

3: THE STUDY AREA

3.1: Location

The Phosiri Dome, or Fortdraai Anticline, is located in the northern part of the eastern limb of the Bushveld Complex (Fig 2.B). Bounded on the western edge by the Stoffpoort Fault, which runs sub-parallel to the Wonderkop Fault Trace, the anticline curls in a southeasterly direction, paralleling the eastern limb. Farm Dwarsrand, reference 500 KS on the 2428 Nylstroom map, the area from which the data were collected, is situated on the southern flank of the Phosiri Dome and forms part of a 20 x 10km target area investigated by Trojan Exploration in 1990 (See 3.3 below).

3.2: Geology of the Phosiri Dome

The sedimentary rocks, which form the footwall to the Bushveld Complex, reappear as an anticlinal structure within both the layered sequence and the overlying granites at the Phosiri Dome. As illustrated in Figure 3.A, moving from the centre of the anticline outwards, the lithologies include: andalusite metapelites, calc-silicate rocks and intercalated Machadodorp volcanics of the Silverton Formation, Magaliesberg Quartzite, cordierite hornfelses of the Vermont Formation, and Lakenvalei Quartzite (Sharpe and Chadwick, 1982). An interpretation of the geophysical data (Trojan Unpub. Rep., 1990), revealed a complex area where the Upper Zone (UZ) appears to transgress the underlying units and now rests directly on the floor rocks of the southern flank of the structure. Although the Phosiri Dome is considered to be attached to the floor of the basin, Sharpe and Chadwick (1982) believe that there has been lateral displacement, by faulting from the floor, which they attribute to the activity within the Wonderkop Fault System. The Bushveld intrusive event is thought to be coincident with the deformation of these floor rocks (Sharpe and Chadwick, 1982). The presence of outcrops of pyroxenite, anorthosite and harzburgite, which have all undergone deformation, along with the chromitite layers and pods, in gullies on the south side of the Phosiri Dome indicate that the Critical, Main and Upper Zones are present (Trojan Unpub. Rep., 1990).

According to the Trojan report (Unpub., 1990), the dome represents an upward diapiric displacement of floor rocks through the Bushveld layered sequence caused by thermal and gravitational forces. Doming and thinning of the layered mafic sequences, which occurred at approximately the same time as magma crystallisation, involved tectonic stretching or reduced crystallisation over the dome (Trojan Unpub. Rep., 1990). Mafic units up to, and including, the level of the Upper Zone have been affected, but further away from the centres of domes like the Phosiri, thinning of the units becomes rapidly less pronounced (Trojan Unpub. Rep., 1990).

Domed areas, such as the Phosiri, are important economically because mineralised deposits are closer to the surface than in the typical sequence, which has not been affected by thinning (Trojan Unpub. Rep., 1990). In some areas, the underlying mineral deposits are more readily accessible due to shearing and fracturing of the basic rocks, which Marlow and van der Merwe (1978) found to be the case on the flanks of the Malope Dome.

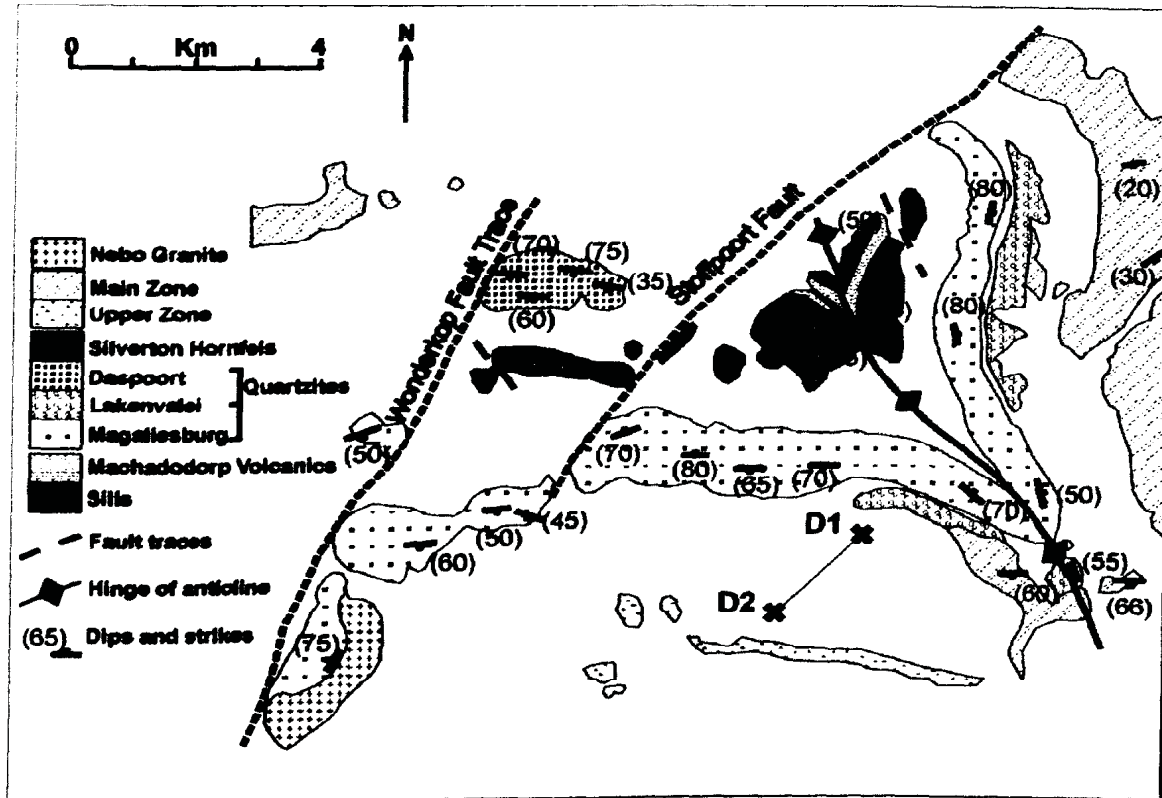


Figure 3.A The Phosiri Dome, bounded in the west by the Wonderkop Fault, after Sharpe and Chadwick (1982), with the locations of boreholes D1 and D2 indicated.

3.3: Previous Investigations

Exploration for platinum, in the past, primarily focused on the laterally extensive areas of the eastern and western limbs of the Bushveld Complex, where extraction of large amounts of the Merensky Reef was relatively easy. The more complex areas, such as the Phosiri Dome, were perceived as less attractive target areas. More recently, however, as reserves are being exhausted elsewhere in the Bushveld Complex, these structurally complex features are being considered for development.

The first exploration in the Phosiri Dome was carried out, in the early 1990's, by Trojan Platinum (Pty) Limited and Lydenburg Exploration Limited in a joint venture programme, under the company name Trodex. Based on a preliminary geophysical study, carried out by Trojan Platinum (Pty) Limited, Trodex carried out mapping, trenching and drilling of both percussion and diamond

boreholes. The geophysical data, produced in the early stages of exploration, included regional and infill gravity studies, helicopter-borne and detailed ground magnetics, and electric soundings (Trojan Unpub. Rep., 1990). Further work, carried out by Broken Hill Proprieties (BHP) Minerals in 1997, included the drilling of two boreholes along with the re-mapping of existing trenches. The borecores from boreholes D1 and D2 originate, respectively, from work carried out by Trodex in the early 1990's and by Broken Hill Properties (BHP) Minerals in the first half of 1997.

3.4: Location of Boreholes D1 and D2

D1 and D2 boreholes were drilled, 2.2km apart, on the southern flank of the Phosiri Dome, with D2 located to the southwest of D1 as shown in Figure 3.B. D1 was oriented north, at an inclination of 20° to the vertical, *i.e.* drilling into the hillside. D2 was oriented to the south, at an inclination of 25° to the vertical.

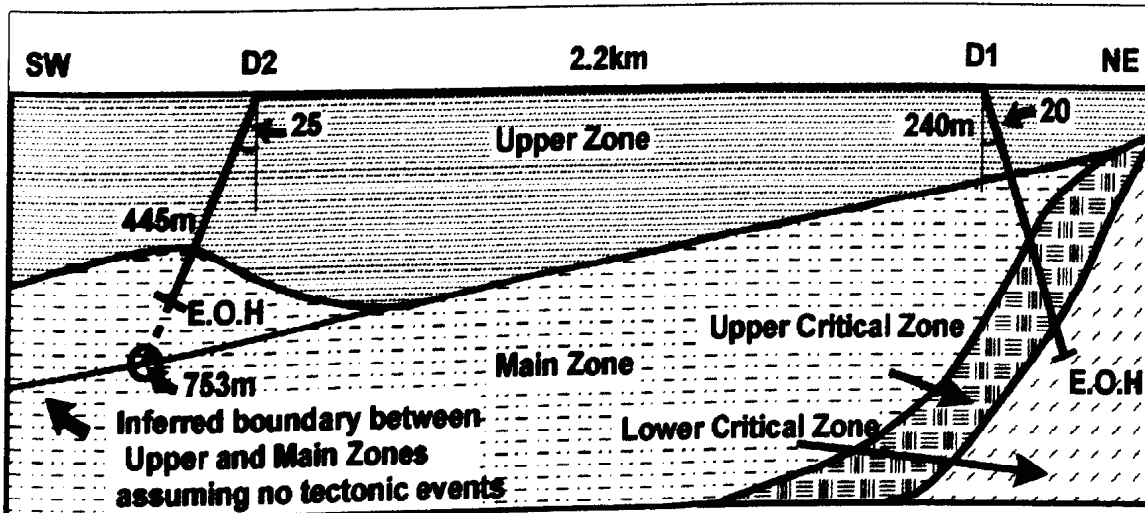


Figure 3.B Schematic cross section showing the relationship between boreholes D1 and D2 and the Bushveld Complex units using the inferred dip of 10° for the MZ/UZ boundary (Trojan Unpub. Rep., 1990).

4: BOREHOLE LOG DESCRIPTIONS

The following descriptions are of the stratigraphic columns of each borehole, which were compiled from borecore logs described by Scoon and Long, for D1 and D2, respectively. There has been no correction for the true thickness of the lithological units as the dips for either the layering or the boreholes is not known accurately. Hence all thicknesses reported exceed the true stratigraphic thickness. For ease of reference, the lithologies are separated into zones, in accordance with the placement of boundaries by SACS (1980). For both D1 and D2, the boundary between the Main Zone (MZ) and Upper Zone (UZ) is placed at the horizon where magnetite first appears. In D1, this is at a depth of 240m, and within D2, magnetite occurs at 445m. These two depths are taken as the 0m reference datum for sample analyses within the respective boreholes. A negative symbol prefixing a given depth, in the following sections and accompanying tables, indicates that the sample is taken from below the base of the UZ. This renumbering method is to allow for a more direct comparison between the two boreholes and the typical sequence of the Bushveld Complex throughout the study.

4.1: Borehole D1

D1 was collared at an elevation of 806.61m above sea level, in overburden above the UZ. It is interpreted to end within the Lower Critical Zone (CLZ) of the Bushveld Complex, due to the low feldspathic content of the pyroxenites. The stratigraphic column of D1 is given in Appendix 1, p i-iii. A simplified log can be referred to in Figure 4.A. The key for both D1 and D2 stratigraphic logs (Figures 4.A and 4.B) is provided below.

The CLZ is dominated by feldspathic pyroxenites and two groups of chromitites. Several of the feldspathic pyroxenites appear to have suffered fracturing, alteration and deformation, which was recognised from the broken nature of the extracted borecore. These may be the result of activity in tectonic shear zones that occur throughout the area. A 10m thick leuconorite, at -522.30m, would appear to be out of place in this sequence. This may have arisen from the faulting out of lithologies in the CLZ, which provided a conduit for later magmas, typical of higher zones, to pass through.

Five chromitite layers occur at depths of -505.10m, -431.20m, -414.60m, -410.80m and -397.50m, and range in width from 6cm to 14cm. Seven more chromitite layers, encountered at -355.15m, -345.75m, -353.87m, -353.66m, -353.41m, -351.88m and -349.56m depths and vary in thickness from 0.02m to 1.02m. The basal contacts of these chromitites are often irregular. This indicates an erosional surface and possibly a non-continuous depositional sequence. Situated above a feldspathic pyroxenite, which forms the hangingwall to the uppermost chromitite parting, is a layer of norite, marking the upper boundary of the CLZ at -346.90m.

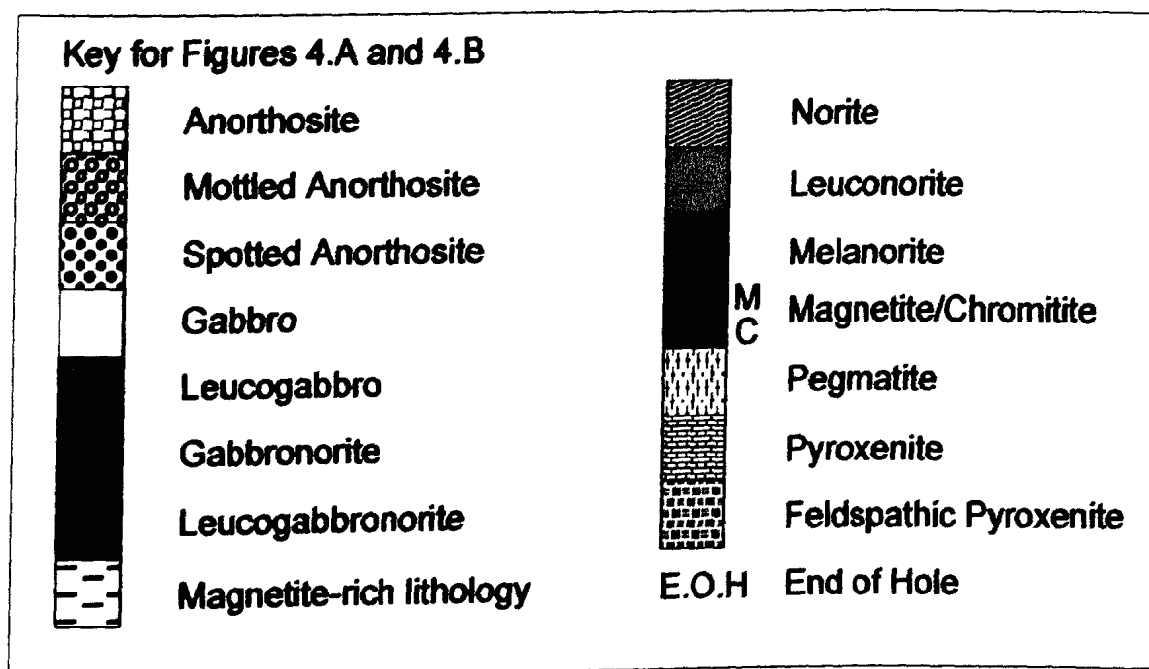
The lithological assemblage of the lower 29m of the Upper Critical Zone (CuZ), between -346.90m and -317m, chiefly consists of an alternating sequence of norites and melanorites, with three feldspathic pyroxenites. A quartz-feldspar vein, 0.10m thick, is found between -345.20m and -345.10m near the base of the CuZ and represents fracture infill. From -317m upward, leuconorite appears 0.50m below a 27.5m thick feldspathic pyroxenite. The remainder of the sequence, to -245.10m, consists of norites, with both melanocratic and leucocratic varieties; pegmatitic pyroxenites, at -284.30m and -252.10m, which are 9.25m and 3.83m thick, respectively; and a single mottled anorthosite, at -258.90m, which is 1.43m thick. There are seven mottled anorthosite layers in the CuZ stratigraphic sequence, ranging in thickness from 0.85 to 31.15m.

From -245.10m, there are two noteworthy feldspathic pyroxenites: the Merensky Pyroxenite, between -245.10m and -240.70m; and the Merensky Callboy, so named by Wagner (1929), between -233.80m and -228.40m. They are separated by three mottled anorthosite layers, alternating with norite. Two further mottled anorthosites dominate the upper portion of the CuZ. The first 30.51m thick layer, which is found at -227.10m, directly above the leucogabbro hangingwall to the Merensky Callboy, forms the footwall to the 0.49m thick Bastard Reef, at -196.60m. Dividing the Bastard Reef from the thickest mottled anorthosite, is another and much thinner (0.85m) mottled anorthosite, that forms part of a short norite-leuconorite sequence. Deformation and fracture zones, with alteration to epidote and chlorite assemblages, are evident throughout the majority of the lithological sequence, between -227.10m and -158.20m. This hydrothermal alteration has tainted green the otherwise white-grey anorthosites. The thickest anorthosite layer extends to the top of the Bastard Cyclic Unit, which marks the boundary between the CuZ and MZ, at -158.20m.

The MZ is represented by an alternating series of gabbronorites, leucogabbronorites and mottled anorthosites. The gabbronorite units appear intermittently to almost the top of the zone, the base layer being the thickest at 34.70m. Leucogabbronorites are more prevalent than gabbronorites between -89m and -0.5m, and range in thickness between 4.60m and 11.57m. Jointing and fracturing are clearly evident in the lowest gabbronorite unit suggesting that brittle deformation has taken place. Epidote and chlorite, the products of hydrothermal alteration associated with such a phenomenon, are also present. These physical features and associated minerals are also evident higher up in the sequence, not only in the gabbronorites, but also in the anorthositic units.

Three mottled anorthosites are present in the zone, varying in thickness from 4.95m to 9.43m. Two, occurring at depths of -123.50m and -113.30m, are separated by a very narrow gabbronorite, and the third unit, at -72.23m, is sandwiched between two leucogabbronorite units. Directly above, at the -54.50m depth, a single layer of spotted anorthosite measures 5.20m. Spotted and mottled anorthosite differs in that included pyroxenes are smaller, and appear in greater numbers, in the former. At a depth of -21.60m, minor stringers of pyroxenite are present within a leucogabbronorite unit. The unit ends at the top of the uppermost leucogabbronorite.

The UZ boundary is determined by the first appearance of magnetite, which occurs within a gabbro from the depth of -0.50m. In the lower half of the zone, norite appears in a mixed unit with gabbro and pyroxenite, between 7.93m and 37m. This unit is deformed and contains epidote and chlorite mineralisation, indicating hydrothermal activity. Melanorite appears in an overlying 18m thick layer. The first of five feldspathic pyroxenites, which are all between 0.10m and 2m thick, occurs directly above it, at 55m. The second gabbronorite gives way, at a depth of 66.40m, to a mottled anorthosite, followed by a magnetite-rich leucogabbro. Overlying this is a succession of thin layers, up to 108.30m, comprising gabbronorite, gabbros, feldspathic pyroxenite and melanorite. Dominating the upper half are five magnetite-rich gabbroic layers, between 1.40m and 58.30m thick. These are interrupted by two magnetite layers at 114.80m and 173.27m, which are 0.20m and 0.03m thick, respectively. Situated between the magnetites are a leucogabbro at 122.28m, followed shortly by the only spotted anorthosite in the zone, which lies beneath a feldspathic pyroxenite, at 149.50m. Another two thinner feldspathic pyroxenite layers appear above and below the uppermost magnetite. Above, at 173.70m, the largest magnetite gabbro continues uninterrupted for 58.30m to beneath the overburden, which constitutes 8m of quartz scree to the surface.



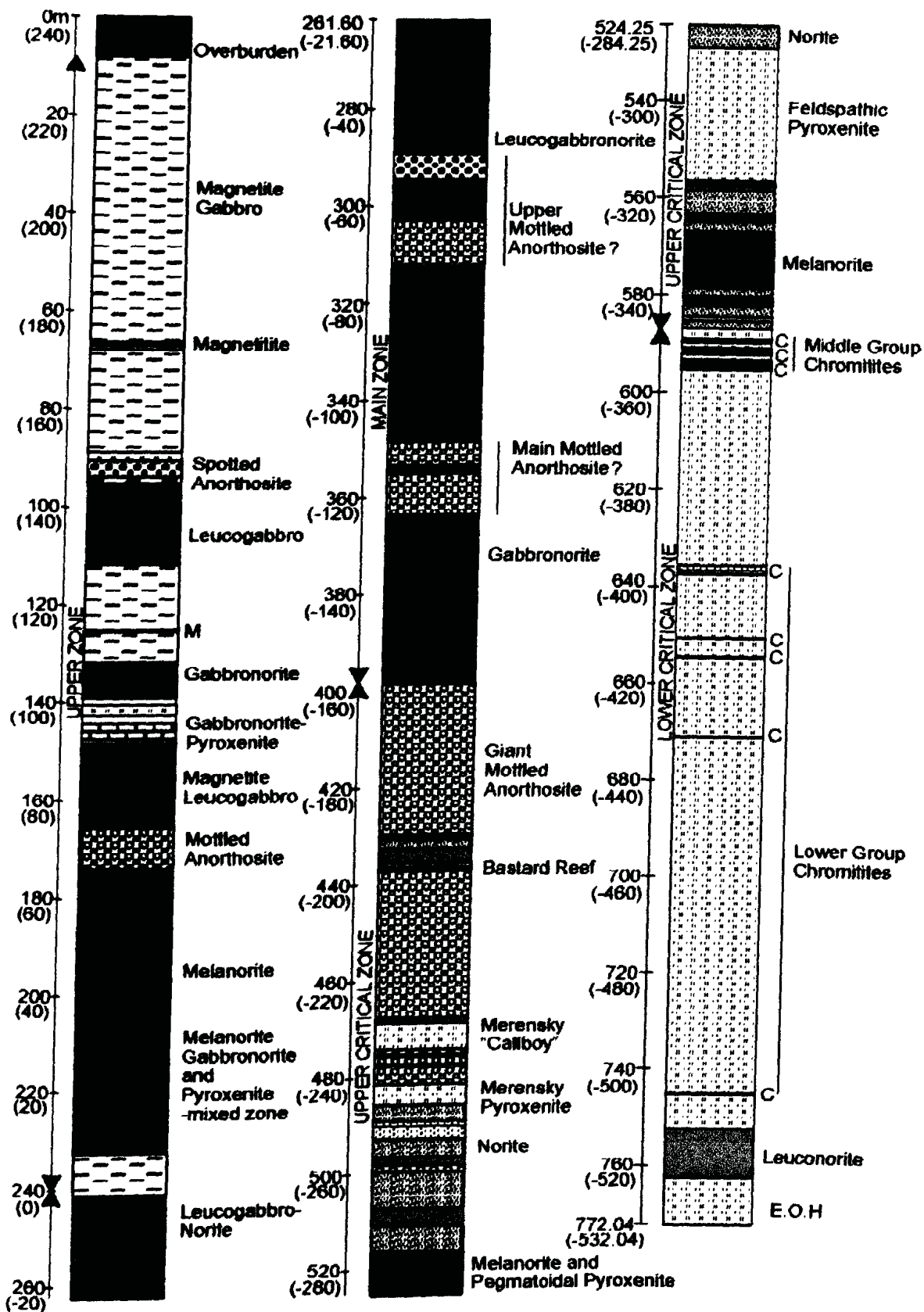


Figure 4.A Stratigraphic log of borehole D1. Numbers in brackets are depths relating to the MZ/UZ boundary.

4.2: Borehole D2

D2 was collared at an elevation of 792.92m within overburden above the Upper Zone. Only the Main and Upper Zones of the Rustenburg layered Suite are represented within this borecore. The stratigraphic column can be referred to in Appendix 1, p iv-vi. A simplified stratigraphic log can be referred to in Figure 4.B, with the same key as for Figure 4.A.

The basal 37m of the Main Zone (MZ), from -152.47m to -115.55m, comprise a five-layered sequence of anorthosites. The spotted form occurs at the base of the sequence, which also includes two mottled layers, at -150.75m and -135.82m. Alteration and fractured contacts are noted in the anorthosite at -109.65m. Anorthosites do not reappear until the Upper Zone (UZ). In the overlying 116m, a single gabbro, at -14.70m, is found in a predominantly leucogabbro-noritic layer. Within a 19.10m thick gabbro-noritic unit, the boundary between the MZ and UZ is marked at 0m, where cumulus magnetite first appears.

The UZ units are mainly gabbros, gabbro-norites and anorthosites. Most contain magnetite, and for a total of 105m from the base of the UZ, the three lithologies appear in roughly equal proportions. Gabbros dominate the central section for 169m, up to a depth of 319.40m, where the lithology changes to a sequence of eleven anorthosite layers appearing in quick succession to within 23.50m of the surface. A single spotted anorthosite occurs at 230.81m. Unlike the MZ, gabbros are more prevalent than leucogabbros in the UZ, the latter lithology occurring only seven times and varying in thickness between 0.45m and 8.40m. The first pegmatitic gabbro occurs at 42.45m, followed by a second at 52.90m. Magnetite-rich pegmatites do not appear until 175.70m, within a unit containing gabbro, measures 3.05m thick. Six more pegmatite partings appear in the sequence from 207.20m to 276.10m.

Magnetite plays an important role in the formation of this zone. It first appears, as an intercumulus phase, in a gabbro-norite straddling the zonal divide, before becoming a major component of the upper section. Intermittently, from 106m above the base to 13m below the surface, eleven individual magnetite layers, between 0.07m to 4.70m thick, can be identified. All alternate with either anorthositic or gabbroic units, which contain disseminated magnetite. Also, occasional poikilitic clusters of magnetite were observed within the anorthosites.

The lower third of the UZ is represented by magnetite-rich gabbros and magnetite gabbro-norites. Between these, two anorthosite accumulations are separated by a leucogabbro-norite-pegmatite sequence. The lower group of anorthosites, situated between the depths of 16.89m and 31.66m, comprise three layers. The lower two are mottled and have formed above and below a gabbro. The upper accumulation totals four layers and, overlying a pegmatite at 52.90m, ends below the first

magnetite layer at 105.81m. A leucogabbro unit has formed between the first anorthosite and the second, which is mottled, and a gabbro unit separates the third and fourth anorthosites.

Within the middle section of the zone, gabbro, the dominant rock formation up to a depth of 275.82m, is interrupted by several interesting lithologies. A magnetite layer, at 152.15m, is followed by another at 166.16m, which is sandwiched between two magnetite-rich anorthosites. The only two magnetite-rich feldspathic pegmatites in the borecore formed 0.54m apart, between 175.70m to 178.85m. A third magnetite at 230.74m occurs beneath a spotted anorthosite.

Within the upper third section of the UZ, at a depth of 319.40m, a 49m thick sequence containing six layers of anorthosites with leucogabbro and leucogabbro ends. The series gives way to a magnetite-rich anorthosite and magnetite-rich gabbro. Between 330.74m and 373.95m, magnetite anorthosite alternates with three magnetite layers. At 392.60m, a further magnetite overlies a sequence of magnetite gabbros and anorthosites, which includes a thin leucogabbroic layer. The lithological composition changes again with the occurrence of two feldspathic pyroxenites on either side of an anorthosite layer. The two uppermost anorthosites are separated by a 4.70m thick magnetite layer at 412.50m, the thickest in the sequence, a mottled anorthosite and a leucogabbro, in that order. Gabbros, cut by magnetite layers at depths of 428.06m and 431.40m, end at 432.20m, 12.80m below the surface, beneath an overburden of soils.

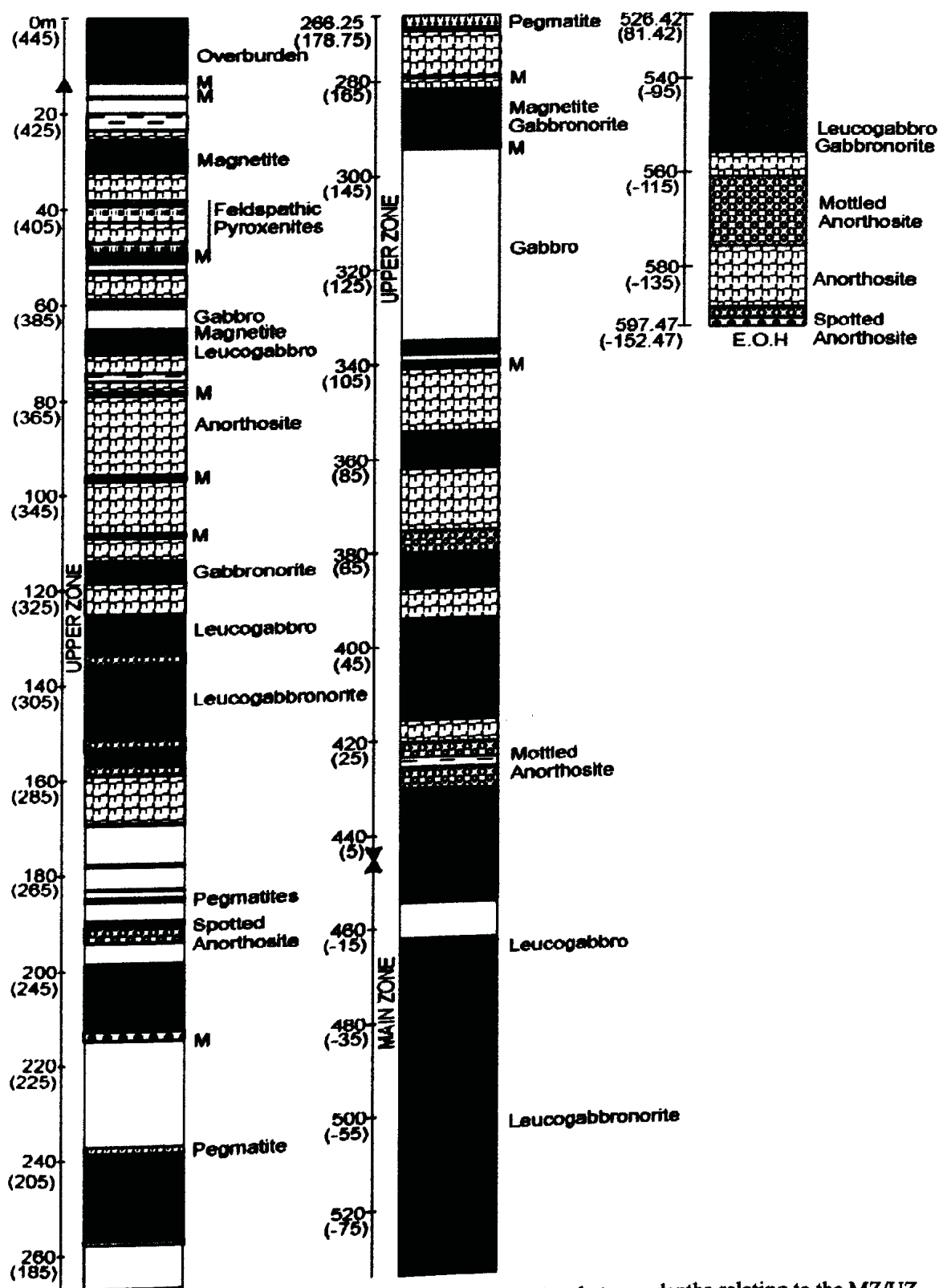


Figure 4.B Stratigraphic log of borehole D2. Numbers in brackets are depths relating to the MZ/UZ boundary.

5: PETROGRAPHIC OBSERVATIONS

The samples were initially chosen at approximately 20m intervals. Sample intervals are wider where there was no change in lithology. Conversely, where the lithologies change more frequently, the sample intervals are more closely spaced. As geochemical analyses became available during the course of this study, it was necessary to re-sample particular horizons, in order to ascertain the positions of boundaries.

Often, the modal proportions of the mineral phases are mis-representative of the lithological nomenclature assigned to that particular unit. This is due to the presence of mafic mottles, which are found to have an uneven distribution throughout the lithologies. Therefore, modal proportion determinations could not be assessed. However, normative calculations from XRF data, for both D1 and D2, provide a more accurate representation and are included in Chapter 7.

The photographs, in Figures 5.A to 5.K in section 5.1, and Figures 5.L to 5.P in section 5.2, are taken of thin sections using a Leitz microscope and a Leica DC100 Digital Camera, at the Department of Geology, University of the Witwatersrand. All photographs have a width of 1.6mm.

5.1: D1 Petrographic Descriptions

As the bottom of the magnetite-bearing horizon, at the depth of 240m, represents the base of the Upper Zone (UZ), all future sample depths described for D1 will use this as the reference datum.

Between -357m, near the top of the Lower Critical Zone (LCZ), and 121m, within the UZ, sixty-three samples were taken at intervals up to 46m from the borecore, and thin sections were prepared for petrographical observation. Table 5.i summarises the data and includes approximate percentage values for the individual minerals. Detailed descriptions of each of the thin sections examined are presented in Appendix 2, p vii-xvii.

Plagioclase and pyroxene both occur as major, minor cumulus and intercumulus phases. In Anorthosites, the plagioclase is the major cumulus phase, with other phases present as minor or intercumulus phases. In pyroxenites, it is the pyroxenes that form the cumulus phase. In many of the lithologies, an ophitic texture is observed where fine-grained plagioclase is enclosed within pyroxene grains. Pyroxenes are present as clinopyroxene, orthopyroxene and inverted pigeonite. The latter two types are both low-calcium pyroxenes. Alteration products include sericite, chlorite, epidote and hornblende. Biotite and quartz are also present, as are the spinel minerals, magnetite and chromite.

The majority of thin sections prove that, throughout the sampled section, plagioclase is the major cumulus phase, which commonly shows an overgrowth of minor interstitial plagioclase. Plagioclase grains are also included within all three forms of pyroxene, where they display an ophitic to sub-ophitic texture. Although these textures occur throughout, it is mainly observed in samples close to the bottom and top of the Upper Critical Zone (CuZ), and from the Main Zone (MZ).

Alignment of plagioclase grains exists in only a few thin sections. Unfortunately, orientation studies were not carried out at the time of extraction of the borecore, so that a reconstruction of the direction of the alignment was not possible. Grain shape varies from elongate to blocky, but the majority of grains appear sub-euhedral to sub-anhedral. Major cumulus plagioclase grains range from 1 - 8mm in length and are usually 1 - 2mm wide. Intercumulus grains are less than 0.5mm in length. Plagioclase grains enclosed within pyroxenes tend to be smaller than the major cumulus grains found elsewhere in the thin section, and have a maximum length of 1mm and a width, often less than 0.5mm.

Alteration is prevalent throughout the thin sections, and patches of sericite are observed within many of the individual plagioclase grains. Where there are zones of alteration in the lithological sequence, the degree of alteration from plagioclase to clay products is consequently severe. Often, where much of the original mineralogy has been replaced, only minor remnants remain. Deformation is pronounced in most of the thin sections, as illustrated in Figures 5.A and 5.B, where the albite lamellae within plagioclase grains are bent. However, there are several instances where deformation, with corresponding alteration, has altered much of the original grain with respect to the mineralogy, internal structures and textures. Zonation is distinct in only one thin section corresponding to -25m depth.

On occasion, the pyroxenes are represented solely by interstitial grains among cumulus plagioclase. Both clinopyroxene and orthopyroxene coexist in approximately equal proportions in the gabbro-norites. However, in the majority of thin sections only orthopyroxene is observed. Inverted pigeonite is conspicuous between -159m and -176m in the lower portion of the MZ, to the exclusion of primary orthopyroxene. Inverted pigeonite is also noted at 45m and 56m in the UZ, and grains are less than 1mm in diameter. Possible inverted pigeonite occurs at -87m, within the MZ, but this is inconclusive due to the scarcity of the mineral. The sizes for all pyroxenes range from less than 0.5mm up to 17mm in diameter, although the majority of grains are less than 5mm in diameter. Often, grains greater than 4mm in diameter are optically continuous and have formed mottles enclosing plagioclase grains. The shapes are generally sub-anhedral to anhedral.

Alteration to chlorite has affected both clinopyroxene and orthopyroxene grains. Chloritisation is quite extensive and several thin sections, corresponding to the CZ and MZ exhibits highly altered pyroxenes. Alteration of the pyroxenes is evident in thin sections from the -19m, -36m and -134m depths, where hornblende is present, and at the -197m, -133m, -51m and 16m depths, where epidote

also appears. Deformation is less obvious than in the plagioclase, as only sporadic pyroxene grains exhibit bent exsolution lamellae. However, where extensive chloritisation has taken place, as outlined above, deformation is also more severe, although the plagioclase within the same thin sections appear to be totally unaffected (Figures 5.C and 5.D).

Small quantities of cumulus chromite, visible in minor amounts as cubic grains, are finely disseminated in eleven thin sections corresponding to the CuZ. Two of the samples came from two separate feldspathic pyroxenite units, one came from a mottled anorthosite, situated above the Merensky Reef, and the remaining eight from the mottled anorthosite forming the footwall to the Bastard Reef.

Magnetite is found in the majority of thin sections in the UZ. It comprises more than 2 modal % within each of these thin sections. Mainly, the mineral is present as rounded blebs, up to 5mm in length, which encompass grains of plagioclase and pyroxene. Otherwise, the magnetite occurs mainly as exsolution needles less than 0.1mm in length, which are incorporated within pyroxenes, but in a few thin sections, it is also apparent within the fractures of plagioclase and pyroxene grains (Figure 5.E).

Biotite is an interstitial component throughout all the thin sections. In two of the samples, taken from the CuZ, it extends as fibrous needles from the rims of pyroxene grains, where it is associated with chlorite alteration. These needles then appear to cut across adjacent plagioclase grains. The photographs in Figures 5.F and 5.G of a thin section, corresponding to the -179m depth at the top of the CuZ, illustrate these relationships. Frequently, biotite is associated with chlorite and magnetite at pyroxene grain boundaries.

Quartz is found in several of the samples, mainly within the interstitial component, where grains are less than 0.5mm in diameter. It is also noticeable as fracture infill in highly altered sections, and where veins cut across primary mineral phases.

Epidote is a common occurrence in highly altered zones, such as the mottled anorthosite footwall to the Bastard Reef at -197m, and the mixed unit of gabbro, norite and pyroxenite 16m above the base of the UZ. Examples of extensive epidotisation, with remnant grains of pyroxene and blebs of magnetite, are in Figures 5.H and 5.I. The presence of epidote and chlorite is indicative of hydrothermal fluid activity. The hydrothermal overprint is confined to units within the sequence where the lithologies are notably deformed.

Both primary and secondary hornblende, evident at a depth of -134m, are depicted in Figures 5.J and 5.K, respectively. This mineral is absent in all other samples examined.

Table 5.i Summary of petrographic observations from D1 thin sections.

Depth m	Sample	Plagioclase				Low-Ca Pyroxene						Clinopyroxene				Magnetite		Chromite	Alteration		Other	Lithology	Zone				
		%	C/I	A/DZ	O/SO	%	C/I	L	A/D	O/SO	IP	%	C/I	L	A/D	O/SO	%	C/I	%	C/I	%			CHL	%		
121	D1.119	50	C	A	O	30	I	0	A	O		15	I	1	A	O	5	I			Y	CHL	Y	B	MGT-G	UZ	
111	D1.129	85	C/I	AD								5	MC	1	A							10	CHL	Y		MGT-G	UZ
102	D1.138	45	C	AD								35	MC	2	A		10	I			5	CHL	5	B	G-N	UZ	
56	D1.184	50	C/I	AD		7	MC	3	A		Y	10	MC	27	A		30	I			2	CHL	1	B	G-N	UZ	
45	D1.195	40	C	AD		10	MC	37	A			23	MC	2	A		20	I			2	CHL	5	B	M-N	UZ	
16	D1.224	8	C	A								8	MC	1	A		2	I			55	CHL/E	25	A Q/B	G-NM-NPX	UZ	
-9	D1.249	20	C/I	D		20	MC	1	A			50	MC	2	A						5	CHL	5	Q/B	G-N	MZ	
-19	D1.259	20	C/I	A		20	MC	1	A			40	MC	2	A					15	CHL/HBL	5	B	L-G-N	MZ		
-25	D1.265	50	C/I	ADZ	O	20	I	1	A	O		20	I	2	A	O				8	CHL	4	B	G-N	MZ		
-31	D1.271	35	C	AD	O	15	I	0	A	O		35	I	2	A	O				10	CHL	5	B	G-N	MZ		
-36	D1.278	53	C/I	A	SO	10	I	1	A	SO		10	MC	37	A					25	CHL/HBL	2	B	G-N	MZ		
-42	D1.282	50	C/I	AD		5	MC	1	A			10	MC	2	A					25	CHL	10	B	G-N	MZ		
-48	D1.288	70	C/I	A		5	MC	?	A										25	CHL	Y	B	L-G-N	MZ			
-51	D1.291	?		A		?			A										10	CHL/E	Y	Q	SP-AN	MZ			
-58	D1.298	70	C	AD	O	30	I	1	A	O									Y	CHL	Y	B	L-G-N	MZ			
-64	D1.304	65	C	A	O							30	I	2	A	O				2	CHL	3	B	MT-AN	MZ		
-69	D1.309	72	C/I	AD	O							20	I	1	A	O				5	CHL	3	B	MT-AN	MZ		
-76	D1.316	55	C/I	AD		5	MC		A			15	MC	27	A					20	CHL	5	B	L-G-N	MZ		
-79	D1.319	85	C/I	AD								10	MC	17	A					5	CHL	Y	B	L-G-N	MZ		
-81	D1.321	50	C/I	AD	SO							40	I	2	A	SO				5	CHL	5	B	L-G-N	MZ		
-82	D1.322	55	C/I	AD	SO	5	I	1	A	SO		25	I	1	A	SO				10	CHL	5	B	L-G-N	MZ		
-85	D1.325	20	C/I	AD	SO	35	I		A	SO		35	I	1	A	SO				5	CHL	5	B	L-G-N	MZ		
-87	D1.327	55	C/I	AD	O	10	I	1	A	O	?	30	I	2	A	O				2	CHL	5	B	L-G-N	MZ		
-92	D1.332	45	C	AD		20	MC	0	A			25	MC	0	A					10	CHL	1	B	G-N	MZ		
-96	D1.338	45	C/I	AD		20	MC	1	AD			20	MC	1	AD					5	CHL	10	B	G-N	MZ		
-108	D1.348	75	C	AD	SO	7	I		A	SO		8	I		A	SO				5	CHL	5	B	MT-AN	MZ		
-115	D1.355	50	C/I	AD	O	10	I	1	AD	O		30	I	1	AD	O	Y	I		5	CHL	5	B	MT-AN	MZ		
-121	D1.361	88	C/I	AD	SO	10	I	0	A	SO		10	I	1	A	SO				10	CHL	2	B	MT-AN	MZ		
-128	D1.368	50	C/I		O	15	I	1	A	O		25	I	1	A	O				5	CHL	5	B	G-N	MZ		
-133	D1.373	?		AD					AD						AD				?	CHL/E	10	Q	G-N	MZ			
-134	D1.374	70	C/I	A	O	2	I		A	O		3	I		A	O				25	CHL/HBL	Y	Q/B	G-N	MZ		
-140	D1.380	70	C	AD	O	18	I	1	AD	O		8	I		A	O				2	CHL	2	B	G-N	MZ		
-144	D1.384	60	C/I	AD		25	MC	0	A			10	MC	1	A		Y	I		2	CHL	3	B	G-N	MZ		
-156	D1.398	?		A								?		1	A					5	CHL	5	Q	G-N	MZ		
-159	D1.399	69	C	AD	SO	15	I	2	A	SO	Y	15	I	27	A	SO				Y	CHL			MT-AN	CUZ		
-176	D1.418	90	C			3	I		A		Y	7	I		A					Y	CHL	Y	B	MT-AN	CUZ		
-179	D1.419	75	C/I	AD	O	10	I		A	O		10	I		A	O				5	CHL	1	B	MT-AN	CUZ		
-182	D1.422	50	C/I	D	SO	28	I	1	A	SO		23	I	1	A	SO				1	CHL	1	B	MT-AN	CUZ		
-184	D1.424	50	C	D	SO	30	I		A	SO		20	I	1	A	SO				5	CHL	Y	B	MT-AN	CUZ		
-186	D1.428	90	C/I	AD		3	I		A			3	I		A					3	CHL	Y	B	MT-AN	CUZ		
-189	D1.429	80	C/I	A	O							15	I		A	O				5	CHL	Y	Q/B	L-N	CUZ		
-190	D1.430	45	C/I	A								55	MC		A						Y	Q		N	CUZ		
-193	D1.433	90	C/I	A		2	I		A			3	MC		A					5	CHL			L-N	CUZ		
-194	D1.434	60	C/I		O	20	I		A	O		15	I		A	O				2	CHL	3	B	L-N	CUZ		
-195	D1.435	48	C/I	A		5	MC		AD			35	MC	2	A					Y	CHL	14	B	N	CUZ		
-196	D1.438	98	C	AD																2	CHL	1	B	MT-AN	CUZ		
-197	D1.437	50	C	AD	O							35	I		A	O		Y	C	10	CHL/E	5	Q/B	MT-AN	CUZ		
-201	D1.441	60	C	AD		30	I		A								Y	C	5	CHL	2	B	MT-AN	CUZ			
-202	D1.442	90	C/I	A		5	I		A			7			A					Y	C	5	CHL	Y	Q	MT-AN	CUZ
-214	D1.454	87	C	D		7	I		A			2	I		A		Y	C	5	CHL	5	CHL	Y	B	MT-AN	CUZ	
-215	D1.455	80	C	AD		10	I	1	A			5	I		A		Y	C	5	CHL	Y	CHL	Y	B	MT-AN	CUZ	
-218	D1.458	67	C	AD								20	I		A		Y	C	5	CHL	5	CHL	3	B	MT-AN	CUZ	
-220	D1.460	90	C/I	AD					A			?	I		A		Y	C	2	CHL	2	CHL	2	B	MT-AN	CUZ	
-224	D1.464	70	C		SO	25	I	0	A	SO		5	I		A	SO	Y	C	Y	CHL	Y	CHL	2	B	MT-AN	CUZ	
-227	D1.467	58	C		O	20	I		A	SO		20	I		A	SO	Y	C	Y	CHL	Y	CHL	Y	Q/B	L-N	CUZ	
-228	D1.468	60	C	D	SO	20	MC			SO		20	MC			SO				2	CHL	Y	B	L-N	CUZ		
-236	D1.478	76	C		SO							20	I	2	A	SO	Y	C	2	CHL	2	CHL	2	B	MT-AN	CUZ	
-257	D1.487	70	C/I		SO	30	I		A	SO									1	CHL	Y	B		MT-AN	CUZ		
-274	D1.514	75	C/I	D	O	15	I	1	A	O		5	I	2	A	O				1	CHL			N	CUZ		
-288	D1.538	80	C		SO	30	I	1	A	O		5	I	2	A	SO	Y	C	5	CHL				M-N	CUZ		
-318	D1.558	40	C/I		SO	55	I	1	AD	SO										5	CHL	Y	B	N	CUZ		
-336	D1.578	45	C/I	A	SO	50	I	1	A	SO		5	I			SO				5	CHL	3	B	N	CUZ		
-357	D1.597	10	I	D	O	50	C	1	AD	O		40	C	2	AD	O	Y	C	2	CHL	Y	B		F-PX	CLZ		

KEY TO TABLE

A	Alteration	AN	Anorthosite	B	Biotite
C	Cumulus	F-	Feldspathic	CHL	Chlorite
D	Deformation	G	Gabbro	E	Epidote
I	Intercumulus	L-	Leuco-	IP	Inverted Pigeonite
L	Number of Lamellae visible	M-	Mela-	HBL	Hornblende
MC	Minor Cumulus	MGT	Magnetite/Magnetite rich	Q	Quartz
MYL	Mylonitized	MT-	Mottled		
O	Ophitic	N	Norite	UZ	Upper Zone
SO	Sub-Ophitic	PX	Pyroxenite	MZ	Main Zone
Y	Presence observed	SP-	Spotted	CUZ	Upper Critical Zone
Y*	Orthopyroxene and inverted pigeonite coexisting (D2 only)			CLZ	Lower Critical Zone
Z	Zonation				
?	Possible indicators				
%	Proportionate amount present				

Depth* Depth of sample relative to the Upper Zone/Main Zone boundary



Figure 5.A (D1.380) - Deformation of plagioclase percline twinning (xpl)



Figure 5.B (D1.380) - Deformation of twinning in plagioclase (xpl)



Figure 5.C (D1.558) - Ductile deformation of orthopyroxene with augite exsolution lamellae (xpl)



Figure 5.D (D1.396) - Deformation of pyroxene resulting in a wavy appearance (xpl)

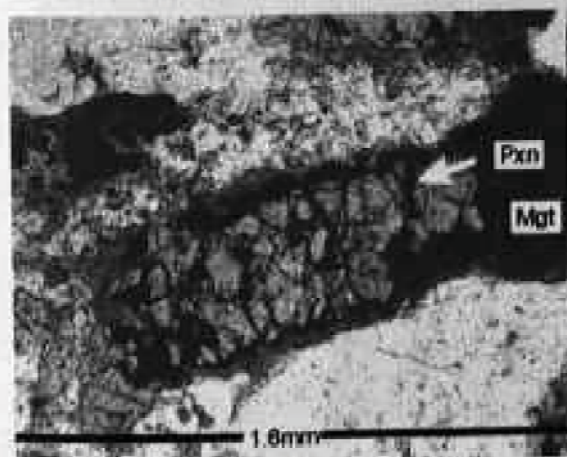


Figure 5.E (D1.184) - Magnetite enclosing pyroxene and in filling fractures within the pyroxene (ppl)

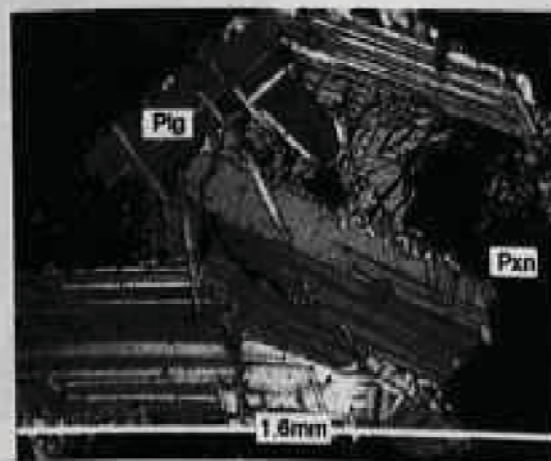


Figure 5.F (D1.419) - Needles of biotite extending from the pyroxene and cutting across plagioclase (xpl)

Figures 5.A -5.F Grain textures and relationships between the minerals found in borehole D1, where: xpl -crossed polarized light; ppl -plane polarized light; pxn -pyroxene; plg -plagioclase; mgt - magnetite.

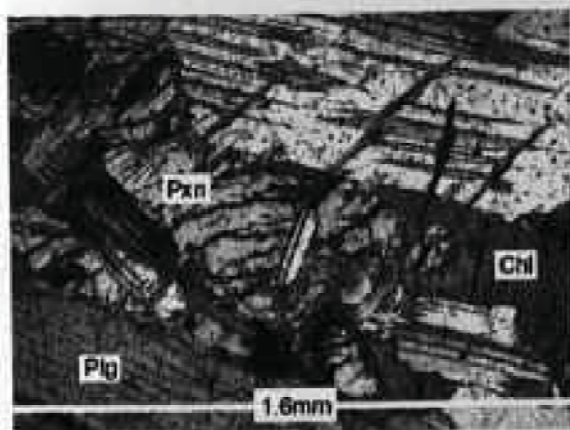


Figure 5.G (D1.419) - As for Figure 5.A but with chlorite alteration of the pyroxene (xpl)

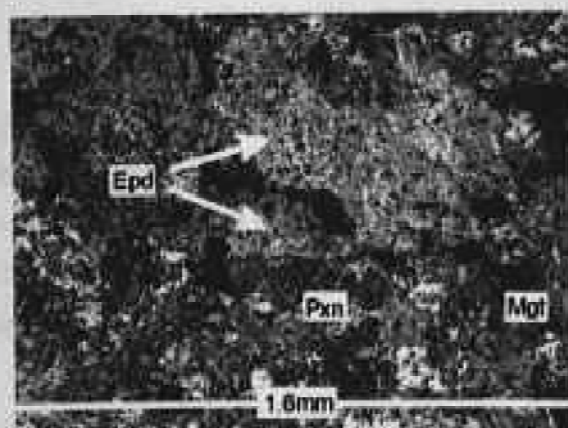


Figure 5.H (D1.224) - Extensive epidotisation of grains within a mixed gabbro-norite-pyroxenite assemblage (ppl)

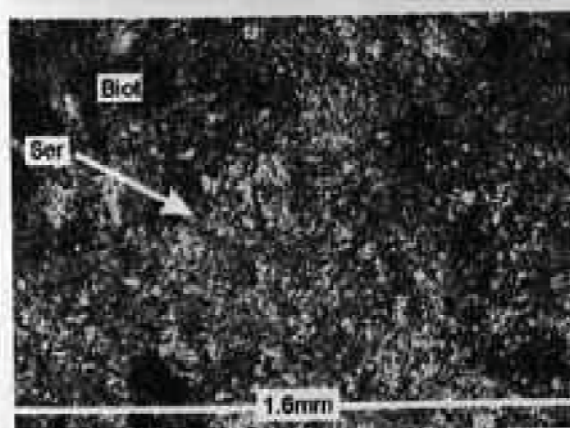


Figure 5.I (D1.291) - Extensive alteration to clays, epidote and chlorite within a spotted anorthosite (ppl)

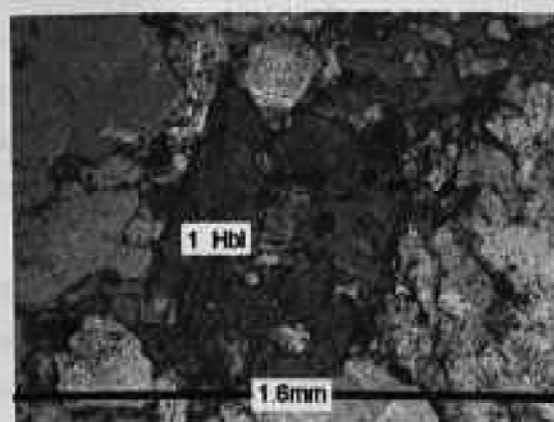


Figure 5.J (D1.374) - Primary hornblende with quartz and plagioclase (xpl)

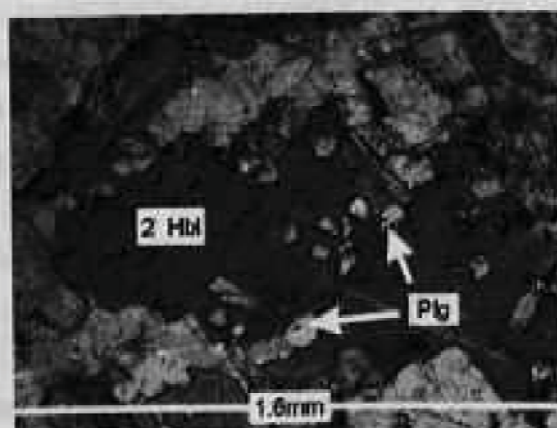


Figure 5.K (D1.374) - Secondary hornblende with remnant ophitic textures between plagioclase and the original pyroxene (xpl)

Figures 5.G - 5.K Grain textures and relationships for borehole D1, where: ppl -plane polarized light; xpl -cross polarized light; chl -chlorite; epd -epidote; biot -biotite; hbl -hornblende; ser -sericite.

5.2: D2 Petrographic Descriptions

Between the depths of -152m, within the Main Zone, and 418m, within the Upper Zone, twenty-eight samples were taken from the borecore at intervals of 4 - 57m. From these, thin sections were prepared for petrographic examination. Table 5.ii below summarises the data, and includes estimated percentage values for the individual minerals. The key is the same as for Table 5.i. Detailed descriptions of the individual thin sections are presented in Appendix 2, p xviii-xxiii.

Although only the Main and Upper Zones are represented, a wide range of minerals and mineral textures were observed in the borecore. Plagioclase, the dominant mineral, appears as the major cumulus phase, as individual grains within pyroxenes, and as an interstitial component. Minor cumulus pyroxene includes clinopyroxene, which is the second most abundant mineral, orthopyroxene and inverted pigeonite, which is most notable in the Upper Zone (UZ). The alteration products, sericite and chlorite, regularly appear throughout the thin sections, but secondary hornblende is found less often. Biotite is the only accessory mineral, apart from a singular occurrence of quartz. Magnetite is the least abundant of the cumulus minerals.

In the majority of samples plagioclase is the major cumulus phase, except in pyroxenites where pyroxene is the major cumulus phase. Interstitial plagioclase occurs throughout the UZ thin sections, but appears only once in those representing the Main Zone (MZ). The single sighting corresponds with the -152m depth, at the base of the sampled section. Individual plagioclase grains, which are incorporated in all three pyroxenes, clinopyroxene, orthopyroxene and inverted pigeonite, display an ophitic texture throughout the MZ and the lower portion of the UZ (Figure 5.L). Some plagioclase grains display a myrmekitic texture, but this occurs only in the UZ, where inverted pigeonite is also present in the sample. Often this texture is found in small areas of larger grains or the entire area of smaller grains. Figure 5.M shows a rounded grain of plagioclase exhibiting the myrmekitic texture whilst the surrounding plagioclase remains normal.

The majority of thin sections show randomly oriented grains, with grain shapes varying from sub-euhedral to sub-anhedral. Enclosed plagioclase grains within pyroxenes are euhedral and normally less than 1mm in length. Cumulus plagioclase grains are 2 to 8mm in length and 0.5 to 2mm in width, whereas the interstitial plagioclase is frequently less than 1mm long and 0.5mm wide.

Alteration, of both intercumulus and cumulus plagioclase, to sericite occurs throughout most of the sampled section, but it is patchy. Mild deformation is also evident throughout and is expressed as curved twinned lamellae within the plagioclase grains as seen in Figure 5.N.

In the majority of thin sections, a greater proportion of the pyroxene component is clinopyroxene. It coexists with orthopyroxene in all but four thin sections, where one phase appears to the exclusion of

the other. Three samples at -148m, -123m and 418m, contain only clinopyroxene, whereas in the fourth, which is at -152m, the base of the sampled section, orthopyroxene alone represents the pyroxenes. As all four samples came from anorthositic units with mottles, it is possible that this exclusivity results from the way the thin sections were cut. Inverted pigeonite appears at the base of the UZ, at 4m, and is distinct in several thin sections, as can be seen in Figure 5.O. It occurs alongside primary orthopyroxene and clinopyroxene in only two thin sections that represent the 298m and 384m depths, in the upper half of the zone. The inverted pigeonite is coincident with the plagioclase grains, which exhibit myrmekitic textures. Grain sizes vary between 0.5 and 1 mm for the three pyroxenes, all of which are optically continuous where they form mottles enclosing plagioclase.

Although only minor alteration is evident throughout the thin sections, the majority of samples contain chlorite at the grain boundaries. A second alteration product, hornblende, is present in only six thin sections, at -152m, -76m, -22m, 14m, 62m and 298m. Deformation evidence, as seen in bent exsolution lamellae, is observed in only three thin sections. These are at -76m, -39m and 234m. Not all pyroxenes grains within these thin sections are affected, but those that are appear highly deformed.

Magnetite is a minor cumulus phase in all thin sections taken from the UZ. The proportion of magnetite found in these varies between 1 and 25%. Four samples containing interstitial magnetite are found at -148m, -113m, -62m and -22m in the Main Zone, but only in trace amounts. Minor cumulus magnetite occurs as rounded blebs, and also as tiny exsolution needles within pyroxenes, which are often observed aligned with respect each other (Figure 5.P). Size ranges from less than 0.1mm up to 5mm in length.

Biotite occurs as a fine-grained interstitial component, mainly at the boundaries of pyroxene grains, in association with magnetite. Grains are commonly less than 1mm in length.

Quartz is evident in a single sample at 234m.

Table 5.ii. Summary of D2 thin section observations

Depth m	Sample m	Plagioclase					Low-Ca Pyroxene						Clinopyroxene					Magnetite		Chromite	Alteration		Other		Lithology	Zone		
		%	C/I	A/D/Z	O/SO		%	C/I	L	A/D	O/SO	I.P	%	C/I	L	A/D	O/SO	%	C/I	%	C/I	%	CHL/HBL	%	B/Q			
418	D2.27	75	C/I	AD									14	MC		A		10	MC			1	CHL	Y	B	L-G	UZ	
405	D2.40	10	C	AD			15	MC	1			Y	58	MC	2			2	MC			Y	CHL	Y	B	F-PX	UZ	
384	D2.81	27	C/I	AD			30	MC	3			Y*	30	MC	3	A		10	MC			1	CHL	2	B	G-N	UZ	
329	D2.116	55	C	ADZ			25	MC	2			Y	20	MC				5	MC			Y	CHL	Y	B	G-N	UZ	
298	D2.147	55	C	AD	O		30	I	1	A	O	Y*	15	I		A	O	Y	MC			1	CHL/HBL	Y	B	L-G-N	UZ	
241	D2.204	55	C/I	AD			5	MC		A		Y	25	MC	2	A		10	MC					3	B	G-N	UZ	
234	D2.211	45	C/I	AD			17	MC	2	D		Y	18	MC	2	D		20	MC					1	B/Q	G-N	UZ	
202	D2.243	45	C/I	ADZ			5	MC				Y	25	MC	2			25	MC						B	G-N	UZ	
183	D2.282	35	C	Z			30	MC	3?	A		Y	30	MC	3?	A		5	MC			Y	CHL	Y	B	MGT-G-N	UZ	
111	D2.334	20	C/I	AD			10	MC		A		Y	35	MC		A		10	MC			Y	CHL	Y	B	MGT-L-G-N	UZ	
105	D2.340	85	C/I	A			2	I	2	A		Y	13	I	2	A		Y	MC			Y	CHL	Y	B	AN	UZ	
89	D2.356	60	C	AD	SO		15	I	3?	A	SO	Y	5	I		A	SO	15	MC			4	CHL			G-N	UZ	
82	D2.383	65	C	ADZ	SO		19	I	1?	A	SO	Y	15	I	3?	A	SO	1	MC			1	CHL/HBL	Y	B	L-G-N	UZ	
46	D2.399	60	C	AD	SO		20	I	2?	A	SO	Y	25	I	2	A	SO	5	MC			Y	CHL			L-G-N	UZ	
37	D2.408	63	C	A	SO		15	I	2?	A	SO	Y	15	I	2?	A	SO	5	MC			Y	CHL			L-G-N	UZ	
14	D2.431	55	C	AD	SO		22	I	2?	A	SO	Y	22	I	2	A	SO	1	MC			2	CHL/HBL	Y	B	G-N	UZ	
4	D2.441	70	C	D	O		15	I	2	A	O	Y	15	I	2?	A	O	1	MC			3	CHL			B	G-N	UZ
-3	D2.448	55	C		SO		10	I		A	SO		35	I	2	A	SO					1	CHL	Y	B	G-N	MZ	
-22	D2.467	60	C	AD	O		20	I	1	A	O		5	I	1	A	O	Y	I			15	CHL/HBL	Y		L-G-N	MZ	
-39	D2.484	45	C	AD	SO		25	I	1	A	SO		30	I	2	AD	SO					Y	CHL	Y	B	L-G-N	MZ	
-62	D2.507	60	C	D	SO		20	I	1	A	SO		20	I	2	A	SO	Y	I			1	CHL			L-G-N	MZ	
-76	D2.521	60	C		SO		30	I		AD	SO		10	I	2	AD	SO					Y	CHL/HBL	Y	B	L-G-N	MZ	
-88	D2.533	45	C	ADZ	O		25	I	1	A	O		20	MC	2	A						Y	CHL			L-G-N	MZ	
-96	D2.541	50	C	AD	SO		10	I		A	SO		40	MC	2	A	SO					Y	CHL	Y	B	L-G-N	MZ	
-113	D2.558	70	C	D			15	MC	1	A			15	MC	2	A		Y	I			Y	CHL			G-N	MZ	
-123	D2.568	80	C	AD									20	I	2									Y	B	MT-AN	MZ	
-148	D2.593	95	C	A	SO								5	I	1	A	SO	Y	I			2	CHL			AN	MZ	
-152	D2.597	70	C/I	A	O		30	I	1	A	O											5	CHL/HBL	Y	B	SP-AN	MZ	

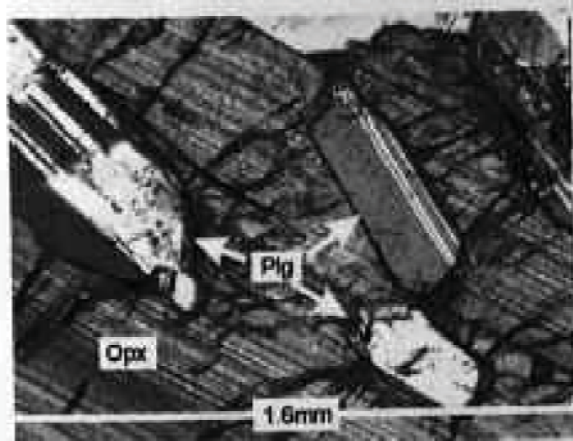


Figure 5.L (D2.448) - Plagioclase encapsulated within orthopyroxene (xpl)



Figure 5.M (D2.399) - Rounded grains of plagioclase exhibiting myrmekitic texture (xpl)

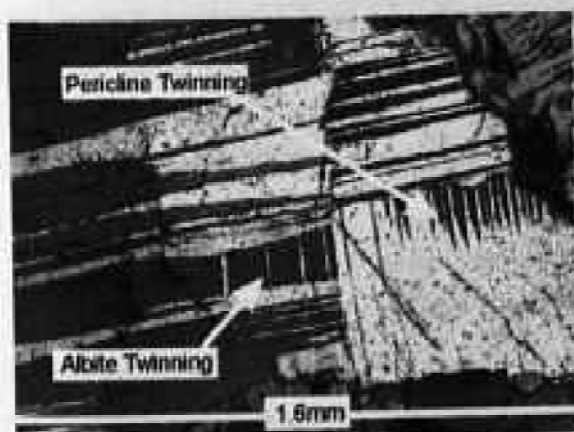


Figure 5.N (D2.61) - Pericline and albite twinning (xpl)

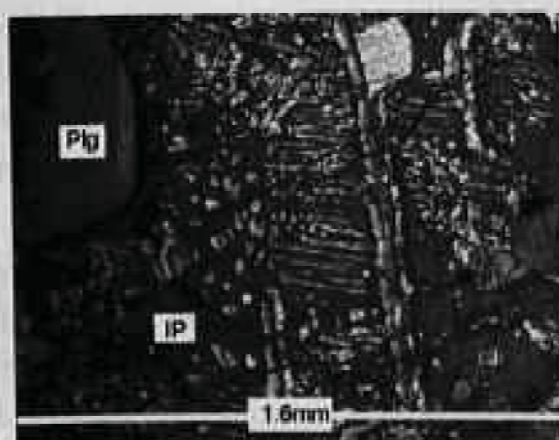


Figure 5.O (D2.399) - Inverted pigeonite with plagioclase enclosed, exhibiting an ophitic texture (xpl)



Figure 5.P (D2.431) - Sub-parallel alignment of magnetite exsolution needles in orthopyroxene (ppl)

Figures 5.L -5.P Grain relationships and textures from selected samples within borehole D2, where; ppl -plane polarised light; xpl -crossed polarised light; opx -orthopyroxene; plg -plagioclase; ip -inverted pigeonite.

5.3: Comparisons of Borehole Observations and Petrographic Analyses with the Typical Sequence for the Eastern Bushveld Complex

An initial analysis, carried out by Scoon and Long, ascertained the following. D1, which is 772.04m long, intersects the CZ at a depth of approximately -158m, and terminates in the ClZ at a depth of -532m, with respect to the MZ/UZ boundary. The Critical, Main and Upper Zones are present. Lower and Middle Group chromitites occur in the ClZ and the Merensky and Bastard Reefs are situated in the CuZ. D2 intersects the MZ/UZ boundary 445m from the collared position, at 0m, and terminates at a depth of -152.47m, with respect to the MZ/UZ boundary, within the MZ.

The comparisons drawn between the two boreholes, described in Sections 4.1 and 4.2, and the typical sequence in the eastern limb, are based on the characteristics and mineralogical properties, of the lithologies encountered. As no CZ is represented within D2, comparisons between the two boreholes are made for the MZ and the UZ only. The CZ in D1, however, is compared with that in the typical sequence. The depth, at which the CuZ appears in the borecore sample of D1, is shallow and highlights the attenuation of the subzones within the MZ.

Within the ClZ of the typical sequence, there are a maximum of seven layers representing the LG chromitites, LG1 to LG7, and two layers representing the Middle Group, MG1 and MG2. In D1, the two groups of chromite partings are consistent with these Lower and Middle Groups in that both are found within feldspathic pyroxenitic sequences. The five chromitite partings are located between -505.10m, and -397.50m correspond to the LG chromitites. The seven partings, encountered between -355.15m and -349.56m, equate with MG1 and MG2. Harzburgite, an olivine-bearing lithology, is found within the typical ClZ, but is absent from the sequence in D1. A norite, found above the MG chromitite partings in D1, marks the onset of plagioclase and, therefore, the base of the CuZ. Fracturing of the units suggests that faulting out of portions of the lithologies has occurred after consolidation of the zone. Potholes at the base of chromitite layers in the typical sequence suggest possible interruptions in the depositional sequence, *i.e.* periods of non-deposition.

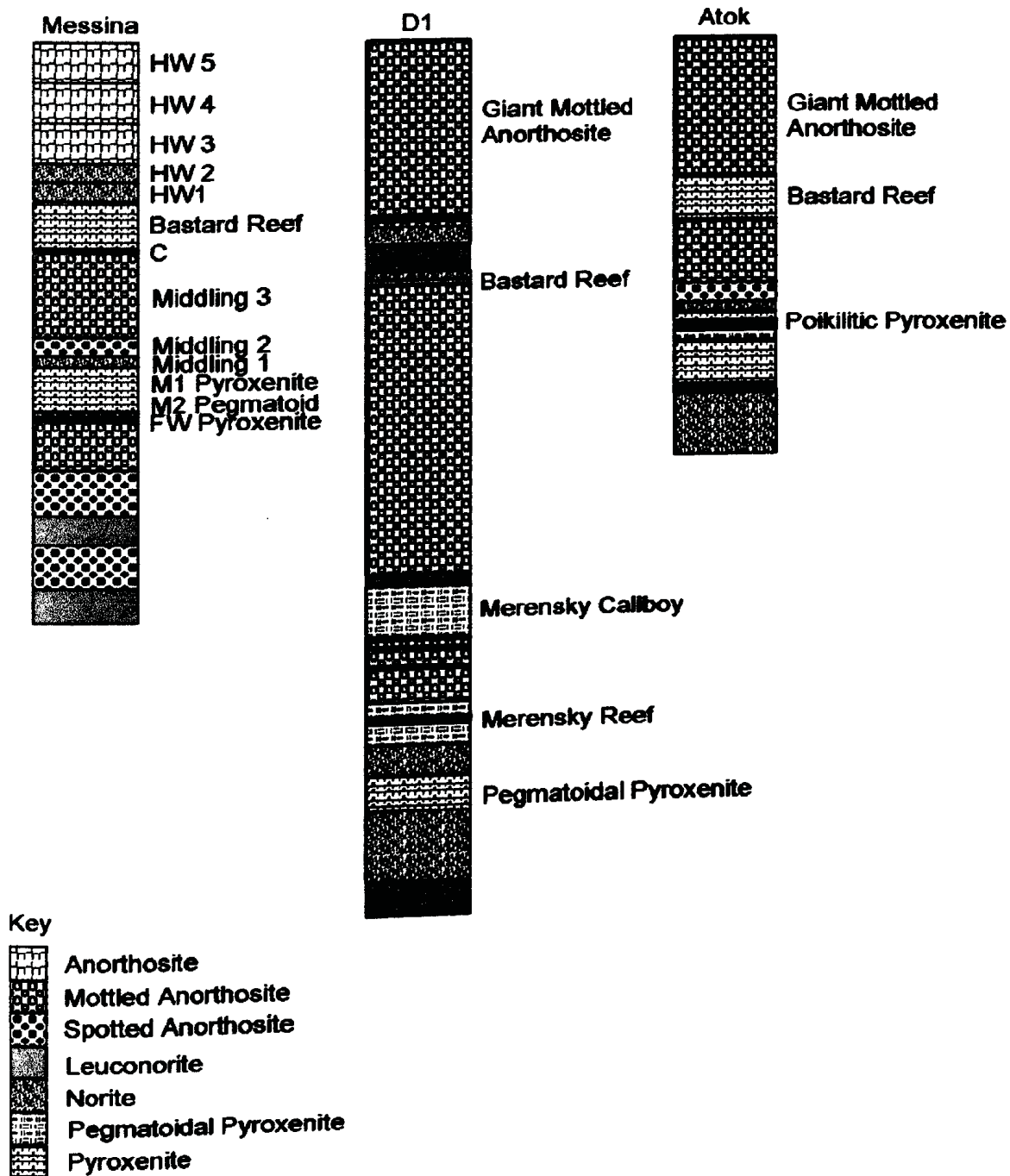
Within the known CuZ, eight cyclical units represent the sequence of lithologies. The D1 lithologies, from -346.85m to -189.35m, do not show a similar cyclicity, as the CuZ does not contain the complete sequence of chromitites, pyroxenites, norites and anorthosites. The MG chromitites, MG3 and MG4, and the UG chromitites, UG1, UG2 and UG3, normally present at the base of cycles, are not present in this borehole. Anorthosite, which typically forms the upper most unit of each cycle, and therefore the footwall to the overlying chromite, is absent until 12m below the base of the Merensky Reef.

The lithology of the interval, between the UG2 chromitite and the Merensky Cyclic Unit, varies within the eastern limb, from predominantly anorthositic with minor norite, at Messina, to a norite with thin layers of anorthosite and leuconorite, at Maandagshoek (Cameron, 1982; Gain, 1985; Lea, 1986).

Furthermore, the interval also varies in thickness from 110m to 140m at Messina, to 370m at Maandagshoek. In D1, from the base of the CuZ to the Merensky Reef, there is a 101.80m of norites, pyroxenites and a single mottled anorthosite, suggesting that this sequence, although substantially thinner, is similar to the equivalent interval at Maandagshoek.

The Merensky Reef is contained within a three-layered pyroxenite at both Atok Mine (Mossum, 1986) and Messina (Lea, 1986). In D1, the lowermost poikilitic feldspathic pyroxenite is not apparent and the reef unit, at 4.38m, is more than twice the thickness recorded at Atok, as shown in Figure 5.Q. Otherwise, it reflects the typical sequence of a pegmatoidal pyroxenite beneath a feldspathic pyroxenite, with two chromitite layers delineating the reef. The Merensky Reef hangingwall is also the footwall to the Bastard Reef at both mines. Typically, it is formed by a norite, which grades into a spotted anorthosite, followed by a 6m to 10m thick mottled anorthosite (Lea, 1986; Mossum, 1986). The lithology is dissimilar in D1, in that it starts with a mottled anorthosite followed by two pyroxenite layers, one of which is the Merensky Callboy, and ends in a considerably thicker 30m unit of anorthosite. As found elsewhere, the Bastard Reef in D1 is a thin (0.49m) feldspathic pyroxenite, with a well defined chromitite stringer located at the base of the unit, resembling that seen at Messina and Atok (Lea, 1996; Mossum, 1986).

Lea (1986) and Mossum (1986) describe the hangingwall to the Bastard Reef as either a norite or an anorthosite. The typical overlying units are mottled anorthosite, gabbro-norite and leuconorite, over a distance of 50m to 59m (Cameron, 1982; Mossum, 1986; Lea, 1986). The succession in the CuZ of D1 is similar, in that the base of the 37.80m hanging wall is a norite, which gives way to leuconorite and then mottled anorthosites. The uppermost and largest of these is identified as the Giant Mottled Anorthosite (GMA), which SACS (1980) place at the top of the CuZ. Inverted pigeonite also occurs in this zone and has been discovered 93m above the Merensky Reef (Von Gruenewaldt, 1973), effectively within the GMA. Comparing well with this observation are two D1 borecore samples containing inverted pigeonite, from 86m and 70m above the Merensky Reef *i.e.* within the GMA. Alteration of the lithologies, from the Merensky Reef to the top of the CuZ, is apparent in the form of hydrothermal alteration and deformation. These processes clearly infer that fault activity, and subsequent percolation of hydrothermal fluids into the units, have occurred.



Not drawn to scale

Figure 5.Q Borehole sections from Atok, Messina and D1 borehole, located between the footwall to the Merensky Reef and the hangingwall to the Bastard Reef, with data acquired from Mossom (1986) and Lea (1986).

Subzone A of the Main Zone (MZ), as shown in Figure 5.R, is typically represented by a noritic sequence in the lower reaches, which contains a 200m porphyritic norite unit above the GMA (Von Gruenewaldt, 1973; Molyneux, 1974). The upper portion of Subzone A is gabbro-noritic, and contains two prominent anorthositic markers. The noritic units, including the Porphyritic Norite Marker, are entirely missing above the base of Subzone A in D1. Instead, a 158m gabbro-norite-anorthosite sequence lies directly above the GMA, which contains alteration assemblages as seen in the underlying CuZ. This would suggest that faulting out of the lower portion of the Main Zone had possibly resulted in the attenuation in this part of the zone. Another indicator is the location of the Main Mottled Anorthosite (MMA) in relation to the Merensky Reef. Halfway up the typical Subzone A, the MMA is encountered at 300m and 700m above the Merensky Reef in the Sekhukhuneland and Roossenekal areas respectively (Von Gruenewaldt, 1973; Molyneux, 1974). In D1, this same interval is only 117m. The MMA consists of alternating spotted and mottled anorthosite and gabbro-norite over some 150m to 200m. It is possible that the mottled anorthosites, at -123.5m and -113m, which are also interlayered with gabbro-norites, correspond to the MMA of the typical sequence. D1 contains a further sequence of spotted and mottled anorthosites, between -72.23m and -49.3m, which is similar to the second anorthosite marker, i.e. the Upper Mottled Anorthosite (UMA) in the typical sequence, as described in the Roossenekal area (Von Gruenewaldt, 1973).

Noritic lithologies are also absent from the MZ in D2. The lower 37m are exclusively anorthositic and the following 115m gabbro-leucogabbro-noritic sequence, which includes 90m thick leucogabbro-norite, represents the remainder of the zone. The anorthosites from D2 cannot be correlated with the typical sequence, without any knowledge of the lithologies stratigraphically below. It would be pure conjecture to suggest that the spotted anorthosites in D1 and D2 belong to the UMA. Should this anorthositic package be assigned to Subzone C in D2, it is noted that the thickness of the package is anomalous. Although several anorthositic packages occur in this uppermost subzone of the MZ, the approximate thickness of each anorthositic layer is 10m (Von Gruenewaldt, 1973; Molyneux, 1974).

No inverted pigeonite is found within any of the Main Zone lithologies of either D1 or D2. This immediately precludes this subzone from the Bushveld Complex sequence seen at the location of the Phosiri Dome. The absence of this mineral, and therefore Subzone B, makes the distinction between Subzones A and C difficult. It is entirely possible that for D1, Subzones A and C are juxtaposed or that Subzone C may be missing altogether. In the case of D2, it is possible that only Subzone C of the Main Zone is present.

The base of Subzone A, in the typical sequence of the UZ, is marked by the first appearance of magnetite (SACS, 1980), below a sequence of magnetite-rich lithologies. These are predominantly gabbro-norites interspersed with minor anorthosites, which contain disseminated sulphides and magnetite layers (Von Gruenewaldt, 1973). Magnetite anorthosites form the Lower Layers 1 and 2,

and there is also a Main Magnetite Layer (MML), which marks the top of the subzone. From 0m to 240m in D1, the UZ, which is mainly gabbroic in nature, contains magnetite-rich layers. This suggests that the Lower Layers 1 and 2, plus the Main Magnetite Layer are missing from the stratigraphy. Magnetite layers do exist within D1, but they are not well developed, so cannot easily be matched with either the Lower or Upper Groups normally found in the eastern Bushveld Complex. D2 compares more favourably with the typical sequence. Although magnetite is first observed as an intercumulus phase within the MZ, it reappears as a minor cumulus phase within a mottled anorthosite, corresponding with the basal marker of Subzone A of the Upper Zone. Gabbros and anorthosites dominate the lower section, as in D1, but this changes, above 330.74m, to a predominantly magnetite-rich anorthosite lithology for the remainder of the UZ.

Generally, inverted pigeonite is present from the base to the top of Subzone A (Von Gruenewaldt, 1973; Molyneux, 1974). Inverted pigeonite is seen in only two samples in D1, at 45m and 56m above the base of the UZ. The only other sample to contain low-Ca pyroxene is at 121m, where it is primary orthopyroxene. The presence of the inverted pigeonite in D1, indicates that the UZ is possibly comparable with D2, which contains inverted pigeonite to the exclusion of primary orthopyroxene throughout this zone.

Normally, in the UZ, the mineral olivine, appears at the base of Subzone B, and is present in minor amounts throughout the remainder of this zone (SACS, 1980). Its absence from the UZ sequence in D1 and D2 would indicate only Subzone A is present. Overall it would appear that D2 contains a more representative, but by no means complete, succession of Subzone A.

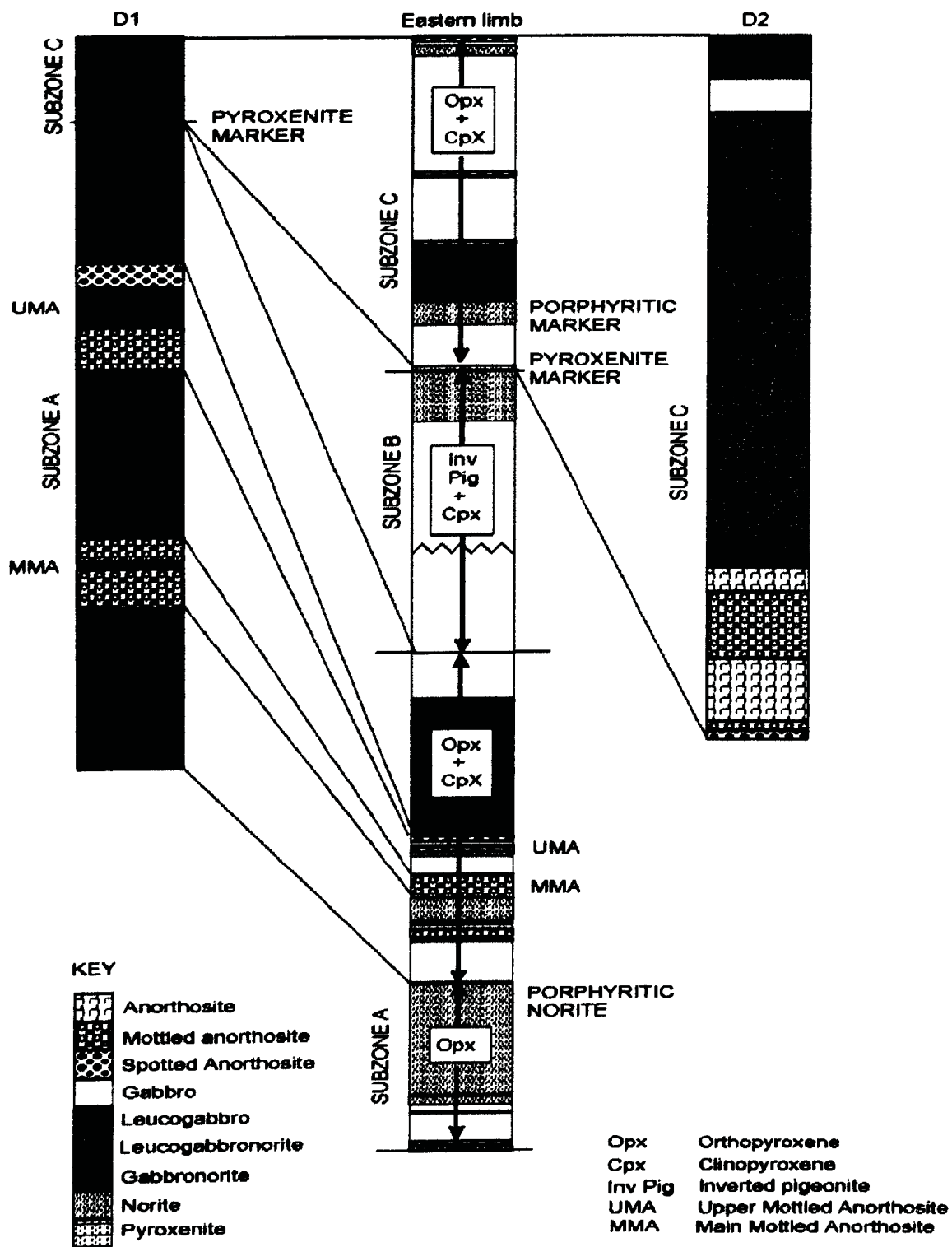


Figure 5.R The Main Zone sequence as found in the D1 and D2 boreholes are compared with the typical sequence in the eastern limb of the Bushveld Complex.

6: MINERAL ANALYSES

6.1: Electron Microprobe Analysis

The data, which provide the basis for discussion in this section, were acquired using the Cameca Camebax Electron Microprobe facility at the University of the Free State, Bloemfontein. Polished thin sections were analysed. The least altered thin sections, as determined from petrographic inspection (Chapter 5), were selected for electron microprobe analyses. A 2 μm diameter beam, with a 15KV acceleration voltage and a 30nA beam current, was fired at each selected point on each of the grains. For both peak and background values, the beam was fired for 10 seconds per count. Standard deviations of the measurements of the oxide elements range between 0.0052 - 0.1243 wt % as seen below in Table 6.i.

Table 6.i Standard deviations as calculated from data run on three standards, with a total of 90 points being measured (30 points on each standard).

Element (wt %)	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	Cr ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O
Standard Deviation	0.1243	0.0374	0.1031	0.0374	0.0182	0.0087	0.0451	0.0283	0.0064	0.0052

Plagioclase separates were collected from samples removed from the Upper Critical Zone (CuZ), Main Zone (MZ) and Upper Zone (UZ), between the depths of -338m and 138m, using a Franz Magnetic Separator, set at 20A. To ensure that the samples were pure, they were cleaned in alcohol and subjected to ultra-sonic booming to remove clay particles. The purified samples were prepared, according to the method by Norrish and Hutton (1969), then analysed as fusion discs by XRF.

The data were recalculated using the "MinPet" software program, which employs the methods of Deer *et al.* (1966) and Yoder and Tilley (1962) for feldspars and pyroxenes, respectively. Pyroxene end-members were calculated, according to the method reported by Cawthorn and Collerson (1974) and the cation site distribution by Morimoto (1988).

Analyses for major and minor element concentrations of the minerals, orthopyroxene, clinopyroxene and plagioclase, were carried out on polished thin sections. In every polished thin section, 3 or 4 grains of each mineral were analysed to ensure reproducibility. The values attained for each mineral were averaged for all the sample depths and plotted in order to generate profiles as seen in Figures 6.A to 6.C and 6.E to 6.G. Therefore, for the purpose of discussion, all values referred to should be accepted as average values. Data described for the pyroxenes include the Magnesium Number (Mg #) $[\text{Mg}/(\text{Mg}+\text{Fe}) \times 100]$ and the Enstatite Content (En #) $[\text{En}/(\text{En}+\text{Fs}) \times 100]$, wt % TiO₂, Al₂O₃ and Cr₂O₃. The Enstatite Number is referred to for the orthopyroxenes only. As Clinopyroxene cannot have an Enstatite content, the magnesium-iron ratio is referred to as the Magnesium Number in the

text and in the following tables. The plagioclase data includes descriptions for the Anorthite Content (An #) $[\text{Ca}/(\text{Ca}+\text{Na})\cdot 100]$, wt % K_2O and FeO .

6.1.1: Borehole D1

Samples were removed at intervals of 7m to 103m, from over ten layers within the Upper Critical and Main Zones, between the depths of -338m and -19m. Analyses of grain cores and rims produced a total of 415 points. Figures 6.A to 6.C show profiles of the average values, which are summarised in Tables 6.ii to 6.iv below. A full data set is provided in Appendix 4, p xxviii- lii. Table 6.v contains the plagioclase separates data.

6.1.1.1: Clinopyroxene

Mg #

Core values vary between Mg # of 71 to 83 and rim values vary between Mg # 71 to 85. The difference in range between these is minimal, suggesting that the grains have undergone sub-solidus internal homogenisation, which destroyed any original zoning. Figure 6.A shows that both core and rim analyses indicate a decreasing trend from Mg # 77 - Mg # 71 from the depth of -236m to -159m. The sample from further up the sampled section, at -140m, records a sharp increase in the magnesium concentration of 15%. This coincides with a change in lithology from a mottled anorthosite, where the clinopyroxene is represented only in the interstitial component, to a gabbro-norite. Both core and rim values attain a maximum at -140m, with Mg # 83 and Mg # 85, respectively. The gabbro-norites sampled from the depths of -140m and -98m have the highest values, but gabbro-norites higher in the stratigraphy show a gradual decrease in their magnesium concentration. At the top of the sampled section at 19m, within a leucogabbro-norite, core and rim values are Mg # 71 and Mg # 72, respectively. The pyroxenes from these lithologies are cumulus and therefore, reflect the differentiation trend of Mg # through the sequence.

Wt % TiO_2

The cores show a greater spread of titanium concentration than the rims, with respective value ranges of 0.08 - 0.29 wt % and 0.07 - 0.15 wt %. Cores have slightly higher average concentrations than their rim counterparts (Figure 6.A). The spread of data for individual analyses masks any systematic trend in abundance. The lower section, from -236m to -140m, indicates a decrease from 0.18 wt % to 0.10 wt % in the core. Between -140m and -115m, a sharp increase from 0.10 wt % to 0.29 wt % is

noted, dropping down to 0.13 wt % at -98m. Upwards from -98m, a gradually increasing trend is noted, to -19m, where core values range in the vicinity of 0.13 - 0.23 wt %. Overall, the samples from the Main Zone indicate an upward enrichment with respect to the Critical Zone. No lithological control is noted.

Wt % Al_2O_3

The minimum and maximum values for aluminium concentration range between 0.93 - 1.46 and 0.78 - 1.16 for cores and rims, respectively. Throughout the sampled sequence, core values are generally greater than equivalent rim values. From the base of the section upward, there appears to be little change indicated in the relatively constant profile shown in Figure 6.A. The lithology appears to have some control over the aluminium concentration within the cores, as the highest values are derived from anorthosites. No such correlation can be made for the rim averages.

Wt % Cr_2O_3

For each of the sampled depths, the wt % Cr_2O_3 values are greater for cores. Values were found to range from 0.03 to 0.29 for cores and from 0.02 - 0.25 for rims. The profile, in Figure 6.A, indicates a decrease in the chromium concentration for both cores and rims upwards from -236m to -19m, with the maximum values occurring at the base of the sampled sequence. The three highest values of chromium in the core are derived from anorthosites, at depths -236m, -159m and -115m, indicating a lithological control, which is not evident within the rims.

6.1.1.2: Orthopyroxene

En Content

Values vary between En_{60-78} for cores and between En_{58-78} for rims. Figure 6.B indicates an initial decrease in the enstatite content in cores from -338m to -159m, where values change from En_{78} to En_{60} . However, the vertical gap is too great to draw any conclusions from this. Also, the mottled anorthosite at -159m contains only intercumulus pyroxene. At -140m, where the lithology changes from anorthosite to gabbro-norite, the En increases by approximately 10% to 70. Between -140m and -98m, little variation in the core and rim values about En_{70} is reflected in a relatively unchanging profile. Highest values are typically found in the more mafic units, such as norites and gabbro-norites.

Wt % TiO₂

Figure 6.B shows a non-deviating profile about the 0.10 wt % TiO₂ concentration for cores and rims. Values are in order of 0.07 - 0.12 for cores and 0.07 - 0.13 for rims, with no breaks in the trend. A lithological control is not apparent.

Wt % Al₂O₃

Core values range from 0.57 - 0.87 for aluminium concentration. Rim values vary between 0.58 - 0.73 and are usually less than their counterpart core values. The profile in Figure 6.B is relatively constant throughout the entire sampled sequence.

Wt % Cr₂O₃

The core and rim values range between 0.09 - 0.33 and 0.08 - 0.24 wt %, respectively. The cores have a marginally higher concentration of chromium than the rims. The lowermost sample, a norite, at -338m indicates a wide spread of data points, from less than 0.01 to 0.45 wt % Cr₂O₃. From -140m upward, the profile for cores and rims remain within 0.09-0.15 wt %. The highest chromium concentration for both core and rim are generally found within the more mafic units, such as the norites, with the lowest values being derived from anorthositic layers.

6.1.1.3: Plagioclase

Plagioclase separates analysed by XRF are also included in this section. Data points are plotted on Figure 6.C along with the electron microprobe data, and are presented in Table 6.v.

An Content

As plagioclase is a cumulus phase from -338m upwards, the data are more informative than for the analyses carried out on the pyroxenes, which are intercumulus in many of the samples. Throughout the sampled section of the borehole, from -338m to -19m, core values reach a maximum of An₇₄ and a minimum of An₆₅. Rim averages are less, with a maximum of An₇₆ and a minimum of An₆₂. The anorthite content of the cores in samples from -338m to -140m is relatively constant, with the average core values found between An₇₁ - 74. Upwards of -140m up to -19m, the An content decreases gradually from 72 to 65. This is indicative of the plagioclase becoming more sodic with increasing