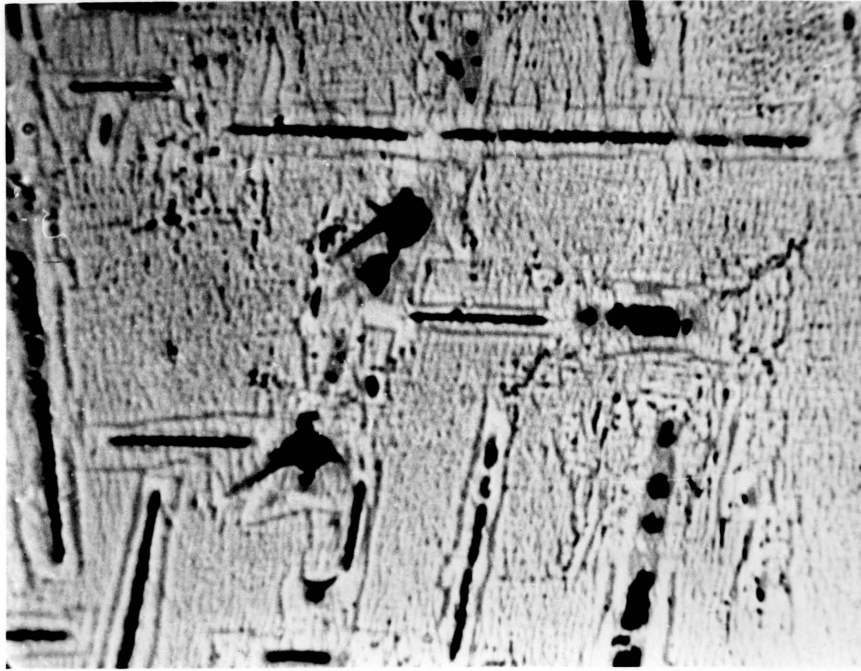


Fig. 38 Spinel (black) possibly partly segregated from plates into irregular grains. The grey fine network is ulvite. Feldspathic centre of the Main Seam. Section 6. Oil immersion, X 500.

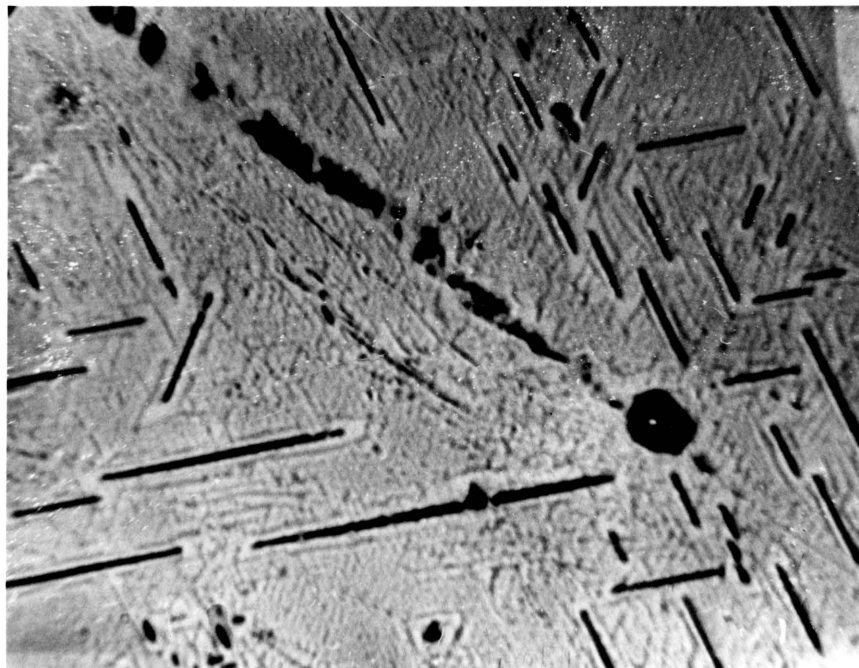


Fig. 39 Spinel veinlet and plates (black). The large spinel grain has a chalcopyrite nucleus (white) Feldspathic centre of the Main Seam. Section 6. Oil immersion, X 500.

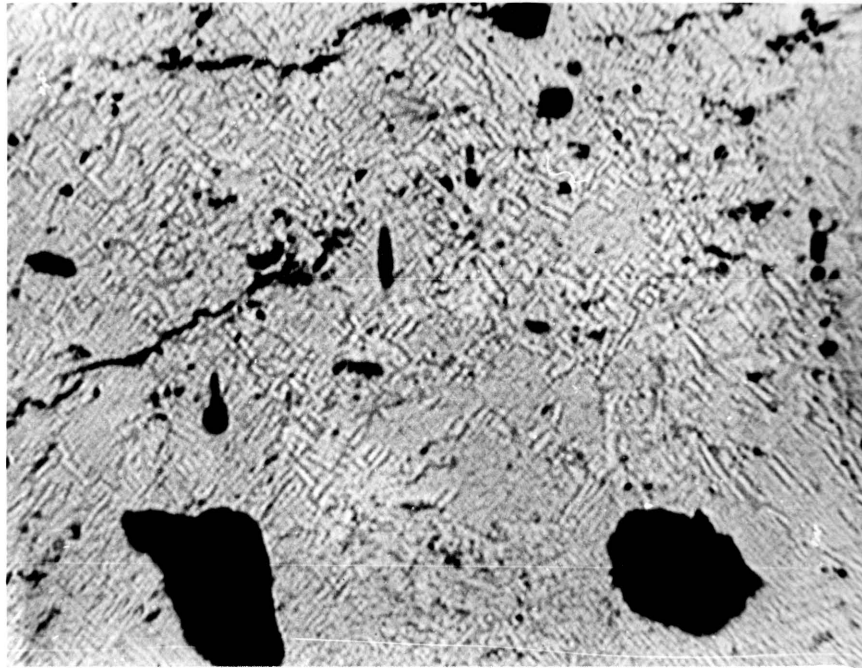


Fig. 40 The dark grey grains are concluded to be segregated spinel in pale groundmass of ulvite (grey) and magnetite (pale grey). Plug on Steelpoortdrift 365, KT. Section 32, X 350.



Fig. 41 Veinlets and subhedral crystals, probably of spinel (dark grey) in magnetite (pale). Upper Seam No. 1. Section 10. X 350.

including Seam No. 11 and those below it, have retained their spinel plates. Compared with the other seams and plugs, the Main Seam contains the largest spinel plates (Figs. 34 and 35).

- (5) Martite is a secondary mineral formed by alteration of magnetite in veins (Fig. 42) and is most common in the uppermost seams. Magnetite lamellae, exsolved from ilmenite, are sometimes altered to martite.
- (6) Maghemite is fairly common in the ore (Fig. 43), but no special attention was given to its conditions of formation. It is also commonest in the uppermost seams.
- (7) Sulphides are present in all the fresh magnetite. The sulphide ores constitute a study in themselves, which is beyond the scope of this work. The following incidental information is presented here.

The sulphides identified are chalcopyrite, pyrrhotite, pyrites, bornite, covellite, pentlandite, chalcocite and almost always occur in gangue. An exception is in Seam No. 6, in which subhedral chalcopyrite crystals are included in ilmenite. Feldspar crystals contain more sulphide than any other of the gangue minerals. The sulphide content of the sections examined is, in a few cases, as high as one per cent.

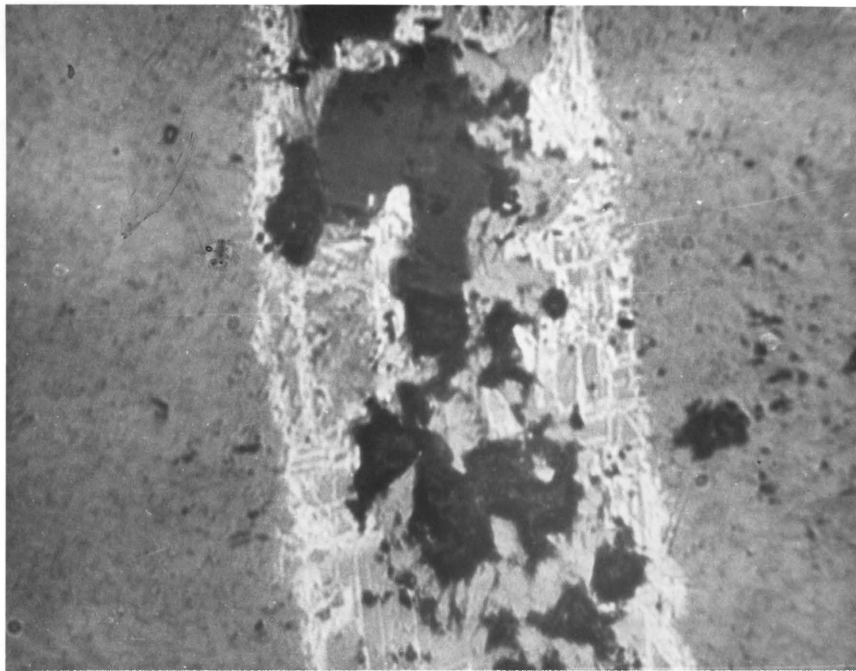


Fig. 42 Vein of magnetite in weathered primary magnetite. The magnetite vein contains martite (white) and possibly spinel (dark uniform grey). Upper Seam No. 21. Section 30. Oil immersion, X 200.

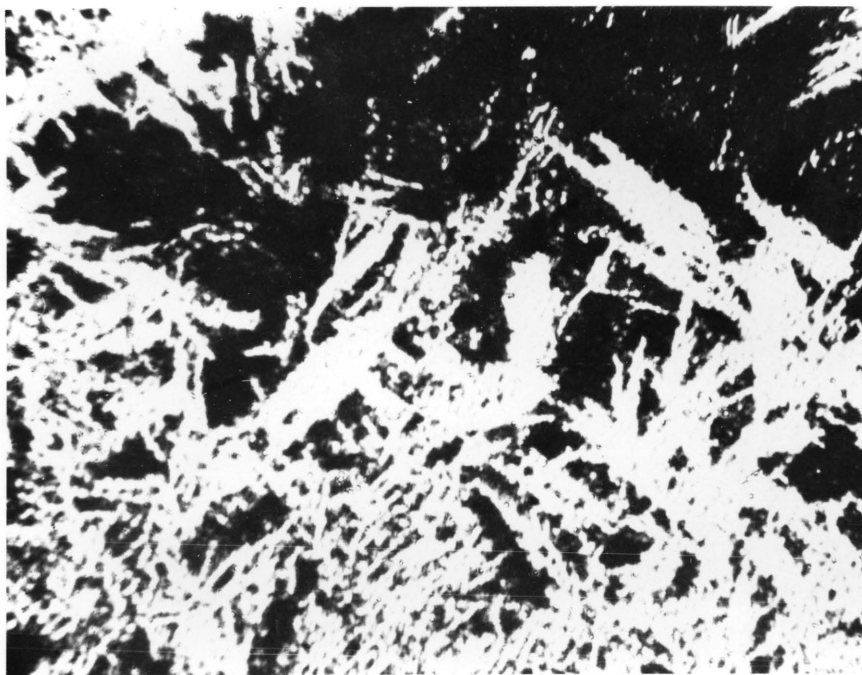


Fig. 43 Magnetite altered to ~~magnetite~~ martite (white). The composition of the dark area is unknown though much of it is polished out. Upper Seam No. 18. Section 29, X 200.

TABLE 1. SUMMARY OF PROPERTIES AND RELATIONSHIPS OF THE MAGNETITITE SEAMS

Seam Number	Thickness	Position in Col.	N° OF V <sub>2</sub> O <sub>5</sub> ASSAYS	V <sub>2</sub> O <sub>5</sub> CONTENT	Hanging-wall	Footwall	SIZE OF WEATHERED BLOCKS
21	36"	3960'	6	0.3%	?	Gabbro	<3"
20	48"	3940'	-	-	?	?	SMALL
19	12"	3920'	-	-	?	Gabbro	SMALL
18	30"	3890'	3	0.3%	?	Gabbro	SMALL
17	15"	3820'	3	0.3%	?	Gabbro	10"
16	12"	3800'	-	-	?	Gabbro	SMALL
15	24"	3400'	-	-	Pure Anorthos.	Troctolite	SMALL
UPPER 14	4"	2660'	1	0.55%	?	Gabbro	2"
LOWER 14	3"	2650'	1	0.55%	?	Gabbro	2"
13	13"	2370'	3	0.55%	Pure Anorthos.	Gabbro	6"
UPPER 12	9"	2060'	4	0.55%	?	Gabbro	5" to 7"
LOWER 12	12"	2050'	4	0.55%	?	Gabbro	
11	20"	1700'	6	0.6%	Mag. Anorthos.	Anorthosite	12"
10	9"	1620'	-	-	?	?	4"
9	9"	1540'	2	0.75%	?	?	4"
8	7"	1500'	-	-	?	?	2"
UPPER 7	5"	560'	5	1.35%		Anorthosite	4"
LOWER 7	25"	556'			Gabbro		
UPPER 6	9"	440'	5	1.35%	?	?	4" to 6"
Mid. 6	11"	432'			Mag. Anorthos.	Gabbro	
5	8"	150'	2	1.35%	?	Gabbro	SMALL
4	18"	100'	10	1.35%	Gabbro	Gabbro	10"
3	6"	90'	4	1.35%	Mag. Anorthos.	Anorthosite	SMALL
2	30"	20'	30	1.5%	Mag. Anorthos.	Anorthosite	10"
1	14"	8'	20	1.5%	Mag. Anorthos.	Anorthosite	5"
Upper Portion	44"	0'	3	1.6%	Mag. Anorthos.	Fels. Magnet.	up to 36"
Lower Portion	34"		3	1.6%	Fels. Magnet.	Anorthosite	
4	12"	-390'	-	-	?	Gabbro	4"
3	60"	-530'	1	2.0%	?	Gabbro	SMALL
2	12"	-690'	1	2.0%	?	Anorthosite	4"
1	14"	-900'	1	2.10%	Mag. Anorthos.	Anorthosite	6"

TABLE 2 SUMMARY OF PROPERTIES OF THE ORE MINERALS OF THE MAGNETITITE

	N° OF POLISHED SECTION	N° OF SEAM	DEGREE OF WEATHERING			EXSOLVED PLATES OF SPINEL			SPINEL MIGRATED INTO ILMENITE CRYSTALS	ULVITE BOXES AROUND SPINEL	ULVITE	FINE ILMENITE LAMELLAE	COARSE ILMENITE LAMELLAE	SECONDARY ILMENITE	LARGE ILMENITE GRAINS		CONTAINS EXSOLVED MAGNETITE & LAMELLAE	SPINEL IN MAGNETITE LAMELLAE	SULPHIDES
			FRESH	MEDIUM WEATHERED	VERY WEATHERED	LENGTH IN MMS.	UNSEGREGATED	PARTLY SEGREGATED							COMPLETELY SEGREGATED	● TWINNED			
SUB ZONE D	30,31	21			●			●	●	●				●	●	●			
	29	18			●			●	●	●				●	●	●			
	28	17			●			●	●	●				●	●	×	●		
SUB ZONE C	26,27	13		●				●	●	●				●	●	●			
	25	UPPER UNIT OF SEAM N° 12		●		0.02		●	●	●			●	●	●	●			
	24	LOWER UNIT OF SEAM N° 12		●		0.02		●	●	●			●	●	●	×			
	21, 22, 23	11	●			0.05		●	●	●			●	●	●	●			
	20	10	●			0.05		●	●	●			●	●	●	×	●	●	●
	19	9		●		0.1		●	●	●			●	●	●	×	●	●	●
SUB ZONE B	18	7		●		0.04		●	●	●				●	●	●			
	17	UPPER UNIT OF SEAM N° 6	●			0.02		●	●	●				●	●	×	●	●	●
	15,16	MIDDLE UNIT OF SEAM N° 6	●			0.02		●	●	●				●	●	×	●	●	●
	13,14	4	●			0.04		●	●	●				●	●	●	●	●	●
	11,12	2	●			0.04		●	●	●				●	●	×	●	●	●
UPPER SEAMS	42	3' ABOVE 1	●					●	●	●			●	●	●	×			
	9,10	1	●			0.05		●	●	●			●	●	●	×			
	41	4' ABOVE MAIN SEAM	●					●	●	●			●	●	●	×			
	8	FELSPATH. TOP	●			0.05		●	●	●				●	●	×			
	7	TOP HALF	●	●		0.05		●	●	●				●	●	×			
	6	FELS. CENTRE				0.1		●	●	●			●	●	●	×			
	5	SILICATE IN LOWER HALF	●			0.1	●		●	●	●	●	●	●	●	×			
	4	LOWER HALF		●		0.1		●	●	●	●			●	●	×			
LOWER SEAMS	3	BASAL CONTACT	●			0.1	●		●	●	VERY LITTLE	●		●	●		VERY FEW		
	2	3	●			0.02		●	●	●				●	●	×	●	●	●
	1	1		●		0.02		●	●	●			●	●	●	×	●	●	●
	32	STEELPORT DRIFT		●		0.03		●	●	●				●	●	×			
33	BELOW 8 MAG. HTS.		●				●	●	●				●	●	●	●	●	●	
34	BELOW 11 MAG. HTS.		●				●	●	●				●	●	×	●			

C H A P T E R VI

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THE INDIVIDUAL PETROGRAPHIC UNITS

The magnetitite and the silicate rocks will be listed and described separately.

(i) Magnetitite Seams

The more important properties have been listed in Table I. The thickness and top and bottom relations of the various seams and their position are shown on Map IV. The characteristics of the seams and plugs are listed in Tables I, II and IV.

Lower Seam No. 1 (Polished Section 1) No seam was recorded lower in the geological column in the area mapped. This seam is not a conspicuous one but, nevertheless, provides more rubble than any other of the lower seams. In the area examined, the lower seams outcrop only on Steelpoortdrift 365. KT as elsewhere the geological structure prevents them from reaching the surface.

The sample examined from this seam is weathered, showing magnetite partly altered to maghemite. Spinel plates are rare and show all stages of segregation into larger crystals and veinlets.

Lower Seam Nos. 2 and 4 outcrop poorly and Seam No. 2 is well exposed only in the Magnet Heights River on Steelpoortdrift 365. KT. Seam No. 4 outcrops east of the Main Seam outlier nearest to Ironstone 847. KS, also on Steelpoortdrift 365. KT.

Lower Seam No. 3 (Polished Section 2) is not fully differentiated and consist of five feet of

feldspathic magnetitite. It assays 1.5%  $V_2O_5$  suggesting that, if it was pure magnetitite, it would contain about 2%  $V_2O_5$ . As it is friable, it outcrops poorly spreading in its vicinity a veneer of small magnetite grains. This seam, having similar characteristics, is known to occur with Lower Seam Nos. 1 and 4, twenty miles to the south, on Zwartkop 142. JS.

The magnetite in the vicinity of ilmenite is devoid of spinel but conversely, spinel plates seem to occur preferentially in magnetite adjacent to gangue and fissures. In the polished section, the striking feature is an intergrowth between magnetite and probably olivine (Fig. 24). A thin film between magnetite and plagioclase has straight extinction, low birifringence, no pleochroism and is concluded to be orthopyroxene. Hall (1932, p. 340) is also of ~~that~~ <sup>the same</sup> opinion as to the composition of the rim between magnetite and plagioclase in the Main Seam. The magnetite is generally anhedral, but some subhedral magnetite grains are included in the peripheries of plagioclase laths.

### The Main Seam

is nine feet thick (Fig. 44) and has a sharp basal contact with the underlying anorthosite. The seam is composed of two units of magnetitite separated by one foot of feldspathic magnetitite. The upper unit is about one foot thicker than the lower one and is transitional upwards through one foot of feldspathic magnetitite into magnetite anorthosite. The units have an identical appearance in hand specimens and each contains occasional anorthosite lenses, one to six inches long, and discrete poikilitic pyroxene crystals about one inch in diameter which disappear through weathering, leaving a pitted depression. In the south of Magnet Heights 346. KC in the river, the anorthosite footwall forms a small dome rising about two feet into the magnetitite but without disturbing the top of the seam (Fig. 45). The Main Seam provides the most spectacular outcrop of all the seams, producing huge pavements in places more than a thousand



Fig. 44. Upper Seam No. 1, the entire Main Seam and its anorthosite footwall. The sharp basal contact of the Main Seam and the banding in the lower part of the anorthosite are visible. Magnet Heights River on the northern portion of Ironstone 847.KS.

Flotted Anorthosite

Banded Anorthositic Gabbro



Fig. 45. A "roll" in the anorthosite footwall of the Main Seam in the Magnet Heights River on Magnet Heights 846. KS.

feet wide (Fig. 48). Such pavements are surprisingly unbroken and only towards the 'up-dip' end do they become dislocated. There is no outcrop of the Main Seam north of Magnet Heights, in the area mapped, because it is buried in the core of a faulted anticline (Profile AE).

The Main Seam appears, for the first time, in the Magnet Heights River 1,300 feet south-east of the Trading Store and its outcrop continues southwards until it is buried under sand north of the Magnet Heights granite. Eastwards from the first outcrop, overlooking the east bank of the Magnet Heights River (Fig. 67), the seam is repeated three times by strike faults (~~see~~ Profile CE).

South of the Magnet Heights granite, the Main Seam again outcrops in the Magnet Heights River and can be traced nearly 20,000 feet southwards to the Steelpoort Fault. In this distance it is dislocated by numerous small dip-faults and outlying fragments cap two conspicuous kopjes. The seam reappears 28,000 feet further south-west on De Hoop 386. 23, on the opposite side of the fault.

In the Magnet Heights area, the Main Seam shows no measurable thinning but at Zwartkop 142. 30 twenty miles south, it is seven and a half feet thick and at De Lagersdrift 178. 38, still further south, it is only six feet thick.

In the lowest few inches of the Main Seam there is very little ulvite but abundant small ilmenite lamellae have been exsolved along the (111) plane of the magnetite (Figs. 34 and 35). Where these ilmenite lamellae are well developed, inspection under a X 2,000 magnification reveals no ulvite. The magnetite crystals contain large spinel rods orientated in the (100) plane.

A chain of olivine crystals lies parallel to, and about one millimetre from, the base of the Main Seam (Fig. 50). Olivine also occurs as thin interstitial films extending up into the magnetite (~~Section~~<sup>Slide</sup> 3). There are some idiomorphic magnetite crystals associated with the olivine chain, the crystals of which are subhedral. At the actual



Fig. 46 Banded feldspathic centre of the Main Seam containing an anorthosite xenolith; in the Magnet Heights River in the south of Magnet Heights 846. KS.

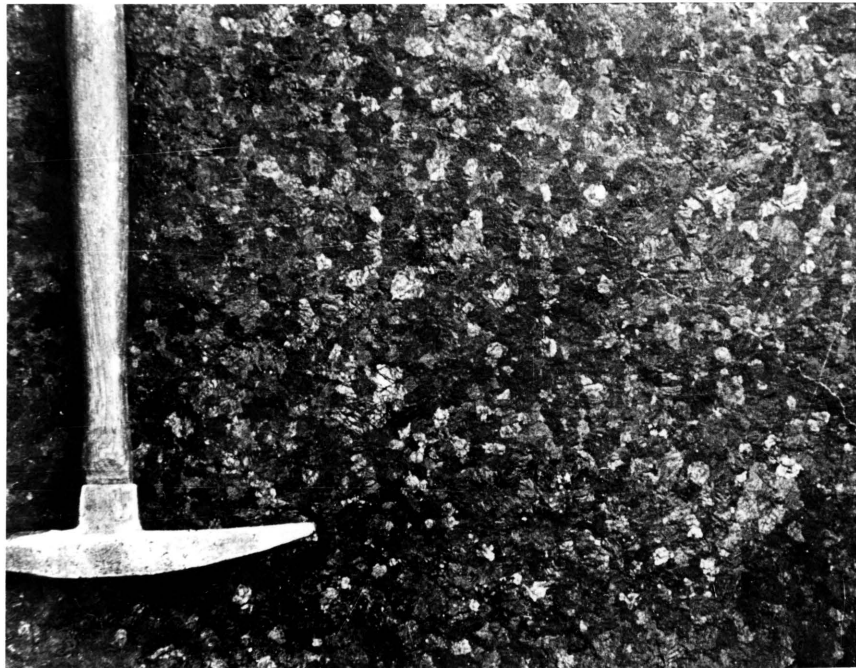


Fig. 47 Coarsely crystalline magnetitite of the Main Seam in Magnet Heights River in the southern portion of Magnet Heights 846. KS.



Fig. 48 Spectacular pavement of Main Seam a quarter of a mile east of the road and about half a mile south of the Magnet Heights Store.

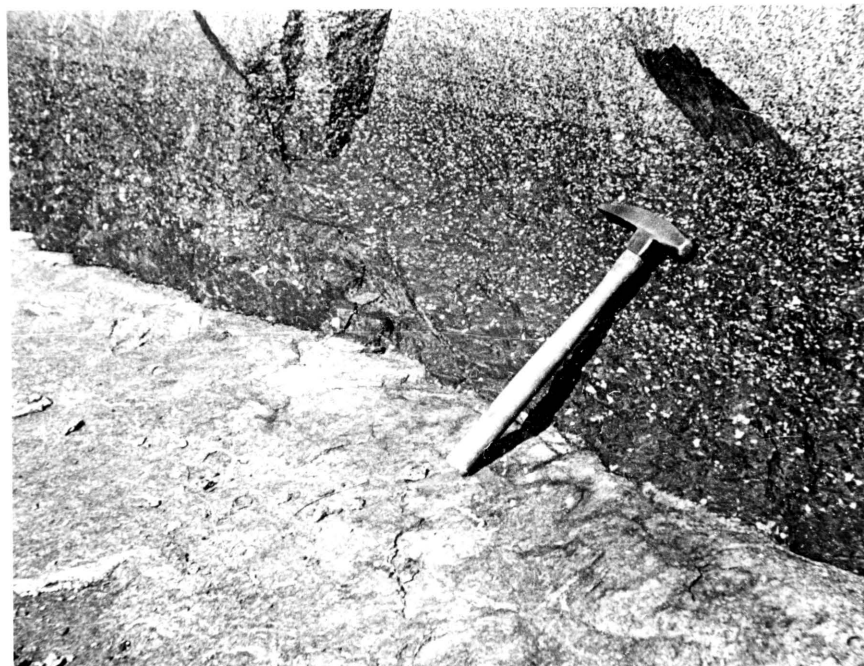


Fig. 49 Upper Seam No. 1, underlain by anorthosite, banded, and grading upwards into magnetite anorthosite. The dark blurs are rock ledges. Magnet Heights River in the southern portion of Magnet Heights 846. KS.

contact of the magnetite and the anorthosite an intergrowth of magnetite with olivine borders the magnetite and an intergrowth of pyroxene with plagioclase borders the anorthosite (Fig. 50). In the anorthosite there is distinctly interstitial magnetite (Slide 3).

One foot from the base of the Main Seam the magnetite contains small ilmenite lamellae, large spinels and a little ulvite (Polished Section 5). As some of the magnetite crystals contain abundant ulvite and no fine ilmenite, and vice versa, in the same section, these two minerals appear to be antipathetic.

Most of the silicate is poikilitic orthopyroxene enclosing clinopyroxene (Slide 5). The biotite is subhedral, penetrating the margin of the feldspar and magnetite crystals. The pyroxene crystallised, either simultaneously with, or later than, the magnetite and may have partly replaced magnetite (Fig. 51). A poikilitic plagioclase crystal also includes magnetite (Slide 5).

In the feldspathic centre of the Main Seam the large plates of spinel show all stages of segregation into discrete crystals and veinlets. Ulvite is well developed and there is only a little ilmenite present. The silicate is mostly plagioclase, but there is an unusually large amount of biotite (3%). A rim, which was identified as orthopyroxene, occurs between biotite and plagioclase (Polished Section 6).

The polished section of the upper unit of the Main Seam was of weathered magnetite and therefore uninformative. Spinel plates show advanced segregation into large bodies and there is a considerable amount of fine ilmenite thought to have been produced by oxidation of ulvite.

The plagioclase laths in the transitional top of the Main Seam are joined by films of silicate lying between the magnetite grains. This silicate is thought to be pyroxene (Polished Section 8). This rock is composed almost entirely of magnetite and plagioclase with a little anhedral orthopyroxene and subhedral biotite.

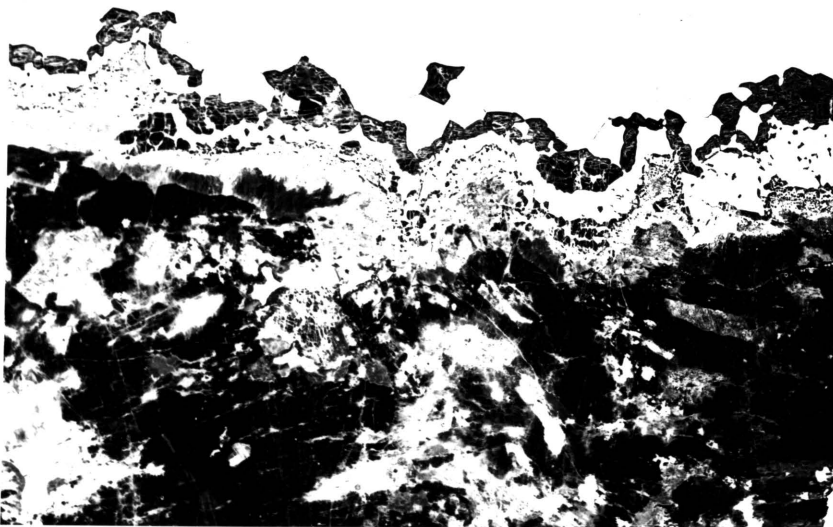


Fig. 50 The chain of crystals (dark grey) about 1 mm from the base of the magnetite (white) is olivine. The predominantly black area in the bottom of the photo is anorthosite. Base of Main Seam. Slide 8. Negative photograph, X 12.

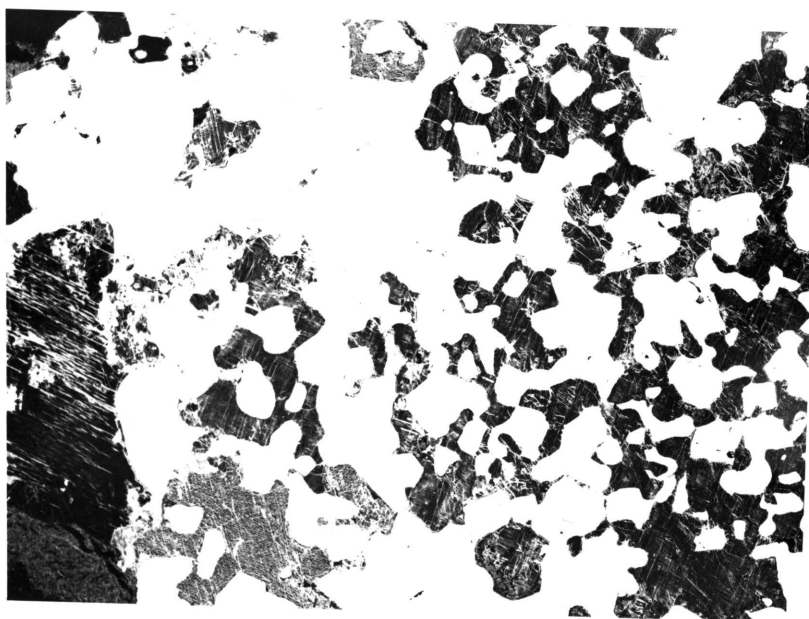


Fig. 51 Poikilitic pyroxene (dark) enclosing magnetite (white). The large dark crystal on the left is plagioclase. Basal portion of Main Seam. Slide 5. Negative photograph X 10.

Four feet above the Main Seam in the magnetite anorthosite the magnetite has been corroded by the silicates and contains a speckling of sulphides and some ilmenite lamellae (Fig. 33), which are thought to have been produced by oxidation of ulvite. Vincent (1960, p.1000 to 1010) also reports the partial oxidation of ulvite to ilmenite in the Skaergaard Intrusion. No spinel plates remain but there are boxes of ulvite which originally presumably accommodated spinel plates which subsequently migrated out of the magnetite.

The magnetite is generally interstitial to plagioclase but one euhedral magnetite crystal is included in a feldspathic lath (Slide 41). The orthopyroxene rim between the magnetite and the plagioclase is not continuous along the interfaces. An intergrowth between pyroxene and plagioclase may be due to replacement of the plagioclase by pyroxene.

#### Upper Seam No. 1

is thin and is usually partly obscured by broken pavement of Seam No. 2 (Fig. 3). The spinel rods show all stages of segregation and some of the discrete spinel grains contain chalcopyrite cores. Irregular spinel lamellae lie on the (111) plane of the magnetite crystals. Three feet above the seam the magnetite in the magnetite anorthosite seems to have crystallised later than the feldspar. Subhedral magnetite and biotite crystals are rarely included in feldspar laths.

#### Upper Seam Nos. 2 and 4

are equally resistant to erosion and, on Magnet Heights 846KS often form pavements a few hundred feet wide. Seam No. 4 is transitional upwards and downwards (Fig. 52), so that its blocks are pock-marked on both sides, the pock-marks being weathered out feldspar crystals.

The rim between magnetite and plagioclase is faintly pleochroic and brownish with straight extinction and is probably orthopyroxene.



Fig. 52 Upper Seam No. 4 with upper and lower contacts transitional into magnetite anorthosite. Magnet Heights River near the boundary between Magnet Heights 846. KS and Ironstone 847. KS.



Fig. 53 Main Magnetite Seam in river on Magnet Heights 846. KS

In Seam No. 4 an ilmenite crystal was observed inside a plagioclase lath. There are rims, considered to be orthopyroxene, between biotite and plagioclase and also between magnetite and plagioclase. A little secondary hornblende has replaced pyroxene.

Upper Seam Nos. 3 and 5 are thin and composed of friable feldspathic magnetite. Seam No. 3 can easily be recognised as it is underlain by a hard conspicuous, four feet thick, anorthosite. Seam No. 5 is visible only in areas of good rock exposure; it is considered worth recording these insignificant seams because, even though they cannot often be mapped, they appear in the various drill cores that have been obtained of the two hundred feet of rock above the Main Seam.

Upper Seam No. 6. Although this seam consists of three closely spaced units of magnetite, in the general course of mapping it is convenient to treat it as a single seam. The topmost unit of magnetite has a sharp basal contact. The middle unit, eight feet below, is transitional upwards and downwards, and the lowest, eight feet farther below, is composed of two inches of friable magnetite. It is important to record such a thin unit as the lowest one, because it is still present on Zwartkop 142. JS, twenty miles farther south.

In the uppermost unit, orthopyroxene exsolving clinopyroxene, is usually abundant. The rim between plagioclase and magnetite is orthopyroxene, or possibly amphibole.

The middle unit has a transitional basal contact. The amount of magnetite in the gabbro increases upwards until the rock grades over a distance of one inch into magnetite (Fig. 19). In this transition, there is intergrowth of magnetite with pyroxene and of pyroxene with plagioclase.

Below the seam the rock consists of clinopyroxene enclosing euhedral plagioclase and magnetite crystals. The magnetite crystals increase upwards in number over a distance of one inch until the rock is composed predominantly of magnetite. In one case a large ilmenite contains small idiomorphic chalcopyrite crystals (Polished Section 15). The spinel is more segregated near the base than in the higher, purer, magnetite of the seam.

Upper Seam No 7 consists of two thin discrete magnetite units above, and separated by two feet of anorthosite from, two feet of friable feldspathic magnetite. Seam Nos. 6 and 7 outcrop in the vicinity of the Main Seam and both produce sizable pavement slopes on Magnet Heights. On Aapjesboom 884. KS, the seams outcrop poorly and erratically. Both seams have the same character and position relative to the Main Seam on Zwartkop 142. JS, twenty miles to the south. The ulvite compartments are very small but it is estimated that they form about one third of the ore. Upper and lower limits of the amount of ulvite present are set at 40% and 25%. In the thin section that was made of the feldspathic portion of Seam No. 7, a feldspathic aggregate about half an inch in size is composed of several feldspar laths and some orthopyroxene grains and it must be a tiny xenolith. Magnetite crystals enclose some quite large idiomorphic biotite flakes. The fabric of part of the seam is shown in Fig. 20 (Slide 18). Euhedral magnetite and subhedral plagioclase crystals are enclosed in orthopyroxene, which has exsolved clinopyroxene.

Upper Seam Nos. 8, 9 and 10 all are inconspicuous in the field, being less than one foot thick and with sharp basal and transitional upper contacts. They are visible only in areas of good exposure on Magnet Heights 846. KS and Ironstone 847. KS. In Seam No. 9 the magnetite crystals enclosed in gangue have lost most of their spinel plates whereas the spinel plates have been retained by purer magnetite. The magnetite contains large ilmenite lamellae, some of which may possibly have partly migrated out into the interstices. The gangue is mostly olivine which has grown poikilitically around euhedral magnetite crystals. There are also some large plagioclase laths in the magnetite.

Upper Seam No. 11 (Fig. 56) is relatively thin (18 inches) but is extremely hard and forms conspicuous pavement slopes especially on Magnet Heights (Fig. 6). Apart from the Main Seam and Seam No 21, it is the most easily mapped of all the seams and is a good marker band. On Magnet

Heights 346. VS it contains a xenolithic lens of hyperite, about 18 inches long (Figs. 56 and 70, Slide 22). Seam No. 11 resembles Seam No. 17 in the field, but it can be distinguished from the latter, when mapping, by noting the fact that above Seam No. 17 lie only fine pebbles from the friable uppermost seams whereas above Seam No. 11 are sizable blocks derived from Seam Nos. 12 and 13.

#### Seam No. 11

has a sharp basal contact with anorthosite (Figs. 54 and 56). Against the magnetite is an intergrowth of magnetite and pyroxene and against the anorthosite one of pyroxene and plagioclase. This has been compared with a diagram of a lode cast (Fig. 55). About one inch from the base of the seam is a hyperite xenolith which ~~shows~~<sup>has</sup> allotropic texture (Fig. 70). In this rock (Slide 22) is the rare occurrence of small plagioclase crystals included in magnetite. The anorthosite footwall of the seam is speckled with small idiomorphic magnetite crystals (Fig. 54). Most of the magnetite of these crystals has been replaced by silicate, which is probably pyroxene, leaving only a lattice of ilmenite. (Figs. 58 and 59).

Most of the spinel has migrated out of the magnetite of the seam and what is left occurs beside cracks and near boundaries with silicate and ilmenite. Farther from the base of the seam the spinels are less segregated.

The large ilmenite grains contain exsolved magnetite lamellae in a single plane. These lamellae are sometimes club-shaped (Sections 23 and 24). One euhedral six-sided spinel crystal is enclosed in a large ilmenite grain.

Included in the magnetite of the seams are small idiomorphic biotite plates. The biotite is darker than that lower in the sequence (Slide 23).

#### Upper Seam No. 12

consists of two units eight feet apart. The topmost has a sharp basal contact while the lower one has a five inch thick core of slightly feldspathic friable magnetite with a five inch transition upwards and a two inch transition downwards into magnetite

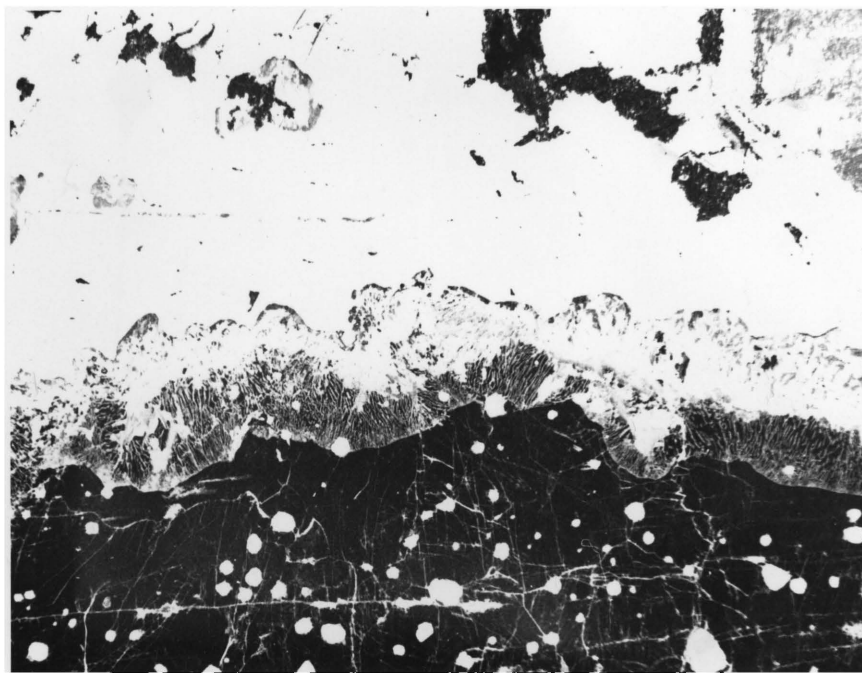


Fig. 54 Base of Seam No. 11. Magnetite (white) overlies anorthosite (black) with an undulating contact. At the contact, pyroxene is intergrown with plagioclase on the anorthosite side and with magnetite on the magnetite side. The anorthosite contains a speckling of idiomorphic magnetite crystals, two of which are photographed in Figs. 58 and 59. Slide 22. Negative photograph, X 7.

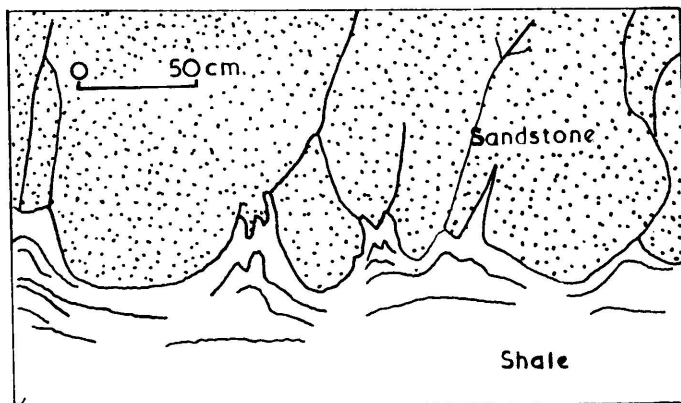


FIG 55. SECTION OF A LARGE LODGE CAST.  
(TEN HAAF 1959 P 43)



Fig. 56 Seam No. 11 which has a sharp basal contact with anorthosite, is transitional upwards into magnetite anorthosite and contains a hyperite xenolith.



Fig. 57 Seam No. 13, which is overlain with a sharp contact by weathered anorthosite (white) and is transitional downwards into magnetite anorthosite.

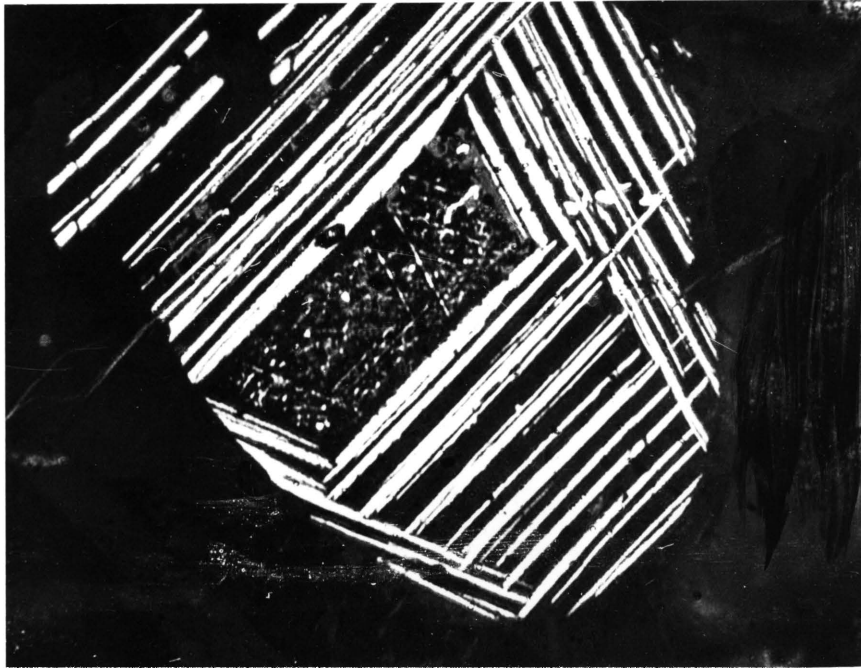


Fig. 58 Ilmeno-magnetite grain partially replaced by gangue (probably pyroxene) leaving only an ilmenite skeleton. Anorthosite footwall of Seam No. 11. Section 22. Crossed Nicols, X 200.

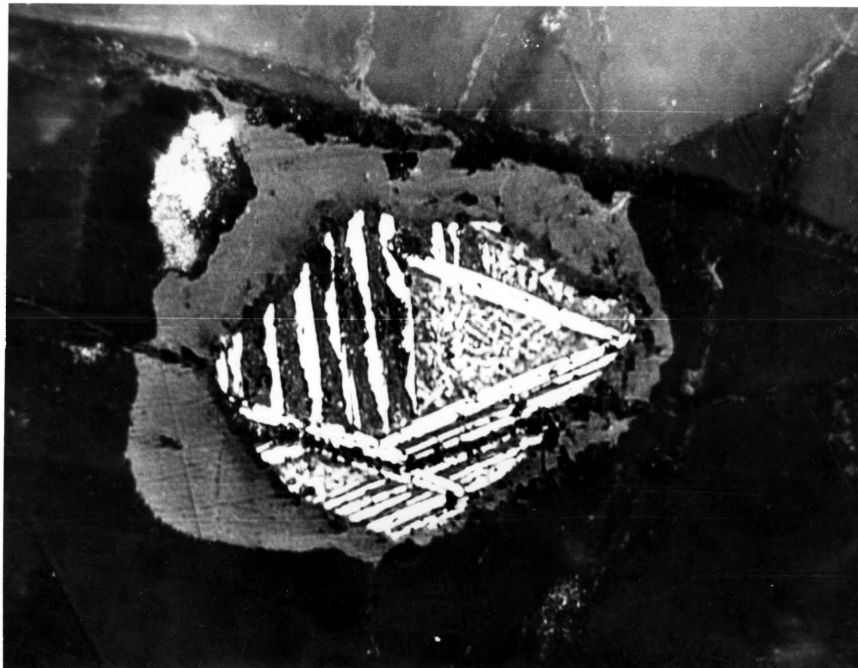


Fig. 59 Ditto Fig. 58 but showing clearly the pyroxene rim surrounding the corroded ore grain. Section 22. Crossed Nicols, X 200.

anorthosite. Like other seams, which are transitional upwards and downwards, the weathered blocks are pock-marked on both sides. The units are quite resistant to weathering and, on Magnet Heights 846. KS, form pavements up to two hundred feet wide. They outcrop strongly southwards as far as Aapjesboom 004. KS where they are buried under recent deposits. Northwards from Magnet Heights 846. KS the seam can be traced across 'The Flats' by identifying loose blocks of rubble.

The spinel content of the magnetite is less than in seams lower in the sequence. A magnetite crystal is included in a large ilmenite grain (Section 24). In the two thin sections which were made (Slides 24, a and b), poikilitic olivine predominates in one (24a) and plagioclase in the other (24b). Clinopyroxene is a minor constituent of each section. The fact that the feldspar includes idiomorphic grains of magnetite means that, before the feldspar finished crystallising, magnetite crystals existed in the magma. The fabric of the seam is shown in Fig. 27. The large ilmenite grains are concluded to be primary crystals. The olivine and plagioclase are partly interstitial to the magnetite.

In the upper unit of Seam No. 12 spinel plates are very scarce but there are a number of ulvite boxes suggesting that originally spinels ~~were~~<sup>were</sup> more abundant. Two interesting features are evident (Section 25, Fig. 6C) - spinel plates protrude into the rim, probably of pyroxene between magnetite and gangue, and a 'ghost' crystal of magnetite has been made over completely to silicate, also probably pyroxene. The internal structure of this magnetite crystal is still visible and therein several replaced spinel plates are situated adjacent to a fissure. There is no spinel throughout the rest of the crystal suggesting that there was a low spinel content before the magnetite was replaced by gangue.

The plagioclase crystals are subhedral and tend to be surrounded by chains of small olivine crystals. In the seam and higher in the sequence, the feldspar crystallised slightly later showing less tendency to be idiomorphic than lower in the geological column, e.g. compare Fig. 21 and Fig. 27. The magnetite on the contrary, exhibits <sup>an</sup> increasing tendency towards idiomorphism, e.g. compare Figs. 21 and 61), suggesting that it began to crystallise earlier in greater quantities than lower in the sequence.

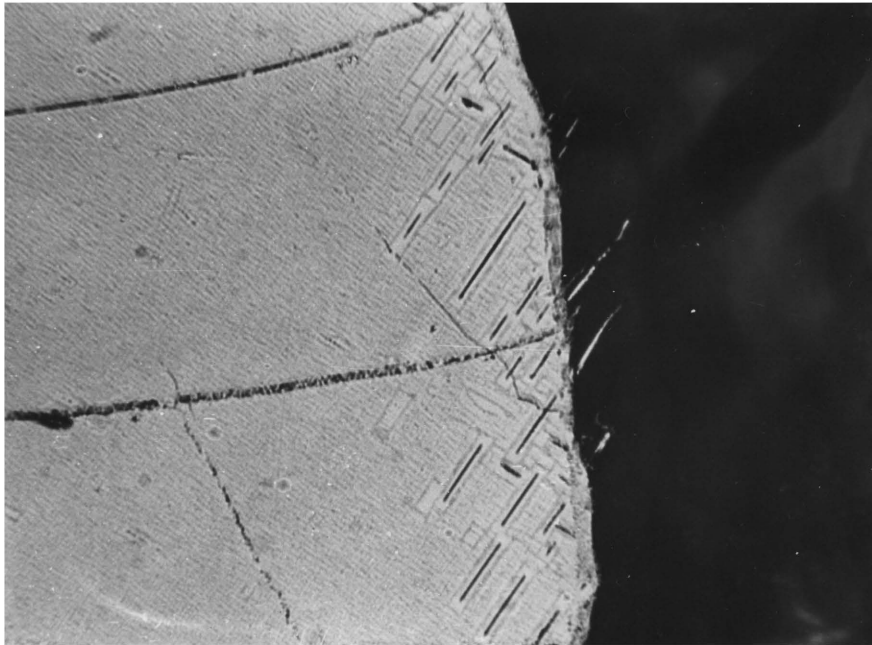


Fig. 60 Magnetite (white) including ulvite (grey) and spinel plates (black) has been partly replaced by pyroxene which now includes white spinel pseudomorphs. Neither the significance nor the composition of the horizontal streak is known. Upper unit of Seam No. 12. Section 25. Oil immersion, X 400.

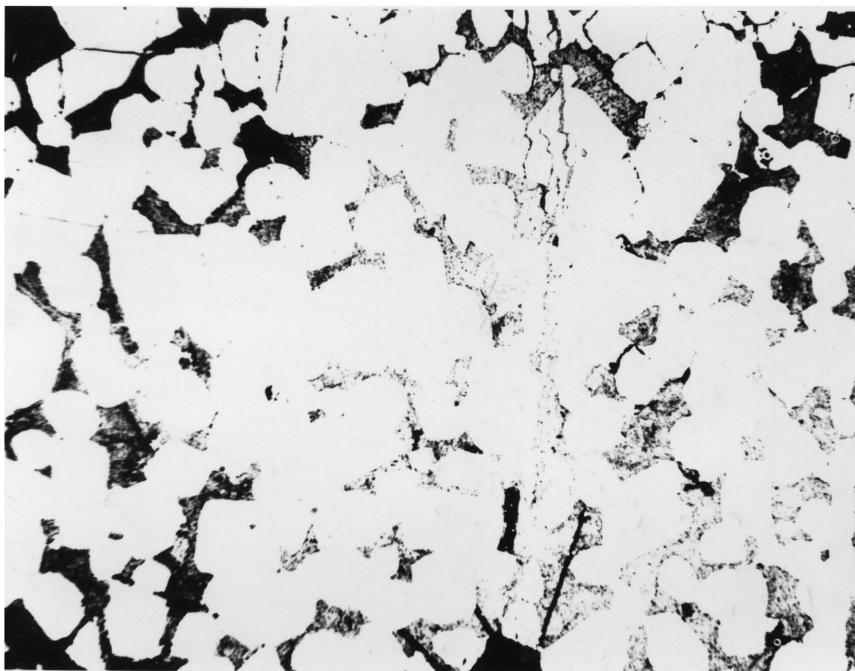


Fig. 61 Idiomorphic magnetite (white) included in altered pyroxene (dark). Seam No. 13. Section 27. Negative photograph, X 10.

Upper Seam No. 13

is exceptional in that it grades downwards into magnetite anorthosite and is overlain with a knife-edge contact by 30 feet of pure anorthosite (Fig. 57). This is a complete reversal of the normal sequence. In the field this seam is easily distinguished by identifying the thick anorthosite <sup>10 ft</sup> which overlies it. It is not as resistant to erosion as Seam Nos. 11 and 17 but, nevertheless, outcrops fairly strongly and, unless there is a deep soil cover, it can be followed in the field.

The polished section (No. 27) is of badly weathered magnetite. The magnetite has been altered to ~~martite~~ <sup>magnetite</sup> and the ulvite has turned grey. There are plenty of ulvite boxes but few spinel plates. Veinlets exist of a fresh transparent mineral which can only be spinel or quartz as all the other silicates are extremely weathered. This vein mineral is considered to be spinel.

A large ilmenite grain was observed to enclose a smaller ilmenite crystal. Ilmenite grains, in contact with magnetite, tend to be subhedral, whereas those bordering gangue are anhedral. This may be due to partial replacement of ilmenite by gangue. The silicate is weathered, but is considered to be poikilitic, probably orthorhombic, pyroxene (Fig. 61).

Upper Seam No. 14

consists of two small units ten feet apart, both of which are about four inches thick. The blocks are less than two inches in size, but are sufficient to indicate the position of the horizon across the 'Flats' north of Magnet Heights 846. KS.

Upper Seam No. 15

is problematical as it was encountered only on Ironstone 847. KS. No trace of it is to be found on Magnet Heights 846. KS or elsewhere. It is very friable and is either discontinuous or obscured.

Upper Seam Nos. 16, 18, 19 and 20

are friable, poorly differentiated and two to four feet thick. They have no resistance to weathering and are exposed only in favourable stream sections on Magnet Heights 846. KS.

Upper Seam No. 17

consists of one foot of hard magnetitite, which is transitional upwards into magnetite anorthosite. The blocks of this seam are mingled only with fine magnetitite pebbles from the uppermost seams. Seam Nos. 17 and 21 are the only seams of the uppermost group which can easily be traced on 'The Flats'.

The magnetitite is strongly weathered, and most of it is composed of closely packed magnetite crystals separated by a thin film of weathered gangue. Abundant ulvite shows up clearly and ulvite boxes are present though no spinel plates remain. There are veinlets of secondary magnetite and martite containing also patches of possible spinel (Fig. 42).

Upper Seam No. 21,

fully thirty feet thick, is the giant and the uppermost of the seams (Fig. 62). The lowest ten feet is composed of thin units about two inches thick of friable magnetitite interstratified with irregular bands and lenses of anorthosite (Fig. 62). Upwards, the magnetitite becomes more feldspathic and the anorthosite ill-defined, until the seam passes gradually into magnetite gabbro. Under the shadow of the Signal Hill quartzite, which sinks to within one hundred feet of Seam No. 21, it is estimated that the seam is only about two-thirds as thick as elsewhere.

Seam No. 21 outcrops as a low ridge covered with fine magnetite sand and small magnetite blocks. To determine the value of the dip, it is usually necessary to sink a pit. The succession of layers can be identified by implementing the fact that below this seam lie such prominent markers as Seam No. 17, the spotted gabbro and its underlying thick anorthosite.

Southwards from Magnet Heights 846. KS, Seam No. 21 runs parallel to and about one-third of the way up the steep escarpment which rises to the Roof. It is obscured by recent deposits on Droogehoek 882. KS, but reappears and can be traced southwards on De Hoop 886 KS. On Ironstone 847. KS it seems to be interrupted for about one thousand feet by a large transgressive hornfels xenolith.

In the west of Magnet Heights 846. KS, Seam No. 21 dips to the

west and continues northwards out of the area. On the eastern portion of Magnet Heights 346. KS the seam outcrops dipping east, near the north end of the Magnet Heights granite. It can be traced northwards with some interruption, repetition and a persistent easterly dip of  $10^{\circ}$  to  $15^{\circ}$ . In this eastern part of the area, Seam No. 21 forms part of the easterly limb of a faulted anticline (Profile AB). The identification of this seam and its direction of dip has been most useful in unravelling the geological structure in the western part of the area.

The magnetite is extremely <sup>altered</sup> martitized (Fig. 43). There are plenty of ulvite boxes but no spinel plates remain. The ilmenite is subidiomorphic but exhibits some perfect crystal faces (Sections 30 and 31). The magnetite in the vicinity of ilmenite is less weathered than elsewhere.

## 2.) MAGNETITITE PLUGS

The only place in the area mapped where the rocks below the Main Seam are fully exposed, is on Steelpoortdrift 365. KT. On this farm, below the lowest seam, are five magnetitite plugs. They are monomineralic and cut vertically through the gabbro. Due to their superior hardness, they rise about ten feet above the surrounding landscape. Also on Steelpoortdrift 365. KT, in Sub-zone A of the seams, are three plugs. One is elliptical in plan, one is composite, consisting of three more or less circular plugs and another is a dyke-like body about three hundred feet long and twenty feet wide.

Composite plug on Steelpoortdrift 365. KT. It is made of three adjacent, discrete, approximately circular bodies of magnetitite. The smallest is about 10 feet and the largest is about 100 feet in diameter. The magnetitite is <sup>altered</sup> martitized and contains the usual amount of ulvite, which amounts to 25% - 40% of the ore. A speckling of discrete transparent grains are individually about 0.02 mm in size (Fig. 40). In thin section (Slide 32) they are too small to be identified but they are probably isotropic and are tentatively regarded as spinel. In the polished section (No. 32) there is also a little interstitial ilmenite present, and about 1% of unidentified silicate.



Fig. 62 Maximum development of Seam No. 21 in river cutting on Ironstone 847. KS.

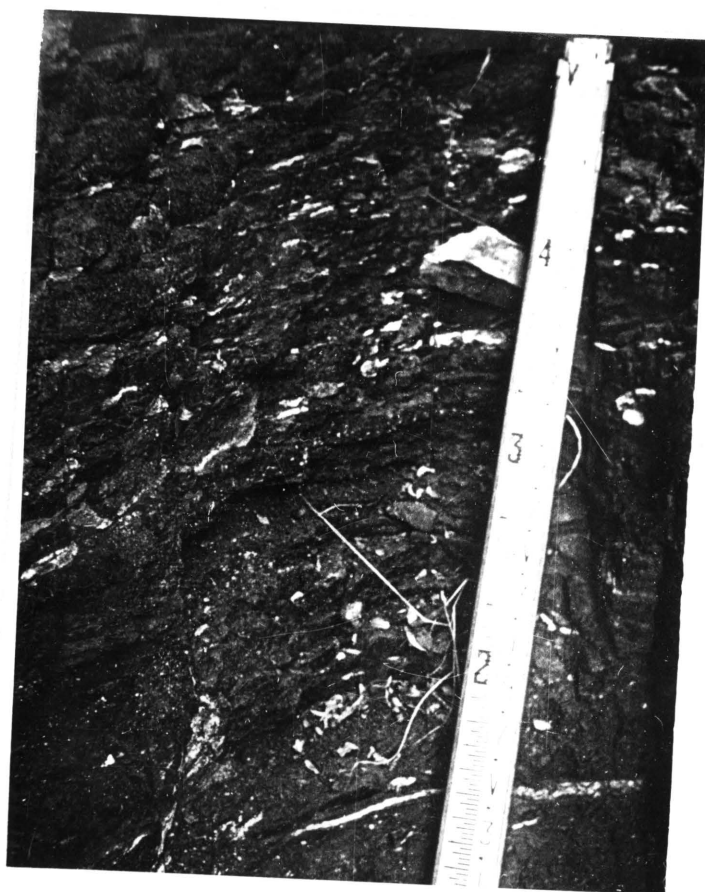
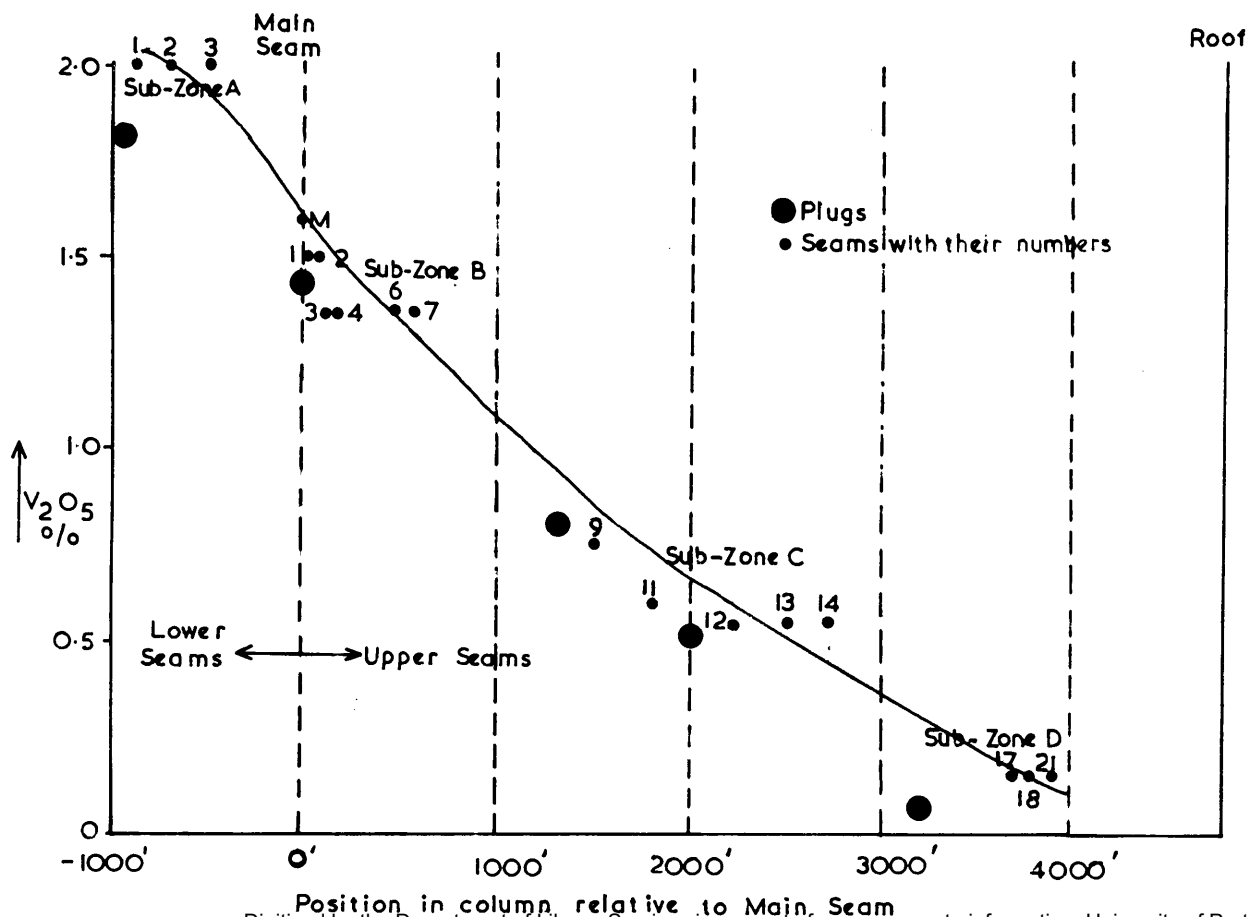


Fig. 63 'Close-up' of Seam No. 21 in the same locality demonstrating banding of the magnetite and ~~its~~ the inclusion of anorthosite lenses.

TABLE 4 PROPERTIES OF THE MAGNETITITE PLUGS

HORIZON	NUMBER PRESENT	V <sub>2</sub> O <sub>5</sub> CONTENT	APPROX. DIAMETER
SUB-ZONE D	1	0.07%	10 FEET
SUB-ZONE C	2	0.65%	50 FEET
SUB-ZONE B	3	1.3%	30 FEET
SUB-ZONE A	3	1.5%	70 FEET
BELOW SUB-ZONE A	6	1.75%	100 FEET

FIG.64. Available V<sub>2</sub>O<sub>5</sub> Analyses of Bushveld Magnetitite seams & plugs



In Sub-zone E there are three small plugs which are nearly circular and are composed of pure magnetite.

Sub-zone C on Magnet Heights 246. X8 contains two plugs both of which are associated with anorthosite. The larger one outcrops in hard troctolite below Seam No. 8. It consists of a discontinuous ring of magnetite surrounding anorthosite. There is a transition over about a foot through feldspathic magnetite into the anorthosite, which contains a little magnetite, pyroxene and sulphide, and probably represents an outlier of the anorthosite band below Seam No. 8.

The magnetite is ~~magnetite~~ <sup>altered to magnetite</sup> and contains ulvite which sometimes forms ulvite boxes but no spinel plates remain.

Below Seam No. 11 is a crescent of magnetite partly encircling anorthosite. The striking feature of this ore is the abundance of ilmenite lamellae with oblique extinction (Fig. 31).

No spinel was detected but some very fine ulvite present is barely visible under the highest magnification (X2000).

The highest plug in the sequence is ten feet across and occurs in Sub-zone D, near the horizon of the spotted gabbro about 1,500 feet below the Roof.

### 3.) THE CHEMICAL COMPOSITION OF THE MAGNETIC IRON ORE

The Anglo American Corporation has kindly made available to the author for publication  $V_2O_5$  assay results of magnetite of different seams and plugs in the Magnet Heights area. The  $V_2O_5$  content and the number of assays from which the average value was derived, are shown on Table I. The information obtained from these  $V_2O_5$  analyses can be summarised as follows:

(a) The  $V_2O_5$  content of the magnetite seams and plugs

TABLE 3 VOLUMETRIC COMPOSITION OF THE MAGNETITITE ROCKS												VOLUMETRIC COMPOSITION OF THE ORE				
POLISHED & THIN SECTION NUMBERS	SEAM NUMBER	ORE CONTENT	PLAGIOCLASE	FELDSPAR/MAGNETITE RIM	ORTHOPIROXENE	CLINOPYROXENE	INTERGROWTH (Pyroxene + Feldspar)	OLIVINE	BIOTITE	Small Euhedral Crystals in Magnetite	MAGNETITE	ILMENITE LAMELLAE & GRAINS ESTIMATED IN POLISHED SECTION	ILMENITE GRAINS ESTIMATED BY ETCHING POLISHED SLAB	SPINEL PLATES	ULVITE	
30, 31	21										?	5	5.5	None Left	25-40	
29	18										?	5	?	None Left	25-40	
28	17										?	5	3.5	None Left	25-40	
26, 27	13	A <sup>o</sup> 60 <sup>o</sup>					B <sup>40</sup> Poikilitic Pyrox.				?	5	?	None Left	25-40	
25	UPPER UNIT OF SEAM N° 12	A 80	A 17	Orthopyr.	B Trace	—	—	B 2.5	A 0.5	Biotite	?	5	5	Very Little	25-40	
24	LOWER UNIT OF SEAM N° 12	A 60	A 22	Orthopyr.	B 0.5	B 1	—	C 15	A 1	Biotite	60	5	?	2	25-40	
21, 22, 23	11	A 65	A 28	Orthopyr.	B 4	—	1	—	A 2	Biotite	60	5	?	Up To 5	25-40	
20	10								Dark Light		60	5	1.4	5	25-40	
19	9	A 65	A 10	Orthopyr.	B Trace	—	A Little	B 24	A 0.5	Biotite	60	7	2.5	7	20-30	
18	7	A 60	A 28	Orthopyr.	B 8	B 2	C 0.5	C 1	A 0.5	Biotite	60	5	?	5	25-40	
17	UPPER UNIT OF SEAM N° 6	A 70	A 23	Orthopyr.	B 5	B 1	C 0.5	—	A 0.5	Biotite	60	5	< 0.5	5	25-40	
15, 16	MIDDLE UNIT OF SEAM N° 6	A 84	A 14		B Very	Little	B 1	—	A 0.5	Biotite	60	5	3	5	25-40	
13, 14	4	A 85	A 13		B 1	—	A Little	C 0.5	A 0.25	Biotite	60	5	3.5	5	25-40	
11, 12	2	A 47	A 50	Orthopyr.	—	B 1	B 0.5	—	A 1	—	60	5	?	5	25-40	
42	3' Above 1	B 20	A 76	Orthopyr.	—	—	B 1	—	A 3	Biotite	60	5	?	None Left	25-40	
9, 10	1	A 50	A 49	Orthopyr.	B Trace	—	B 1	—	A Trace	Biotite	60	5	< 0.5	5	25-40	
41	4' Above Main Seam	B 10	A 85	Orthopyr.	C 1	C 0.5	C 2	—	A 1.5	Biotite	60	5	?	None Left	25-40	
8	Felspathic top	B 50	A 49	Orthopyr.	B	—	A Little	—	A 1	Biotite	60	5	?	5	25-40	
7	Top Half	100			0.5						60	5	1.7	5	25-40	
6	Felspathic centre	A 50	A 47	Orthopyr.	—	—	Trace	—	A 3	Biotite	60	2	?	7	25-40	
5	Silicate in lower half	A 50	A 5	Orthopyr.	B 40	C 5	—	—	A Trace	Biotite	70	12	?	7	5-15	
4	Basal half	100		Orthopyr.							60	5	1	5	25-40	
3	Basal Contact		Predomin. below seam	—	—	—	—	Crystal Chain 1mm. from base	—	—	75	12	?	8	0-10	
2	3	A 70	A 27	Orthopyr.	B 0.5	—	MAGNETITE WITH OLIVINE 1%	B 1.5	—	—	60	5	?	5	25-40	
1	1										60	5	1.25	1 left	25-40	
32	PLUGS Steelpoortdrift	100									60	2	?	2 left	25-40	
33	Below 8 Seam Magnet Heights	100									60	3	2.5	None Left	25-40	
34	Below 11 Seam Magnet Heights	100									80	10	?	None Left	5-15	

\* LETTERS IN ALPHABETICAL ORDER INDICATE THE ORDER OF CRYSTALLISATION

o NUMBERS ARE PERCENTAGE OF TOTAL COMPOSITION.

o PLATES ARE INFERRED ORIGINALLY TO HAVE BEEN PRESENT BUT LATER TO HAVE MIGRATED ELSEWHERE.

is a function of their position in the stratigraphical column and is not related to their size or thickness (Fig. 64 and Table I)

- b.) The seams show no lateral variations in  $V_2O_5$  content. This appears to be true over the entire Bushveld Complex, results from Northam in the West Transvaal being directly comparable with those from Magnet Heights.
- c.) The  $V_2O_5$  content of the plugs is slightly less than, but similar to <sup>that of the</sup> magnetite seam near the same horizon (Fig. 64).
- d.) The seams, and to a large extent the plugs, can be grouped into four sub-zones with  $V_2O_5$  contents of approximately 2%, 1.5%, 0.6% and 0.3% (See Map IV). There is an overall decrease in the  $V_2O_5$  content and Fe content, and an increase in  $TiO_2$  content upwards in the column. The result of plotting  $V_2O_5$  content against position in the stratigraphical column is shown on Fig. 64. (The  $V_2O_5$  content is plotted on the ordinate so that the graph can be compared with that of Vincent & Phillips (1954,p.18).

Average assays of the Main Seam and Seam No. 21 follow: -

	<u>TiO<sub>2</sub></u>	<u>Fe</u>	<u>V<sub>2</sub>O<sub>5</sub></u>
Seam No. 21	13%	50%	0.3%
Main Seam	14%	57%	1.6%

As already pointed out by Schwelinus and Willems (1943, p.33-34) the fact that, when  $TiO_2$  increases,  $V_2O_5$  decreased<sup>s</sup>, proves almost conclusively that the  $V_2O_5$  is not contained in the titanium minerals.

#### 4.) LAYERED BASIC ROCKS

The four important rock minerals encountered are plagioclase, pyroxene, magnetite and olivine. The first three are locally concentrated into monomineralic anorthosite, pyroxenite and magnetite.

Olivine reaches a maximum concentration of about 30% in troctolite.

Orthopyroxene does not decrease conspicuously in amount relative to clinopyroxene, upwards in the sequence. The mafic rocks are generally gabbroic, though locally they are hyperitic, noritic or troctolitic.

Within a few hundred feet of the roof, dark patches appear in the layered rocks. These represent poikilitic hornblende crystals, which have replaced pyroxene and this rock is monzonite (Slide 53 of sample taken in layered rocks below conical hill capped by quartzite, in the eastern part of Magnet Heights 846. KS).

In the following account of the rocks, the distance of a layer from the Main Seam is stated in feet, and the rock numbers, which are the same as their slide numbers, are indicated on the regional map (No. 1).

Anorthosite (-1,000 feet, Slide 59) contains little interstitial clinopyroxene and there is some overlap of feldspar and magnetite crystallisation, though magnetite tends to be later than the plagioclase. Some of the larger plagioclase grains are bent (Fig. 65) and between these large laths is late crystallising feldspar (Fig. 66).

Troctolite (-100 feet, Slide 40). This rock, on weathering, gives rise to an uneven knobby surface. It contains a little pyroxene, and plagioclase, which crystallised first, was followed by magnetite and olivine. There is some intergrowth of olivine with magnetite, and orthopyroxene sometimes forms a rim between olivine and plagioclase.

Anorthosite directly below the Main Seam (Slide 3 and 60)

This is the best known anorthosite in the area and is about six feet thick, being mottled, with a banded lower portion (Fig. 68) and a sharp upper contact (Fig. 44). The uppermost foot contains disseminated sulphide specks. According to Prof. J. Willemse (verbal communication) the sulphides present constitute the typical copper-nickel-iron association to be found in mafic complexes and their presence in this position was noted, probably for the first time, by Prof. F. Ramdohr during the International Geological Congress tour of the Bushveld Complex in 1929.

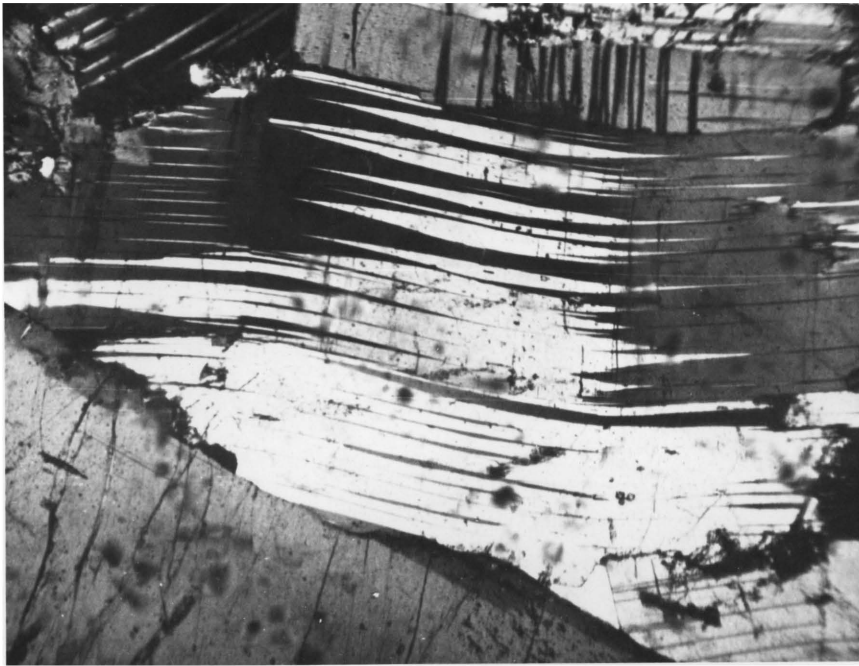


Fig. 65 A bent plagioclase lath in anorthosite (-1,000 feet, Steelpoortdrift 365. KT, Slide 59). Crossed Nicols, X 35.

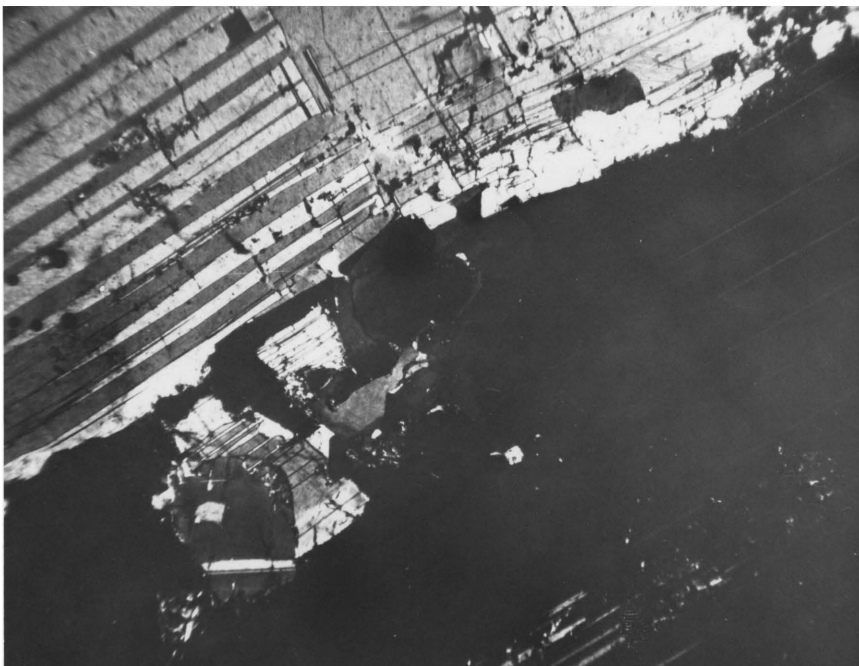


Fig. 66 Small late-crystallised plagioclase grains interstitial to large laths. Anorthosite (-1,000 feet, Slide 59), Crossed Nicols, X 50.

Within one inch of the top of the anorthosite is some olivine which crystallised late in company with pyroxene. Further below the seam the only dark mineral is about 5% of poikilitic pyroxene, partly altered to hornblende and chlorite.

Norite (150 feet, Slide 43) This rock sample was taken on Magnet Heights 846. KS and it is the only true norite that was identified. The orthopyroxene contains exsolved clinopyroxene and there are also a few discrete crystals of the latter mineral. Feldspar began to crystallise first but later crystallised simultaneously with orthopyroxene.

Pyroxenite (420 feet, Slide 45) Magnet Heights 846.KS This rock was sampled in the western tributary joining the Magnet Heights River about a mile south of the Store. It contains about 80% of pyroxene and there is twice as much ortho- as clinopyroxene. Pyroxene is included in plagioclase crystals and grew simultaneously with, or earlier, than plagioclase. This is the only rock in which pyroxene was seen to be included in feldspar.

Gabbro below Seam No. 6 (440 feet, Slide 15) Magnetite and plagioclase crystallised first (Fig. 19), being embedded in a pyroxene groundmass. The rim between clinopyroxene and plagioclase and between clinopyroxene and magnetite is orthopyroxene. That between orthopyroxene and plagioclase is clinopyroxene. In an intergrowth of pyroxene and feldspar, the former seems to be replacing the latter.

Troctolite below Seam No. 8 (Slide 46)\* forms a prominent scarp (T1 on Fig. 2.). This sheet is about twenty feet thick and outcrops strongly northwards across 'the Flats'. It is exposed near the sisal hedge on the road to Jane Furse Hospital. It is easily traced southwards until it disappears beneath recent deposits on Aapjesboom 834. KS.

Anorthosite below Seam No. 8 (Slide 61) consists of four closely spaced bands. The uppermost three are each one foot thick and the lowest one, which lies directly above the troctolite, is eight feet thick.

Hyperite Xenolith in Seam No. 11 (1,700 feet, Figs.56 & 70, Slide 22). Orthopyroxene is three times as common as clinopyroxene and the

\* the olivine of this rock was examined by Reckhow (1958, p.3). & was found to contain between 39% & 58% Fe. / 86 .....

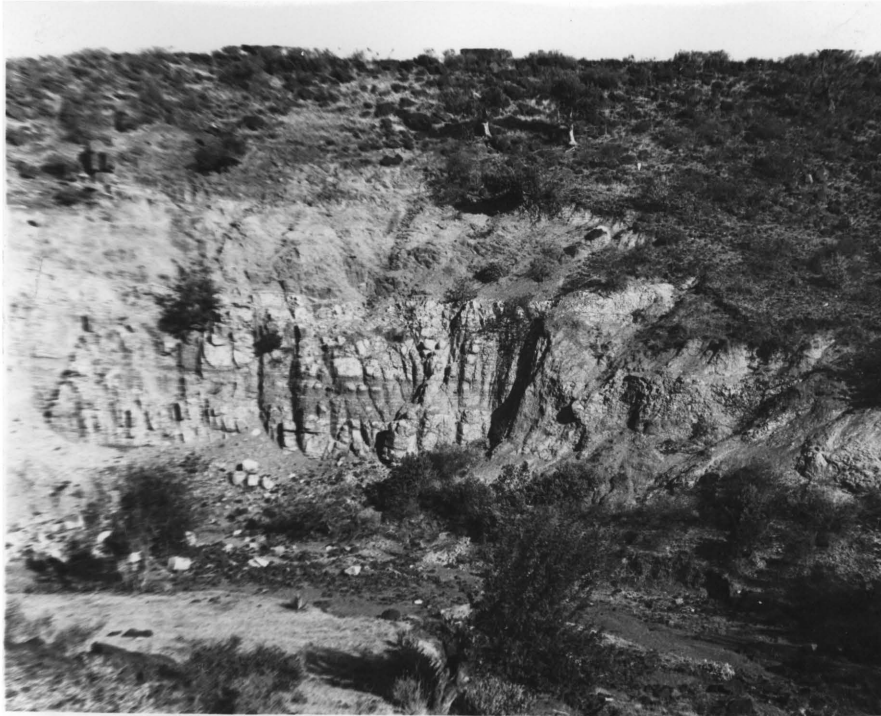


Fig. 67 Thick banded anorthosite (white) below the Main Seam (on the skyline). Blocks of magnetitite have slumped down the slope. This cutting is in Magnet Heights River about half-a-mile south of the Trading Store on Magnet Heights 846. KS.

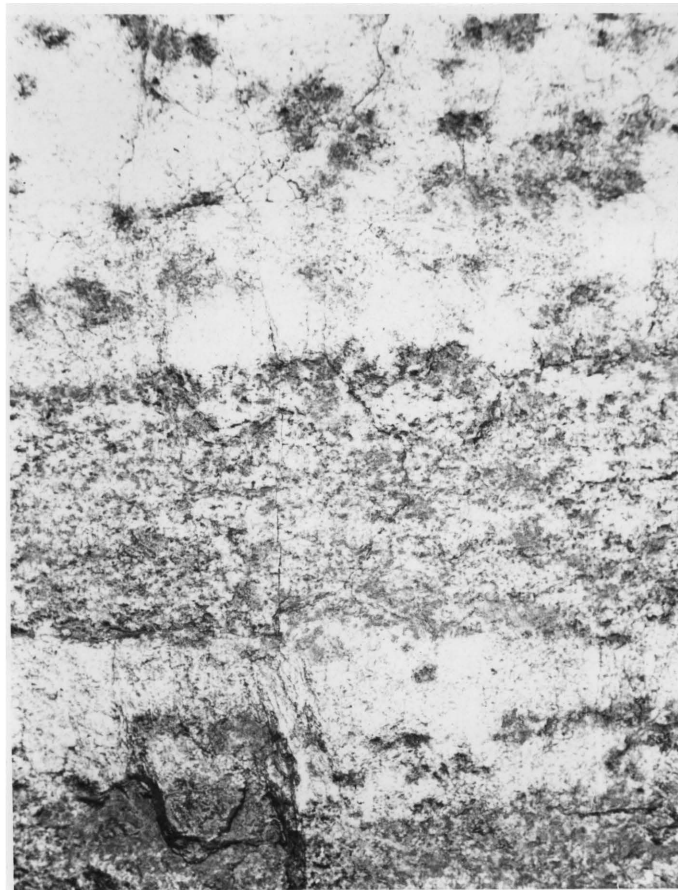


Fig. 68 Prominent banding in the base of the anorthosite band directly below the Main Seam (not in photo). The dark mineral in the anorthosite is poikilitic pyroxene. Locality - Magnet Heights River on Ironstone 847. KS.



Fig. 69 Spotted gabbro (3,500 feet). The white ovoidal spots are plagioclase.

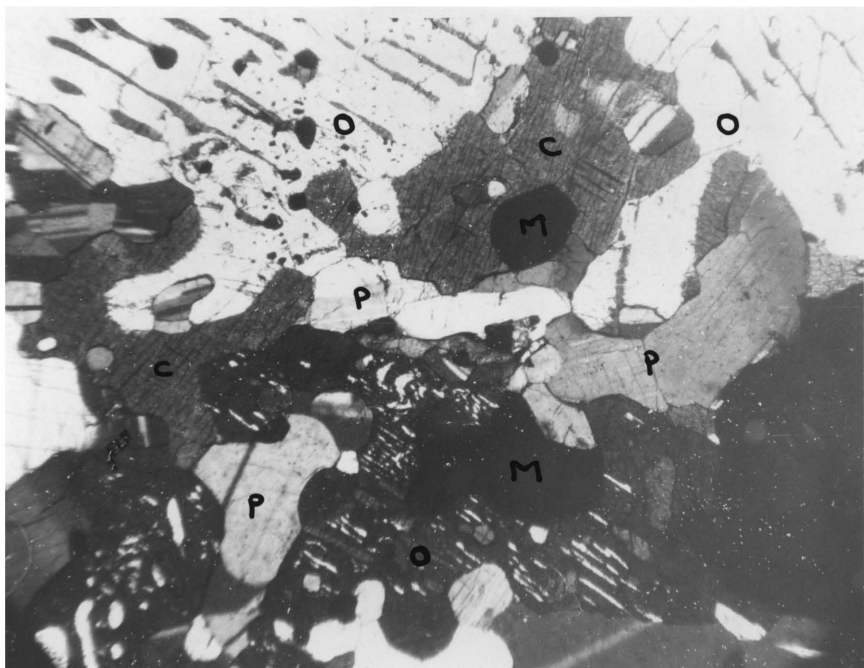


Fig. 70 Hyperite occurring as a xenolith in Seam No. 11.  
O - orthopyroxene exsolving clinopyroxene  
C - clinopyroxene, P - plagioclase, M - magnetite.  
Slide 22. Crossed Nicols, X 30.

biotite has become darker than lower in the sequence. The orthopyroxene has exsolved clinopyroxene and magnetite includes small plagioclase crystals, a phenomenon which was observed only in this rock.

Troctolite (1,800 feet, Slide 48) forms another conspicuous scarp (Fig. 4) and is about fifty feet above Seam No. 11. Troctolite outcrops as unbroken sheets in contrast to gabbro, which weathers along its joints and disintegrates into blocks. It contains little pyroxene and its olivine crystals are considerably cleaved. There is some intergrowth of magnetite with olivine.

Anorthosite above Seam No. 13, (Slide 63)

It is mottled and overlies the seam with a sharp contact. The pyroxene present in the rock has formed poikilitic grains (Fig. 72). There is some interstitial magnetite present.

Plagioclase, magnetite and olivine are interpreted as having crystallised simultaneously, though the magnetite was possibly first.

Rising from Seam No. 14 is a steep scarp composed of gabbro at the base and capped by a sheet of troctolite (Fig. 2, Slide 50). This scarp is a prominent feature and outcrops across 'the Flats' to the north as a ridge a few feet high and is also the last ridge to be submerged to the south under the recent deposits on De Hoop 836. KS. The fabric of this troctolite is shown in Fig. 71

Anorthosite above Seam No. 15 (Slides 62. and 64) This forty feet thick band is the highest anorthosite in the sequence and has a sharp upper contact with the overlying spotted hypersthene gabbro. The band outcrops strongly and even on 'the Flats' produces a litter of rubble. It weathers to a particularly sticky red clay and the portion of the road to Jane Furse Hospital, which traverses it, is almost impassible to motor vehicles after heavy rain.

Spotted Hypersthene Gabbro (3,500 feet, Fig. 73, Slide 51) contains ovoidal plagioclase bodies (Fig. 69) and is consequently a good marker band. These bodies are composed of corroded feldspar aggregates which contain a weathered dark mineral, probably pyroxene. These

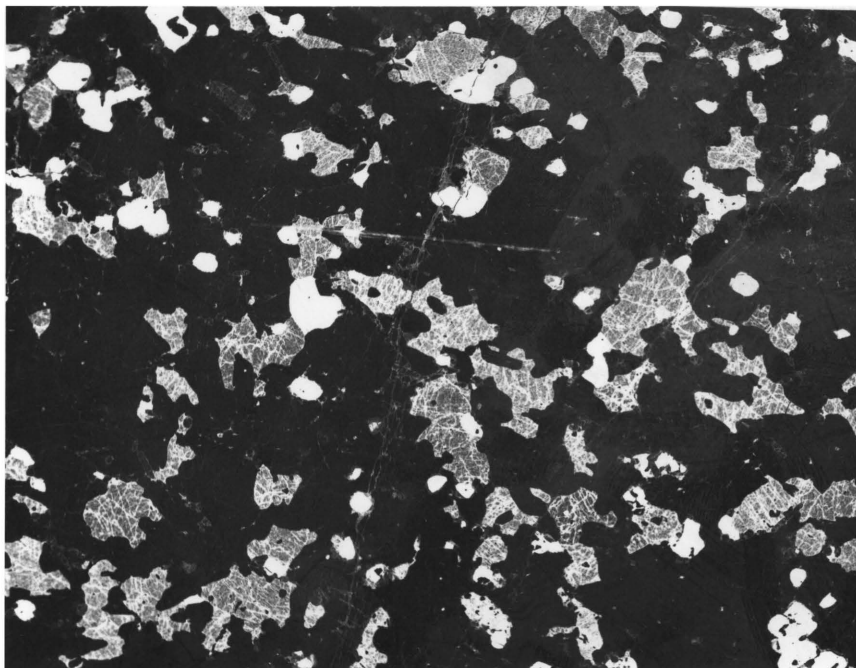


Fig. 71 Textural relationship between plagioclase (black) olivine (grey) and magnetite (white). It is interpreted as indicating simultaneous crystallisation of the three minerals, though magnetite may be slightly earlier than the others. Troctolite (3,200 feet). Slide 50. Negative photograph, X7.



Fig. 72 Plagioclase laths (black) enclosed in a poikilitic pyroxene crystal (white) towards the right hand side of the photograph. Anorthosite above Seam No. 13. Slide 53. Negative photograph, X 5.

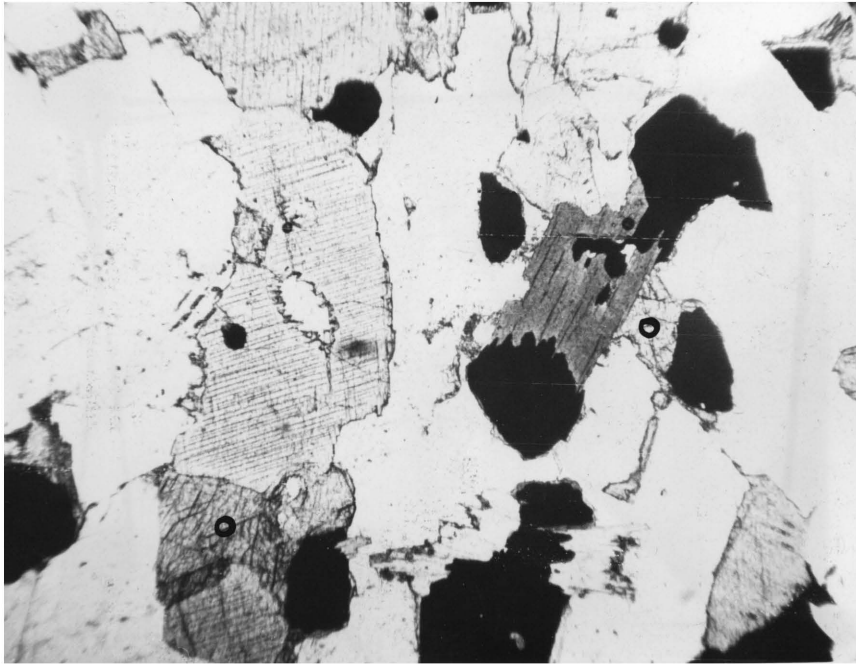


Fig. 73 Biotite (grey plates) is interpreted as having crystallised simultaneously with magnetite (black), and likewise clinopyroxene (grey and hatched) with plagioclase (white). A little orthopyroxene (o) is present. Spotted hypersthene gabbro (3,500 feet). Slide 51, Polarised light, X 35.

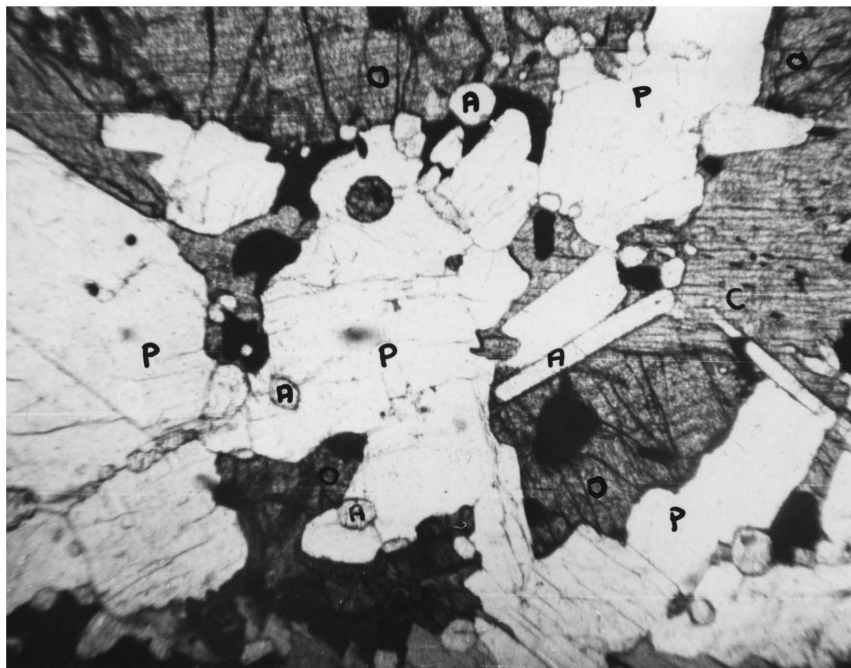


Fig. 74 Apatite (a), plagioclase (p), olivine (o) and clinopyroxene (c). Olivine gabbro (4,200 feet). Slide 52. Polarised light, X 35.

These feldspathic inclusions in the gabbro may be corroded phenocrysts, or may have been crystal clots suspended in the magma. In the rest of the rock, clinopyroxene is the dominant pyroxene and there is a considerable amount (10%) of magnetite in the rock.

Biotite ~~shows simultaneous growth~~<sup>is well grown</sup> with magnetite and likewise ~~does~~ clinopyroxene with feldspar (Fig. 72).

Between one hundred and one thousand feet of gabbro lies above Seam No. 21. Where the roof material is diabase, leptite or granite, the gabbro is nearly a thousand feet thick, but the quartzite outlier of Signal Hill has sunk unconformably to within one hundred feet of Seam No. 21 (Fig. 11).

Olivine Gabbro below Signal Hill Quartzite (4,200 feet, Fig. 76, Slide 52)

Apatite is always idiomorphic. Magnetite and plagioclase crystallised early followed by olivine which is cleaved. Biotite is very dark and crystallised simultaneously with magnetite. Clinopyroxene has exsolved a little magnetite. A little pyroxene is altered to hornblende, which also seems to have replaced biotite.

The topmost part of the gabbro is contaminated by Roof material. Evidence of granitisation in the field is reddening of the gabbro and the appearance of irregular pegmatite stringers. Hornblende has replaced poikilitic pyroxene crystals in the gabbro. Where the gabbro is in contact with sediments of the Roof, it is intermingled with hard, grey, flinty, intensely metamorphosed, material.

Dark Patch in Gabbro (4,700 feet, Slide 53)

The dark mineral is a large poikilitic hornblende crystal which seems to have replaced pyroxene. As the rock contains a little quartz, and nearly equal quantities of orthoclase and plagioclase, it is called monzonite.

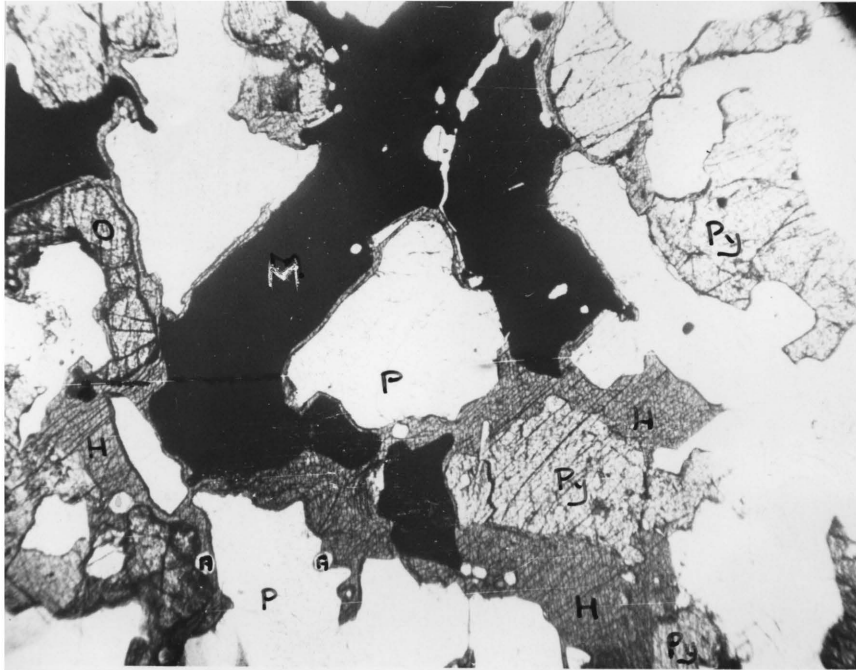


Fig. 75 Hornblende (h) replacing pyroxene (py). Also in the photograph are plagioclase (p), olivine (o), magnetite (m) and apatite (a). Olivine gabbro (4,400 feet). Slide 56. Polarised light, X 35

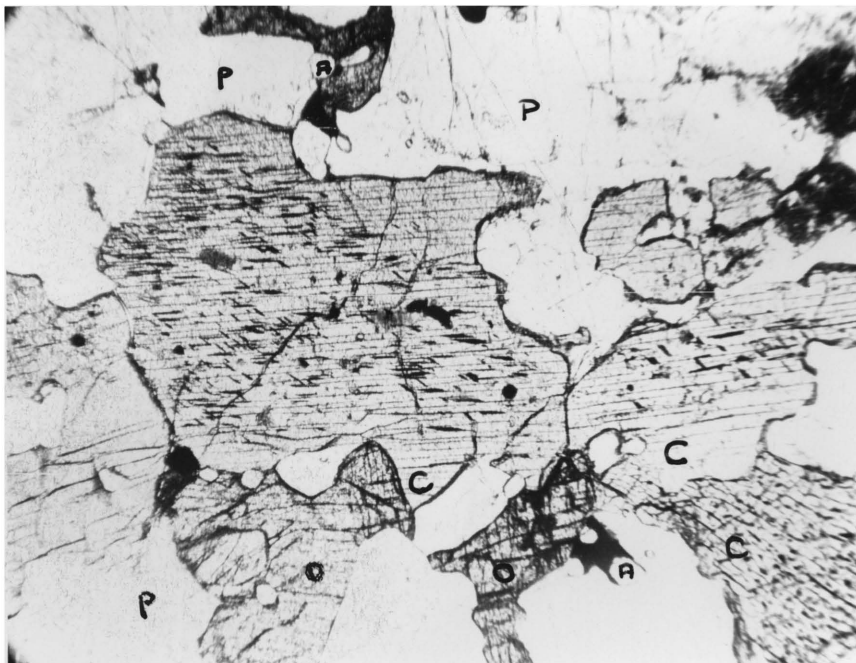


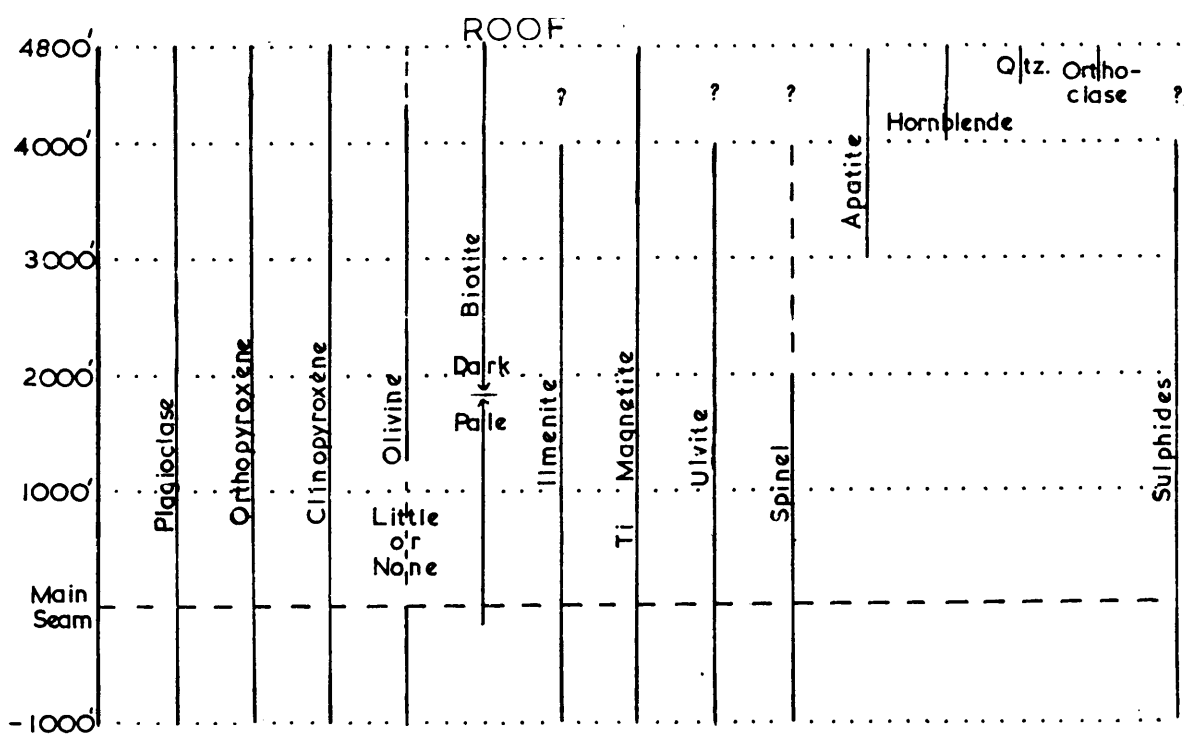
Fig. 76 Clinopyroxene (c) exsolving magnetite (black). Also present are plagioclase (p), olivine (o) and apatite (a). Olivine gabbro (4,400 feet). Slide 56. Polarised light, X 35.

TABLE 5

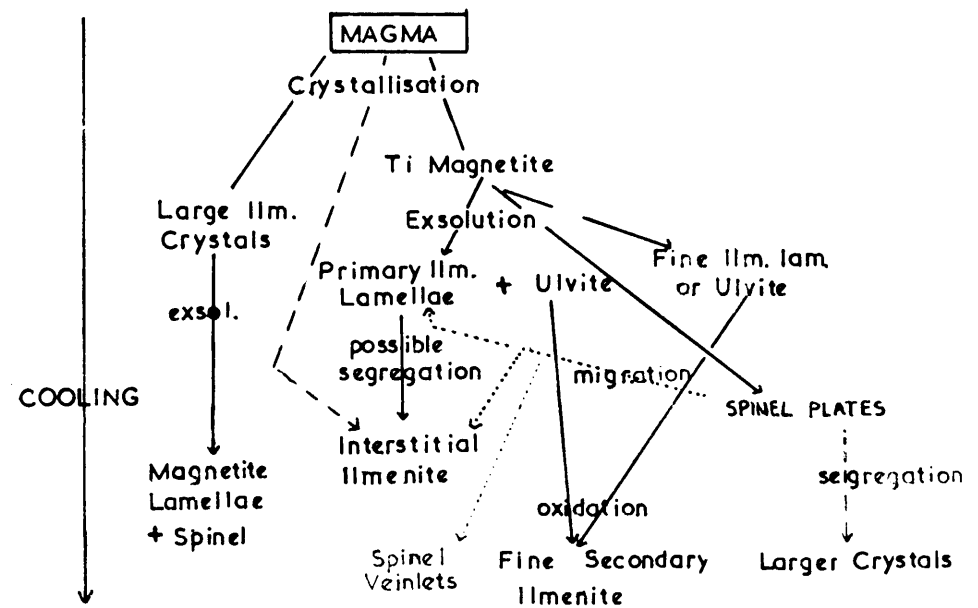
VOLUMETRIC COMPOSITION OF THE SILICATE ROCKS												
SLIDE N°	Position in Column Relative to Main Seam	Plagioclase	Orthopyroxene	Clinopyroxene	Olivine	Magnetite	Biotite	Apatite	Hornblende	Quartz	Orthoclase	ROCK TYPE
54	Roof 4800' Against Leptite	A <sup>o</sup> 20*		B 1		A Little	B 2	A Little	C 2	C 25	C 50	Normal Granite
55	Roof 4800' Against Diabase	A 40	7	C 12		B 8	A Little	A Little	D 8	D 20	D 5	Quartz Diorite
53	4700'	A 30				A	A 1	A	B 25	B 9	B 35	Monzonite
56	4400'	A 56	B 2	B 26	B 10	A 2	Trace	A 1	C 3			Olivine Gabbro
52	4200'	A 56	B 8	B 22	B 5	A 4	A 4	A 1				Gabbro
51	3500'	A 60		C 20		A 10	B 3					Spotted Hypersthene Gabbro
62	3400'	A 98		C 1		B 0.5	B 0.5					Anorthosite
50	3200'	A 67			C 24	B 6	B 0.5	A 2.5				Troctolite
49	2900'	A 42	B 15	B 35		B 7	B 1					Hypersthene Gabbro
48	1800'	A 65	B 2	B 1	B 26	A 4	A 2					Troctolite
22	1700'	A 36	B 50	B 13		B 2	A 1					Hyperite Xenolith
47	1500'	A 80	B 20				Dark					Noritic Anorthosite
61	1250'	A 90	B 5				Pale		C 5			Anorthosite
46	1200'	A 45	B 3		A 45	A 6	A 1					Troctolite
15	440'	A 78	C 4	C 11		B 6	A 1					Magnetite Gabbro
45	420'	C 16	B 58	B 22		B 2	A 2					Pyroxenite
44	340'	A 65	B 13	B 20		B 2	A Trace					Hypersthene Gabbro
43	150'	A 55	A 40	B 5								Norite
42	16'	A 76	B 1			A 20	A 3					Magnetite Anorthosite
41	4'	A 86	C 2	C 0.5		B 10	A 1.5					Magnetite Anorthosite
60	Main Seam -2'	A 95		B 5					C Trace			Anorthosite
37	-30'	A 80	B 5	A 15		Little	Trace					Gabbroic Anorthosite
40	-100'	A 71	B 2		B 26	A Little	A Trace					Troctolite
39	-900'	A 40	B 19	B 32		B 9						Hypersthene Gabbro
59	-1,000'	A 96		B 3		A 1						Anorthosite

\* NUMBERS ARE PERCENTAGE OF TOTAL COMPOSITION

o LETTERS IN ALPHABETICAL ORDER REPRESENT CRYSTALLISATION.



**FIG 77**  
 Mineral Distribution in the Uppermost 6000' of the Bushveld Gabbro  
 at Magnet Heights



**FIG 78**  
 DIAGRAMMATIC REPRESENTATION OF PARAGENESIS OF IRON  
 TITANIUM OXIDES & SPINEL IN MAGNETITITE AT MAGNET HTS.

Granite against Leptite roof (4,800 feet on Schoonoord 326. KT Slide 54)

This rock contains 25% quartz and abundant microperthite, evidently a replacement perthite. It is obviously a granite. Biotite and pyroxene are being replaced by an amphibole which, in places, has a conspicuously green pleochroic colour. Apatite and magnetite are also present and the rock is regarded as a granitised gabbro.

Quartz Diorite in contact with Diabase roof on Duizend Annex, 816. KS (Slide 55)

In this slide are small euhedral biotite and apatite crystals. The clinopyroxene contains exsolved magnetite. In the rock is a considerable amount of magnetite. A little orthoclase has replaced plagioclase and this rock is also considered to be a granitised gabbro.

C H A P T E R VII .

PETROGENESIS

I.) PARAGENESIS OF ILMENITE, ULVITE AND SPINEL IN THE MAGNETITITE

Before considering the petrogenesis of all the minerals together, the salient paragenetic features of each will be summarised.

a.) Ilmenite. Four varieties of ilmenite were observed in the magnetitite.

- (i) Coarse subhedral crystals (Figs. 26 and 27) are often twinned and many contain exsolved magnetite and spinel (Figs. 28 and 29). There is some slender evidence that these grains are younger than the magnetite, but it is, nevertheless, very likely that they are primary crystals precipitated directly from the magma. The large size

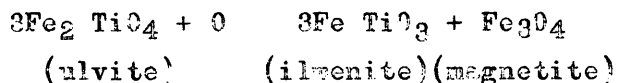
and difference in appearance (twinning and exsolved magnetite lamellae) of these ilmenite grains in the Bushveld magnetite compared to the obviously exsolved ilmenite suggests strongly that these large crystals were precipitated directly from the magma.

According to Vincent (1960, p.1013) in the Skaergaard Intrusion, not until perhaps 75% of the whole magma had crystallised, was the remaining liquid able to deposit titaniferous magnetite (and probably also ilmenite) in quantity as a primary precipitate mineral.

The exsolved magnetite lamellae in the Bushveld ilmenite are often interrupted by spinel sheets (Fig. 29). Randohr (1956, p. 10) pointed out that spinel in ilmenite often occurs next to magnetite or haematite. Vincent and Phillips (1954, p. 3)<sup>also</sup> recorded that magnetite lamellae exsolved by ilmenite probably contain spinel and Vincent (1960, Fig. 7) has <sup>even</sup> ~~also~~ photographed this <sup>later</sup> ~~phenomena~~.

- (ii) Interstitial Ilmenite Grains (Fig. 30) usually are untwinned and have not exsolved magnetite lamellae. They may have been precipitated directly from the magma or, otherwise, have grown ~~from~~ through segregation of ilmenite lamellae originally exsolved by magnetite. It is tentatively suggested that ilmenite lamellae in the magnetite may sometimes have segregated into the interstices between the magnetite crystals leaving ~~small grains~~ ~~behind~~ small spinel grains as a discontinuous sheet (Fig. 39).
  
- (iii) Primary Ilmenite Lamellae (Fig. 32) are scattered sparsely and irregularly throughout the magnetite grains of the seams and were exsolved directly from the magnetite early during its cooling. They are conclusively not formed by oxidation of ulvite as this mineral <sup>is present</sup> ~~exists~~ directly in contact with the lamellae. As mentioned previously, these lamellae may sometimes have segregated into the interstices to form small interstitial ilmenite grains.

(iv) Ilmenite of doubtful origin. According to Sandohr (1953, p.622) small ilmenite lamellae showing oblique extinction, have been produced by oxidation of ulvite. If this ~~is true~~<sup>holds throughout</sup>, the fine lamellae near the base of the Main Seam (Figs. 34 and 35), and those in the plug below Seam No. 11 (Fig. 31), have been produced ~~by oxidation of ulvite.~~<sup>in this way</sup> Evidence possibly corroborating this is the fact that they are antipathetic in quantity to ulvite. Sandohr (1956, p. 10) recorded that "ilmenite has been seen in all stages of change to ulvite. Inside the triangle  $Fe_2TiO_4-Fe_3O_4-FeTiO_3$  simultaneous separation of ilmenite and ulvite is to be expected near the magnetite corner ~~(Fig. 8)~~. Foslje's assumption that ulvite oxidises to give ilmenite is not always correct. Nevertheless, secondary ilmenite coming from ulvite is found" .



However, these fine lamellae may have been exsolved directly from the magnetite instead of <sup>from</sup> ulvite if sufficient oxygen was available. All the polished sections contain irregular, very fine, ilmenite which most probably was produced by oxidation of ulvite. In places secondary lamellae may have begun to develop by this process (Fig. 33).

- b.) Ulvite is almost universally present in the magnetite. Where it is rare or absent, its place has been taken by fine ilmenite lamellae . Generally, the magnetite contains about a third of its volume of ulvite.
- c.) Spinel, probably near to  $FeAl_2O_4$  in composition. Spinel plates are present in all the seams as high as Seam No. 12. They reach a maximum concentration of 2% in the magnetite of the Main Seam and Seam No. 9. Ulvite has formed boxes round spinel. In the magnetite above Seam No. 12 are ulvite boxes <sup>without cores of spinel</sup> and it is therefore inferred that some spinel plates were present but subsequently migrated out of the magnetite into the interstices (Fig. 42). Nevertheless, a generalisation can be made that the uppermost seams contain less spinel than

those lower in the sequence. The plates are interpreted as having exsolved later than much of the ulvite (Fig. 37) and then the fine ilmenite lamellae (Fig. 34). Spinel blebs have accumulated in the margin of large ilmenite crystals (Fig. 35) and <sup>of</sup> large ilmenite lamellae (Fig. 32) and the constituents probably reached the ilmenite by direct migration <sup>from</sup> by solid solution with the magnetite.

The spinel plates are considered to have been relatively mobile and to have been capable of segregating into discrete grains (Fig. 40). Plates have not been mentioned by Vincent and Phillips (1954 and 1960) in the Skaergaard magnetite and this may be due to the abundance in the Skaergaard of gangue into which the spinel migrated out of the magnetite. For example, the pure magnetite of the Main Seam contains plenty of spinel plates while, four feet above the seam, there is none.

Spinel sheets occur in the places of magnetite lamellae exsolved by ilmenite (Fig. 29). Vincent (1960, p.1297 and Fig. 7) also recorded the same phenomenon in the Skaergaard Intrusion.

d.) Generalised paragenetic sequence of exsolution of <sup>the ore</sup> minerals in the Bushveld magnetite

As the solid magnetite cooled, the first minerals to have been exsolved were the primary ilmenite lamellae and ulvite. In places such as near the base of the Main Seam, small ilmenite lamellae may have been exsolved instead of ulvite, implying the availability of oxygen during cooling.

The Main Seam contains approximately 14%  $TiO_2$  and about 35% ulvite and 5% ilmenite. 35% ulvite and 5% ilmenite recalculated to  $TiO_2$  gives about 14%  $TiO_2$ , which is approximately that present in the Main Seam. Therefore all, or nearly all, of the  $TiO_2$  has been expelled from the magnetite lattice and is now incorporated in ilmenite and ulvite.

The  $TiO_2$  content of Seam No. 21 is 13% but, as there is only a small increase in the amount of ilmenite compared to the Main Seam, ulvite probably increases slightly in quantity upwards in the sequence.

The third mineral to have been exsolved from the magnetite was spinel. Spinel ( $\text{FeAl}_2\text{O}_4$ ) contains about 31.3% Al. Magnetite exsolving 5% spinel must have held about 1.6% Al in its lattice. H.D.B. Wilson (1953, p.370-407) listed the following atomic radii: Al  $^{+++}$  0.57, Fe  $^{+++}$  0.67, Fe  $^{++}$  0.87, Ti  $^{+++}$  0.69 and pointed out that the ease, with which an ion is accommodated in the lattice of a crystal of another ion, depends on the degree of correspondence of their atomic radii, their valancies being equal. Fe $^{++}$  shows the biggest discrepancy in the above list and it is also Fe $^{++}$  which combines with Ti and O in ulvite and ilmenite. Possibly these minerals were hurriedly exsolved by magnetite because of this discrepancy in the atomic radius of Fe $^{++}$ . However, it is also possible that ilmenite and ulvite were exsolved first because the magnetite contained much more Ti than Al. There is some overlap of the exsolution of these two Ti minerals with that of spinel.

The large ilmenite crystals, probably precipitated directly from the magma, developed twinning and exsolved magnetite lamellae during their cooling.

The last chemical reaction to have taken place during the cooling of the magnetite was the oxidation of some of the ulvite to fine irregular ilmenite.

Physical reorganisation of the minerals, thought to have taken place at a late stage of cooling, includes

- 1.) <sup>The</sup> Segregation of spinel plates into discrete grains and <sup>the</sup> migration of spinel into ilmenite and gangue.
- 2.) <sup>The</sup> Possible migration of ilmenite lamellae into the interstices of the magnetitite. Edwards (1954, p. 77) recorded that migration of ilmenite into the interstices between magnetite grains is possible if cooling is slow!

Weathering of the magnetitite produced martite, maghemite and veins of secondary magnetite containing lamellae of hematite.

2.) Petrogenesis of the monomineralic rocks in the upper Portion of the layered rocks of the Bushveld Complex

a.) General characteristics of the magnetitite and the anorthosite rocks.

The following aspects have to be borne in mind in trying to explain the origin of the monomineralic rocks in the upper Portion of the Bushveld Igneous Complex.

- (i) Plagioclase and magnetite are intimately associated in the magnetitite seams (Figs. 18 and 21) whereas pyroxene and olivine are scarce.
- (ii) Plagioclase and magnetite started to crystallise before pyroxene and olivine in nearly all the layered rocks.
- (iii) When the contact of a magnetitite seam is transitional, the gradation is into magnetite anorthosite. They generally take place upwards (Fig. 49), though Seam No. ~~18~~<sup>13</sup> is exceptional in that it is overlain with a sharp contact by pure anorthosite and grades downwards into gabbro (Fig. 57). Contacts of magnetitite with pure anorthosite are sharp (Fig. 54). Near the middle of the Main Seam there is a feldspar-rich zone (Fig. 46).
- (iv) Below each group of magnetitite seams is a considerable amount of anorthosite (Fig. 67).
- (v) Monomineralic bands do not transgress from one horizon to another, though occasional bulging and thinning developed contemporaneously with the formation of the bands.
- (vi) Platy crystals and elongated xenoliths are orientated parallel to the igneous layering implying some type of flow during the formation of the rocks (Fig. 49). Currents can not have been strong, however, as there was little or no erosion of the floor of the magma chamber.
- (vii) The floor, on which the monomineralic bands were

extraordinary lateral persistence of even the thinnest units. The sequence at Zwartkop 142.JS, twenty miles south, is similar to that at Magnet Heights 846. KS, even in detail. Seams at Northam, 250 miles to the west, can be correlated with those at Magnet Heights 846. KS.

- (viii) There is a steady decrease in  $V_2O_5$  content of the seams upwards in the sequence, (Fig. 64).
- (ix) Plugs of magnetite transgress the layering of the gabbro and have a  $V_2O_5$  content similar to seams near the same horizon (Fig. 64).
- (x) The same mechanism is likely to have been responsible for the formation of different layered monomineralic rocks.

b.) Theories suggested by other workers to explain the formation of the monomineralic rocks

- (i) Differentiation at depth followed by separate intrusions aided by gravity settling of crystals within the individual heaves was postulated by Lombaard (1934, p.32/33).
- (ii) Sinking of residual magnetite liquid and floating upwards through this liquid of plagioclase crystals was suggested by Hall (1932, p.347-350) to explain the formation of the Main Seam. The main objection to this hypothesis is that much of the magnetite crystallised early, a fact that was not observed by Hall when he suggested this theory, for example, Seam No. 6 starts with an increase in the number of magnetite crystals in the gabbro and this fact directly contradicts the idea that the seams formed by accumulation of residual magnetite liquid.
- (iii) The magnetite seams are sheet-like bodies which were fed by the plugs and were intruded into the gabbro as sills (Coertze 1964, p. 51/68). If a magma is capable of differentiating to produce magnetite, it appears more likely that it did so in the present magma chamber and to have deposited the seams directly on its floor instead of by differentiating in a hypothetical magma reservoir at depth.

Differentiation at depth entails squeezing out and intrusion of the magnetite magma to a higher level, to spread out as a uniform sheet seventy miles long and six to nine feet thick. No seam at Magnet Heights or elsewhere was seen to transgress from one horizon to another nor was any evidence observed suggesting a break in the layered rocks at the horizon of the Main Seam. This hypothesis also fails to explain the feldspathic parting in the Main Seam.

If the plugs were feeders bringing up magnetite from below to feed the seams, at the Main Seam horizon for example, one would expect to find plugs with  $V_2O_5$  contents corresponding to all the seams higher in the sequence. What is, in fact, the case is that the  $V_2O_5$  content of all the plugs is similar to that of the seams near the same horizon (Fig. 64). This suggests that plugs originated not far from the horizon at which they now occur.

(iv) Crystal settling, aided by convection currents, was first put forward by Grout (1913) as a mechanism to explain the formation of monomineralic rocks in the Duluth gabbro. Wager & Deer (1939) suggested the same theory to explain the differentiation of the Staergaard intrusion. Differentiation of the Stillwater Complex was concluded by Hess (1956) also to have been produced by this mechanism. Cameron (1959), dealing with the chromitite seams of the Eastern Bushveld Complex, decided that the seams were formed by sorting and deposition of chromite crystals by magnetic currents followed by subsequent enrichment of this crystal pile by the process of diffusion to produce pure chromitite. Steyn (1950, p. 47) working at Magnet Heights, made the following important observation: -

" Die relatief vroeg kristalliserende magnetiet het deur swartekrag - differensiasie uitgeskei en versamel op 'n meer soliede bodem om daar 'n laag te vorm. "

Wager, Brown & Wadsworth (1957, p.75-30) introduced the following useful terms. Cumulus material is that which accumulated on the floor of the magma chamber by crystal settling. Intercumulus material is the matrix which cemented this cumulus crystal pile

Crystal settling is the mechanism favoured by the writer, for the following reasons, to explain the formation of the monomineralic rocks at Magnet Heights.

Plagioclase and magnetite began to crystallise early and, therefore, in the partly consolidated magma ~~there were~~ crystals of these minerals, ~~which~~ could have been deposited as layers of magnetite or <sup>plagioclase</sup> ~~anorthosite~~ crystals by magmatic sedimentation. In contrast olivine, which crystallised late in this part of the Bushveld Complex, does not form dunite or harzburgite. Pyroxene, which also crystallised late, rarely formed pyroxenite.

As magnetite and plagioclase were the first minerals to start crystallising, it is reasonable that they should occur together as they, in fact, do. If a shower of magnetite and plagioclase crystals started to descend towards the floor of the magma chamber, the first to arrive would have been the denser, though smaller, magnetite crystals which would then have been followed by the slowly travelling feldspar. Crystal settling would have produced a conformable layer of crystals on the floor of the magma chamber, if that floor was level and provided the conditions in the magma were uniform and magmatic currents were not erosive.

Evidence of flow, which exists, can be incorporated into the theory of crystal settling by assuming that currents could have helped in the formation of monomineralic rocks by selective magmatic sedimentation. Small anorthosite xenoliths in the Main Seam might have risen from the anorthosite footwall, but were more likely to have been crystal aggregates suspended in the magma.

The one foot thick feldspathic parting in the centre of the Main Seam can be explained by the theory of crystal settling by postulating that the parting may represent a short break in the deposition of magnetite crystals. The steady change in the  $V_2O_5$  content of the seams upwards in the sequence, which corresponds closely to that in the Skaergaard Intrusion, suggests some continuous process of differentiation. While

magnetite began to crystallise early, it also continued to separate from the magma for a long time. It is possible that residual magnetite-rich liquid in the interstices of the nearly solid gabbro was locally concentrated into late pegmatoid segregations which were intruded upwards as magnetite plugs. This is also the opinion of van Rensburg (1962, p. 78). The parent magma of the layered mafic rocks is thought to have been basalt as this is the only type of magma which has been proved to have been generated in large quantities in the earth's crust. With regard to the intrusion of this magma, there are two possibilities: a) it was continually or intermittently added to a considerable amount of magma, which was already present and differentiating in the magma chamber, or b) all the magma was intruded before differentiation began. Cooling must have taken place through the roof of the magma chamber, which was not necessarily level. Mapping shows that portions of the Signal Hill quartzite sank several hundred feet into the gabbro. To have had a level undisturbed bottom, the magma chamber must have been at least a thousand feet deep at its deepest point so that the corrugated roof was floating clear of the floor. There is evidence of magmatic currents but they cannot have been as strong as they were in the Skaergaard Intrusion or the Stillwater Complex where they eroded the floor of the magma chamber and deposited the rocks as very elongated, lenticular units.

As the gabbro of the Main Zone crystallised, the concentration of ferric iron is postulated to have increased and magnetite consequently began to crystallise progressively earlier. Below the horizon of the lowest magnetite seam, magnetite did not crystallise early enough to have ~~been~~ <sup>been</sup> ~~abled it to be~~ sorted as a separate phase by crystal settling. The magnetite in this locality rather formed late dykes and plugs.

It is suggested that, at the horizon of the lowest seam, the magnetite crystallised sufficiently early to have allowed it to be separated mechanically by magmatic sedimentation into a layer of magnetite crystals. Another possibly relevant fact is that, shortly below the Main

Seam, biotite appears in the layered rocks implying the presence of water in the magma. This might have increased the fluidity of the magma and thereby facilitated crystal sedimentation.

The large amount of anorthosite, which separated out by crystal sorting about fifty feet, <sup>below</sup> and also directly, below the Main Seam may have tilted the balance in favour of magnetite crystallisation so that, when magnetite began to separate, a considerable shower of crystals was released by the magma. These magnetite crystals would have made their way to the floor influenced by gravity and magmatic currents to form a layer of magnetite crystals about three feet thick, constituting the basal portion of the Main Seam. A temporary slackening of the magmatic currents or a decrease in the rate at which magnetite was being precipitated may have caused the formation of the one foot thick feldspathic parting in the middle of the Main Seam. Then the return to the almost exclusive deposition of magnetite crystals would have produced another thick layer, which now constitutes the upper portion of the Main Seam. Plagioclase may then have been precipitated at the expense of magnetite or a change in conditions of sedimentation may have taken place to have produced the transition over one foot from magnetite through feldspathic magnetite into the overlying magnetite anorthosite. This transition may be analogous to a graded bed.

Assuming that the seams originated by crystal settling, one must look for an explanation of their rhythmic occurrence. Either magnetite was precipitated rhythmically from the magma and settled as seams at the intervals observed in the column or else, crystallisation of all the minerals took place at a constant rate and the different monomineralic rocks were produced through selective sedimentation by magmatic currents. Adherents of the theory of convective overturn of basic magma might attribute the rhythmic character of the occurrence of seams to periodic convective overturn of the magma. Because of the lateral persistence of monomineralic bands, rhythmic precipitation

of magnetite appears more likely. This rhythmic precipitation might have been due to intermittent addition of magma to the chamber or, <sup>due</sup> to ~~Wager's theory~~ of differing powers of crystal nucleation <sup>Wager</sup> (1959, p. 75-83).

About four hundred feet above the Main Seam a pyroxenite band possibly resulted from crystal settling. <sup>clear</sup> An example of the rhythmic nature of the layered rocks is the sequence above Seam No. 11. (Table 6)

T A B L E 6

Rock Sequence in the Vicinity of Seam No 11

<u>Thickness</u>	<u>Rock Type</u>	<u>Predominant Minerals</u>
Twenty feet	troctolite	olivine and plagioclase
ten feet	banded anorthosite	plagioclase
six feet	gabbro	plagioclase and pyroxene
one foot	pyroxenite	pyroxene
eight feet	magnetite anorthosite	plagioclase
one foot	magnetite (Seam No. 11)	magnetite
six inches	anorthosite	plagioclase

Approximately at the horizon of Seam No. 12 magnetite began to crystallise earlier than it had done lower in the sequence, as indicated by the fact that the uppermost magnetite seams are composed of smaller magnetite crystals and are <sup>friable</sup> ~~poorly cemented~~ compared to the seams lower in the column. This may have been because, as more magnetite crystallised earlier, less magnetite remained in the intercumulus magma to enrich the cumulus magnetite to form pure magnetite.

c.) Conversion of cumulus material to adcumulate rocks

A layer of cumulus crystals still contains more than 25% of interstitial liquid. Normal crystallisation produces a rock of the composition derived in Fig. 79.

Magnetite contains up to 97% magnetite and, therefore,

is an adcumulate rather than an orthocumulate rock - <sup>tyhe</sup>  
Hess (1956, p.146-148) describing the Stillwater Complex  
and Cameron (1959, p.1151-1214) working on the chromitite  
seams of the Bushveld Complex, both invoked diffusion  
and rejected partial remelting of sunken crystals as a  
mechanism to produce an adcumulate rock. Hess produced  
the following hypothetical statistics: "The crystal mush  
on the floor was about five feet thick. The rate of  
diffusion was comparable to the rate of sedimentation and  
was 90% effective over a distance of one metre". As the  
Bushveld Complex is bigger than <sup>the</sup> Stillwater <sup>Complex</sup>, crystal sett-  
ling <sup>in</sup> of the former is likely to have been slower. Diffusion  
therefore, if it is a valid mechanism, would have been  
more effective than it was in the Stillwater Complex.

The partial remelting of magnetite crystals would have  
produced grains with corroded outlines and these were  
not seen. Though the possibility of partial remelting  
cannot be excluded, the writer prefers the diffusion  
theory as a mechanism to explain the conversion of cumu-  
lus material to adcumulate rock.

Magnetite usually contains poikilitic pyroxene crystals  
and, less commonly, olivine. Therefore, the only mineral  
which needed to be replaced in the intercumulus liquid  
was plagioclase. Many seams have a sharp lower contact  
and Seam No. 13 has a sharp upper contact with anorthosite.  
It may be that these contacts were 'diffusion interfaces'  
across which plagioclase diffused out of the magnetite  
into the anorthosite and magnetite diffused in the oppo-  
site direction. This suggestion has no evidence whatso-  
ever to support it and, therefore, is extremely speculative.  
The thin layer of olivine near the base of the Main Seam  
may have migrated from the adjacent rock to the interface  
between the magnetite and the anorthosite.

#### d) The Genesis of Anorthosite

Nearly all the anorthosite, like the magnetite, con-  
tains poikilitic pyroxene crystals. A pile of plagioc-  
lase crystals plus its interstitial liquid would crystal-  
lise to produce the rock derived theoretically in Fig. 30.

Fig. 79      Genesis of Orthocumulate Magnetite

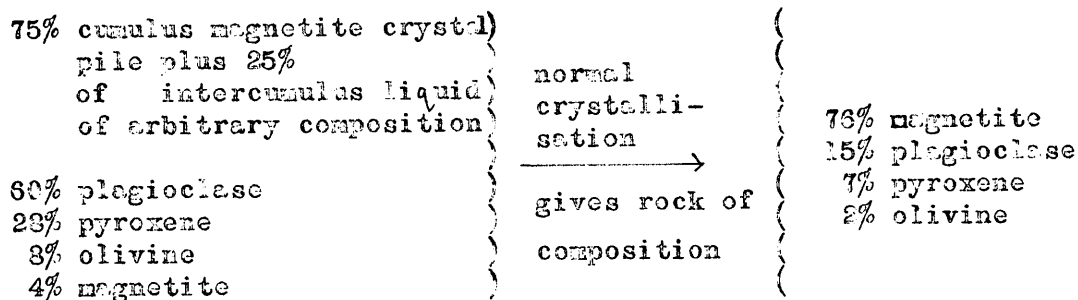


Fig. 80      Genesis of Orthocumulate Anorthosite

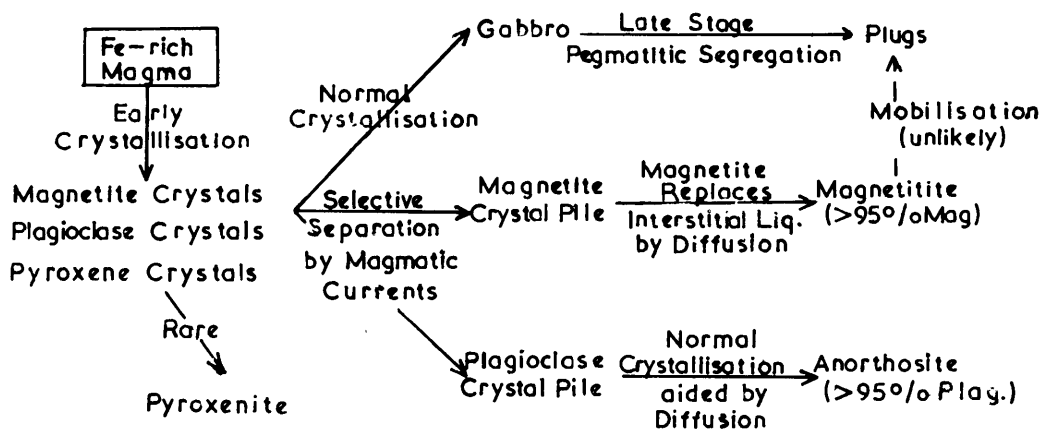
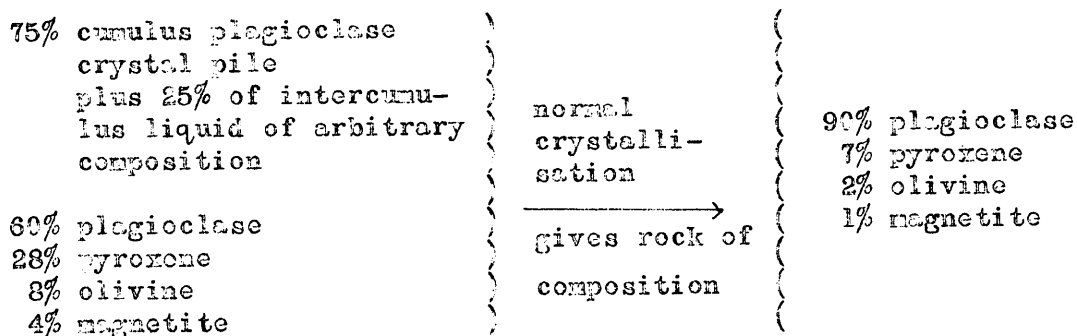


FIG 81      The suggested Genesis of the Plugs, Anorthosite Bands,  
 & Magnetite Seams

Much of the anorthosite has a composition similar to the <sup>ortho</sup> cumulate rock derived in ~~Table 8~~ <sup>Fig. 80</sup>. Where the anorthosite is nearly pure, some pyroxene may have diffused out making the rock a meso-cumulate type.

Genesis of pyroxenite

The pyroxenite four hundred feet above the Main Seam, if it was formed by crystal settling, is an orthocumulate type (see composition in Table 5) with no enrichment of the cumulus pyroxene crystals from a source other than that of the intercumulus liquid. The pyroxene above Seam No. 11 has a sharp basal contact against anorthosite and a transitional upper contact similar to, and suggesting the same mode of formation as, the magnetite seams.

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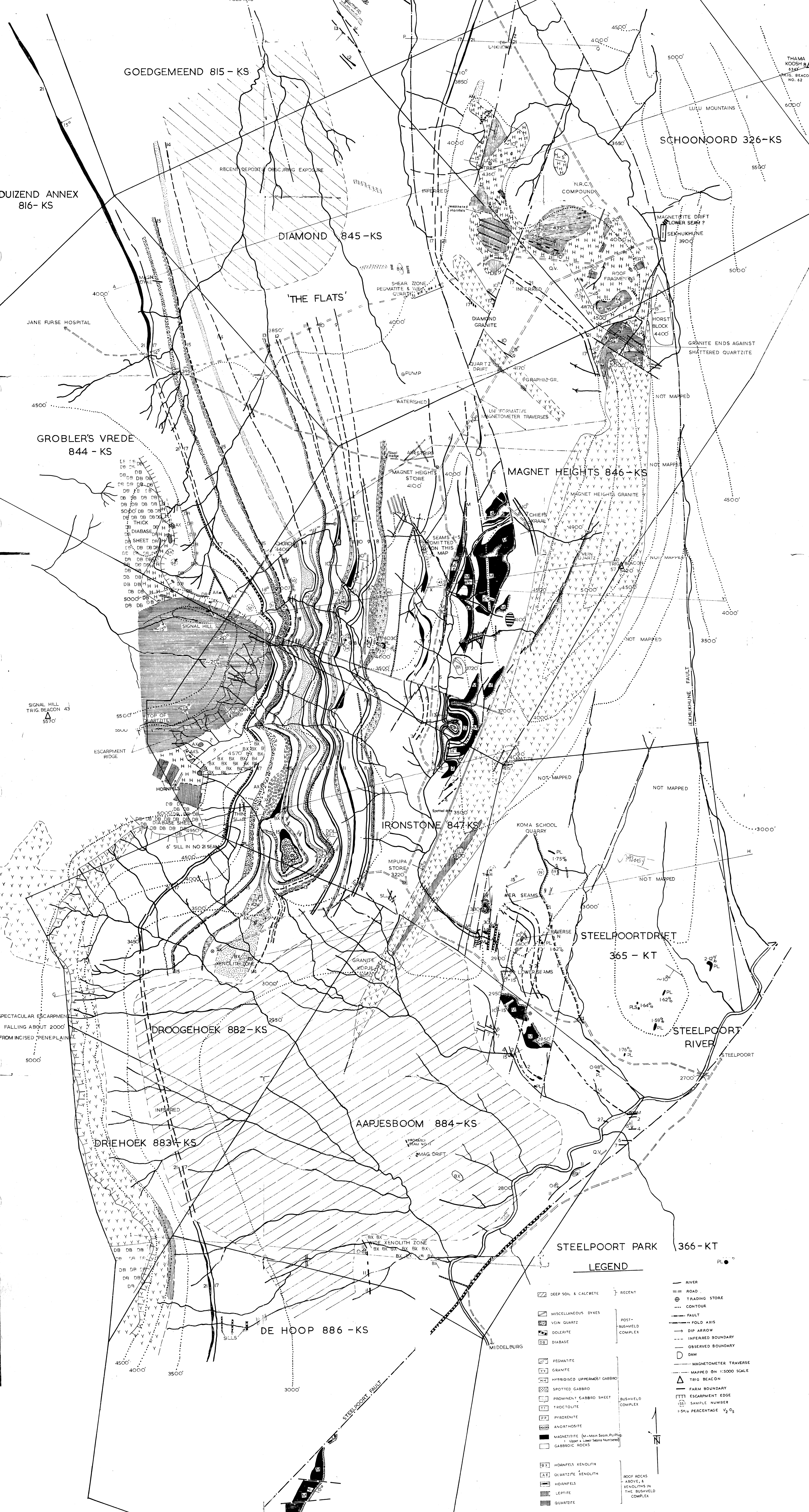
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MAP NO. I

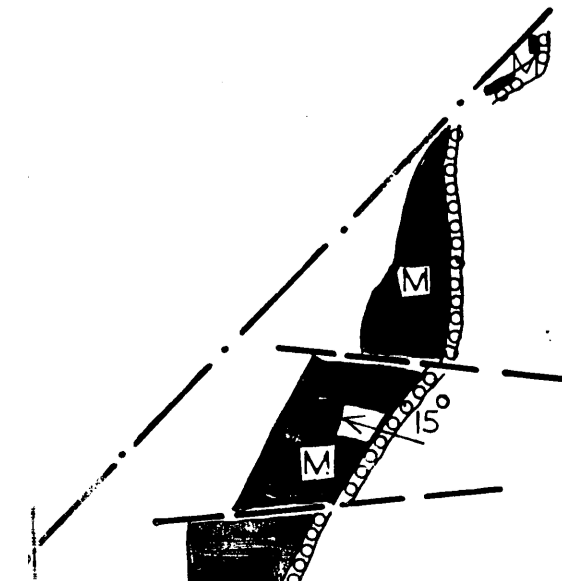
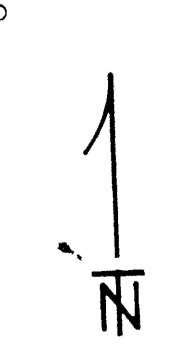
REGIONAL MAP OF MAGNET HEIGHTS AREA

SCALE 1:20,000



LEGEND

- [Symbol] DEEP SOIL & CALCRETE
- [Symbol] MISCELLANEOUS DYKES
- [Symbol] VEIN QUARTZ
- [Symbol] DOLERITE
- [Symbol] DIABASE
- [Symbol] PEGMATITE
- [Symbol] GRANITE
- [Symbol] HYBRIDISED UPPERMOST GABBRIO
- [Symbol] SPOTTED GABBRIO
- [Symbol] PROMINENT GABBRIO SHEET
- [Symbol] TROCTOLITE
- [Symbol] PYROXENITE
- [Symbol] ANDRTHOSITE
- [Symbol] MAGNETITE (M-Main Seam, P-Plus Upper & Lower Seams Numbered)
- [Symbol] GABBRIOIC ROCKS
- [Symbol] HORNFELS KENOLITH
- [Symbol] QUARTZITE KENOLITH
- [Symbol] HORNFELS
- [Symbol] LEPTITE
- [Symbol] QUARTZITE
- [Symbol] RIVER
- [Symbol] ROAD
- [Symbol] TRADING STORE
- [Symbol] CONTOUR
- [Symbol] FAULT
- [Symbol] FOLD AXIS
- [Symbol] DIP ARROW
- [Symbol] INFERRRED BOUNDARY
- [Symbol] OBSERVED BOUNDARY
- [Symbol] DAM
- [Symbol] MAGNETOMETER TRAVERSE
- [Symbol] MAPPED ON 1:5000 SCALE
- [Symbol] TRIG BEACON
- [Symbol] FARM BOUNDARY
- [Symbol] ESCARPMENT EDGE
- [Symbol] SAMPLE NUMBER
- [Symbol] 1:50% PERCENTAGE  $V_2O_5$
- [Symbol] RECENT
- [Symbol] POST-BUSHWELD COMPLEX
- [Symbol] BUSHWELD COMPLEX
- [Symbol] ROOF ROCKS ABOVE & KENOLITHS IN THE BUSHWELD COMPLEX



DETAILED MAP OF GEOLOGY OF SOUTHERN PART OF  
 FARM MAGNET HEIGHTS, 846 - KS, SEKHUKHUNELAND  
 MAP NO. II



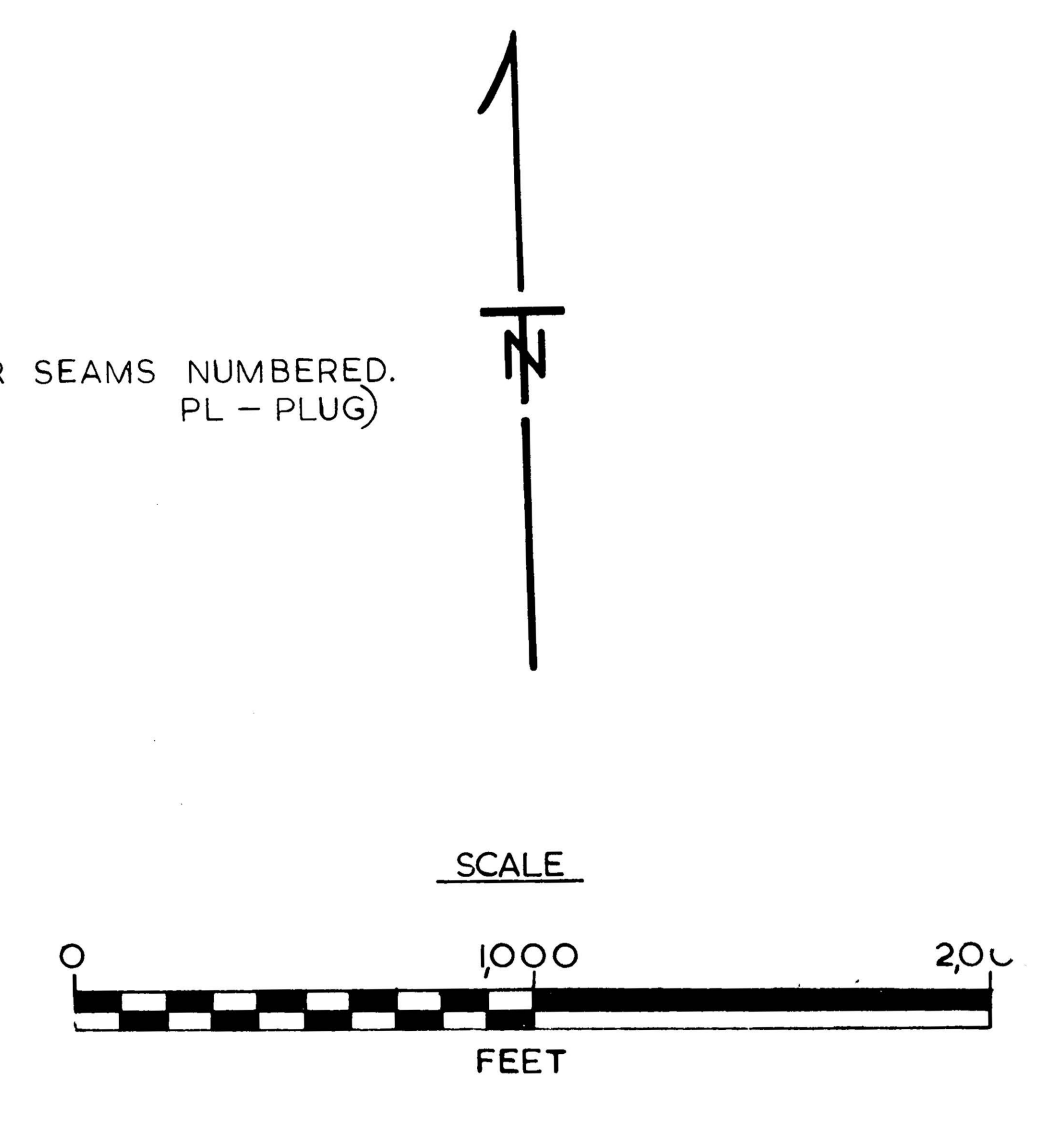
GROBLERS VREDE  
844-KS

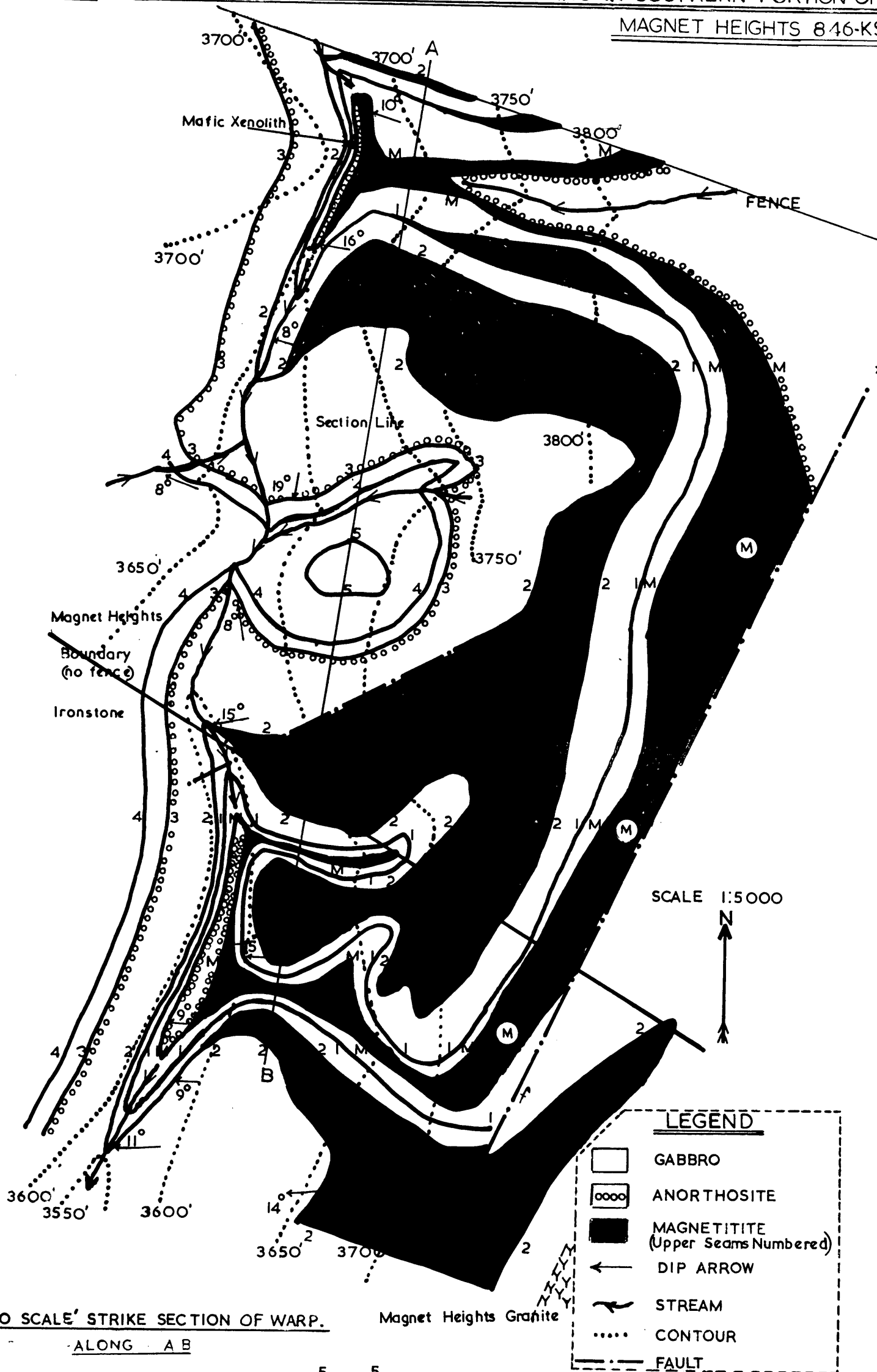
IRONSTONE  
847-KS

MAGNET EIGHTS  
846-3

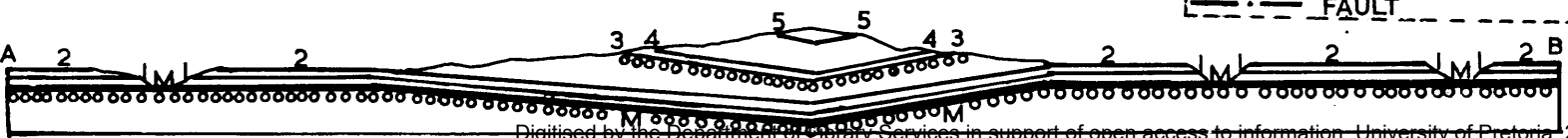
LEGEND

- EPIDOTISED ZONE
- CARBONATITE
- ANALCITE PICRITE
- COMPOSITE DYKE OF BIOTITE LAMPROPHYRE & ALBITITE
- MISCELLANEOUS DYKE
- DOLERITE
- QUARTZ VEIN
- PEGMATITE
- GRANITE
- PYROXENITE
- TROCTOLITE
- ANORTHOSITE
- MAGNETITE, (M - MAIN SEAM, UPPER SEAMS NUMBERED, PL - PLUG)
- PROMINENT GABBRO SHEET
- SPOTTED GABBRO
- GABBROIC ROCKS
- QUARTZITE
- XENOLITH
- ROADS & TRACKS
- CONTOURS, 250' INTERVALS
- DIP ARROW
- FAULT
- RIVER
- GEOLOGY INFERRED
- GEOLOGY OBSERVED
- AREA MAPPED BY R. JACOB
- POSITION OF ROCK SAMPLE





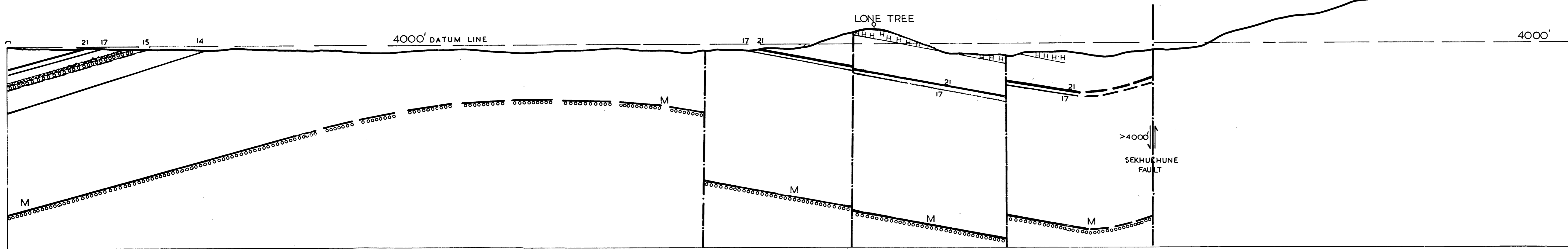
'TO SCALE' STRIKE SECTION OF WARP.  
ALONG A B



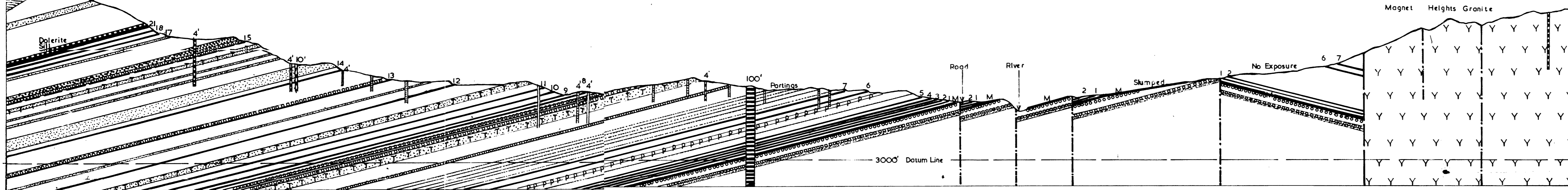
MAP NO IV GEOLOGICAL SECTIONS & STRATIGRAPHICAL COLUMN. — MAGNET HEIGHTS AREA - SOUTHERN SEKHUKHUNELAND.

(SEAMS & BANDS ARE PERSISTANT & THOSE NOT RECORDED IN A PARTICULAR SECTION ARE NOT EXPOSED. SECTION LINES REFER TO MAPS I & II)

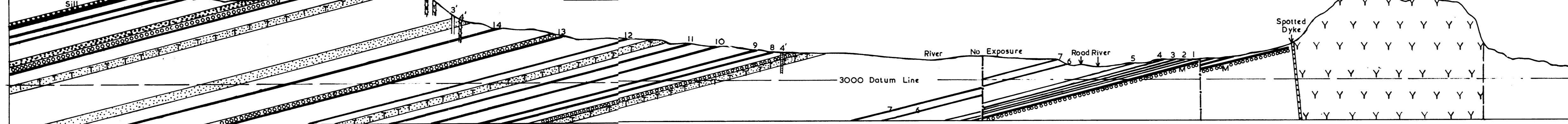
SECTION LINE A-B  
VERTICAL & HORIZONTAL SCALE 1:20,000



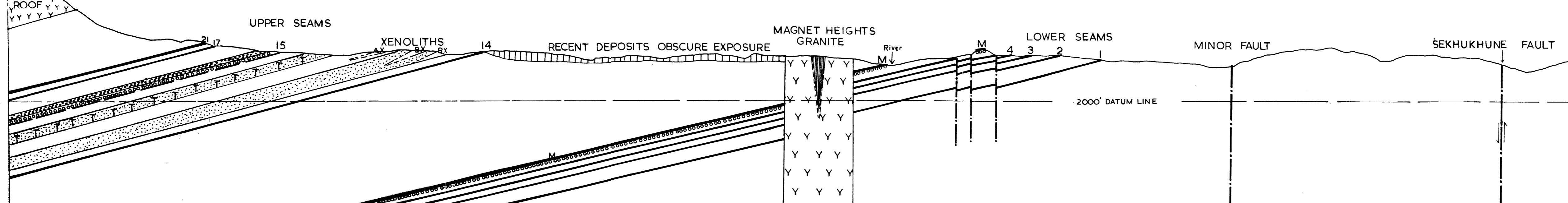
SECTION LINE C-D. VERTICAL & HORIZONTAL SCALE 1:10,000.



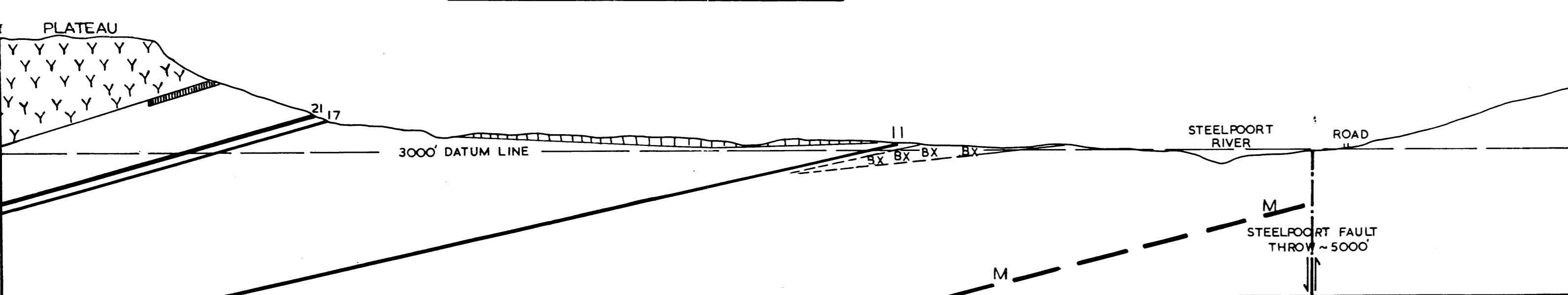
SECTION LINE E-F  
HORIZONTAL & VERTICAL SCALE 1:10,000



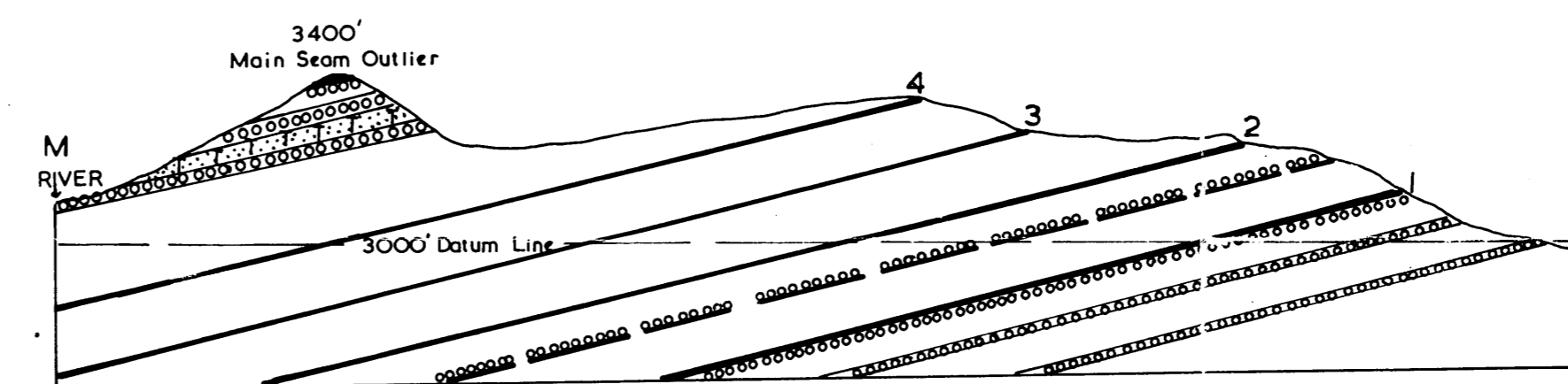
SECTION LINE G-H  
HORIZONTAL & VERTICAL SCALE 1:20,000



SECTION LINE I-J ACROSS DE HOOP 856-KS  
HORIZONTAL & VERTICAL SCALE 1:20,000



EAST-WEST SECTION ACROSS LOWER SEAMS ON STEELPOORTDRIFT 365-KT  
HORIZONTAL & VERTICAL SCALE 1:5,000



LEGEND

- |          |  |          |  |
|----------|--|----------|--|
| [Symbol] | RECENT PIEDMONT DEPOSIT                        | [Symbol] | PROMINENT GABBRO SHEET                                 |
| [Symbol] | MISCELLANEOUS MINOR INTRUSIVES                 | [Symbol] | SPOTTED GABBRO   |
| [Symbol] | DOLERITE                                       | [Symbol] | GABBROIC ROCKS   |
| [Symbol] | DIABASE  | [Symbol] | QUARTZITE  |
| [Symbol] | PEGMATITE                                      | [Symbol] | LEPTITE  |
| [Symbol] | GRANITE  | [Symbol] | QUARTZITE OR (BX) HORNFELS XENOLITH                    |
| [Symbol] | PYROXENITE                                     | [Symbol] | FAULT  |
| [Symbol] | TROCTOLITE                                     | [Symbol] | OBSERVED GEOLOGICAL BOUNDARY                           |
| [Symbol] | ANORTHOSITE                                    | [Symbol] | INFERRED GEOLOGICAL BOUNDARY                           |
| [Symbol] | MAGNETITITE (M—Main Seam—Other Seams Numbered) | [Symbol] | % V <sub>2</sub> O <sub>5</sub> CONTENT OF MAGNETITITE |
| [Symbol] | FELDSPATHIC MAGNETITITE                        |          |  |

