

2

Geological Setting

2.1. Introduction to the Bushveld Complex, South Africa

The Bushveld Complex, of Palaeoproterozoic age, is located in the central northeast portion of the Kaapvaal Craton in southern Africa, and has an estimated total area of 65 000 km² (Hunter, 1976). The Complex is composed of four lobes in the north, east, south and west about an east-northeast and north-northwest set of axes, and it has a long axis of approximately 470 km and a short axis of approximately 380 km (Figure 2.1).

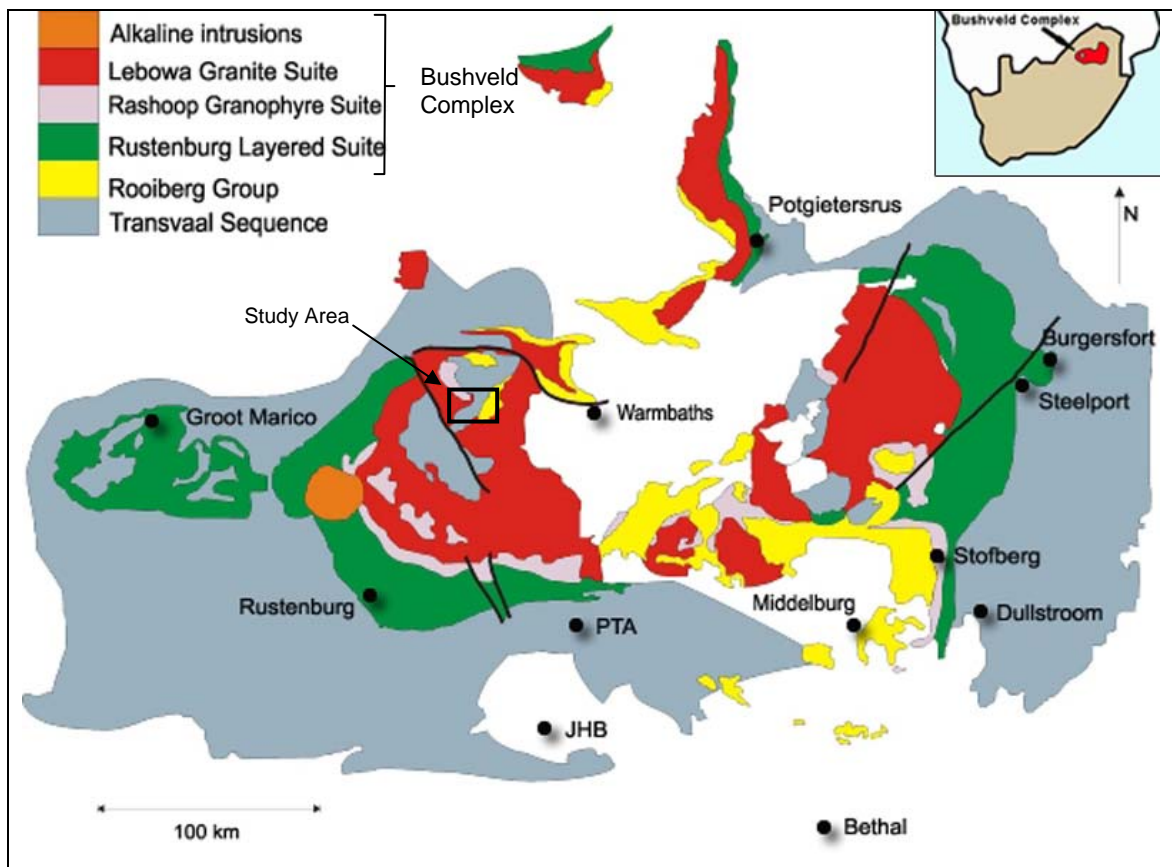


Figure 2.1. Distribution and Stratigraphy of the Bushveld Complex, South Africa.

Interest and exploration efforts within the Bushveld Complex have largely been concentrated on the more economically important mafic rocks of the Rustenburg Layered Suite, which host vast resources of platinum, platinum group elements, chromium, nickel, vanadium and titanium in quantities unparalleled elsewhere in the world.

Documentation of the granites belonging to the Lebowa Granite Suite and their associated roof rocks has concentrated principally on tin mineralisation, most notably developed at mines such as Zaaiplaats, Union, Stavoren and Rooiberg, and on fluorite mineralisation located at the Vergenoeg, Zwartkloof and Buffalo fluorite mines.

Vergenoeg Fluorite Mine, situated approximately 65 kms north of Pretoria, is possibly one of the single largest fluorspar mines in the world with an estimated 178 Mt @ 28.1 % CaF₂ and 195 Mt @ 42 % Fe (Fourie, 2000). Vergenoeg is of particular significance to this study because it represents a well-developed and well-documented example of fluorite-hematite mineralisation in the Lebowa Granite Suite, similar in mineralisation and geological setting to deposits found throughout the acid rocks and roof rocks of the Bushveld Complex. It also demonstrates the potential for development of sizeable mineralised targets. Its characteristics are distinctly IOCG in nature and it has been broadly correlated with Olympic Dam (South Australia) and Kiruna-Aitik (Sweden).

Numerous small deposits similar to the Vergenoeg massive iron oxide-fluorite deposit occur distributed in around the Bushveld granites and its associated roof rocks. Most of these deposits possess an intrinsic iron oxide component, and usually possess some polymetallic association, such as that found at Albert silver mine (Robb *et al.*, 1994), Klipdrift molybdenum deposit (Bailie, 1997), Rooibokkop-Boschhoek copper deposit (Smits, 1986) and Spoedwel copper mine (Scoggins, 1991) (Figure 2.2). Deposits and occurrences in the western Bushveld, such as those on the farms Ruigtepoort, Slipfontein, and Blokspruit will be examined in this study.

With the growing significance of this style of mineralisation, a detailed understanding of the geological setting, controls on mineralisation, mineral paragenesis, and associated alteration is imperative for the development of an effective exploration model.

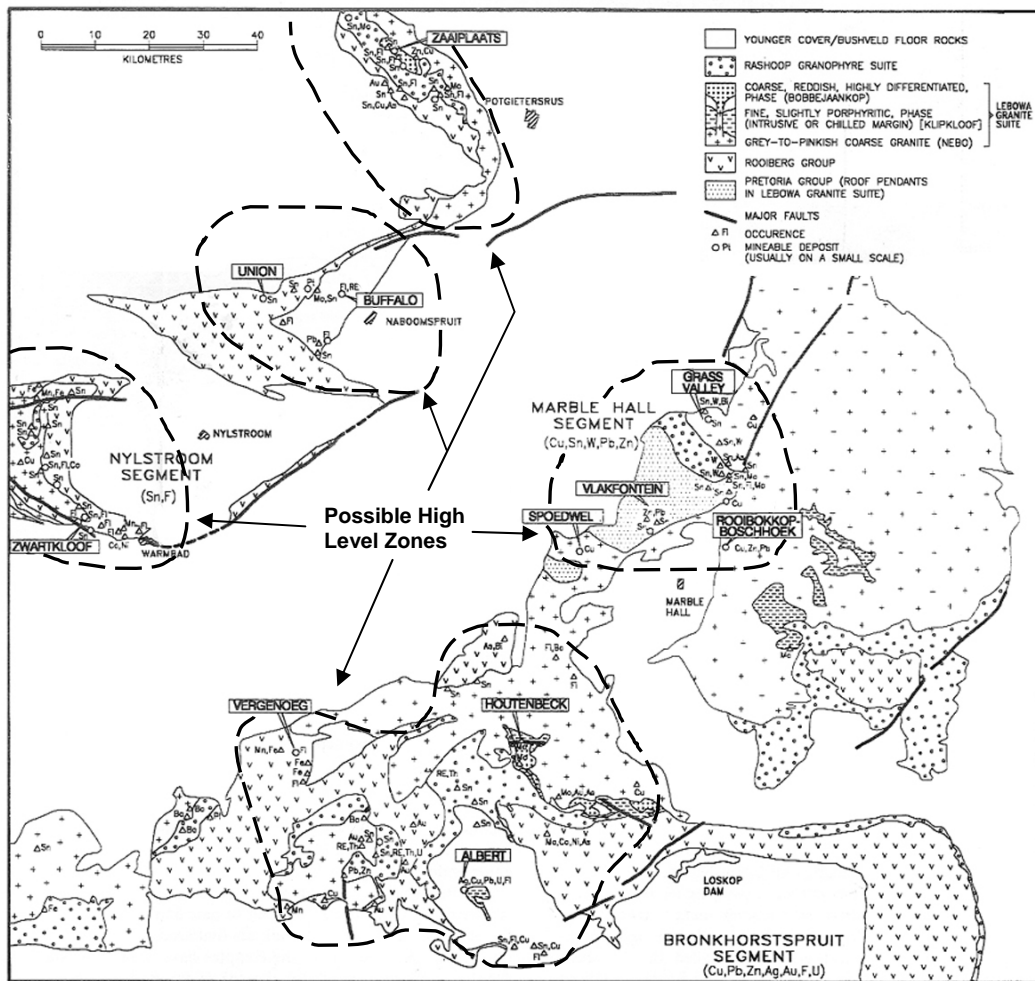


Figure 2.2. Simplified map of the central and eastern Bushveld Complex, with an enlarged plan showing the exposed Lebowa Granite Suite (LGS) and Rooiberg Group in the eastern section of the Complex and the widespread distribution of granite-related polymetallic ore deposits (modified from Robb *et al.* 2000).

2.2. Regional and Tectonic Setting

The Bushveld Complex is seated in the central northeast portion of the Kaapvaal craton and is regarded as having been emplaced in an intra-cratonic, anorogenic setting possibly related to mantle pluming. The Kaapvaal Craton covers an area of approximately 1.2×10^6 km² and comprises predominantly granitoids interspersed with greenstone belts, covered by a variety of Neo-Archean to Mesoproterozoic sedimentary and volcanosedimentary basins (Good & De Wit, 1997).

The emplacement of the Bushveld Complex is thought to have been controlled by crustal-scale structures or relict terrane boundaries. The Kaapvaal craton is divided into a number of discrete sub-domains, or terranes, and represents one of the few well-preserved and extensive portions of relatively pristine Meso- to Neo-Archean rocks anywhere on Earth (Figure 2.3, Eglinton & Armstrong, 2004). Some of the more prominent trans-cratonic linear features follow two dominant orientations, namely east-northeast to west-southwest and north-northwest to south-southeast, and may be represented in part by the Thabazimbi-Murchison lineament, the Magaliesberg-Barberton lineament and the Palala-Zoetfontein fault which follow the former trend and the Rustenburg and Brits faults which follow the latter trend (Figure 2.4) (Simpson and Hurdley, 1985).

The Archean history of the craton spans a period of more than 1.0 Ga, from 3.65 to 2.6 Ga, including the collision and stabilisation of the Kaapvaal Craton and the Zimbabwe craton to form the Kaapvaal-Limpopo-Zimbabwe Block. The Palaeo-Proterozoic evolution of the now stable block was dominated by extensional regimes, in particular, intracratonic, pull-apart sedimentary basins, such as the Witwatersrand Basin and others (Eriksson *et al.* 1996).

Bumby *et al* (1998) and Hartzler (1995) recognised pre-Bushveld deformation and that various Transvaal Supergroup sedimentary inliers may be floor projections or domes resulting from pre-Bushveld interference folding (northwest and east-

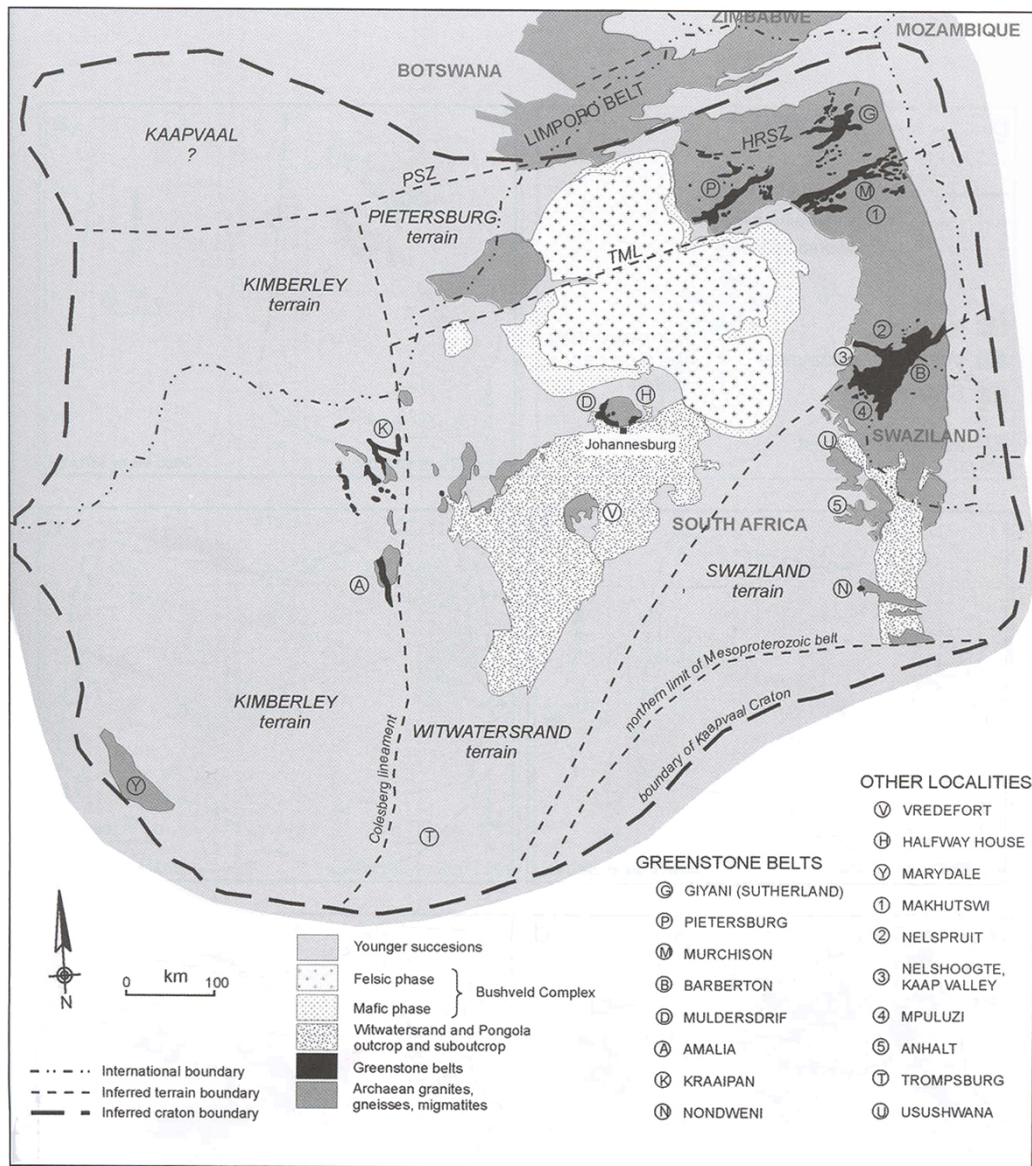


Figure 2.3. Proposed cratonic architecture as suggested by terrane boundaries within the Kaapvaal Craton. Thick dashed line delineates the geophysical boundary of the Kaapvaal Craton, with terrane boundaries chosen to coincide with the Colesberg lineament, the Thabazimbi-Murchison lineament (TMZ), the Hout River Shear Zone (HRSZ), the Palala shear zone (PSZ) and a south-westerly extension of the Inyoka Fault (reproduced from Eglington & Armstrong, 2004).

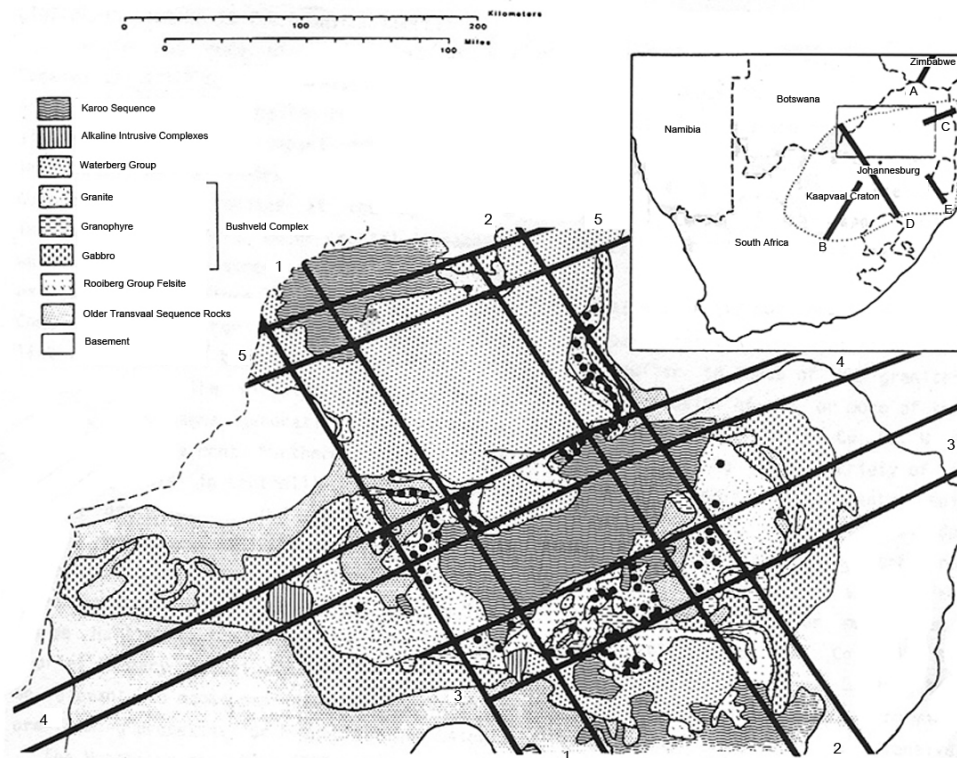


Figure 2.4. Lineaments traversing the Bushveld Complex shown in relation to older megalineaments of the Kaapvaal and Zimbabwe Cratons (see inset) (Davies *et al.*, 1970,; Wilson, 1977, 1979) and radiometric anomalies over the Lebowa Granite Suite denoted by black dots. The megalineaments are as follows: A) Great Dyke, B) Losburg-Trompsburg, C) Murchison, D) Koppies continental arch, E) Ushushwana. The corresponding Bushveld lineaments are as follows: 1) Franspoort Zone, 2) Grobblaars Hoek-Hlabisa Zone, 3) Soutpan-Spitskop Zone, 4) Murchison Zone, 5) Glenover-Grobbelaars Hoek Zone. All known deposits of fluorspar and tin and eighty-five percent of the radiometric anomalies are confined within these zones. Some of the radiometric anomalies are so closely spaced that they are not individually represented here (after Simpson & Hurdley, 1985).

northeast trending fold axes), which may have also acted as physical barriers against which Bushveld magmas accumulated.

After the emplacement of the Bushveld Complex between 2.060 and 2.050 Ga, the craton accreted new material principally along its western margin with the Kheis (Eburnian) orogeny between 1.999 – 1.928 Ga (Kruger *et al.* 1999), the Kibaran (Grenville) orogeny between 1.220 – 1.170 Ga (Robb, *et al.* 2000), and the Panafrican (Namaquan) orogeny between 1.060 - 1.030 Ga (Robb, *et al.* 2000). Exhumation of the Bushveld Complex is thought to have coincided with the deposition of the Waterberg and Zoutpansberg formations at around 1.770 Ga

(SACS, 1980) from reset isotopic systems, which indicate a closure at *c.* 1.800 Ga (Robb, *et al.* 2000). The deposition of Karoo sediments took place between 280 and 190 Ma (Friese *et al.*, 1995).

Subsequent to the emplacement of the Bushveld Complex, reactivation of the Mesoproterozoic south-southeast (150°) trend, along which the Rustenburg fault was initially formed, disrupted the western limb of the Complex. Pilanesberg alkaline dykes (~1450-1200 Ma. Harmer, 1992) were intruded predominantly along the north-northwest orientated extensional structures.

Karoo Supergroup sedimentary stratigraphy was deposited in basins related to epeirogenic flexuring of the sub-continent associated with the break-up of Gondwanaland, initiated in the Early Cretaceous (130 Ma) (Moore, 1999). Uplift in the Pliocene and Plio-Pleistocene (4-2 Ma) occurred on the western margin of the continent, with flexuring along a southwest-northeast axis forming depressions in the Bushveld, Bushmanland, Karoo-Lesotho and Botswana.

The general geological characteristics of the Transvaal Supergroup and the components of the Bushveld Complex are discussed below in more detail.

2.3. General Stratigraphy of the Transvaal Supergroup and the Bushveld Complex

The Bushveld Complex comprises the voluminous, bimodal intrusive magmas of mafic and felsic characteristics into predating Transvaal Supergroup sediments and Rooiberg Group volcanics. The country rocks to the intrusive magmas are important with regard to chemical assimilation and mineralisation potential.

Transvaal Supergroup

The Transvaal Supergroup comprises a 15 000 m thick sequence of relatively undeformed clastic sediments and volcanics. The principal elements of the Supergroup include the clastic sediments of the Black Reef Formation, the chemical and clastic sediments of the Chuniespoort Group, and the clastic sediments and volcanics of the Pretoria Group. The Bushveld Complex intruded into the Transvaal Supergroup at a palaeo-unconformity between the Rooiberg Group and the underlying Pretoria Group (Cheney & Twist, 1991). The surficial distribution of the Transvaal Supergroup extends across the central and southern parts of the Transvaal into Botswana. The Supergroup comprises two correlated sub-basins known as the Transvaal Sub-basin in the east and the Griqualand Sub-basin in the west.

Deposition began in a relatively small protobasin during the Godwan, but in time spread to an area of over 500 000 km² (Button, 1986). The basin then decreased in size in its terminal stages. The basin is assymetrical, thinning rapidly to the north and more gradually to the south of an east-northeast-trending depositional axis (Button, 1986). The present shape of the basin was largely controlled by post-Transvaal events, such as the Bushveld intrusion. The age of the basin is c. 2643-2061 Ma (Walraven, 1997; Walraven *et al*, 1999), which corresponded in part to the probable collision between the Kaapvaal and Zimbabwe cratons at

about 2 400 Ma. The clastic sediments were derived from a mountainous source to the north-northeast of the basin (Button, 1986).

The depositional facies grade from braided fluvial arkoses, through tidal flat sediments to mature sandy shelf deposits that consist primarily of shales and carbonate shales. Up to 3 000 m of carbonate and iron formation were deposited on the macro-tidal shelf, indicating that the shelf and its surroundings must have been tectonically very stable for a considerable period of time.

Rooiberg Group

The Rooiberg Group consists of an unusually thick and extensive sequence of epicrustal acid volcanics comprising dacites, rhyolites and rare andesites. Lavas, air-fall tuffs, ash-flow tuffs and phreatic (hydrothermal) tuffs are all present with interbedded shales, sandstones and volcanic mudflows. Although the Rooiberg Group has long been viewed as the terminal stage of deposition in the Transvaal Basin, it is now more-widely considered to represent the preliminary stage of magmatism related to the Bushveld Complex, with a possible 30-40 million year hiatus between sedimentary deposition in the Transvaal Basin and the eruption of the Rooiberg volcanics (Robb, *pers. comm.*). With a thickness of more than 5 km in places and an estimated volume of 300 000 km³, the Rooiberg Group represents one of the world's largest acid volcanic provinces (French & Twist, 1983). It has been assigned an age of 2057.3 ± 3.8 Ma obtained by single U-Pb SHRIMP zircon analysis (Harmer & Armstrong, 2000), and may be seen to represent the earliest episode of magmatic activity pertaining to the Bushveld Complex. It forms the "roof" rocks to the rest of the Complex with unequivocal intrusive relationships between the Rooiberg Group and all the components of the Bushveld Complex. The distribution of the Rooiberg Group is shown in Figure 2.5.

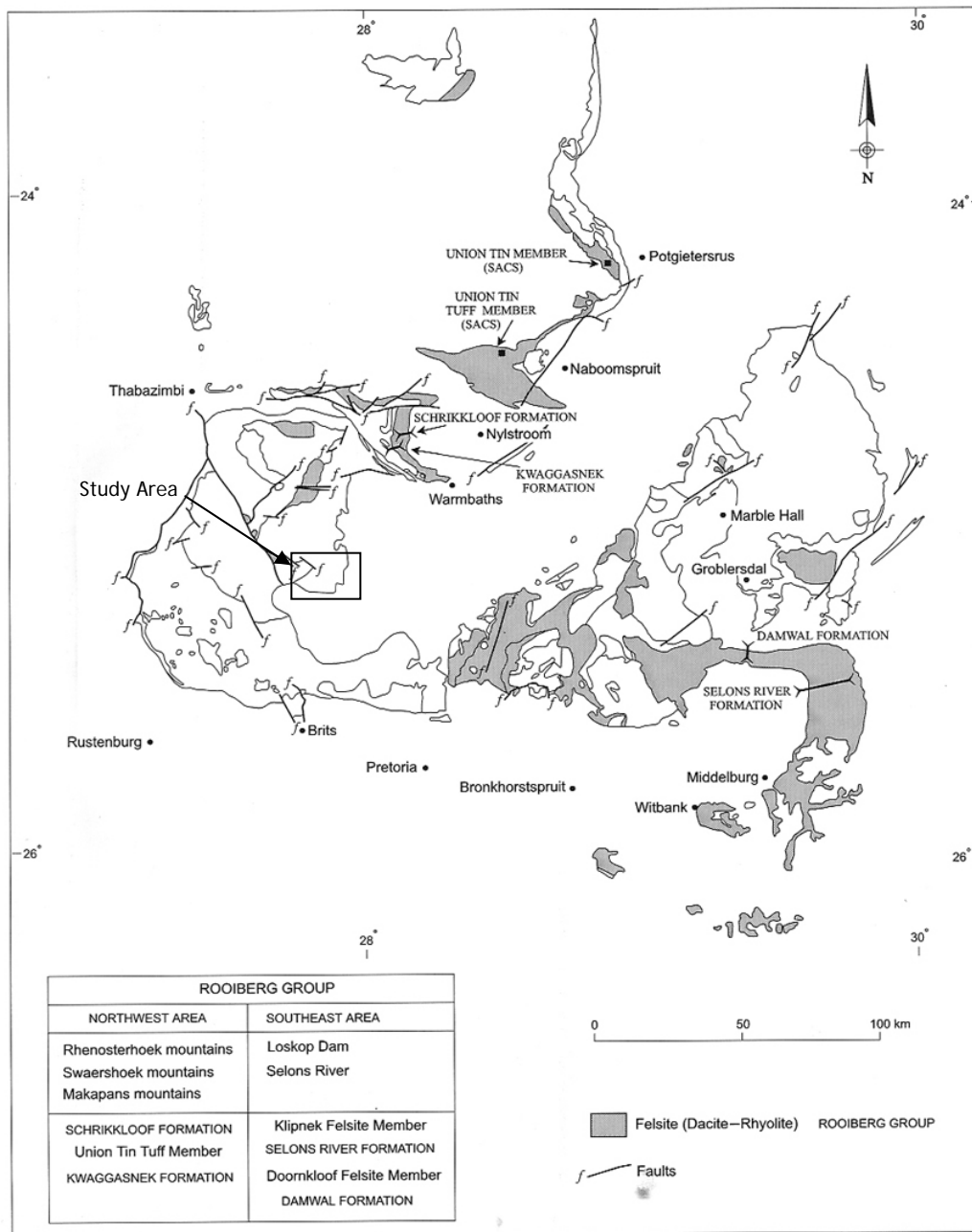


Figure 2.5. Distribution of Rooiberg Group rocks (taken from Crocker *et al.*, 2001).

The stratigraphic succession begins with a basal suite, approximately 1 300 m thick, of porphyritic and pseudospherulitic rhyolite, amygdaloidal rhyolite, agglomerate and volcanic breccia, tuff & sandstone (Twist, 1985). This is followed by a 2 600 m succession including a prominent sandstone bed, rhyodacites and flow-banded rhyolites with interbedded mudstones (Figure 2.6)

(Crocker *et al.* 2001). This stratigraphy varies between outcrops north and south of outliers of Karoo rocks situated central to the Complex.

Contrary to expectations, most of the litho-types observed in the study area correspond to the Damwal Formation rocks observed in the eastern Bushveld but which are generally regarded as being undeveloped in the western Bushveld. What is apparent is that any Rooiberg Group rocks in the area correspond to the lowest portions of the volcanic stratigraphy.

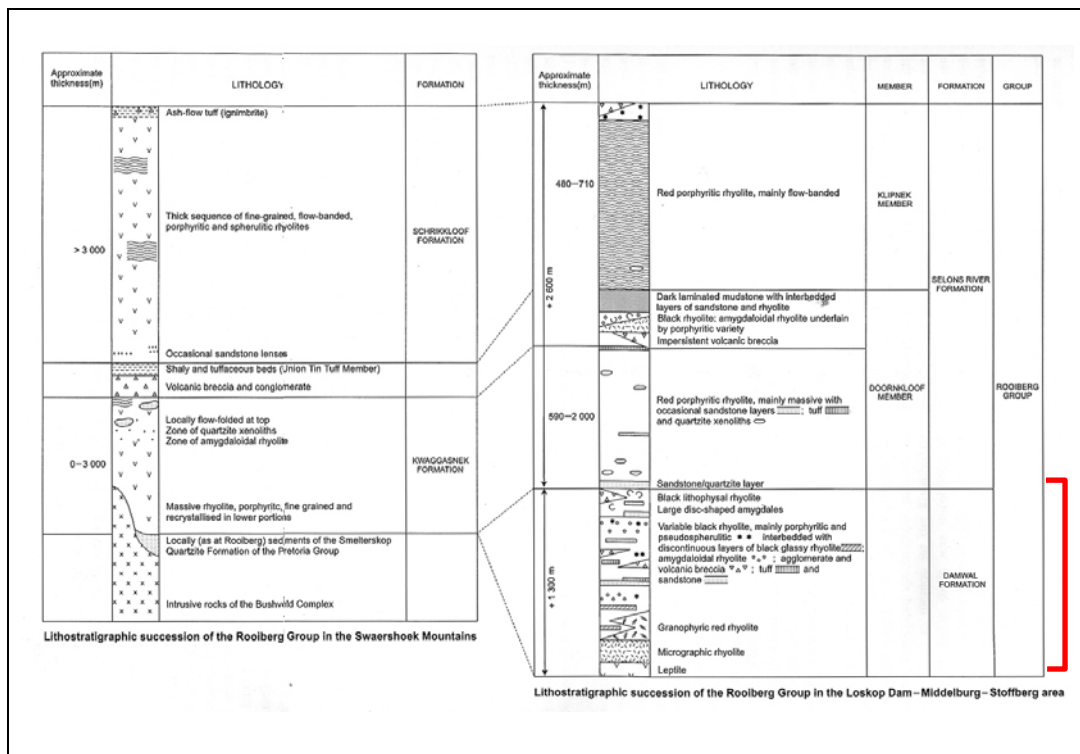


Figure 2.6. Variation in the lithostratigraphic succession of Rooiberg Group rocks between the eastern and western lobes of the Bushveld Complex. Red bar indicates litho-types that have been potentially identified within the study area, corresponding to the Damwal Formation in the eastern Bushveld but largely undeveloped in the western Bushveld (taken from Crocker *et al.*, 2001).

Bushveld Complex

The Bushveld Complex is Neoproterozoic in age, and is located in the central northeast portion of the Kaapvaal Craton in southern Africa. The Bushveld Complex consists of three major plutonic suites – the granophyres, the layered mafic rocks and the successive granite plutonism. Geochronological data for the mafics of the Rustenburg Layered Suite and the felsics of the Lebowa Granite Suite yield age constraints for emplacement over a 6 my period (2060-2054 Ma), but is thought that these two elements were essentially emplaced coevally from petrogenetic considerations (Robb *et al*, 2000). The Complex was mainly intruded beneath the older cover of the Rooiberg Group volcanics. The total area of the complex has been estimated at 65 000 km² (Hunter, 1976). Table 2.1 presents the best currently available age estimates after Walraven (1997) and Harmer & Armstrong (2000).

Table 2.1. Lithostratigraphic subdivisions of the Bushveld Complex according to SACS (1980). Ages in bold print represent best current age estimates according to Walraven (1997) and Harmer & Armstrong (2000).

Bushveld Complex	Radiometric Age (Ma)	Method & Reference
<u>Lebowa Granite Suite</u>		
Nebo Granite	2054.2 ± 2.8 2054 ± 2	U-Pb SHRIMP Harmer & Armstrong (2000) Pb-Pb Walraven & Hattingh (1993)
<u>Rashoop Granophyre Suite</u>		
Rooikop Granophyre (Granite) Porphyry	2061.8 ± 5.5	U-Pb SHRIMP Harmer & Armstrong (2000)
Rooikop Granophyre (Granite) Porphyry	2053± 12	U-Pb Coertze <i>et al.</i> (1978)
Rooikop Granite Porphyry	2066±10	U-Pb Faurie (1977)
Zwartbank Pseudogranophyre	2060± 2	Pb-Pb Walraven (1997)
<u>Rustenburg Layered Suite</u>		
Critical Zone	2095 ± 24	Rb-Sr Hamilton (1977)
Lower Zone	2054.4 ± 2.8	U-Pb SHRIMP Harmer & Armstrong (2000)
Critical Zone	2049 ± 152	Sm-Nd M.R. Sharpe unpublished data
Main Zone	2054 ± 32	Rb-Sr in von Gruenewaldt <i>et al.</i> ,
Upper Zone	2058 ± 155	Sm-Nd (1985)
Upper Zone	2057 ± 24	Rb-Sr
Upper Zone	2061 ± 27	Rb-Sr Walraven <i>et al.</i> (1990)
<u>Rooiberg Group</u>	2057.3 ± 3.8	U-Pb SHRIMP Harmer & Armstrong (2000)

The Bushveld Complex is composed of four lobes in the north, east, south and west about an east-northeast and north-northwest set of axes (Figure 2.7). The eastern and western lobes are better exposed than the northern and southern lobes. The eastern lobe extends from Warmbaths to Burgersfort, and the western lobe extends from Warmbaths to Zeerust. The northern lobe extends from Warmbaths towards Potgietersrus in the east and Villa Nora in the west, and is postulated to continue towards Botswana beneath the Waterberg Group sediments, which unconformably overlie a large portion of the lobe. The southern lobe is known from gravity data and drill holes through overlying Karoo sediments and where correlated inliers of Rooiberg Group and Nebo granites are exposed. It is presumed to extend from Groblersdal southwards to Bethal (*c.f.* Figure 2.3).

The Bushveld Complex intruded at an unconformity between the Rooiberg Group and the Transvaal sediments. It consists of an initial mafic-ultramafic component up to 8 km thick package comprising the Rustenburg Layered Suite (2054.4 ± 2.8 Ma U-Pb SHRIMP; Harmer & Armstrong, 2000) and the subsequent felsic component up to 4 km thick package comprising the Lebowa Granite Suite (2054.2 ± 2.8 Ma U-Pb SHRIMP; Harmer & Armstrong, 2000).

The complete stratigraphy is found in all four lobes but is not always fully correlative. The Rustenburg Layered Suite has been postulated to be continuous between the eastern and western lobes (Cawthorn *et al.*, 1998). The southern and northern lobes are poorly exposed or known only from geophysical results, and are less well constrained.

The Bushveld Complex is fairly coincident with the rocks of the Transvaal Basin and in a general sense, is for the most part, conformable to the Transvaal Supergroup. The floor to the Complex in the west consists of the Magaliesberg Quartzite Formation; to the north of Pretoria it is floored by the Rayton Formation (which is stratigraphically higher than the Magaliesberg Formation); and to the north of the Pilanesberg Alkaline Intrusive Complex it is floored by the

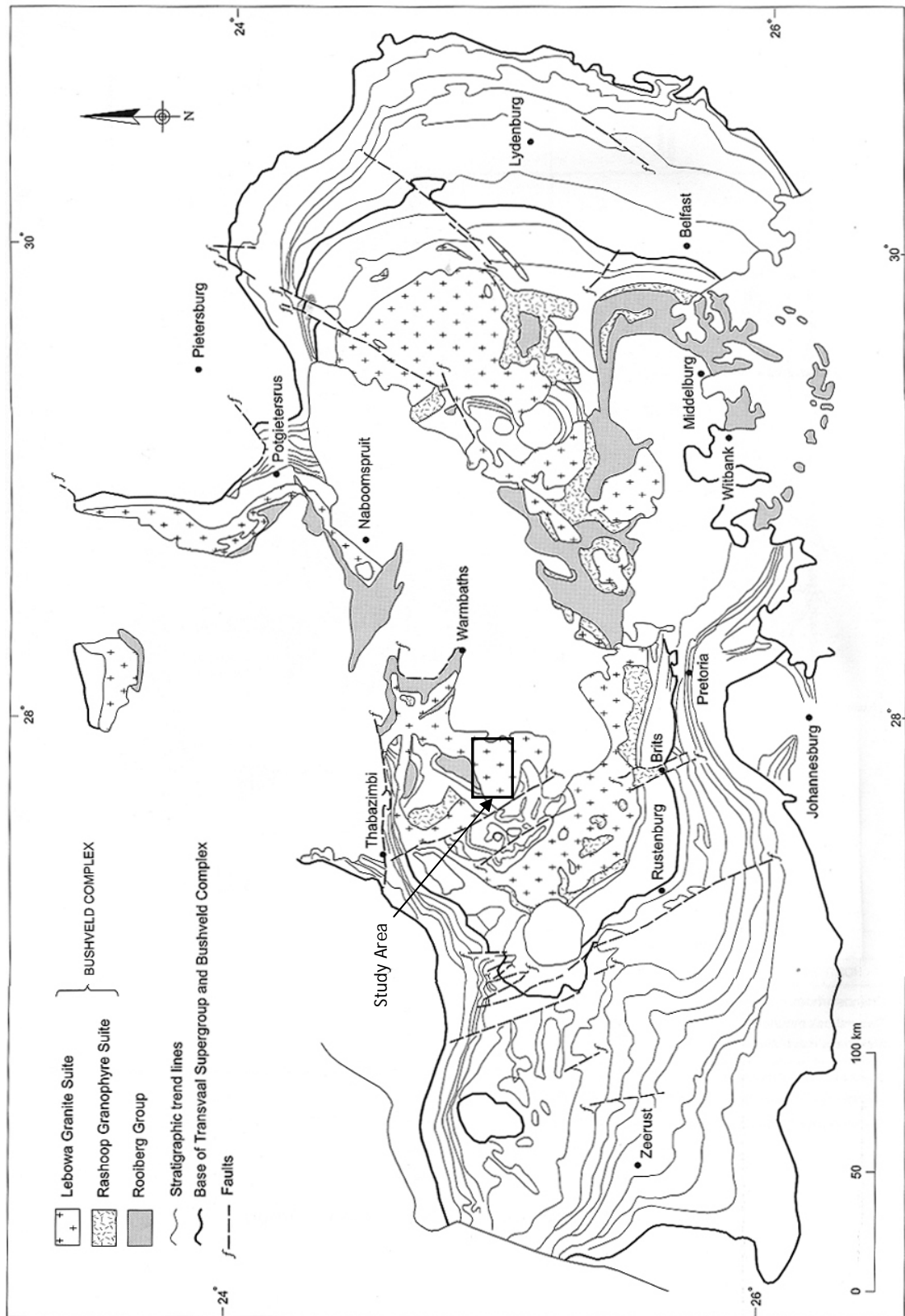


Figure 2.7. The Acid Rocks of the Lebowa Granite Suite (taken from Crocker *et al.* 2001).

Daspoort Quartzite Formation (which is stratigraphically lower than the Magaliesberg Formation). That is to say that the Bushveld Complex overlies successively higher Transvaal stratigraphy towards the south and the east. The roof rocks are likewise stratigraphically higher with Rooiberg Group volcanics roofing the Complex in the northern and central portions, and the Pretoria Group sediments roofing the Complex in the far western and Stavoren regions.

Rashoop Granophyre Suite

Field relationships indicate that the Rashoop Granophyre Suite (2061.8 ± 5.5 Ma; Harmer & Armstrong, 2000) predates the intrusion of the Rustenburg Layered Suite (2054.4 ± 2.8 Ma U-Pb SHRIMP; Harmer & Armstrong, 2000) and occurs as an intrusive sheet into the Rooiberg rhyolites and the Transvaal Supergroup rocks (Kleeman, 1985). The granophyres are thought to be a cogenetic, shallow intrusive equivalent of the Rooiberg Group volcanic event. The granophyre-rhyolite magma is largely thought to be derived from partial melting of the lower crust, presumably with a granitic composition (Walraven, 1982). Some varieties of granophyre, however, possibly formed as a result of metamorphic/metasomatic effects related to the intrusion of the Rustenburg Layered Suite acting on the Pretoria Group sedimentary roof rocks; or by the partial melting of Rooiberg Group rhyolites also a consequence of the hot intrusive magmas of the Rustenburg Layered Suite (Walraven, 1982).

The Rashoop Granophyre Suite comprises three units based on textural variations; the Stavoren Granophyre, the Zwartbank Pseudogranophyre and the Rooikop Granite Porphyry (SACS, 1980). Many more varieties have been proposed by extensive work by Walraven (1977, 1979, 1982). Figure 2.8 shows the distribution of the Rashoop Granophyre Suite.

The Stavoren granophyre is a granophyre *sensu stricto*, and is the most prominent and abundant of the various types of granophyre in the Bushveld Complex. It

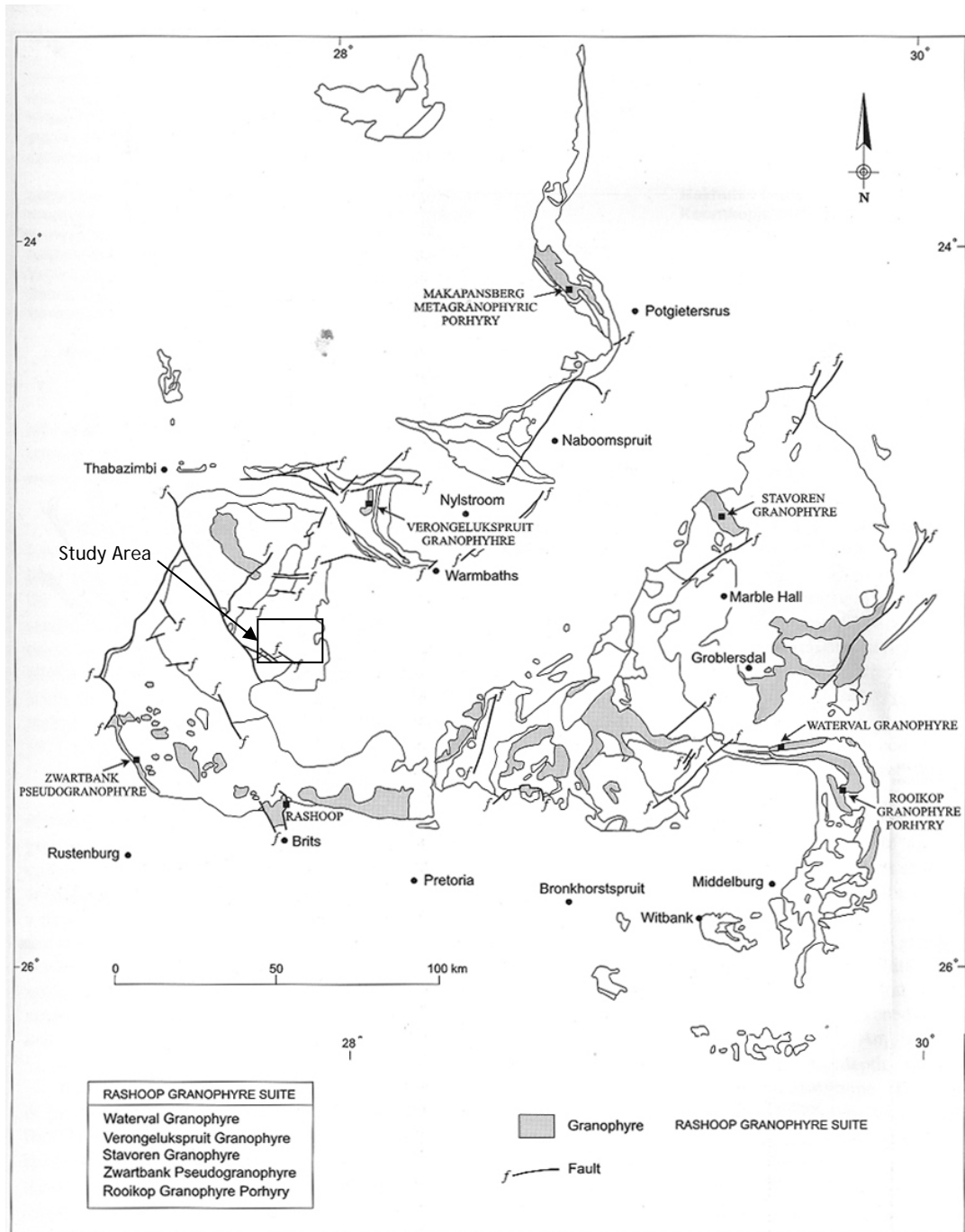


Figure 2.8. Distribution of the Rashedo Granophyre Suite (taken from Crocker *et al.*, 2001).

consists almost exclusively of micrographic intergrowths of quartz and perthitic feldspar (Walraven, 1982) and displays a range of colours from brick-red to grey. The proportion of quartz to feldspar is a remarkably constant ratio of 45:55, which has been suggested to indicate cotectic crystallisation at the ternary minimum melting point, and hence evidence for a magmatic origin (Walraven, 1977).

The Zwartbank pseudogranophyre is distinguished from the Stavoren granophyre by the variability in proportions of quartz and feldspar and the distinctly less regular intergrown textures. Walraven (1977) proposed that this rock formed from metamorphic/metasomatic effects of the intrusion of the Rustenburg Layered Suite acting on the Pretoria Group sedimentary roof rocks.

The Rooikop Granite Porphyry forms sills in the Rooiberg Group in the Loskop Formation of the Transvaal Supergroup. It consists of a fine-grained matrix containing abundant phenocrysts of quartz and feldspar (usually perthite). Embayments in the quartz and feldspar indicate partial resorption (Walraven, 1982). The micrographic texture observed in the other granophyric varieties is rarely present.

Other varieties of granophyre occur but in limited quantity and distribution; including a spherulitic variety of the Stavoren granophyre referred to as Spherulitic granophyre (Walraven, 1982), which is regarded as originally having been Rooiberg Group rhyolites which was incorporated into the Stavoren Granophyre.

The granophyres themselves do not have associated mineralisation but often act as trap-sites to mineralising fluids from the underlying granites.

Rustenburg Layered Suite

Notes on the Rustenburg Layered Suite are included here for completeness. No rocks of this suite have been identified in this study nor are they expected in the area.

The Rustenburg Layered Suite has an assigned age of 2054.4 ± 2.8 Ma (Critical Zone U-Pb SHRIMP; Harmer & Armstrong, 2000), which is roughly equivalent to the age obtained for the Rooiberg Group rhyolites of 2057.3 ± 3.8 Ma (Kwaggasnek Formation U-Pb SHRIMP; Harmer & Armstrong, 2000), consists of approximately 8 kms of pyroxenite, norite, gabbro and other mafic to ultramafic lithologies. The Rustenburg Layered Suite has been subdivided into four main stratigraphic units, being the Lower Zone (1 500 m harzburgite-bronzitite), the Critical Zone (1 500 m pyroxenite-anorthosite-norite), the Main Zone (3 750 m norite-anorthosite-gabbro-norite), and the Upper Zone (2 250 m gabbro-norite-magnetite gabbro-olivine diorite).

The Critical Zone, found in both the eastern and western lobes of the Bushveld Complex, contains the largest stratiform chromitite deposits in the world, which account for nearly 55 % of the world's reserves. Numerous chromitite layers have been identified and have been subdivided into Lower Group, Middle Group and Upper Group chromitite seams. The Critical Zone is also host to the world's largest platinum-PGE deposit, situated primarily in the Merensky Reef, at the Critical Zone-Main Zone interface, and the UG2 chromitite seam, some 500 m stratigraphically below, and accounts for approximately 40 % of the world's reserves.

The Upper Zone is host to about 25 titaniferous–vanadiniferous-magnetite layers. Open-castable reserves throughout the Bushveld Complex are estimated at about 26 000 Mt (Reynolds, 1986).

Lebowa Granite Suite

The Bushveld granites form a 2-3 km thick sheet-like sill of batholithic proportions, which gently dips centripetally towards the centre of the Complex, although it is gently folded locally to expose inliers of the underlying sedimentary rocks, such as the Marble Hall and Crocodile River fragments (Kleeman & Twist, 1989) (see Figure 2.9 for the distribution of the LGS). The main granites of the Lebowa Granite Suite, or **Nebo granite** (SACS, 1980), are highly potassic, magnetite-bearing, A-type* granites. Straus (1954) noted several variations within the Nebo granite such as an upwardly decrease in hornblende contents and a gradual colour change from grey at its base to a distinctive deepening red colour towards the upper parts, caused by the trapping of hematite in the feldspar lattices during deuteric alteration of the feldspar. The Nebo granites are by and large the most common variety and occupy most of the central core of the Complex. The zonation within the Nebo granite from base to roof is characterised below by the following general trends shown in Table 2.2.

Table 2.2. General trends in Nebo granite from base to roof (Gain & Twist, 1995).

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- Grey at the base, becoming pink and then red upwards corresponding to an upwards decrease in the Fe^{2+}/Fe^{3+} ratio (Baillie, 1997);
 - Upwardly-increasing perthite and quartz contents;
 - Upwardly-increasing obliquity values in K-feldspar;
 - Upwardly-increasing Si, K, Rb and Th contents;
 - Upwardly-increasing signs of hydrothermal alteration, like albitisation, microclinisation and tourmalinisation;
 - Upwardly-decreasing hornblende and plagioclase contents;
 - Upwardly-decreasing Fe, Ti, Ca, Ba, Sr, Zr, and Zn contents.
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* The A-type nature of the Bushveld granites denotes their essential characteristics: anorogenic, anhydrous, and mildly alkaline. (Chappell & White, 1974; Collins *et al.*, 1982; and Whalen *et al.*, 1987).

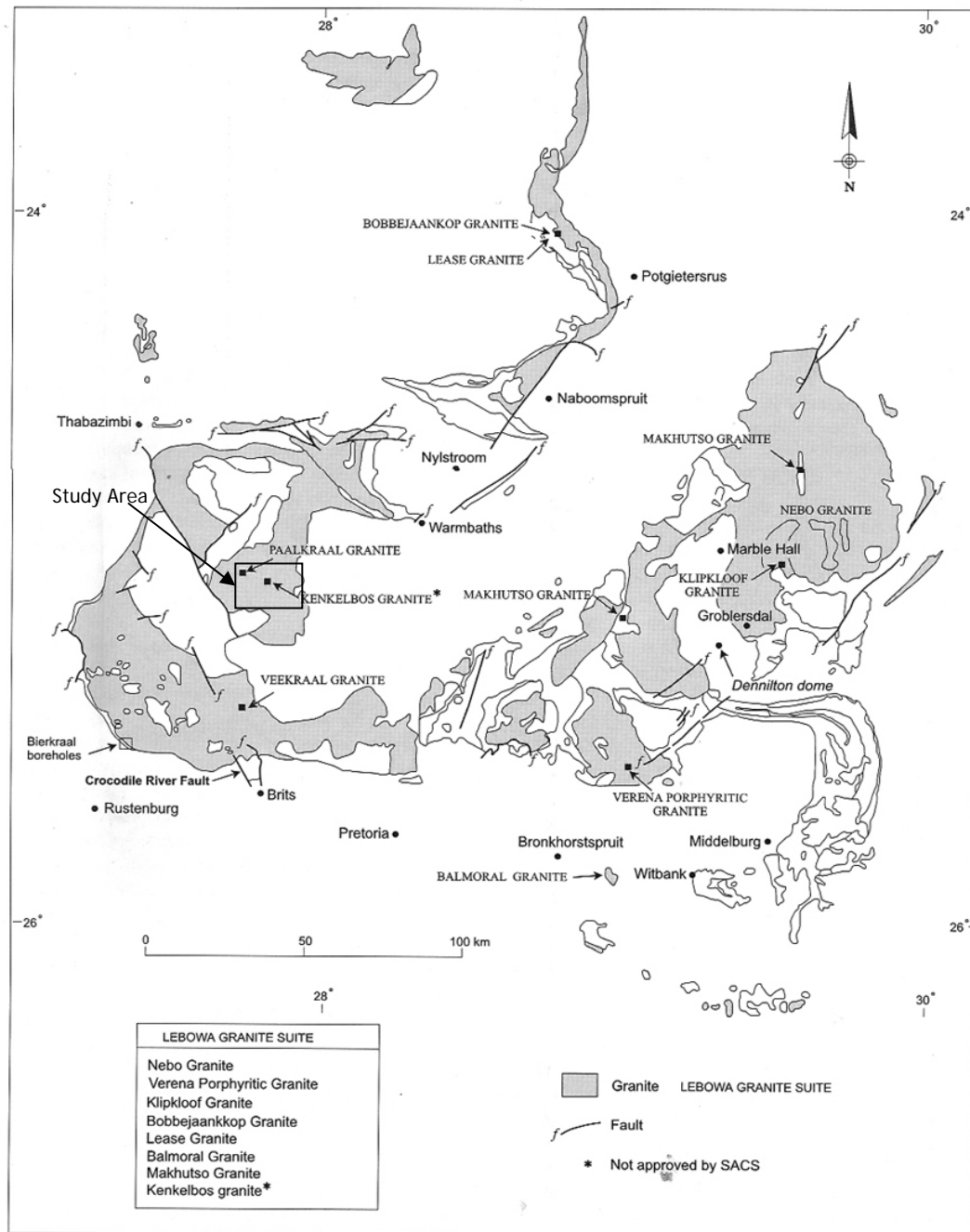


Figure 2.9. Distribution of the Lebowa Granite Suite (taken from Crocker *et al.*, 2001).

In general, the granites intrude and overlie the Rustenburg Layered Suite, and underlie the Rashoop Granophyre Suite and the Rooiberg Group wherever these are present. The granites are chilled against the granophyre (Willemse, 1964), and the contact is often marked by a zone of quartz-feldspar pegmatite associated with late differentiate aplite (Crocker *et al*, 2001) which is locally referred to as the **Klipkloof granite** or microgranite. The occurrence of Klipkloof granite increases towards the roof, and forms intrusive sills, dykes and veins within the Nebo granite.

A variety of Klipkloof granite, the **Lease granite**, has been locally identified in the Zaaiploats area and represents intense hydrothermal alteration towards the roof of the sill. This granite variety is host to orthomagmatic tin mineralization.

The **Bobbejaankop granite** is considered to be a distinct hydrothermally-altered, medium-to-coarse variety of Klipkloof granite. It is red in colour, characterised by linked chains and clusters of quartz, and it is generally confined to the upper parts of the sill.

All of these varieties are believed to be comagmatic from demonstrated similarities in gross mineralogy and chemistry. Variations are considered to be a consequence of fractional crystallisation with the granites being variably subjected to late-stage hydrothermal alteration (Gain & Twist, 1995). The exception is the **Makhutso granite**, which is of limited distribution and appears to be somewhat distinct from the other granites. The Makhutso granite is slightly younger than the Nebo granite with an assigned age of 2053 ± 3.9 Ma (U-Pb SHRIMP; Harmer & Armstrong, 2000).

Several varieties of granite have been identified both regionally and locally based on texture and colour. Their general characteristics are summarised below in Table 2.3.

Table 2.3. Typical three-fold subdivision of the Lebowa Granite Suite (Crocker *et al.* 2001).

Dominantly grey or light-pink, quartz-two feldspar-hornblende-bearing granite. Fractionated but not mineralised	Dominantly red to dark-pink, quartz-K perthite-biotite-chlorite granite. Quartz forms subhedral grains set in chains or clusters in perthite. Associated with mineralisation.	Late intrusive white, grey or light-pink quartz-two feldspar-biotite granite. Not mineralised.
Nebo Granite Klipkloof Microgranite Veekraal Granite[†] Sekhukhuni Granite[†] Verena Granite Balmoral Granite Baviaansberg Granite[†]	Bobbejaankop Granite Lease Microgranite Kenkelbos Granite[†] Paalkraal Granite[†] Zwartkloof Granite[†]	Makhutso Granite Koornkopje Microgranite[†]
Microporphyritic and granophyric facies of the above		

[†]These varieties of Nebo granite have not been recognised by SACS (1980).

2.4. Mineral Deposits of the Bushveld Complex

Mineralisation associated with the Bushveld granites is distinguished by Sn-mineralisation. There exist other polymetallic occurrences and deposits in the acid rocks of the Bushveld Complex and their associated roof rocks (Figure 2.10). A number of small Fe-rich mineral occurrences were documented by Crocker *et al.* (1988; 2001) and Robb *et al.* (1994) with various metal associations involving Fe-F (-Cu-REE-F-Au-Mo).

The most significant of these deposits is represented by the Vergenoeg Fluorite (Iron) Mine, situated north of Pretoria, due to its size, volume of mineralisation,

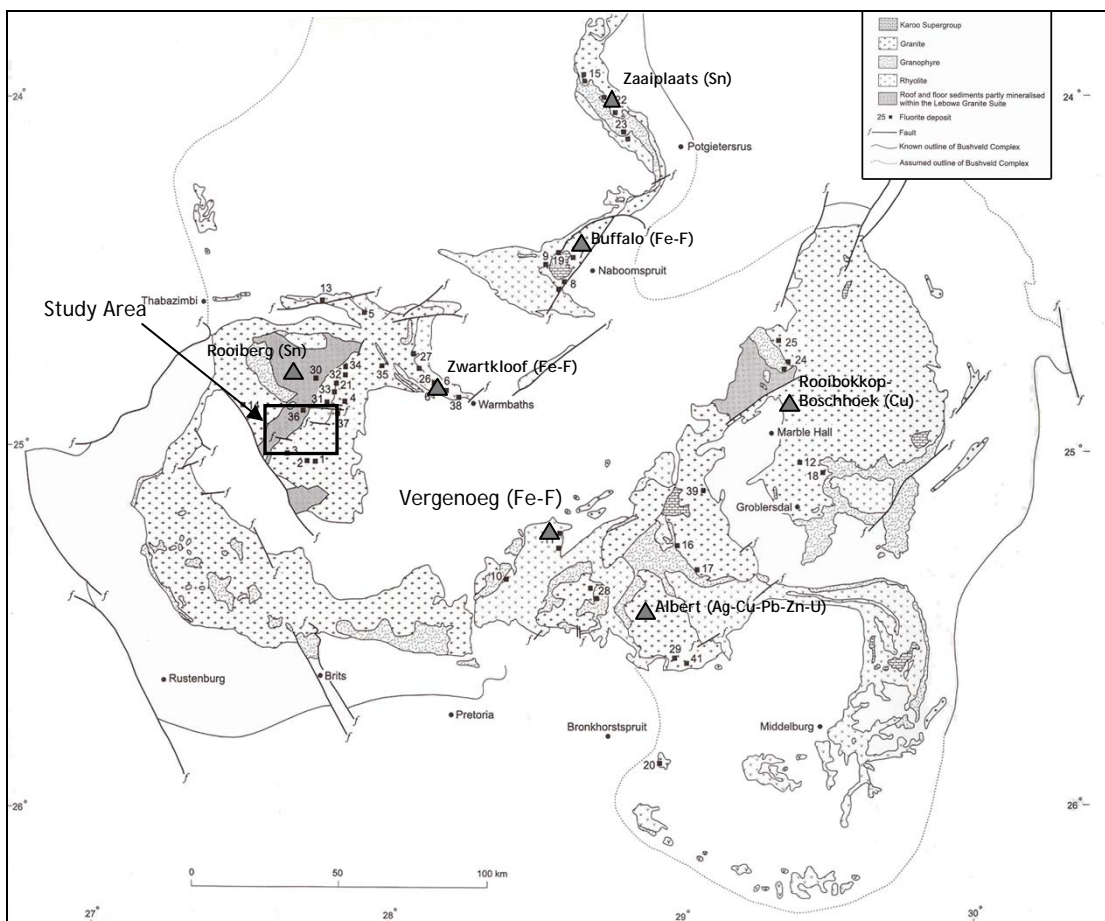


Figure 2.10. Distribution of fluorite occurrence in the Bushveld Complex (numbered squares – refer to source). Vergenoeg Fe-F mine is located in the near geographic centre of the Complex. The detailed study area is indicated by the black frame to the left of the picture (taken from Crocker *et al.* 2001).

setting and mode of emplacement, and its metallogenic and mineralogical composition. This deposit will be discussed in greater detail below.

A description of the *Phalaborwa* (carbonatite-hosted magnetite-Cu-P-REE) deposit is included in this section. The deposit occurs outside the limits of the Bushveld Complex but was formed coeval to the emplacement of the Bushveld granites, and the observed mineral assemblages has led some authors to include the deposit among the IOCG class of deposits (Groves *et al.*, 2001; Vielreicher *et al.*, 2000; Harmer, 2000 b).

Vergenoeg Exogranitic Fe-F Pipe

The Vergenoeg fluorite-bearing massive iron oxide deposit, located roughly 100 km north north-east of Pretoria, is a large, near-vertical, discordant, brecciated pipe-shaped body that cuts through Rooiberg Group rhyolites, and has been shown to be related to intersecting structural and magnetic lineaments trending north-westerly and north-easterly (Fourie, 2000). A surface geological plan of the deposit is given in Figure 2.11. Although hosted in Rooiberg Group lithologies, the deposit is considered to be genetically related to late-stage differentiates of the Lebowa Granite Suite, namely the Bobbejaankop-type granites (Crocker, 1985).

The deposit consists of a volcanogenic suite, termed the Vergenoeg suite, consisting of an uppermost stratiform sedimentary unit, followed by fragmental, conformably-stratified hematite and hematite-fluorite units, followed by a breccia agglomerate and a basal ignimbrite unit. The entire sequence is discordantly cut by the volcanic pipe (Figure 2.12). At surface (0-50 m), the orebody is composed of oxidised gossan of massive to porous hematite-goethite, specularite and fluorite (shown in purple) (Plates 2.1 (a)-(d)). Below this, to a depth in excess of 600 m, the orebody consists of a primary fayalite-fluorite-apatite-ilmenite and magnetite assemblage. This has been further subdivided based on dominant

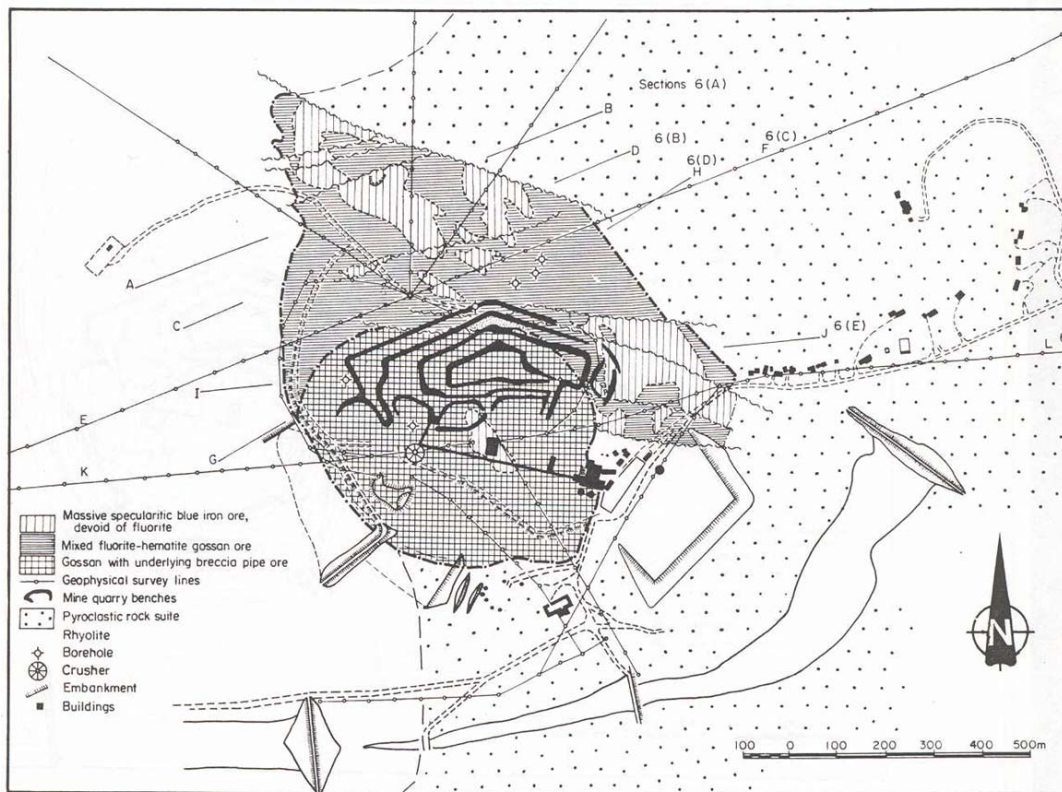


Figure 2.11. Surface geology of the Vergenoeg mine breccia pipe orebody. (taken from Crocker, 1985).

assemblages to reveal a vertical zonation in the orebody magnetite-fluorite assemblages (shown in red) to a depth of ~200 m; magnetite-fayalite assemblages (shown in maroon) to a depth of ~300 m; and fayalite dominated assemblages below this (shown in green). An early overprint assemblage of magnetite-siderite-grunerite-fluorite and sulphides (shown in brown) is widespread throughout the pipe. Late overprint assemblages are developed towards the upper portion of the pipe and may consist of combinations of siderite, hematite, ferropyrrosmalite, stilpnomelane, biotite, sphene, quartz and apatite (Borrok *et al*, 1998)

At 178 Mt of ore grading 28.1 % CaF_2 , the deposit represents the largest single fluorite deposit in the world, with additional mineable reserves of iron ore of 195 Mt @ 42 % Fe (Fourie, 2000). Although mined throughout its history for fluorite, the deposit possesses an, as yet, unestablished polymetallic resource, with sulphide minerals including pyrite, chalcopyrite, arsenopyrite, sphalerite,

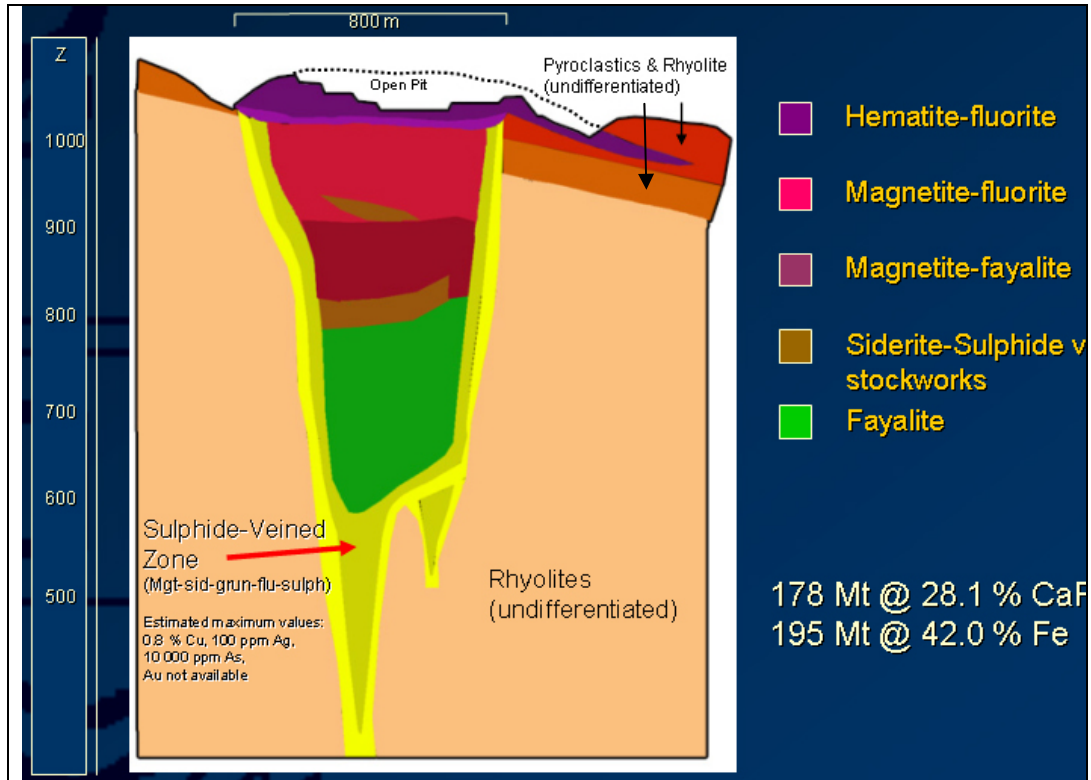


Figure 2.12. Simplified schematic cross-section of the Vergenoeg Fe-F breccia pipe showing clear vertical zonation with respect to mineralisation assemblages. Z = mean height above sea level. (modified after Crocker, 1985; Fourie, 2000).

molybdenite and galena developed at depth and remnant in the gossan ore. The mineral paragenesis of the deposit is given in Figure 2.13.

Borrok *et al.* (1998) recognised distinct sulphide and iron oxide stages. Primary assemblages were only observed in the lower portions of the pipe, which only comprised ~15 % of the total assemblage. This included: fayalite, fluorite and ilmenite (in approximate 3/2/1 proportions) with minor pyrrhotite (< 2 %), apatite (< 5 %) and allanite (< 2 %), and unidentified Nb-Y-REE minerals, U-silicates and Co-Sn oxides. The assemblage dominated by siderite-grunerite-magnetite-fluorite represents an alteration of the primary assemblage, and is not primary itself, as suggested previously by Crocker (1985).

The early secondary (alteration) assemblage identified by Borrok *et al.* (1998) generally occurs at depths in excess of 300 m and includes ferroactinolite

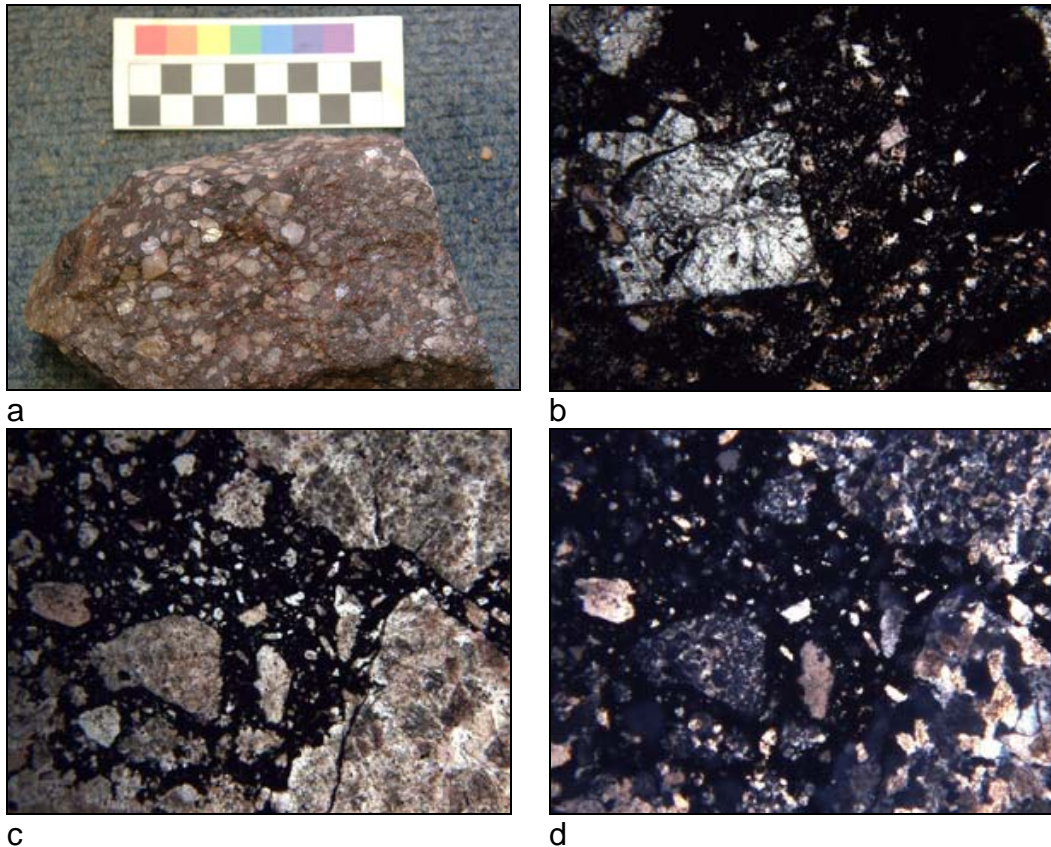


Plate 2.1. Mineralised Fe-F breccia from Vergenoeg mine, South Africa. a) Hematite-fluorite ore sample from Vergenoeg mine. b) Thin section photomicrograph of typical magnetite-hematite-fluorite ore. Plane polars x 4; field of view is 2.75 mm wide; Photo ID: PO1-A. c) Hematite breccia with abundant sedimentary-derived fragments. Plane polars x 4; field of view is 2.75 mm wide; Photo ID: PO2-A. d) Hematite breccia with abundant sedimentary-derived fragments. Crossed polars x 4; field of view is 2.75 mm wide; Photo ID: PO2-B.

(~50 %), grunerite (~20 %), titanian magnetite (~20 %), minor quartz (~10 %) and sulphides. Ferroactinolite and grunerite occur as fine millimetre-long, intergrown needles, forming “haystack-shaped bundles”. The authors interpreted the growth of ferroactinolite to have occurred coeval to alteration of grunerite after primary fayalite.

The late secondary (alteration) assemblage generally occurs at depths less than 300 m and comprises magnetite (~40 %), ferropyrosmalite (~25 %), siderite (~10 %), hematite (~8 %), stilpnomelane (~5 %), apatite (~4 %), quartz (~3 %) and sulphides (~3 %) (Borrok *et al.*, 1998). This assemblage constitutes about 80 %

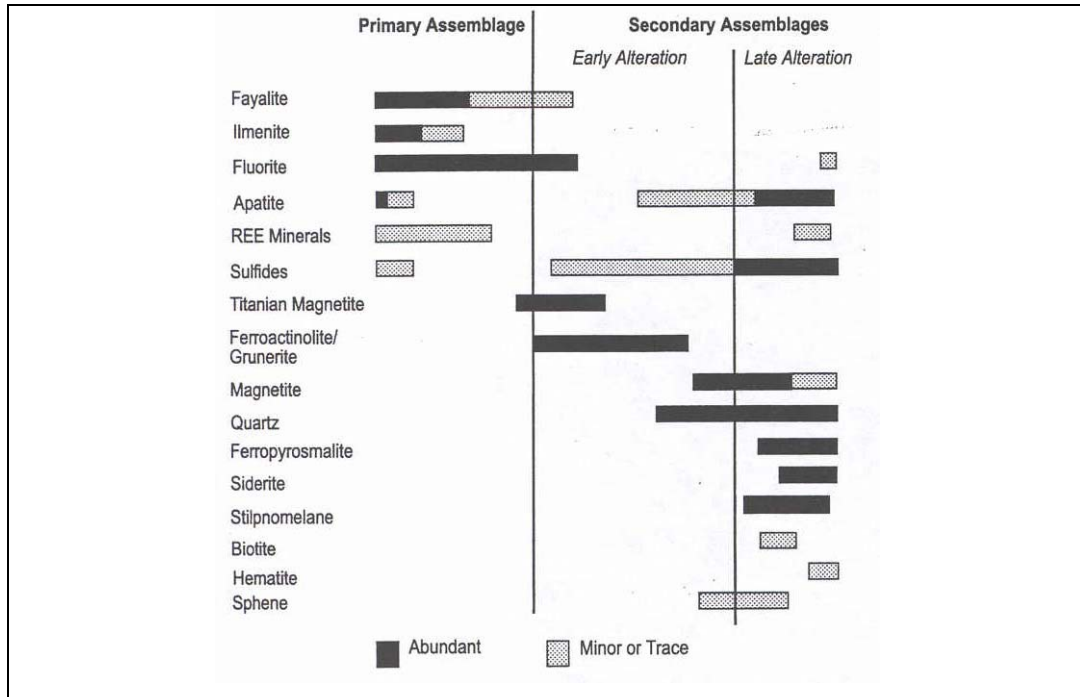


Figure 2.13. Mineral paragenesis of Vergenoeg Fe-F deposit (from Borrok *et al.*, 1998).

of the total volume of the deposit. The magnetite is not spatially related to early generations of magnetite and it is considered to be derived entirely from the alteration of fayalite. This alteration commonly includes quartz. Siderite is commonly found in veins and may have associated with REE minerals.

Crocker (1985) postulated that the pipe formed from a Fe-F-Ca-CO₂-rich immiscible fraction of the Bushveld granites, which erupted due to rapid pressure release caused by structural failure of the roof rocks. These silicate-iron oxide immiscibility effects of felsic magmas have been demonstrated experimentally, but only at temperatures above 1 200 °C, far too high for natural felsic magmas (Freestone & Powell, 1983).

Additional evidence, derived from fluid inclusion work (Borrok *et al.*, 1998), exists for a hydrothermal origin for mineralising solutions in the similarities between Fe-oxide deposits and other established hydrothermal systems. Fluid inclusion waters in fluorites and stable isotope analyses of hematite exhibit both

magmatic and meteoric components. Borrok *et al* (1998) support a magmatic-hydrothermal model for the Vergenoeg deposit, whereby mineralisation formed from hydrothermal fluids of magmatic origin, later modified by an increasingly more dominant meteoric component.

Fluids related to the primary assemblage were high temperature (>500 °C) with a high-salinity (>67 wt% NaCl equiv.) that coexisted with a CO₂-rich vapour phase. The water compositions calculated for these fluids indicated a magmatic source ($\delta^{18}\text{O}_{\text{H}_2\text{O}} = 7\text{-}8 \text{ ‰}$ at 500 °C). Fluids related to the alteration assemblage homogenised at lower temperatures (150-500 °C) with salinities of between 1 - 35 wt% NaCl equiv. The water compositions calculated for these fluids had stable isotope signatures indicating a mixture magmatic and meteoric fluid (Borrok *et al*, 1998).

Vergenoeg is regarded as having formed from an initial immiscible liquid fraction from a magma cell, modified by magmatic-hydrothermal alterations, both of which were related to the emplacement of the Bushveld granites. The abundance of breccias, agglomerates and ignimbrites indicates the presence of explosive fracturing and volcanism (Fourie, 2000).

Phalaborwa Craton-Margin Carbonatite-hosted Mg-Cu-P-REE Deposit

The Phalaborwa Complex is Palaeoproterozoic in age ($2\ 060 \pm 1 \text{ Ma}$; Heaman & Le Cheminant, 1993; Wingate, 1997) and intrusive into Archean basement at the western edge of the Kaapvaal Craton. The Complex consists of a number of intrusions, which are concentrically zoned, decreasing in age from the margin to the core (Vielreicher *et al.*, 2000). The outer portions are generally dominated by clinopyroxenites with younger pegmatoidal pyroxenites towards the core.

The Phalaborwa Complex is intruded at its centre by the Loolekop pipe, which is composed of a transgressive, copper-bearing carbonatite (sövite) core surrounded

by a serpentinised olivine-apatite-magnetite rock, foskorite; all of which is contained in the larger body of pegmatoidal phlogopite-apatite-bearing pyroxenite and syenites (Figure 2.14) (Vielreicher *et al.*, 2000). Numerous syenite and fenite intrusive bodies related to the Complex have been identified in the country rocks up to 10 km away.

The central intrusion of “transgressive carbonatite” is host to the majority of economic iron-oxide copper-gold mineralisation. The Loolekop intrusion is an elliptical, vertical pipe that extends to a depth of at least 1 500 m (from drilling), and is elongated in an E-W direction (1.4 km x 0.8 km). Pyroxenites occupy about 95 % of the surface area (excluding the syenites), 3 % are coarse-grained foskorites, 2 % are carbonatite rocks. Large numbers of younger dolerite dykes

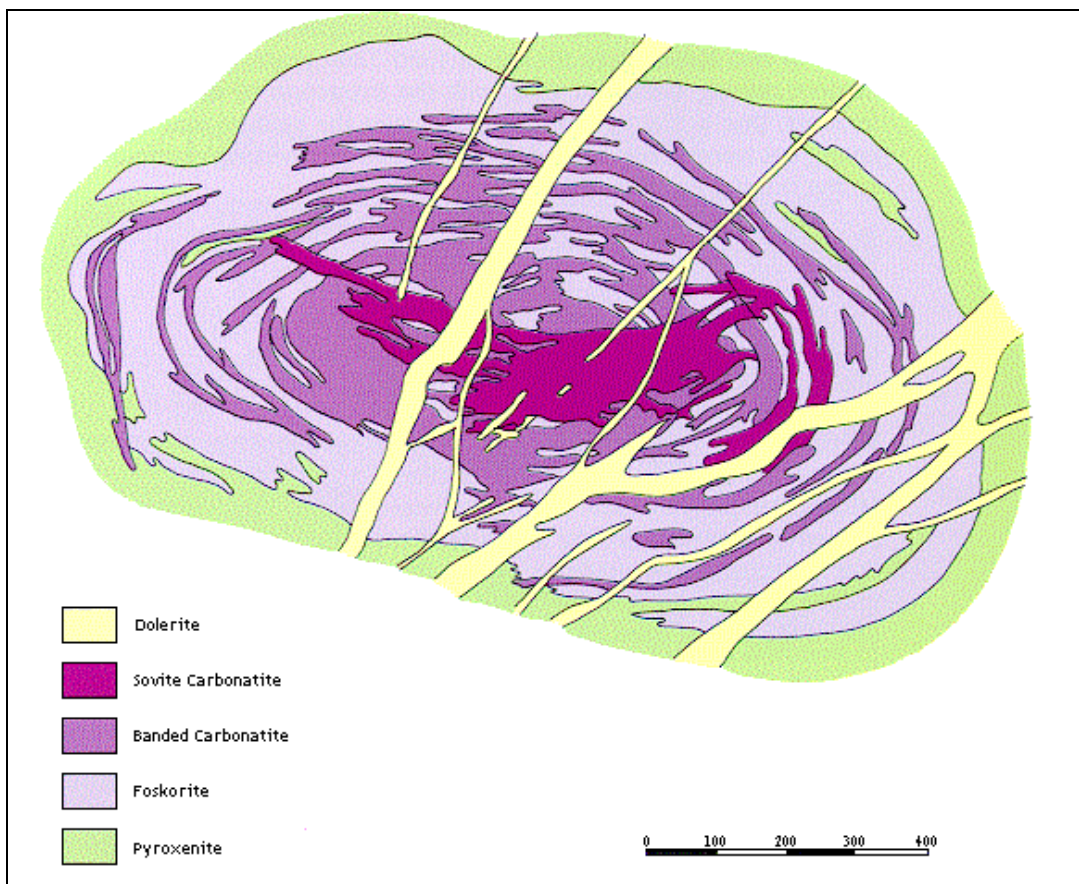


Figure 2.14. Simplified schematic geological plan of the centrally-intruded Loolekop pipe of the Phalaborwa Complex. (from Wilson, 1998).

intrude and cut all of the rocks of the complex, and it is in these that zeolite mineralisation occurs. The total Complex occupies an area of about 20 km² and has been determined to a depth of about 5 000 m (from gravity data).

The orebody contains enormous deposits of copper, magnetite and apatite, as well as the world's largest deposit of vermiculite, which is contained in the ultramafics. The deposit also hosts important concentrations of baddeleyite, uranothorianite, REEs associated with apatites, nickel and precious metals (Ag, Au & PGE occur in a ratio of approximately 50:2:1 respectively).

The low-grade, high-tonnage orebody has been estimated to contain 850 Mt @ 0.5 % Cu (Leroy, 1992) with mineable copper reserves are calculated at 225 Mt @ 0.7 % Cu to a depth of 1200 m. Drill-proven and stockpiled phosphate ore reserves exceed 300 Mt @ 7.45 % P₂O₅ (Wilson, 1998), with the total *in-situ* resources of apatite, to a depth of 600 m, estimated at 13 000 Mt with an average grade of 6.8 % P₂O₅ (de Jager, 1989).

Primary magnetite is paragenetically earlier than copper-sulphide phases, and is found to be inversely distributed with respect to copper. Copper mineralisation occurs as disseminated grains and veinlets of chalcopyrite with lesser bornite and cubanite.

Ore-fluids have been characterised as high temperature, CO₂-rich, magmatic-water dominated brines (Vielreicher *et al.*, 2000). Intense alkali-metasomatism is reported in the country rocks spatially associated to the deposit, although details are not available.

Other Examples from the Bushveld Complex

Bailie & Robb (2004) described the polymetallic mineralisation of the central southeastern portion of the Bushveld Complex and identified four broad types based upon mineral associations (Table 2.4). Type I deposits possess a Sn-F association and occur in the upper portions of the granite such as that of Zaaiplaats Tin Mine and the exogranitic Rooiberg Tin Mine. These deposits are considered to be syngenetic in nature. Type II deposits possess a Mo-F association and are also found in the upper portions of the granite. They further possess a distinctive REE component. Type II deposits are also considered to be syngenetic in nature. Type III deposits are characterised by a sulphide-carbonate association, which may be dominated by either precious or base metal assemblages. Type IV deposits are late-stage overprints of any of the other types and characterised by a fluorite-hematite-pitchblende mineral association. Both Type III and Type IV deposits are considered to be epigenetic in nature.

The broader styles of mineralisation found throughout the Lebowa Granite Suite are briefly reviewed here from selected type deposits, namely *Albert* (Ag, Cu, U, F \pm Pb, Zn, Bi, Sb), *Rooibokkop-Boschoek* (Cu-Au), *Zaaiplaats* (Sn \pm W), and *Rooiberg* (Sn \pm Cu, Pb, Zn, Bi). For complete accounts of these deposits refer to the sources quoted in the text below. These descriptions are included here as an indication of the range of mineralisation that occurs within the acid phase of the Bushveld Complex.

Albert Endogranitic Ag-(Cu-U) Deposit

The Albert Silver Mine is situated 80 km west-northwest of Pretoria. It is hosted within the fine-grained apical phase of the Nebo granites of the eastern Bushveld Complex. The geological setting of the mineralisation is similar to that found at Zaaiplaats Tin Mine and elsewhere in the granites, where mineralising fluids have been confined and concentrated beneath an impervious layer.

Table 2.4. Types of mineralisation in the Bushveld granites (Baillie & Robb, 2004).

Mineralisation Type	Association	Predominant metals	Subordinate metals	Ore mineralogy	Host	Alteration	Morphology of mineralised structures	Occurrences examples
Type I syngenetic	Cassiterite-tourmaline-sulphide	Sn, F	Cu, Pb, Zn, As, W	Cassiterite, arsenopyrite, fluorite, chalcopyrite, molybdenite, tourmaline, galena, dark purple fluorite	Red Bobbejaankop-like Nebo Granite	Chloritic 0-2 m Sericitic 2-5 m Incipient alteration > 5 m	Quartz veins or quartz-hematite veins in granophyre	Enkeldoorn 217 JR, Zustershek 246 JR, Rietfontein 446 JR, Roopoort 440 JR, Vlakklaagte 221 JR
Type II syngenetic	Molybdenite-fluorite-REE-sulphide	Mo, F	Cu, Zn, Pb, As, Th, REE	molybdenite, fluorite, sphalerite, arsenopyrite, chalcopyrite, galena, pyrite, monazite, rutile, bastnaesite	Bobbejaankop Granite, Klipkloof Granite		Pipe-like bodies, breccias, veins	Houtenbek 194 JR, Klipdrift 62 JS
Type III a (base metal) epigenetic	Sulphide-carbonate	Cu, Pb, Zn, Ag, As	Au, Sn	Pyrrhotite, sphalerite, galena, magnetite, argenite, bornite, digenite, chalcocite, goethite, limonite, quartz, hematite at surface	Red Bobbejaankop-like Granite Fine-grained Verena Granite at Albert Silver Mine	Hematitic quartz recrystallisation adjacent to vein; Chloritic 0-2 m Sericitic 2-5 m Incipient alteration > 5 m	Quartz-hematite gossanous ridges oxidised to approx 50m depth on average	Albert Silver Mine, Leeuwfontein 248 JR, Welverdiend 249 JR, Prins Anna 234 JR
Type III b (precious metal) epigenetic	Sulphide-carbonate	As, Au	Pb, Zn, Cu, Ag	arsenopyrite, pyrite, chalcopyrite,	Granophyre	Chloritisation, sericitisation and minor hematitisation of local extent	Quartz veins	Klipdrift 62 JS, Boekenhouhoek 61 JS, Hartebeestspruit 434 JR
Type IV epigenetic	Late-stage fluorite-hematite-pitchblende	Fe, U, F	--	Hematite, pitchblende, purple fluorite, Fe-rich chlorite	Superimposed on other types	Extensive hematitisation characterises this oxidised assemblage	Quartz-hematite veins	Albert Silver Mine, Zustershoek 246 JR

Mineralisation is marked at surface by at least three major ferruginous, quartz vein systems trending roughly east-west, comprising milky quartz, hematite and iron-oxyhydroxide minerals (Robb *et al*, 1994).

A very complex alteration pattern is developed in the wallrock, which intensifies toward the mineralised veins, and is dominated by chloritisation and increasing sericitisation towards the core.

The deposit is generally regarded as subeconomic with estimated ore reserves to a depth of 150 m being 1.2 Mt at 73 g/t Ag, 0.4 % Cu, 0.3 % Pb, 100 ppm U₃O₈, with isolated samples of up to 400 g/t Au and 0.5 % Sb (Robb *et al*, 1994).

Rooibokkop-Boschhoek Endogranitic Fracture-Hosted Cu Deposit

The Rooibokkop-Boschhoek hydrothermal copper prospect is situated about 12 km northeast of the town of Marble Hall. It consists of fracture-hosted, sulphide-bearing siderite veins set within the Nebo granites of the eastern Bushveld Complex. The well-defined zone of fracture varies in width from 400-700 m (Smits, 1986) and parallels the Wonderkop fault, striking roughly 025°. The Wonderkop fault is a regional feature and is also implicated in the mineralised fissures of the Stavoren and Mutue Fides tinfields, which lie stratigraphically higher and roughly 10 km north north-west of the Rooibokkop-Boschhoek prospect (Wagner, 1921).

Subeconomic mineralisation is marked at surface by prominent ferruginous ridges which carry 2.5 % Cu, 0.5 % Zn, 0.7 % Pb, and 20 ppm Ag (Smits, 1986). Sulphide mineralisation is zonally distributed with chalcopyrite (and trace silver) residing in the centre of the elongate, mineralised fracture zone, which is flanked either side by a zone of significant quantities of galena and sphalerite.

Wallrock alteration consists of sericitisation of the host granite, indicating mesothermal conditions for hydrothermal fluids (Smits, 1986). Sericitised plagioclase in hand specimen, acquires a colour suggestive of epidote. This is a useful exploratory indicator in the field. In areas of strong brecciation, the sericite alteration is superimposed by silicification. The influence of late-stage meteoric waters caused hematization of the siderite veins, replacement of chalcopyrite by bornite, chloritisation of perthite and further enhancement of the permeability of the immediate country rock.

The low concentrations and erratic distribution of copper sulphides within the prospect make it economically unviable.

Zaaiplaats Endogranitic Sn Deposit

The Zaaiplaats Sn deposit is located south-west of Potgietersrus, in the northern lobe of the Bushveld Complex. The acid rocks forming the Makapansberg escarpment consist of a westward dipping sheet of granite, granulite and granophyre, capped by rhyolite and covered by younger Waterberg Group clastic sediments (Crocker, 1986).

Mineralisation occurs primarily in Bobbejaankop-variety Nebo granites, ponded beneath impervious granophyre cap rocks. This endogranitic mineralisation resulted initially from late-stage, centripetal fractional crystallisation within the Bobbejaankop granite, producing a low-grade, disseminated cassiterite zone in the order of 2-20 m thick. Structural control only became evident in the closing stages of mineralisation when subsequent stockworks and pipe orebodies developed, allowing fluids to migrate to stratigraphically higher positions.

Lenticular orebodies developed at the contact between the underlying Klipkloof microgranites and the impervious granophyres, producing a high-grade cassiterite zone, characterised by altered dark grey granite rich in chlorite, polymetallic

sulphides, fluorite, scheelite, wolframite, sericite and carbonates. The ore commonly averages 5-10 % Sn, but may contain as much as 60 % Sn in localised, high-grade pockets. The scheelite grade ranges from 0.1-1.0 % WO₃, but more often than not, does not coincide with Sn mineralisation.

Alteration around the orebodies appears to be restricted to hematisation and chloritisation of the surrounding Bobbejaankop granite and intense sericitisation of the Klipkloof granite.

Rooiberg Exogranitic Sn Deposit

The Rooiberg Sn deposit, which consisted of four principal mines, is situated in the western lobe of the Bushveld Complex, approximately 65 km west of the town of Warmbaths. The host rocks to the mineralisation are clastic sediments of the upper Transvaal Supergroup and acid volcanoclastic rocks of the Rooiberg Group. These rocks occur as a roughly triangular shaped fragment, named the Rooiberg fragment, surrounded by the sheet-like granitoid intrusives of the Lebowa Granite Suite and the Rashoop Granophyre Suite. The fragment is thought to have detached during emplacement of the acid phase of the Bushveld Complex (Rozendaal *et al*, 1986)

Just like the low-grade, disseminated cassiterite zone developed by late-stage fractional crystallisation at Zaaiplaats, discussed above, so too is one postulated for the Rooiberg deposits. The development of a system of joints and fissures is subsequently responsible for remobilising the mineralisation and introducing stanniferous fluids into the overlying sediment roof rocks. The morphology of the resultant orebodies may take the form of stratabound bedded lodes, replacement bodies and unconformable, steeply-dipping lodes that strike parallel to major subvertical fractures related to the intrusion of the acid phase of the Bushveld Complex.

The prevailing ore assemblage is cassiterite, pyrite, chlorite, tourmaline, and carbonates associated with varying amounts of magnetite, hematite, chalcopyrite and potassic feldspar (Rozendaal *et al*, 1986). Reported grades in high-grade pockets may contain up to 2.15 % Sn, 400 ppm Cu, and 200 ppm Zn. A complex hydrothermal system with a low temperature of formation (174 - 220 °C) has been attributed with the formation of the tin deposits (Ollila, 1981)

Alteration in the vicinity of the stanniferous mineralisation is mild and pervasive, causing speckling, mottling and weak to intense enrichment of chlorite, tourmaline, sericite, carbonate, sulphides, quartz and hematite (Rozendaal *et al*, 1986). In a more regional sense, the effects of the hydrothermal system have affected the Rooiberg Fragment as a whole over a long period of time, but the effects of this have not been properly investigated.

When the Rooiberg mines were operational, they produced a total of 11.2 Mt ore at 0.62 % Sn, and accounted for one percent of the world's supply of tin.

...

This chapter reviewed the geological setting of the Bushveld Complex and briefly identified some key aspects of similarly styled mineralisation from the granites. Four main mineralisation assemblages were characterised from the central southeastern portion of the Bushveld Complex. The Vergenoeg Suite represents the largest expression of Fe-oxide dominated mineralisation found in the Bushveld and exhibits many of the key characteristics of other IOCG deposits, in particular Olympic Dam. The next chapter will focus on the region near Rooiberg in the western Bushveld Complex and examine the geological characteristics of granites and mineralisation near the farm Ruigtepoort. The mineral deposits and occurrences in this region will be related to that of Vergenoeg and other examples of IOCG mineralisation.