CHAPTER 2 THE GEOLOGY OF THE UITKOMST COMPLEX AND ITS SURROUNDINGS

2.1 Regional geology and host stratigraphy

The Uitkomst Complex intruded the lower parts of the Transvaal Supergroup (Kenyon et al. 1986 Gauert et al. 1995; Theart, 2000; Theart and de Nooy, 2001 and Li et al, 2002). The regional geology of the area into which the Uitkomst Complex intruded is given in Table 2.1 and a simplified geological map is presented in Figure 2.1.

Table 2.1. The stratigraphy of the lower part of the Transvaal Supergroup around the Uitkomst Complex.

Supergroup	**Group**	**Formation**	**Lithology**
Transvaal Supergroup	Pretoria	Timeball Hill	Shale and quartzite
		Rooihoogte	Conglomerate/breccia, quartzite
	Chuniespoort	Monte Christo	Light coloured dolomite and chert
		Oaktree	Dolomite and quartzite
	Wolkberg	Black Reef Quartzite	Conglomerate, grit, quartzite
Basement	Nelshoogte Granite		

In the area of the Uitkomst Complex the basement is composed of the Archean Nelshoogte Granites (Li et al., 2002; Maier et al., 2004). U-Pb dating of zircon from the biotite-rich trondhjemite gneiss indicate an age of 3320 ± 40 Ma for the Kaap Valley and Nelshoogte Plutons (Anhaeusser, 2001). These plutons also host younger Archean syenite intrusions (Anhaeusser, 2001). The Nelshoogte Pluton extents from the southwest of the Barberton Greenstone Belt for a distance of approximately 20 kilometers before it disappears beneath the Proterozoic cover rocks of the Escarpment, approximately 10 kilometers north of Badplaas (Anhaeusser, 2001). The basement is overlain in paleovalleys by basaltic lavas, immature polymictic quartzites and shales and tuffs of the Godwan Formation, a possible correlate of the Ventersdorp Supergroup (Li et al., 2002; Maier et al., 2004), but elsewhere in this area the basement rocks are directly overlain by the sedimentary rocks of the Transvaal Supergroup (Maier et al., 2004).

The lower units of the Uitkomst Complex intrude directly above the basement contact on rare occasions (Kenyon et al., 1986), but more often above the Black Reef Quartzite and quartzites belonging to the Oaktree Formation of the Malmani Subgroup (Gauert et al, 1995; Li et al, 2002; Maier et al., 2004) into the dolomitic counry rock. The Black Reef Quartzites is overlain by 145-300 meters of Malmani subgroup dolomites and minor sandstones which have a maximum age of 2549 ± 2.6 Ma (Pb-Pb single zircon) (de Waal et al., 2001; Maier et al., 2004). The dolomites of the Malmani subgroup have minor intercalations of sulfidic shale (Maier et al., 2004). A 5-10 meter thick transgressive chert- rich conglomerate layer known as the Bevets Conglomerate Member of the Rooihoogte Formation in the area (Maier et al., 2004) lies directly on the Malmani dolomites, representing a regional transgressive erosion plain. Erosion during the deposition of the Brevets conglomerate has completely removed the upper parts of the Malmani Subgroup. This conglomerate is in turn overlain by 1 200 m of graphitic shale with minor quartzites and ironstones (Timeball Hill Formation; Li et al., 2002; Maier et al., 2004). A laterally non-persistent quartzite, the Klapperkop Quartzite is developed several hundred meters above the shale formation's lower contact (Maier et al., 2004).

According to Snyman (1998), corundum in the form of dark, translucent sapphire has been found on the farm Uitkomst 541 JT, but the host rock is not specified. However, corundum-bearing contact metamorphosed shales are exposed on a small hill to the southwest of the Complex on the farm Uitkomst near its northeastern boundary (pers. comm. H.F.J. Theart, 2007).

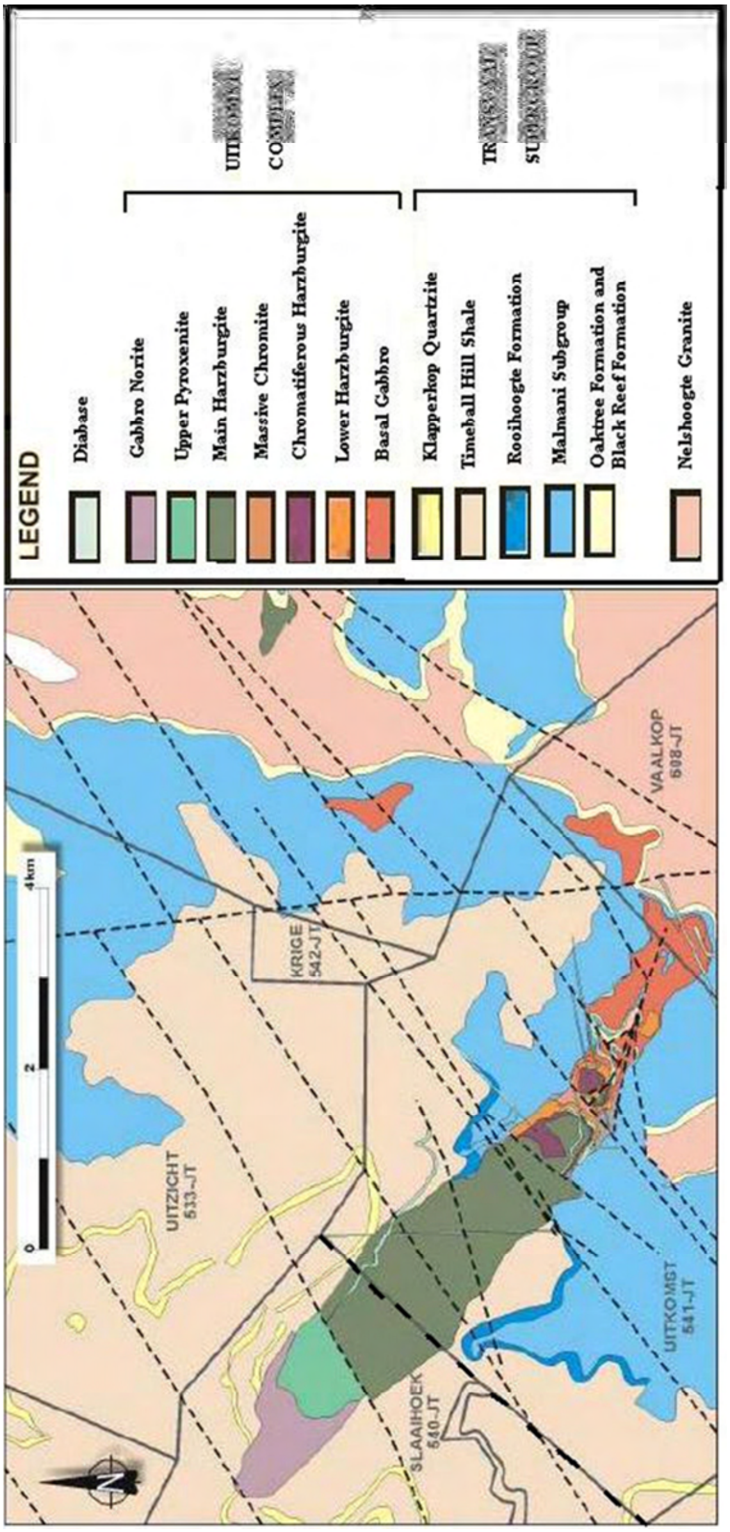

Figure 2.1. Simplified geological map indicating the surface outcrop of both country rock and Uitkomst Complex. The dashed line indicates the Slaaihoek-Uitkomst boundary. (Adapted after pers. comm. Nkomati Mine Geological Staff, 2005).

2.2 Bushveld igneous complex

The Uitkomst Complex is hosted by the 2500 Ma Transvaal Supergroup sediments overlying the Archean granite basement rock of the Kaapvaal craton. The country rocks around the Uitkomst Complex are discussed in more detail in Chapter 2. The Uitkomst Complex has been suggested to be genetically related to the 2060 Ma, Bushveld Igneous Complex (BIC; de Waal and Gauert, 1997), also hosted within the Kaapvaal craton by Transvaal Supergroup sediments (Figure 2.2). The Bushveld Igneous Complex is comprised of a Western-, Eastern-, Northern- and Southern limb. The mafic/ultramafic component of the BIC is subdivided into several zones, arranged form the bottom up: Marginal-, Lower-, Critical-, Main- and Upper Zones and referred to as the Rustenburg Layered Suite (RLS). The stratigraphic classification of the Eastern-, Western- and Northern Limb is given in Table 2.2. The Southern Limb is omitted as it is obscured by later Karoo sediments.

The Northern limb of the BIC contains units closest in composition to the Uitkomst Complex in the mineralized zone referred to as the Platreef. The Platreef is considered to represent a zone of interaction between the Bushveld magma of the Critical Zone and the Pretoria Group sediments that host the Northern limb. The Platreef and the product "parapyroxenite" are discussed in more detail in Chapter two.

The intrusion of magmas of differing composition has been suggested to have resulted in the formation of the BIC and its mineralized horizons (Robb, 2005). The different magmas are referred to as:

- B1 magma, a boninitic magma that formed the Lower Zone
- B2 and B3 magma that gave rise to the Lower- and Upper Critical Zone
- B4 magma is inferred to have been part of the Main Zone due to elevated Sr-isotope ratios, although a pristine example of this magma has not been encountered yet (de Waal and Gauert, 1997).

Table 2.2 Stratigraphic classification of the R.L.S. (Adapted after SACS, 1980)

Zone		Eastern Limb		Western Limb		Northern Limb	
Main	Subzone C	Roossenekal Subunit	Luiperdshoek Olivine Diorite		Bierkraal Magnetite Gabbro		Molendraai Magnetite Gabbro
	Subzone B		Ironstone Magnetite Gabbro				
	Subzone C		Magnet Heights Gabbronorite				
Main	Upper Subzone	Dsjate Subsuite	Mapoch Gabbronorite		Pyramid Gabbronorite		Mapela Gabbronorite
	Lower subzone		Leolo Mountain Gabbronorite				
			Winnaarshoek Norite-Anorthosite				
Critical	Upper Subzone	Dwars River subsuite	Winterveld Norite-Anorthosite	Schilpadnest subsuite	Mathlagame Norite-Anorthosit		Grassvalley Norite-Anorthosite
	Lower Subzone		Mooihoek Pyroxenite		Ruighoek Bronzitite		
Lower	Upper pyroxenite subzone	Croydon Subsuite	Serokolo Bronzitite	Vlakfontein Subsuite	Tweelaagte Bronzitite	Zoetveld Subsutie	Moorddrift Harzburgite-Pyroxenite
			Jaglust Harzburgite		Groenfontein Harzburgite		Drummondlea Harzburgite
	Harzburgite subzone		Rostock Bronzitite		Makgope Bronzitite		Volspruit Pyroxenite
	Lower Pyroxenite subzone		Clapham Bronzitite		Eerlyk Bronzitite		
Marginal			Shelter Norite		Kroondal Norite		
					Kolobeng Norite		

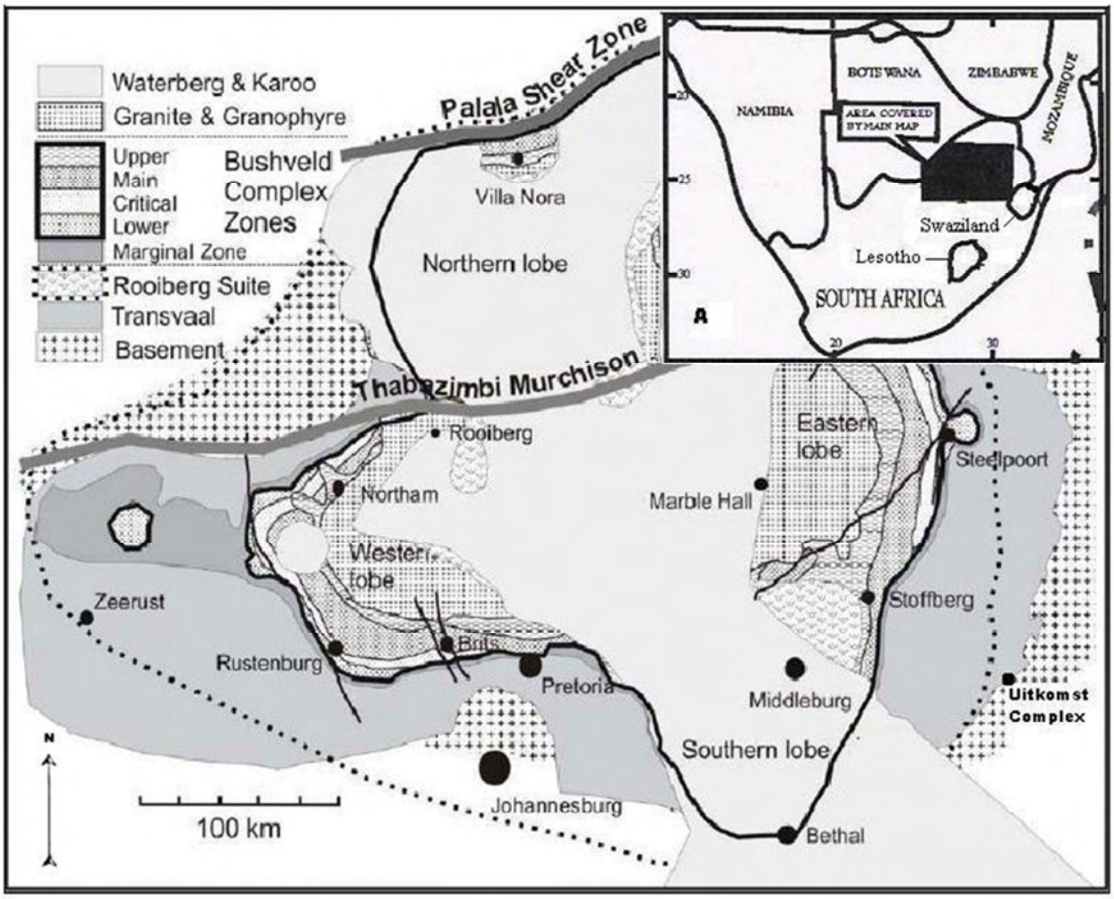

Figure 2.2 The position of the Uitkomst Complex. Insert A. The location of the Bushveld Igneous Complex, South Africa. Insert B. The position of the Uitkomst Complex relative to the Bushveld Complex is indicated by the cross (Adapted after: F.J. Kruger, 2005).

The main mineralized zones in the BIC that are of economic importance are the UG2 and Merensky Reef, containing the world's largest resource of Platinum Group Minerals (PGM's) and chromite. Both these units are hosted in the Critical Zone. The BIC is also host to the world's largest vanadium deposit, associated with the Main Magnetite Layer, found in the Upper Zone.

2.3 Previous gold mining in the area

Gold was mined on Marme 535 JT and Slaaihoek 541 JT and yielded over 10 tons during the life of mine (Ward and Wilson, 1998). The gold mineralization forms part of the Transvaal Drakensberg gold field (Ward and Wilson, 1998). The gold mineralization occurs associated with Cu- and Bi-sulphides within a flat-reef Au-quartz-carbonate-sulphide vein (Ward and Wilson, 1998). The thickness of the vein is between zero and seven meters and the gold is distributed erratically (Ward and Wilson, 1998). The vein is situated in the Timeball Hill shales that form part of the Pretoria Group and immediately overlies the Uitkomst Complex (Ward and Wilson, 1998). The flat reefs or bedding-parallel veins have been linked to "water-sills" that resulted from high fluid pressures of a deep seated magmatic source (Ward and Wilson, 1998). The mineralization is indicated to have taken place at pressures of between 2.2 and 2.5 kilobar, which may represent a possible crustal depth of between 7 and 8 kilometers and at a temperature of 320 ˚C (Ward and Wilson 1998).

2.4 The Uitkomst Complex

The age of the Uitkomst Complex is inferred to be 2044±8 Ma (U-Pb zircon) and that would make it coeval with the Bushveld Complex (Theart and de Nooy, 2001; Li et al., 2001; Maier et al., 2004). In terms of age and composition, the complex may be considered to be a satellite body of the Bushveld Complex (Theart and de Nooy, 2001; Li et al., 2001; Maier et al., 2004). Other complexes and intrusions that are considered to be satellite intrusions to the Bushveld Complex are the Roodekraal Complex, Lindques Drift Intrusion, Rietfontein Complex, Heidelberg Intrusion and the Kaffirskraal Complex (Marsh, 2003; de Waal, Graham, Armstrong, 2006). These intrusions are considered to be syn-Bushveld high-Ti igneous suites and are referred to as HITIS (de Waal et al., 2006).

The shape of the Uitkomst Complex in cross section has been described as either trough- or anvil- shaped (Figure 2.2) (van Zyl, 1996; Gauert et al., 1996; de Waal and Gauert, 1997; de Waal, Maier, Armstrong and Gauert, 2001; Li, et al. , 2002; Maier, et al., 2004). The intrusion plunges at an angle of –4.5˚ (Theart and de Nooy, 2001) and is intruded between the quartzite of the Oaktree Formation of the Malmani Subgroup, forming the floor, and the Klapperkop Quartzite Member of the Timeball Hill Formation, Pretoria Group, forming the roof (Gauert et al., 1996; de Waal and Gauert, 1997; Li et al., 2002). Indications are that the Complex intruded from the NW to the SE (van Zyl, 1996; Hornsey, 1999; de Waal and Gauert, 1997). It has also been determined by means of geophysical methods and drilling that the intrusion extends to the northwest, under the escarpment (Gauert et al., 1996; Theart and de Nooy, 2001, Li et al., 2002). The complex is inferred to have intruded at a depth of 6 - 8 kilometers below the sedimentary cover (Gauert et al., 1996; Gauert, 1998; Ward and Wilson, 1998). The individual units of the complex along the centre of the trough show very consistent thicknesses in the part intersected by drilling over a plunge distance of 12 kilometers (Theart and de Nooy, 2001). The intrusion has an average true thickness along the centre of 670 meters (Theart and de Nooy, 2001), but vertical dilation owing to the intrusion of post-consolidation diabase sills, resulted in a modified thickness of 850 meters (de Waal et al., 2001).

The original field terminology for the stratigraphy was introduced by INCO geologists in the 1980's and was reported by Kenyon et al. (1986). These terms are given along with the lithological subdivision as suggested by Gauert et al. (1995) indicated next to it, with the abbreviation in brackets. The relative thickness of each unit is also given as well as an indication of being part of the conduit or closed stage. The subdivision of the different units of the Uitkomst Complex into a Basal Group and a Main Group (Theart and de Nooy, 2001) is also included in Table 2.2.

Table 2.3. Lithological Subdivision of the Uitkomst Complex.

Lithological Name (Gauert et al., 1995)	**Field Terminology (Kenyon, 1986)**	**Thickness (Woolfe, 1996)**	**Stage (Gauert)**	**Group (Theart and de Nooy, 2001)**
Gabbronorite (GN)	Upper Gabbro (UGB)	10-20 meters	Closed	Main
	Norite (NU)	250-300 meters		
Upper Pyroxenite (PXT)	Upper Pyroxenite (PXT)	60-80 meters		
Main Harzburgite (MHZBG)	Peridotite (Prdt)	200-300 meters	Conduit	
	Massive Chromite (MCR)	0-5 meters		
Chromatiferous Harzburgite (PCR)	Chromitic Pyroxenite (PCR)	30-56 meters		Basal
Lower Harzburgite (LHZBG)	Lower Pyroxenite (LrPXT)	20-40 meters		
Basal Gabbro (BGAB)	Basal Gabbro (BGAB)	0-7 meters		

The ore bodies of the Uitkomst Complex are confined to the lower units of the Uitkomst Complex (Basal Group). The unit terminology as recommended by Gauert (1998) will be used in this study. However, the field terminology as originally proposed by INCO geologist and reported by Kenyon et al., (1986) and subsequently modified by Anglovaal geologists are used in the borehole logs (Appendix 1).

An idealized cross-section of the Uitkomst Complex is given in Figure 2.3. The terminology has been adapted to Gauert's classification.

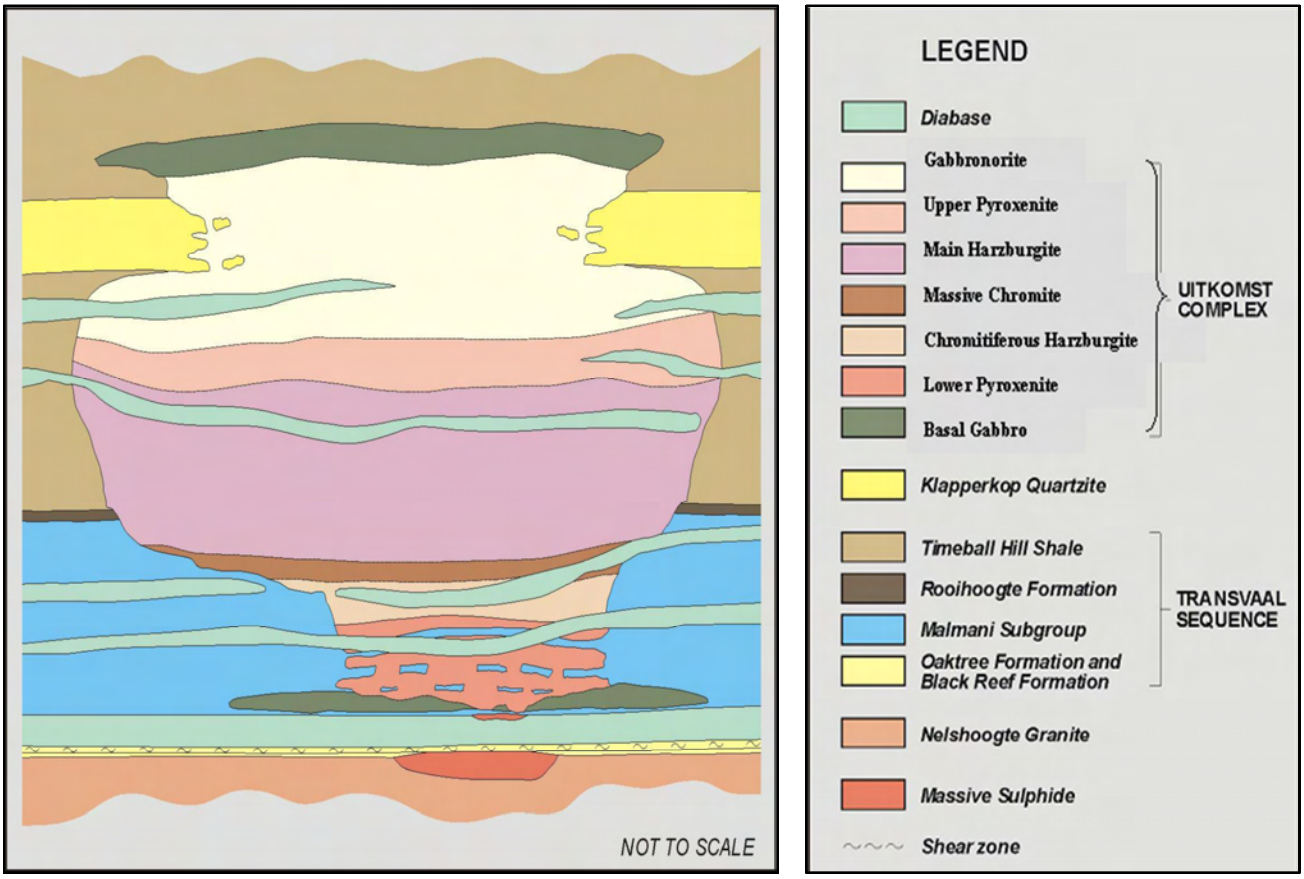

Figure 2.3. Idealized cross-section of the Uitkomst Complex. (Figure adapted after pers. comm. Nkomati Mine Geological Staff and legend adjusted to Gauert classification).

The lower three units are confined to a narrow trough-like keel, following the NW-SE trend of the sub-vertical fracture zones observed in the area (de Waal and Gauert, 1997; Hornsey, 1999).

There are two prominent thrust zones found in and near to the Uitkomst Complex. The first is the Basal Shear Zone and is found in the lower most dolomitic unit of the Oaktree Formation of the Malmani Subgroup (Hornsey, 1999; Theart, 2000). The dominant mineral in the Basal Shear Zone is calcite followed by quartz and minor iron and manganese oxides (Hornsey, 1999). The alteration minerals found in the Basal Shear Zone is tremolite and minor chlorite and biotite (Hornsey, 1999). The second thrust zone is found in the highly altered parts of the PCR and is characterized by chlorite-talc schist zones (Theart, 2000) resulting in duplication of the LHZBG and the PCR in the vicinity of the old MSB mine section (Theart, 2000). In addition to these there are sub-horizontal schistose zones present in both the MHZBG and the PXT Units, consisting mainly of talc, dolomite, magnesite and chlorite and talc-chlorite schist zones respectively, but related duplication of lithological units could not be demonstrated in these cases (Theart, 2000).

A literature review of the tectonic history of the BIC and surrounding areas suggest that post-intrusive was present in the area, e.g. Hattingh (1980), Sharp and Chadwick (19781) and Perritt and Roberts (2007). However, the structures preserved in the intrusion and surrounding country rock does not reflect these events. The shear zones in the intrusion are typical of synchronous or immediately post-intrusive deformation, during solidification of the intrusion (pers. comm. Bumby, 2010).

2.4.1. Basal Gabbro Unit (BGAB)

The average thickness of the BGAB Unit is 6 meters (van Zyl, 1996; Gauert et al., 1996; Gomwe 2000; de Waal et al., 2001) with a maximum thickness of 15 meters (Strauss, 1995; Gauert et al., 1996; Hornsey, 1999; Gomwe, 2002). This zone can also be completely absent (Gomwe, 2002). The base of the unit is marked by a chill margin of between 0.2 and 1.5 meters (Strauss, 1995; van Zyl, 1996; Hornsey, 1999). The gradational contact of the BGAB Unit (Strauss, 1995) with the LHZBG Unit is usually obscured by pegmatitic phases and by the presence of sedimentary xenoliths. The BGAB Unit is laterally more extensive than the overlying LHZBG Unit, with sill-like extensions roughly parallel to the Basal Shear Zone extending up to 400 meters into the country rocks (de Waal and Gauert, 1997; Hornsey, 1999; Gomwe, 2002; Li et al., 2002; Maier et al., 2004). The contact with the Black Reef is sometimes defined by a strongly sheared talc-chlorite-carbonate alteration product (van Zyl, 1996), but the unit is usually developed 2 meters above the Basal Shear Zone in the dolomitic host rock (de Waal and Gauert, 1997). The BGAB is better developed towards the northeastern part of the complex opposed to the uneven development in the rest of the intrusion (de Waal and Gauert, 1997). This unit is unevenly developed due to the undulating nature of the Black Reef Quartzites, and may be in places completely absent (Gauert et al., 1996).

In the vicinity of the Massive Sulphide Body, the Unit appears to have been cross-cut and possibly ingested by the overlying LHZBG Unit magma (Hornsey, 1999). Field observations indicate that the direction of intrusion was from the northwest to the southeast (de Waal and Gauert, 1997; Hornsey, 1999). A sub-ophitic igneous texture is still visible in this unit (van Zyl, 1996), despite the subsequent alteration that affected the unit. de Waal and Gauert (1997) suggest that the magma giving rise to this unit resulted from a mixing of B1- and B2-type magma, which led to the formation of Bu-type magma that chilled against the country-rock. The BGAB thus represents the super-cooled chill zone of the intrusion (Strauss, 1995; Gauert et al., 1996; de Waal et al., 2001; Li et al., 2002).

2.4.2 Marginal Gabbro Unit (MG)

The MG Unit is found close to or forms the northeastern contact of the Uitkomst Complex with the host rock and along this contact of the intrusion on the farm Uitkomst 541JT (de Waal and Gauert, 1997; Gauert, 1998). It is mineralogically similar to the BGAB Unit, but occurs at the same elevation (up to 200 meters above the base of the intrusion) as the LHZBG and MHZBG Units and grades into the cumulate rocks of these units (de Waal et al., 2001; de Waal and Gauert, 1997). The medium to coarse grained MG Unit is generally feldspar- rich and partly mineralized with sulphide minerals. The unit contains traces of graphite (de Waal and Gauert, 1997). It has been implied that the presence of this unit indicates that the chamber was probably filled with gabbroic magma before the formation of the layered sequence (de Waal et al., 2001). The implication of this phenomenon is that the magma of the BGAB had a larger vertical extent in the position of the current central trough. This gabbroic magma may have been completely removed by emplacement of the later magma pulses of the LHZBG and PCR/MHZBG units. The MG is suggested here to represent a relict of the first conduit magmatic emplacement.

2.4.3 Lower Harzburgite Unit (LHZBG)

The LHZBG Unit has an average thickness of 50 meters (van Zyl, 1996; Gauert et al., 1996; de Waal et al., 2001) but a maximum thickness of up to 90 meters (Gomwe, 2002) on the farm Uitkomst 541JT. The contact with the BGAB Unit is gradational, as discussed above (Gauert et al., 1996; Theart, 2000; de Waal et al., 2001). In places the LHZBG Unit thermally eroded the BGAB Unit and now forms the base of the intrusion (Li et al., 2002; Gomwe, 2002). There is also evidence that the BGAB Unit was removed physically in places by thrusting at the base of the Complex (pers. comm., H.F.J. Theart, 2006). The LHZBG Unit occurs in what is known as the central trough (Gomwe, 2002), and consists of a variety of rock types, including poikilitic harzburgite, lherzolite, wehrlite and websterite (de Waal et al., 2001; Li et al., 2002; Maier et al., 2004; Steenkamp, 2004).

This unit contains numerous quartzitic and carbonaceous xenoliths, derived mainly from the Malmani Dolomites (Gauert et al., 1996; Hornsey, 1999; Theart, 2000; de Waal et al., 2001). These xenoliths are flattened in the direction of the original layering and form rafts that are oriented parallel to the igneous layers (van Zyl, 1996; Hornsey, 1999). The preservation of flat-lying sedimentary rafts, at the appropriate elevation relative to the stratigraphy in the sedimentary wall rocks of the Complex, may indicate a passive style of intrusion (Theart, 2000). A “passive style” of intrusion suggests that the magma was emplaced in an infiltrative manner rather than through direct magmatic flow. The metamorphosed dolomites, now preserved as calc-silicate rocks, make up as much as a third of the volume of the unit (Gauert, 1996; Maier et al., 2004). In some cases massive sulphides accumulate around the dolomite xenoliths, possibly filling voids that were generated during devolatization (Maier et al, 2004). Additionally large concentrations of coarse disseminated sulphide grains seem to be associated with the xenoliths (Li et al., 2002). Disseminated sulphides are also more concentrated in the olivine wehrlite layers, where the disseminated sulphides frequently grade into massive sulphides surrounding the dolomite xenoliths (Li et al., 2002). In contrast, the hybrid rock, which may represent the magma-dolomite interaction product, is sometimes less mineralized or completely barren (Hornsey, 1999). In the vicinity of the country rock a pegmatiodal pyroxenite is developed (van Zyl, 1996). The mafic phases within the LRHZB Unit consist dominantly of poikilitic harzburgite, with local variations to feldspar-bearing lherzolite and grading into sulphide-rich feldspathic olivine-wehrlite and into amphibolite (van Zyl, 1996; Gomwe, 2000).

2.4.4 The presence of "Parapyroxenite" in the LHZBG

"Parapyroxenite" is a term for altered pyroxenite, defined by the geologists of Sandsloot Mine (operated by Potgietersrus Platinum Ltd., a subsidiary of Anglo Platinum) as "a highly altered rock of varying thickness which is possibly a mechanical mixture of calcsilicate material (metamorphosed and metasomatised dolomite), pyroxene-rich igneous rocks and minor serpentinites" (Harris and Chaumba, 2001). In the Northern limb of the Bushveld Complex, where the Platreef is in contact with dolomite, parapyroxenite is an important rock type. "Parapyroxenite" has also been defined by MacDonald et al., (2005) as a massive diopside-clinopyroxenite that is locally enriched in metamorphic olivine that suffered variable degrees of serpentinization.

The hybrid rock encountered in the LHZBG Unit in the study area may also be called a parapyroxenite, using the Sandsloot definition. The dominance of diopsidic-clinopyroxene with triple junctions and the presence of fassaite indicate a thermal metamorphic origin for parts of the LHZBG Unit. In addition, the presence of primary orthopyroxene, clinopyroxene and olivine in close proximity to metamorphic clinopyroxene indicates a magmatic component in such rocks.

The large range in texture and mineral assemblages from pristine to mineral assemblages indicative of complete retrograde metamorphism also indicate the important role of hydrothermal fluids that interacted with the rocks of the LHZBG Unit to form more hydrous mineral assemblages.

2.4.5 Chromitiferous Harzburgite Unit (PCR)

The PCR Unit has an average thickness of 60 meters (van Zyl, 1996; Hornsey, 1999; Gomwe, 2002). This unit is confined to the upper portion of the deep central trough, but also drapes onto the sidewalls (Hornsey, 1999; Theart, 2000; Gomwe, 2002). It is hosted by the Malmani dolomite, Bevets Conglomerate and the base of the Timeball Hill Formation (Maier et al., 2004). In comparison with the LHZBG Unit, xenoliths are uncommon to absent in this unit (Gauert et al., 1996; Gauert, 1998; Hornsey, 1999). The contact with the LHZBG Unit is gradational, with the contact being obscured in places by a talc-schist zone interpreted to be a ductile shear zone (van Zyl, 1996; Gomwe, 2000; Theart, 2000). The unit consists of abundant lenses, layers and schlieren of massive chromite in a highly altered harzburgitic matrix (van Zyl, 1996; Hornsey, 1999; Gomwe, 2002). The harzburgite has been almost completely replaced by talc, carbonate, mica (phlogopite), chlorite and serpentine, obscuring the nature of the primary precursor (van Zyl, 1996; Hornsey, 1999; Gomwe, 2002). The unit may contain up to 5 vol% of sulphides, consisting of disseminated sulphides (pyrrhotite with lesser chalcopyrite and pentlandite) (Maier et al., 2004). The sulphides are particularly concentrated in clinopyroxene-bearing lithologies (de Waal et al., 2001).

The stratigraphy appears inverted with a harzburgite (PCR Unit) with a more primitive composition, overlying a pyroxenite (LHZBG Unit) with a less primitive composition. This phenomenon has been attributed to decreasing assimilation of country rock dolomite with stratigraphic height (Dodd, 2004), and not reversed differentiation as suggested by Kenyon, Attridge and Coetzee, (1986).

2.4.6 Massive Chromitite Unit (MCR)

The chromite content increases towards the top of the PCR Unit (van Zyl, 2000), where several massive chromite layers occur, reaching thicknesses of up to 15 meters, probably due to tectonic duplication (Maier et al., 2004). The top of the PCR Unit is marked by a massive chromite layer with a thickness of between 0-15 meters (van Zyl, 1996; Gomwe, 2000). Where the massive chromite layer is present its contacts are marked by schistose, ductile shear zones (Theart, 2000). The massive chromite layers comprise one or more layers of chromite intercalated with highly altered silicate laminations. The thickest part of the Massive Chromite layer occurs in the southeastern part of the Uitkomst Complex and outcrops as three chromite hills on the farm Uitkomst (Gauert, 1998), and pinches out towards the northwest (Li et al., 2002).

Gauert (1998) suggested that the sulphur segregation triggered by the degassing of the dolomite xenoliths and wall rocks caused an increase in volatiles in the magma and this culminated with the precipitation of the Massive Chromite unit. However, the Cr/Fe ratio of chromite grains in the Massive Chromite varies between 1.4 and 1.86. This argues against high oxygen fugacity during its formation and indicates that the Massive Chromite layers formed under low oxygen fugacity conditions (Gauert, 1998).

2.4.7 Main Harzburgite Unit (MHZBG)

The average thickness of this unit is 330 meters (van Zyl, 1996; Gauert et al., 1996; Hornsey, 1999; Gomwe, 2000; Li et al., 2002). It caps the central trough (Gomwe, 2002). The contact with the underlying MCR is sharp, except where the contact is obscured by a talc-chlorite schist zone (Theart, 2000). This unit consists mainly of harzburgite which locally grades into dunite (van Zyl, 1996; Hornsey, 1999; Gomwe, 2000). A number of thin chromite seams with thicknesses not exceeding 30 centimetres, intercalated with harzburgite layers, are found near the base of the unit (Theart, 2000). Towards the top of the unit, the harzburgite contains intercalated pyroxenite layers that have gradational contacts. Small sulphide grains, dominated by pyrrhotite, are present throughout the unit, but are more abundant in irregular patches. These patches are more abundant in the lower 10 meters (van Zyl, 1996; Gomwe, 2000) and again in thin horizons in the upper portions (50-90 meters below top of the unit) of the Complex (Gomwe, 2002; Li et al., 2002). Minor dunite and numerous thin chromite layers become more common towards the northwest (Hornsey, 1999; Li et al., 2002).

The cumulus minerals in the unit are olivine (65-70 vol%) increasing upwards from the base (Gomwe, 2002). The rounded olivine grains are poikilitically enclosed in coarse grained orthopyroxene oikocrysts (40-80%) and less commonly (10-20%) in clinopyroxene (Theart, 2000). Chromite (1-5 vol. %) and oikocrystic orthopyroxene (20-15 vol. %) decreasing from the base upwards (Gomwe, 2002) are also present. The chromite becomes more Fe-rich near the top of the unit, with Mg/(Mg+Fe)=0.4 and Cr/(Cr+Fe+Al) = 0.5 (de Waal et al., 2001). The intercumulus minerals are plagioclase, clinopyroxene and amphibole (5-10 vol%; Gomwe, 2002).

Serpenitinization is the main alteration type that affected this unit (van Zyl, 1996). The extent of serpenitinization decreases from the base of the unit upwards (Gomwe, 2002). Magnetite and magnesite is common in the serpenitinized zone along with lizardite, chrysotile, chrysotile and talc (Gomwe, 2002). Talc-carbonate alteration is rare in this unit (van Zyl, 1996). A sub-horizontal schistose zone, up to 15 meters wide and believed to represent a ductile shear zone. This schistose zone may possibly be related to more than one phase of thrust deformation. The schistose zone consists of talc, dolomite, magnetite and chlorite (Gauert, 1998). Crosscutting and concordant pegmatoidal rocks consisting of pyroxenes and feldspar with minor carbonates and quartz are found in the MHZBG Unit. This pegmatite phase however contain no sulphide mineralization in contrast to the LHZBG. This may be explained by the fact that the oxygen fugacity in this unit is controlled by the quartz-magnetite-fayalite buffer (Gauert et al., 1996), preventing the formation of sulphides. The pegmatoidal rocks have sharp contacts and are intrusive into the surrounding rocks (Theart, 2000).

2.4.8 Lower Peridotite Subunit (LrPRD)

The LrPRD subunit is found within the MHZBG Unit where the underlying MCR Unit is not developed (Theart, 2000). This unit is characterized by numerous lenses and thin layers of semi-massive chromites within the harzburgitic rocks. The subunit also hosts disseminated sulphide mineralization (Theart, 2000). It consists mainly of chromatic-harzburgite with lesser chromite rich pyroxenite and pyroxenite (Theart, 2000). This subunit is not as intensely altered as the underlying PCR Unit, and is developed in the deeper parts of the complex on Slaaihoek 540 - JT (Theart, 2000).

2.4.9. Pyroxenite Unit (PXT)

The PXT Unit has a transitional contact with the MHZBG Unit. It has an average thickness of 60 meters (van Zyl, 1996; Gomwe, 2000). The basal contact is gradational over 1-2 meters (Gomwe, 2002) with appreciable amount of olivine present. The unit consists of a medium-grained pyroxnite intercalated with thinner peridotite layers towards its base (Theart, 2000). A sub-horizontal talc-chlorite schist zone is also present in parts of this unit (Theart, 2000).

The PXT Unit has been interpreted as a transitional interval where the unit may be subdivided into three parts:

i) The lower olivine-orthopyroxenite

ii) The central orthopyroxenite with minor chromite and sulphides

iii) The upper norite to gabbronorite, showing an increase in the amount of plagioclase, clinopyroxene and minor quartz with height (Gauert 1998; van Zyl, 1996; Hornsey, 1999; Gomwe, 2000: Li et al., 2002). This upper part of the unit grades into the overlying Gabbronorite unit (GN).

This unit is markedly unaffected by secondary alteration when compared to the underlying units (van Zyl, 1996). However, in places the orthopyroxene is rimmed by an alteration halo of tremolite, phlogopite and fuchsite which provides evidence of interaction with a late-stage fluid (Gomwe, 2002). This unit is intruded by concordant and discordant pegmatoidal rocks consisting of feldspar, pyroxene and calcite (Theart, 2000).

The cumulus minerals in the unit are orthopyroxene (>80 vol%) and olivine (decreasing form the base to the top where it is completely absent), chromite and clinopyroxene being locally present (± 5 vol%) (Gomwe, 2002). The post-cumulus phases are plagioclase (increasing from the bottom upward 10-50 vol %), clinopyroxene, phlogopite, amphibole and quartz, decreasing from the top of the unit to the base (Gomwe, 2002). Disseminated sulphides up to 1wt% occur in the upper portion of the unit (Li et al., 2002).

2.4.10 Gabbronorite Unit (GN)

The GN Unit has an average thickness of 250 m and a gradational lower contact with the PXT Unit (van Zyl, 1996; Gomwe, 2000). The GN Unit has a sill-like lateral extension of ±1.4 kilometers (Gomwe, 2002), and displays vertical compositional layering, varying from melanocratic at the base of the unit to leucocratic at the top contact (Gomwe, 2002; Li et al., 2002). The top contact of this unit is formed by a chilled margin (van Zyl, 1996) showing a sharp contact with the Timeball Hill Formation (which is thermally altered to hornfels). The gabbroic rocks near the contact are marked by the presence of "feather amphiboles" (Theart, 2000). This unit also contains xenoliths of quartzite and argillaceous rocks derived from the Timeball Hill shale (van Zyl, 1996; Theart, 2000; Li et al., 2002). A thin cumulus magnetite layer occurs near the base of the unit, while magnetite of uncertain paragenesis is observed within the sedimentary rocks above the contact (Theart, 2000).

The upper part of the GN Unit is noticeably more primitive than the underlying diorites. This is shown by a sharp reversal towards higher MgO, Mg#, Ni and Cr values (Maier et al., 2004). It has been proposed that the upper GN Unit represents crystallization of the initial magma pulses against the roof (Maier et al., 2004). The mineralogy of the lower part consists of 50-60 vol. % plagioclase, whereas the clinopyroxene content increases with height from the base while orthopyroxene decreases (Gomwe, 2002).

The principal alteration mineral in the GN Unit is amphibole (hornblende) which increases in abundance from the bottom of the unit and constitutes approximately 10 vol. % (Gomwe, 2002). Chlorite has been found to dominate the centres of some pseudomorphed primary mineral grains (Gomwe, 2002). In the upper part of the GN Unit, the cumulus minerals consist of 40-60 vol. % plagioclase, 20-40 vol. % orthopyroxene and 5-10 vol. % clinopyroxene (Gomwe, 2002). The intercumulus minerals consist of quartz, increasing from 5-10 vol. % from the bottom of the unit, biotite, apatite and zircon (Gomwe, 2002).

This unit contains <1 vol. % disseminated sulphides (Gomwe, 2002). Alteration of the upper part of the GN Unit is more pervasive, where the alteration mineral assemblage comprises amphibole (hornblende and actinolite-tremolite), alkali-feldspars, chlorite and epidote (Gomwe, 2002).

2.5 Previous models of the intrusion of the Uitkomst Complex

A simplified sequence of intrusion for the Uitkomst Complex may be given as:

- A series of NW-SE trending fractures existed in the area of the intrusion according to de Waal et al. (2001).
- **Stage 1**: An initial pulse of magma, represented by the BGAB Unit intruded close to the contact between the Archean granite and the overlying Transvaal sediments. This created and filled the initial conduit, as indicated by the presence of the MG Unit forming a marginal contact higher up in the stratigraphy.
- **Stage 2**: Shortly after emplacement of the BGAB Unit, the magma pulses responsible for the formation of the LHZBG Unit, started flowing through the conduit. These pulses assimilated some of the gabbroic magma and dolomites. The most primitive pulses are represented by the wehrlitic layers. The assimilation of carbonates led to the precipitation of sulphides and the creation of hybrid rocks, such as the parapyroxenite. The passive nature of intrusion of these pulses is demonstrated by the preservation of calc-silicate xenoliths with the preserved layering orientated parallel to the layering in the country rocks. According to Hornsey (1999), the intrusion of these pulses would have led to the creation of a radial tensile fracture pattern in the overlying sediments. The volume of magma increased over time, as indicated by the decrease of xenoliths in the upper part of the LHZBG Unit, the intrusion likely propagated upward rapidly before creating lateral space.

- **Stage 3**: It is inferred that further pulses, creating the PCR Unit, intruded after the LHZBG Unit without a significant hiatus. These more voluminous pulses probably flushed the conduit of xenoliths.
- **Stage 4**: The formation of the MCR Unit layer on top of the PCR Unit probably represents the mixing event of an influx of new, Cr-rich reducing magma. Intrusive pulses of the MHZBG Unit magma followed, until the system eventually evolved to a closed system.

De Waal and Gauert, (1997) and Gauert (1998) found that the magma mixture that constitutes the Uitkomst Complex is dominated by B1 magma towards the NW, while the SE is dominated by B2 magma. This is observed in more abundant sulphide mineralization towards the NW and chromite mineralization towards the SE. The size of the intrusion has also been found to increase towards the SE (Hornsey, 1999; de Waal et al., 2001). The LHZBG and PCR Units are inferred to have been formed by crystal settling from a contaminated basic magma (van Zyl, 1996).

Several genetic relationship models have been proposed. Blom (1988), suggested that the inferred Mooiland Complex, in Mpumalanga, close to the Uitkomst Complex, indicated on the locality map (Figure 2.3) could have acted as a feeder to the Uitkomst Complex. The presence of the Mooiland Complex is inferred from an aeromagnetic and gravity anomaly that was believed to be caused by a magnetized, sill-like body, 1 400 m deep with a thickness of approximately 500 m. The gravity model predicts a 2 500 m thick sill-like body, dipping to the south, which has a density contrast of 410 kg/m^3 with respect to the Archean granites. The high susceptibility used in the two dimensional modelling process is indicative of a high percentage of magnetite present in the body, similar to that of the upper zone of the Rustensburg Layered Suite. Another similarity found between the Mooiland bodies and the Rustenburg Layered Suite is the fact that only the upper unit of the gravitational model is magnetic. From a colour coded aeromagnetic map and Bouguer anomaly map it was found that the Mooiland bodies are not linked to the main Bushveld Complex body, but should rather be seen as an intrusive complex on its own. It should be noted that the Uitkomst Complex is more ultramafic in nature with significant chromite cumulates and no confirmed magnetite cumulates relative to the Mooiland bodies.

Mafic-ultramafic sills that are considered to be analogous to the Uitkomst Complex have been described by Maier et al. (2001). These sills are found near the contact of the sedimentary and volcanic rocks of the Silverton Formation (Transvaal Supergroup), on the farms Blaawboschkraal, Swartkopje and Waterval. The location of these three farms, the inferred location of the Mooiland intrusion and the farms Slaaihoek 540 - JT and Uitkomst 541 - JT is shown in Figure 2.4.

Kruger (2004) suggested that, (referred to by the author as the Nkomati conduit intrusion) the conduit might have served as an upper zone magma conduit of a more extensive southern lobe of the Bushveld Complex. Alternatively the conduit could have fed into a volcanic- or peripheral sill phase that eroded away.

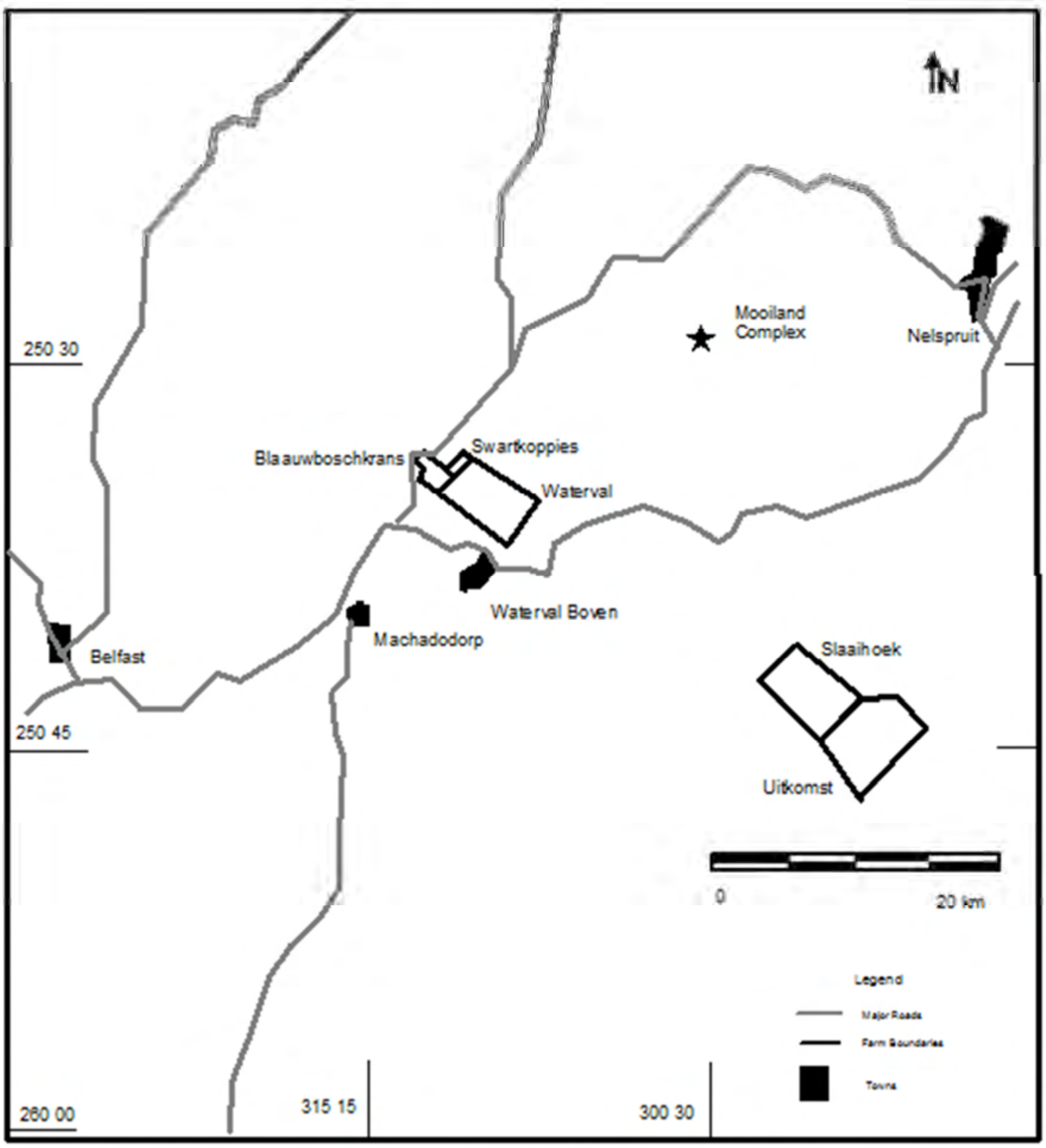

Figure 2.4. Locality Map indicating the position of the mafic-ultramafic intrusions related to the Bushveld Complex on or near the escarpment in Mpumalanga. Image adapted after Maier et al., (2001) with the Mooiland intrusion's position inferred from Blom (1988).

2.6. The Pit 3 open cast operation

The exploitation of the shallow chromite resource, located in the exposed shallow part of the Uitkomst Complex on the farm Uitkomtst 541 JT, will form part of the large scale open pit three operation (Theart, 1997; Anonymous, 2007). The shallow oxidized chromite resource will be mined first as part of the pre-strip (Figure 2.6) to expose the underlying disseminated sulphide ore bodies of the PCMZ and MMZ (Theart, 2000; Anonymous, 2007). The sulphide minerals in this material above the groundwater table is oxidized and rendered unextractable. However in the deeper parts of the orebodies the sulphide minerals may have to be extracted first before the chromite may be utilized. The extent of the pre-strip is indicated in Figure 2.5.

Figure 2.5 Pre-strip in the Pit 3 area, November 2008 (Image, Google Earth, 2008).