Chapter II

GEOLOGICAL SETTING AT IMPALA MINE

The lease area of Impala Platinum Mine lies on the western lobe of the Bushveld Complex (Figure 2.1).

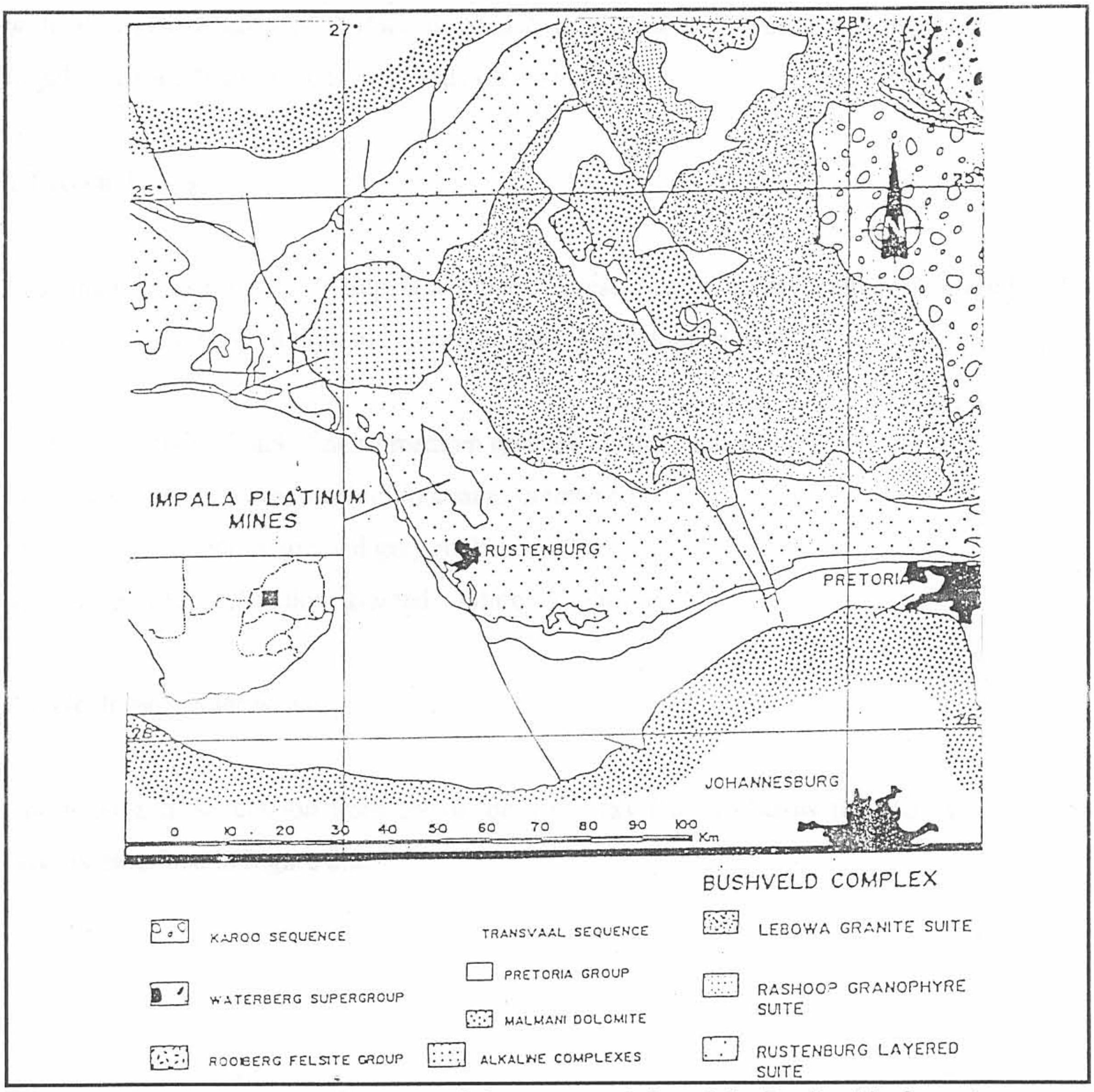

FIG. 2.1 - Locality plan - Geology of the western lobe of the Bushveld Complex showing Impala lease area

This Bushveld Complex is a large layered intrusion covering the central Transvaal. It consists of alternating layers of chromitite, pyroxenite, norite and a variety of anorthosite's which dip towards the centre at an average of 9 to 10 degrees, but this increases with depth. Strike at Impala is north-northwest to south-southeast, although locally east-west strikes can occur.

The combined lease area is 24km along strike. Two reefs, namely the Merensky and UG2, both of which outcrop on surface in places (Mellowship, 1996), are being exploited at Impala for their Platinum Group Metals (PGM) content.

2.1 Rock Types

Four main types are seen at Impala and these repeat themselves cyclically. These are listed in order from darkish to light in colour (increasing anorthosite content).

a) Chromitite is a black, fine to medium grained, tightly packed rock.
b) Pyroxenite is brown, medium to coarse-grained rock.
c) Norite is a medium grained grey rock.
d) Anorthosite is a medium grained – white to light grey rock.

2.2 Geological Succession

The geological succession from above the Merensky Reef to below the UG2 Chromitite layer is described in Figure 2.2.

Thickness (metres)	**Name**	**Description**
34,0	HW5	Mottled and Spotted Anorthosite
3-6	HW4	Large Spotted Anorthosite
5-7	HW3	Large mottled Anorthosite
1,5-3	HW2	Spotted Anorthosite Norite
2-6	HW1	Norite
2-3	Bastard Pyroxenite	*(Medium-coarse grained Pyroxenite may have thin Chromitite Layer at base)*
2-3	M3	Mottled Anorthosite
3-7	M2	Spotted Anorthosite *Norite (Characteristically layered towards top)*
0,5	M1	Norite *(Not well developed, grades into M2 and MR, Pyroxenite)*
1,0-1,5	Merensky Pyroxenite	*(Medium-coarse grained Pyroxenite)*
	Chromitite Layer	*(Pegmatoid usually has thin chromitite stringer at base then 2cm mottled Anorthosite Layer)*
0,4	FW1	Spotted Anorthosite Norite *(Maybe mottled at top)*
0,2	FW2	Cyclic *Unit (Pyroxenite-Spotted Anorthositic Norite-Mottled Anorthosite)*
3-5	FW3	Spotted Anorthositic Norite *(Often split into FW3(a) and FW3(b) by horizontal fault plane*
0,1-0,3	FW4	Mottled *Anorthoiste (Two Anorthositic Layers at base, separated by spotted anorhtositic norite)*
±1,0	FW5	Spotted Anorthositic Norite
1-3	FW6(a)	Mottled Anorthosite
1-3	FW6(b)	Large Spotted Anorthosite
1-3	FW6(c)	Mottled Anorthosite
1-3	FW6(d)	Mottled Anorthosite with Pyroxenite Boulders
		Thin Chromitite Layer with horizontal fault plane
35	FW7	Spotted Anorthosite Norite (Often greenish, chloritic partings towards top five poor ground, ±1,0m thick Olivine platy layer at top
0,8-1,2	FW8	Spotted Anorthosite
3-6	FW9	Mottled Anorthosite
3-5	FW10	Spotted Anorthositic Norite
12-15	FW11	Spotted Anorthositic Norite
10-12	FW12	Mottled Anorthosite (in places large spots) - 1cm Chromitite layer at contact
5-7	UG2 Pr	Pyroxenite with leader Chromite layers
0,7	UG2	Chromitite
0,7-1,0	UG2	Pegmatoid *(May include layers or patches of Pyroxenite)*
9-13	FW13	Spotted Anorthositic Norite *(in places Anorthosite)*

FIG. 2.2 - Impala Platinum Limited - Generalised Geological succession

A name system has been developed at Impala where the succession has been divided into distinct units with a number of marker units, with distinctive characteristics, used to facilitate this process. These units will be dealt with separately. The thickness of many of the units varies across the lease area with a general thinning occurring down dip and north (Figure 2.3).

2.2.1 Hangingwall units to the Merensky Reef

The Bastard Pyroxenite is a non mineralized pyroxenite layer lying approximately 10,0m above the Merensky Unit. Middling 3 is a whitish large mottled anorthosite of up to 3m in thickness. Middling 2 is a spotted anorthosite of approximately 3m in thickness. Middling 1 is a norite of 0,2m – 0,3m thickness. Higher hangingwall units than the Bastard Pyroxenite are rarely exposed in underground workings.

2.2.2 Merensky Reef

The Merensky reef refers to that portion of the Merensky unit and underlying footwall that is economically exploitable for PGM's. Three types of Merensky Reef can be identified depending on the Footwall unit directly underlying the reef.

The Pyroxenite reef has a basal chromitite layer (up to 3cm thick) resting directly on the footwall layers. A pegmatoid Reef has a pegmatoid below the chromitite layer that sometimes has a very thin chromitite layer at the contact with the footwall.

Because of the undulating nature of the reef and the tendency to cut through the footwall layers, locally a system has been developed to differentiate between the different reef settings. Merensky "A" reef describes the reef when resting on Footwall 1. Merensky "B" reef describes the reef when resting on Footwall 2. . Merensky "C" reef describes the reef when it has cut through Footwall 2. Deep Merensky "C" Reef describes the reef when it is resting on or below footwall 6. All of the above can be either a Pyroxenite or a Pegmatoid Reef.

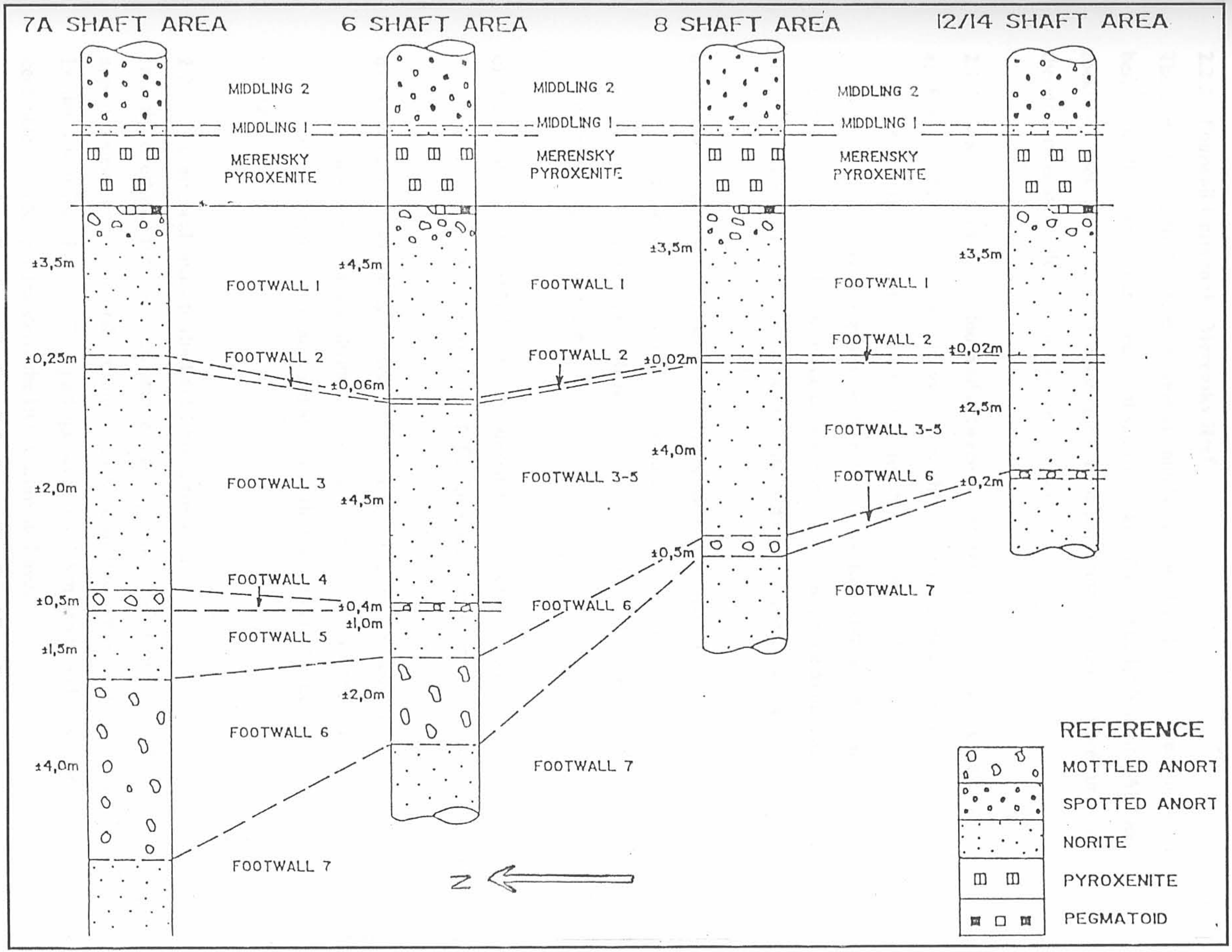

FIG. 2.3 - Section showing thinning of the footwall units at Impala

2.2.3 Footwall Units to the Merensky Reef

The footwall units to the Merensky unit are numbered from 1 to 12 with increasing depth before the UG2 unit is intersected. Footwall's 1,3,5 and 7 are all basically norite. All these rocks will look the same in hand specimens in identification problems. Marker units are therefore essential in allowing sub-division to occur.

2.2.4 Marker Units in the footwall between the Merensky and UG2 (Figure 2.3).

a) **Footwall 2** consists of three distinct layers which are always present despite varying thickness. The top layer is a pink to white anorthosite that grades downward into a layer of spotted anorthosite. The bottom layer is a very dark pyroxenite. This unit has an average thickness of 12cm but can be as little as 1cm in some areas where the spotted anorthosite portions is poorly developed.

b) **Footwall 4** is usually represented by two thin pink white anorthosite layers (2cm) separated by a zone of spotted anorthosite. This footwall is generally not developed in northern parts of Impala but a mud infilled shear is locally developed in its place.

c) **Footwall** 6 is a whitish, large mottled anorthosite with a thin chromitite layer usually associated with the top contact. Thickness can vary from 2cm to 60cm.

d) Near the top of **Footwall 7,** a very distinctive layer is usually present, in which dark greenish-black olivine and pyroxenite form bands. These bands vary from 0,2m to 1,4m in thickness and are called the Olivine Platy Norite Layers (O.P.L.'s).

2.2.5 Hangingwall units to the UG2 Chromitite Unit

Directly overlying the UG2 Chromitite Layer is the UG2 Pyroxenite. This unit is approximately 8,0m thick and contains a package of three chromitite layers called the Leader Chromitite Layers. This package averages 50cm thick and lies from a few centimeters to a few metres above the UG2 Chromitite Layer.

An erratically developed thin chromitite layer is sometimes developed between the UG2 Chromitite Layer and the leader Chromitite Layer and is called the Intermediate Chromitite Layer. Where developed, this layer can cause hangingwall parting where it is developed close to excavations.

2.2.6 UG2 Chromitite Unit

The UG2 Chromitite Layer is a well-defined 50 to 80cm (usually 60cm) thick layer with sharp contacts. Beneath the unit is a coarse-grained pegmatoid varying from 0 to 1,5m in thickness with an average of 50cm. The absence of this pegmatoid usually indicates potholing of the UG2 Chromitite layer.

2.2.7 Footwall units to the UG2 Chromitite Unit

The immediate footwall unit is Footwall 13, which is a spotted anorthosite and varies in thickness from 8,0m to 10,0m. Below this lies the UG1 unit which comprises a 6,0m to a 8,0m thick pyroxenite overlying a 1,0m thick chromitite layer called the UG1 Chromitite layer. This UG1 Chromitite Layer can split into two or more layers of up to a meter in width with lens like layers of either anorthosite or pyroxenite between them.

Beneath the UG1 unit is Footwall 16 which is an anorthositic layer containing numerous chromitite layers over the upper 2,5m These layers are irregular and vary in thickness from a few mm to several cm's.

2.3 Geological Structures

2.3.1 Potholing

Potholes occur when either reef horizon cuts through its footwall units and comes to rest on or in a lower unit than is normally the case. Several effects occur :

a) Different hangingwall or footwall units are exposed.
b) The reef dip changes.
c) An increase in joint density is usually associated with the pothole edge.
d) Parting planes in the hangingwall are moved closer to the hangingwall of the excavation. Where large-scale (deep) potholing occurs, the effect can also be noticed in drive and travellingway development.

2.3.2 Dykes

Dykes are sheet like intrusive rocks which are not parallel to the layering and have one of two possible mechanisms of intrusion. They are either forced into cracks or have created their own cracks due to pressure while in liquid form and have cooled in situ. The dykes could therefore have formed in areas where weaknesses were present prior to their intrusion and are indicators of potentially poor ground conditions while the dyke themselves may also contribute to the conditions of the ground.

Four main types of dykes are exposed in both stoping and development :

Pegmatite veins are white, coarse-grained intrusions on a centimeter scale and have dips of approximately 80 degrees. They can cause sidewall problems due to slabbing on the dyke, which is most evident in drives. They tend to be more common in the UG2 chromitite workings.

Lamprophyre dykes are medium to coarse grained with a shiny brown appearance (sparkles under cap lamp illumination) and vary in size from a few centimeters to the occasional dyke of a metre or more in thickness. Dips are normally near vertical and the trend is E-W across the lease area. These dykes are often friable and tend to deteriorate on exposure to air and water.

Dolerite dykes are dark green to black, fine to medium grained intrusions, usually several metres thick with a near vertical dip. They are blocky by nature and usually have well-developed sympathetic joint zones on either side.

*Dolerite sills are l*ocally dolerite intrusions which can also exhibit a flat dip (10-45 degrees) and are called sills. The flat dipping nature of these sills can have serious implications where these lie within 5,0m of the hangingwall of excavations and usually a restriction on mining in this region is imposed.

2.3.3 Faults

These are discontinuities in the rock along which the strata are displaced. The amount of the displacement is variable and can reach up to 150m. Two types of displacement occur, namely horizontally and vertically, sometimes a combination of the two can be observed.

The faults are usually infilled with soft material such as clays and form weak zones. The infilled material is usually more friable or likely to expand and cause parting when wet. Water and methane are sometimes associated with faulting, but water can also be introduced along this plane during washing and drilling operations. North and northwest trending faults are dominant and the dips encountered tend to dip at an average 70 to 80 degrees.

2.3.4 Joints

Joints are natural breaks in the rockmass, which may be infilled, and occur across the lease area. The density of jointing is significantly higher close to faults, dykes and pothole edges. The immediate hangingwall and footwall are broken up by joints and generally 3 joint sets can be identified although as many as 5 joint sets can occur. Joint directions can vary with dominant joint sets aligned on strike on some shafts but conversely the dominant joint set could be aligned on dip at other shafts. The mean dip angle appears to be within 15 degrees of the vertical, with a scatter of 25 degrees on either side. This general picture does not rule out the sporadic occurrence of low planar joints or sills.

There is a high incidence of low angle curve joints across the lease area which results in large falls of ground if not properly supported and early enough identified. They tend to extend into the hangingwall and can cause alteration of the surrounding rock. They tend to be hidden due to their flat dipping nature and can result in poor hangingwall conditions. While not always continuous, they can extend several meters into the hangingwall and are often difficult to identify. They are sometimes referred to as “cooling domes”.

2.3.5 Replacement Pegmatoid

The most common type of replacement pegmatoid occurs as ultramafic pegmatoid. This is a shiny, black extremely coarse grained rock usually rich in magnetite. This can be confused with chromitite, but it is important to note that the magnetite occurs in irregular patches and does not form a uniform layer similar to the chromitite occurrence in the reef. In general, the replacement process seems to prefer the anorthositic rocks, but occurrences are known where the pyroxenite layers as well as part or all of the Merensky reef has been replaced.

Where the Merensky reef and/or the footwall has been replaced, but the chromitite layer is still unidentifiable, it becomes essential for mining purposes to know what type of reef has been replaced. Replacement Pegmatoid, because of its irregular and unpredictable nature, presents an awkward problem with respect to mining.

2.3.6 Dunite Bodies

Small magnetite-dunite pegmatite pipes or plugs are known to occur in the northern parts of the lease area. They are dark greenish – black colour with a fine to medium grained nature. These bodies are intrusive and displace the reef whilst also causing strike swings in the process. These bodies are often associated with replacement Pegmatoid.

2.4 Water

A feature of mining in the area is the low incidence of underground water. In the shallow parts of the mine the water inflow that does occur is connected to the surface water table.

2.5 Rock Strength

The Rock Strength of the rocks in the Bushveld Complex especially at Impala Mine vary throughout the lease area and vary through the different types of rock (see Table 2.1). The determination of the global mechanical properties of a large mass discontinuous in-situ rock remains one of the most difficult problems in the field of rock mechanics. Stress strain properties are required for use in the determination of the displacements induced around mine excavations, and overall strength properties are required (Brady & Brown, 1985).

TABLE 2.1 - The Uniaxial Compressive Strength on the Rock Strata Horizons directly above and below reef

	Wildebeestfontein North			Wildebeestfontein South			Bafokeng North			Bafokeng South		
	lowest	Highest	Average	lowest	Highest	Average	lowest	Highest	Average	lowest	Highest	Ave
asterd Merensky				62 MPa	154 MPa	106 MPa	85 MPa	118 MPa	106 MPa	100 MPa	168 MPa	142
Middling 3	68 MPa	160 MPa	110 MPa	91 MPa	123 MPa	107 MPa	135 MPa	149 MPa	145 MPa	104 MPa	199 MPa	168
Middling 2	74 MPa	110 MPa	99 MPa	103 MPa	151 MPa	129 MPa	123 MPa	166 MPa	142 MPa	97 MPa	152 MPa	120
Middling 1	NIL	NIL	NIL	92 MPa	145 MPa	120 MPa	90 MPa	108 MPa	99 MPa			
Pyroxenite	62 MPa	109 MPa	92 MPa	57 MPa	109 MPa	86 MPa	61 MPa	98MPa	76 MPa	127 MPa	148 MPa	135
Pegmatoid	43 Chrome band	136 MPa	96 MPa	30 MPa	One Only	30 MPa				51 MPa	152 MPa	87
Footwall 1				45 MPa	134 MPa	83 MPa	123 MPa	155 MPa	137 MPa	80 MPa	115 MPa	93
Footwall 2				138 MPa	One Only	138 MPa					One Sample	71
Footwall 3				72 MPa	109 MPa	96 MPa	82MPa	121 MPa	106 MPa	72 MPa	127 MPa	85
Footwall 4				112 MPa	136 MPa	126 MPa				83 MPa	184 MPa	143
Footwall 5	79 MPa	100 MPa	89 MPa	62 MPa	149 MPa	107 MPa	103 MPa	134 MPa	121 MPa			
Footwall 6	86 MPa	121 MPa	105 MPa				129 MPa	172 MPa	150 MPa	92 MPa	203 MPa	144
Footwall 7	77 MPa	114 MPa	96 MPa				115 MPa	138 MPa	126 MPa	97 MPa	134 MPa	113
Footwall 8							255 MPa	260 MPa	258 MPa			
Footwall 9										262 MPa	264 MPa	263
Footwall 10												
Footwall 11										176 MPa	246 MPa	211
Footwall 12							198 MPa	235 MPa	217 MPa	174 MPa	202 MPa	188
UG2 Pyroxenite							209 MPa	242 MPa	226 MPa		258 MPa	
UG2 Chromite							99 MPa	138 MPa	119 MPa		101 MPa	
UG2 Pegmatoid							133 MPa	209 MPa	171 MPa			
Footwall 13							169 MPa	213 MPa	191 MPa		244 MPa	
UG1 Pyroxenite							141 MPa	233 MPa	187 MPa			
UG1 Chromitite							66 MPa	141 MPa	104 MPa			
Footwall 16							94 MPa	218 MPa	156 MPa		251 MPa	

Because of the difficult of determining the overall strength of a rockmass by measurement, empirical approaches are generally used. An attempt to allow for the influence of rock quality on rock mass strength was made by Bieniawski (1976) who assigned Coulomb shear strength parameters, c and Φ, to the various rock mass classes in his geomechanical classification. The most completely developed of these empirical approaches is that introduced by Hoek and Brown (1980) who proposed the empirical rock mass strength criteria.

$$\sigma_{1S} = \sigma_3 + (m\sigma_c\sigma_3 + s\sigma_c^{\,2})^{0.5} \tag{2.1}$$

Where σ_{1s} is the major principal stress at peak strength, σ_3 is the minor principal stress, *m and s*, are constants that depend on the properties of the rock and the extent to which it had been broken before being subjected to failure stresses, and σ_C is the uniaxial compressive strength of the intact rock material. Hoek and Brown (1980) estimated that the parameters *m and s* varied with the rock type and rock mass quality according to Table 2.2.

TABLE 2.2 - Approximate strength criteria for intact rock and jointed rockmasses (After Hoek & Brown, 1980)

Rock Quality (1)	Carbonite Rocks with well developed crystal cleavage (Dolomite, limestone and marble) (2)	Lithified argillaceous rocks, mudstones, siltstone, shale and slate) (3)	Arenaceous rocks with strong crystal cleavage (sandstone, and quartzite) (4)	Fine grained polymineralic igneous crystalline rocks, (andesite, dolerite diabse and rhyloite) (5)	Coarse grained polymineralic igneous and methamorphic rocks (amphibolite, gabbro, gneiss, granite, norite and quartz diorite) (6)
Intact rock samples – laboratory size rock specimens free from structural defects (CSIR rating 100+; NGI rating 500)	$\sigma_{1n} = \sigma_{3n} + \surd 7\sigma_{3n} + 1$ $\tau_n = 0.816(\sigma_n+0.140)^{0.658}$	$\sigma_{1n} = \sigma_{3n} + \surd 10\sigma_{3n} + 1$ $\tau_n=0.918(\sigma_n+0.099)^{0.677}$	$\sigma_{1n} = \sigma_{3n} + \surd 15\sigma_{3n} + 1$ $\tau_n=1.044(\sigma_n+0.067)^{0.692}$	$\sigma_{1n} = \sigma_{3n} + \surd 17\sigma_{3n} + 1$ $\tau_n=1.086(\sigma_n+0.059)^{0.694}$	$\sigma_{1n} = \sigma_{3n} + \surd 25\sigma_{3n} + 1$ $\tau_n=1.220(\sigma_n+0.040)^{0.705}$
Very good quality rock mass – tightly interlocking undisturbed rock with unwqeathered joints spaced at 3m (CSIR rating 85; NGI rating 100)	$\sigma_{1n} = \sigma_{3n} + \surd 3.5\sigma_{3n}+0.1$ $\tau_n = 0.651(\sigma_n+0.028)^{0.679}$	$\sigma_{1n} = \sigma_{3n} + \surd 5\sigma_{3n} + 0.1$ $\tau_n = 0.739(\sigma_n+0.02)^{0.692}$	$\sigma_{1n} = \sigma_{3n} + \surd 7.5\sigma_{3n}+0.1$ $\tau_n = 0.848(\sigma_n+0.013)^{0.702}$	$\sigma_{1n} = \sigma_{3n} + \surd 8.5\sigma_{3n}+0.1$ $\tau_n = 0.883(\sigma_n+0.012)^{0.705}$	$\sigma_{1n}= \sigma_{3n}+\surd 12.5\sigma_{3n}+0.1$ $\tau_n = 0.998(\sigma_n+0.008)^{0.712}$
Good quality rock mass – fresh to slightly weathered rock, slightly disturbed with joonts spaced at 1-3m (CSIr rating 65; NGI rating 10)	$\sigma_{1n}=\sigma_{3n}+\surd 0.7\sigma_{3n}+0.004$ $\tau_n = 0.369(\sigma_n+0.006)^{0.649}$	$\sigma_{1n}=\sigma_{3n}+\surd 1.0\sigma_{3n}+0.004$ $\tau_n = 0.427(\sigma_n+0.004)^{0.683}$	$\sigma_{1n}=\sigma_{3n}+\surd 1.5\sigma_{3n}+0.004$ $\tau_n = 0.501(\sigma_n+0.003)^{0.695}$	$\sigma_{1n}=\sigma_{3n}+\surd 1.7\sigma_{3n}+0.004$ $\tau_n = 0.525(\sigma_n+0.002)^{0.698}$	$\sigma_{1n}=\sigma_{3n}+\surd 2.5\sigma_{3n}+0.004$ $\tau_n = 0.603(\sigma_n+0.002)^{0.707}$
Fair quality rock mass – several sets of moderately weathered joints spaced ar 0,3-1m (CSIR Rating 44; NGI rating 1.0)	$\sigma_{1n}=\sigma_{3n}+\surd 0.14\sigma_{3n}+0.0001$ $\tau_n = 0.198(\sigma_n+0.0007)^{0.642}$	$\sigma_{1n}=\sigma_{3n}+\surd 0.20\sigma_{3n}+0.0001$ $\tau_n = 0.234(\sigma_n+0.0005)^{0.675}$	$\sigma_{1n}=\sigma_{3n}+\surd 0.30\sigma_{3n}+0.0001$ $\tau_n = 0.280(\sigma_n+0.0003)^{0.688}$	$\sigma_{1n}=\sigma_{3n}+\surd 0.34\sigma_{3n}+0.0001$ $\tau_n = 0.295(\sigma_n+0.0003)^{0.691}$	$\sigma_{1n}=\sigma_{3n}+\surd 0.50\sigma_{3n}+0.0001$ $\tau_n = 0.346(\sigma_n+0.0002)^{0.700}$
Poor quality rock mass – numerous weathered joints spaced at 30-500mm with some gouge filling/clean waste rock (CSIR rating 23; NGI rating 0,1)	$\sigma_{1n}=\sigma_{3n}+\surd 0.04\sigma_{3n}+0.00001$ $\tau_n = 0.115(\sigma_n+0.0002)^{0.646}$	$\sigma_{1n}=\sigma_{3n}+\surd 0.05\sigma_{3n}+0.00001$ $\tau_n = 0.129(\sigma_n+0.0002)^{0.655}$	$\sigma_{1n}=\sigma_{3n}+\surd 0.08\sigma_{3n}+0.00001$ $\tau_n = 0.162(\sigma_n+0.0001)^{0.672}$	$\sigma_{1n}=\sigma_{3n}+\surd 0.09\sigma_{3n}+0.00001$ $\tau_n = 0.172(\sigma_n+0.0001)^{0.674}$	$\sigma_{1n}=\sigma_{3n}+\surd 0.13\sigma_{3n}+0.00001$ $\tau_n = 0.203(\sigma_n+0.0001)^{0.684}$
Very poor quality rock mass numerous heavily weathered joints spaced less than 50mm with gouge filling/waste rock fines (CSIR rating 3; NGI rating 0.01)	$\sigma_{1n}=\sigma_{3n}+\surd 0.007\sigma_{3n}+0$ $\tau_n = 0.042(\sigma_n)^{0.534}$	$\sigma_{1n}=\sigma_{3n}+\surd 0.010\sigma_{3n}+0$ $\tau_n = 0.050(\sigma_n)^{0.539}$	$\sigma_{1n}=\sigma_{3n}+\surd 0.015\sigma_{3n}+0$ $\tau_n = 0.061(\sigma_n)^{0.546}$	$\sigma_{1n}=\sigma_{3n}+\surd 0.017\sigma_{3n}+0$ $\tau_n = 0.056(\sigma_n)^{0.548}$	$\sigma_{1n}=\sigma_{3n}+\surd 0.025\sigma_{3n}+0$ $\tau_n = 0.078(\sigma_n)^{0.556}$