Chapter 2
Geological Setting

2.1 Regional Geology

The Transvaal Supergroup (Fig. 2.1) occurs in three geographically separate outcrop regions, commonly referred to as the Transvaal, Griqualand West and Kanye areas. The Kalahari manganese field is situated in the Griqualand West area. In Griqualand West, the Transvaal Supergroup is subdivided into the Ghaap and Postmasburg Groups (Fig. 2.1). The Ghaap Group can be subdivided, from the bottom upwards, in the Schmidtsdrif, Campbellrand and Asbesheuwels Subgroups. The Postmasburg Group unconformably overlies the Ghaap Group and is separated from the overlying Olifanthoek Group by a marked erosional unconformity at the base of the Neylan Formation (Fig. 2.1). The Postmasburg Group is composed, from the base upwards, of Makganyene diamictite and the Ongeluk lava. The Ongeluk Formation, in turn, is conformably overlain by the manganese bearing Hotazel Formation and dolomites and limestones of the Mooidraai Formation. Together, the latter three are grouped as the Voëlwater Subgroup (Beukes, 1983) (Fig. 2.2). The Hotazel Formation, which is the host rock to the manganese ores of the KMF, is composed of three symmetrical iron-formation→hematite lutite→braunite lutite sedimentary cycles that can be traced across the entire KMF and that display a remarkably uniform fine-scale lithostratigraphy (Nel et al., 1986) (Fig. 2.2). Mapedi shales and Lucknow quartzites rest with a marked erosional unconformity on the Voëlwater Subgroup.

The manganese ores of the Hotazel Formation occupy the centers of the three chemo-sedimentary cycles. Throughout most of the Kalahari deposit the lowermost of the three manganiferous beds is the thickest and it is the only one that is of any current economic importance. The Lower manganese ore bed is currently mined by Samancor at Mamatwan and Wessels Mines. It is approximately 45m thick in the southeastern corner

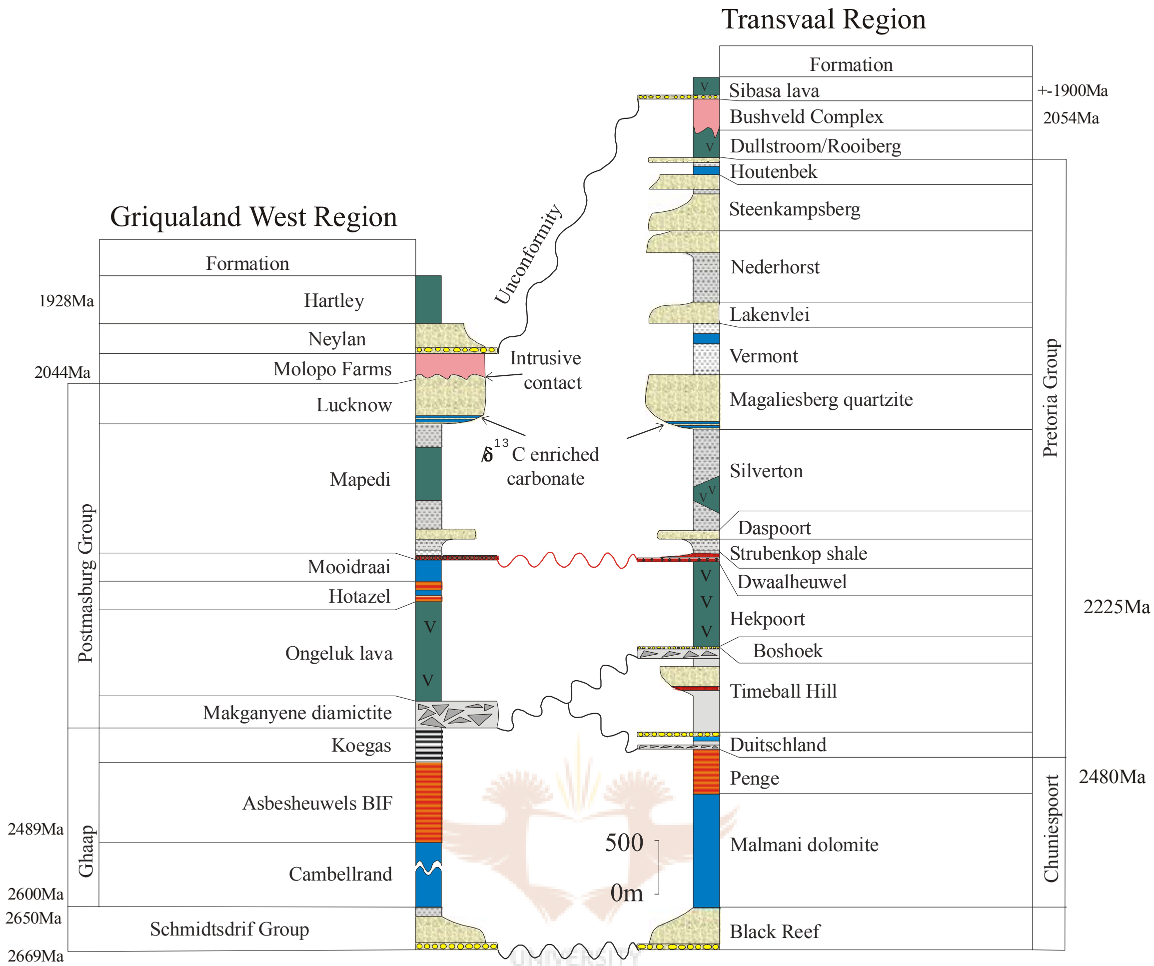

Figure 2.1 Stratigraphic correlation of the strata of the Transvaal Supergroup and overlying beds between the Transvaal and Griqualand West regions. The Hotazel Formation, together with the overlying Mooidraai Formation and the underlying Ongeluk Formation forms the Voëlwater Subgroup of the Postmasburg Group of the Transvaal Supergroup. The Hotazel Formation is only present/preserved in the Griqualand West region. (Modified after Beukes et al., 2002).

of the Kalahari deposit, at Mamatwan Mine, but decreases to 4-8m in thickness in the Wessels and Nchwaning mining areas, in the northern part of the Kalahari deposit. The Lower manganese bed was subdivided into different lithostratigraphic zones by Nel (1986) (Fig. 2.2). Further work done by Preston (2001) subdivided the orebody into even further subzones (Fig 2.3). The predominant ore type present in the Kalahari deposit is low-grade and carbonate rich Mamatwan-type ore of diagenetic to low grade metamorphic origin. It is composed by a dark brown kutnahorite-, braunite- and hematite-rich laminated micritic matrix with white and pink microsparitic carbonate ovoids and laminae (Kleyenstüber, 1984). Wessels-type ore constitutes the second

economically important Mn ore type in the Kalahari deposit. It is restricted to the northernmost part of the Kalahari deposit and originated as product of fault-controlled hydrothermal alteration of Mamatwan-type ore (Gutzmer and Beukes, 1995; Beukes et al., 1995). Its appearance is strikingly different to Mamatwan-type ore in that it is coarse grained with sub-metallic shine and massive texture. Mn-oxide minerals predominate the Wessels-type ore and Mn-carbonates are conspicuously absent.

The iron-formations and interbedded manganese ore beds of the Hotazel Formation are virtually undisturbed in the southern part of the Kalahari deposit. They are only very gently folded and dip with 5-15º to the southwest throughout the Kalahari deposit (Beukes, 1983) (Fig. 2.4). The KMF has had a quite complex geological history with various fault, fold, hydrothermal and erosional events that affected the composition of the primary sedimentary manganese ore. One of the last events that affected the composition of the ore is the supergene alteration that developed prior to and during the deposition of the Kalahari Formation. This alteration is the focus of this study. However, prior to the deposition of the Kalahari Formation the following depositional, tectonic and hydrothermal events took place in the Kalahari manganese field:

a) Deposition of the Hotazel Formation with three interbedded manganese beds at around 2.2 Ga (Fig 2.4).

b) Soon after lithification the Hotazel Formation was intruded by NE-SW- and NNE-SSW-striking bostonite dykes (Fig. 2.5) that caused minor contact metamorphism. The intrusive event preceded erosion, laterite weathering and the deposition of the Mapedi red beds and N-S directed growth faulting intimately associated with the deposition of the Mapedi red beds (Beukes and Smit, 1987) at 2.05 – 2.2Ga.

c) N-S and E-W trending folding and erosion of the Hotazel Formation took place prior to deposition of the Paleoproterozoic Mapedi Formation at 2.06 – 2.2 Ga) (Beukes et al., 2002) (Fig. 2.4).

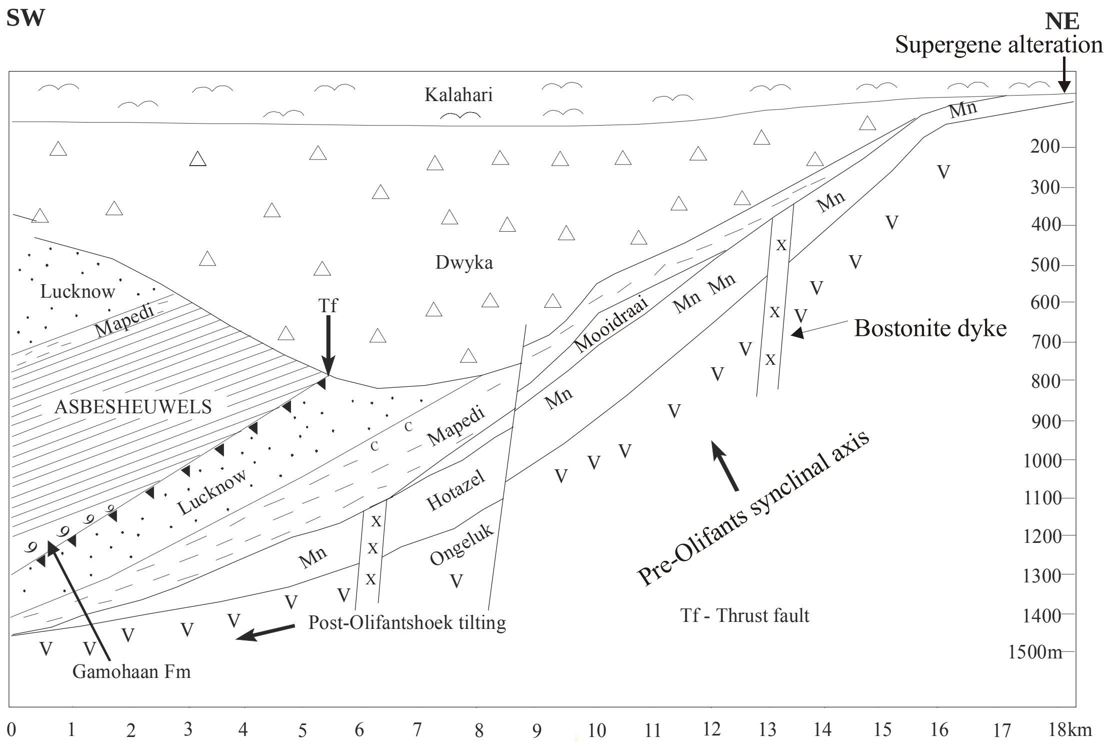

Figure 2.4 NE-SW section through the southern part of the KMF, illustrating the southwestern dip of the strata and the suboutcrop of the Lower manganese body against the Kalahari Formation. Bostonite dykes and post Mapedi normal faults were sketched in for explanatory purposes (modified after Beukes and Smit, 1987).

d) N-S normal faulting related to rifting during Hartley times at 1.92 Ga (pers. comm., Prof. N.J. Beukes, 2002).

e) Thrusting of strata in an easterly direction (fig. 2.4). This led to duplication of the strata in the northernmost part of the Kalahari deposit in the area to the west of Black Rock (Fig. 2.4) (Boardman, 1941; Beukes and Smit, 1987). Beukes and Smit (1987) attribute thrusting to the 1.8-1.9 Ga Kheis-orogeny, but more recent investigations (Van Niekerk, op. cit.) suggest that thrusting may rather be explained as a distal expression of the Namaqua Orogeny at ca. 1.1 – 1.0 Ga.

f) Hydrothermal alteration of ores along pre-existing normal faults and along thrust planes. This alteration led to development of high-grade Wessels-type ore (Gutzmer and Beukes, 1996). Two hydrothermal alteration events have been observed in the presence of two generations of normal faults that acted as hydrothermal fluid pathways. During the first event, Mamatwan-type ore was altered to oxide-rich high-grade Wessels-type ore in the northwestern part of the Kalahari deposit.

g) Glaciation of strata in late Carboniferous to early Permian times followed by deposition of the Dwyka Supergroup (Fig. 2.4). Subsequent to the Namaqua Orogeny, the Kalahari Manganese Field was shaped by glacial erosion, preceding the deposition of the Dwyka Formation of the Karoo Supergroup (Fig. 2.4). A deep Pre-Karoo glacial valley is present in the manganese field (Fig. 2.4).

h) A second generation of NE-SW-striking faults is present in the Kalahari manganese field (Fig. 2.5) but the timing of their formation is uncertain (Gutzmer and Beukes, 1996). A second, younger event of hydrothermal alteration is observed throughout the Kalahari deposit along these faults and joints and led to localized bleaching and ferruginization along NS trending faults as well as minor joints and normal faults that display a NW to SE or W-E strike direction (Gutzmer and Beukes, 1996). This is referred to as the Gloria event of alteration and it is speculated to have taken place in Karoo times during the deposition of Jurassic Karoo basalts (Gutzmer and Beukes, 1996). A second generation of NE-SW mafic dykes (Fig. 2.5) possibly of Jurassic Karoo age, are also present.

i) Finally, the manganese ores were affected by supergene alteration along the unconformity below the Kalahari Formation. Low-temperature fluids that were introduced along joints and faults, overprinted the effects of the previous alteration events. The last alteration event was tentatively constrained by Gutzmer and Beukes (1998), to approximately 35-40 Ma, based on $^{40}Ar/^{39}Ar$ geochronology of asbestiform manjiroite-todorokite from Smartt Mine. Gutzmer and Beukes (2000), tentatively related this so-called Smartt event to low-temperature ground water flow. The latter fluid flow event was tentatively correlated by Gutzmer and Beukes (2000) with the final episode of uplift and tilting experienced by the Kaapvaal Craton prior to the deposition of the sediments of the Kalahari Formation.

j) Deposition of calcretes, sand and clays of the Kalahari Formation (Fig. 2.6) with ongoing supergene alteration.

2.2 Local Geology

The field area selected for this study is located along the eastern suboutcrop limit of the Hotazel Formation, on the farm Rissik, immediately to the north of Mamatwan Mine (Fig. 2.5). The present study focused on the suboutcrop of the Lower manganese bed against the Kalahari unconformity and the effects of supergene alteration, associated with this erosional unconformity on the ore bed (Fig's 2.4, 2.5 and 2.6). Exploration holes were logged in the Rissik area to improve the understanding of the local geology. In addition aeromagnetic interpretations were done to supplement the geological interpretations. The latter was especially important for recognizing faults and dykes.

In the study area the Hotazel Formation is dipping gently at 5-15º to the southwest. The beds are overlain by the Cenozoic Kalahari Formation with marked angular unconformity (Fig. 2.6). The Kalahari Formation varies between 8m and 53m in thickness and is composed of gravels, clays, calcretes, calcareous sand and red wind blown sand (Fig. 2.6). The suboutcrop width of the Lower manganese ore bed is in the order of 100m. The thickness of the visibly supergene altered zone, immediately below the Kalahari unconformity, varies between 5 and 25 meters. The supergene ore is distinctly enriched in manganese (>42wt% Mn). The supergene altered ore has been mined during the 1950's and 1960's in several small open pit operations such as Smartt, Devon and Adams (Boardman, 1964; Cairncross et al., 1997).

Structures in the study area (Fig. 2.5) were deduced by means of drill core logging, aeromagnetic maps and three-dimensional modeling. North-easterly orientated faults and dolerite dykes displace the ore bed in the study area (Fig's. 2.5, 2.7 and 2.8). These faults and dykes, combined with the effect of downward migrating meteoric water, contributed to supergene alteration processes of the manganese ore in the study area. A 3-D structure contour map reveals that the Hotazel Formation is affected by mild warping, with

approximately E-W striking warp axes (Fig. 2.9). An overall SW-directed dip of the strata is evident, resulting in a distinct depression in the southwestern corner of the study area (Rex 44) (Fig. 2.9). The normal fault structures are well illustrated in a north-south cross section (Fig. 2.7). Normal faults are present between Rex 69 and 66; Rex 80 and 73; Rex 74 and 73 and just north of Rex 24 (Fig's. 2.5 and 2.7). Fig. 2.6 reveals the presence of two more normal faults (between Rex 70 and Rex 90; Rex 74 and Rex 94). Fig. 2.9 illustrates that the two normal faults between Rex 74 and 80 define a small graben structure.

Mafic dykes have intruded some of the normal faults. Four mafic dykes of presumably Jurassic (Karoo) age occur in the study area: one between Rex 2 and 19 in the north of the study area as well as three thin dykes between Rex 66 and 57 (Fig. 2.5). The northeastern-most area of Fig. 2.9 illustrates an elevation, which may be related to the position of a dyke. Further dykes of similar strike direction occur immediately to the north of the study area. A mafic sill of unknown age intrudes into the lower Mn ore bed south of the farm Rissik. Thrust fault planes could have acted as feeder channels for the mafic sill. This sill cuts across the Lower manganese bed on Rissik and Smartt and appears to pinch out close to the Botha-Smartt farm boundary (S.J. van der Merwe, op. cit.).

Despite the supergene alteration of the manganese ore in the study area, different lithostratigraphic zones (Fig. 2.3) as defined by Nel (1986) and Preston (2001) at Mamatwan Mine, can still be recognized. Note also the displacement of the lithostratigraphic zones as a result of normal faulting and distinct thinning towards the north in Fig. 2.7. Fig's. 2.7 and 2.8 illustrate the combined effect of the structural deformation and Kalahari Unconformity in the study area on the lithostratigraphic zones from N to S and W to E. The Lower manganese ore bed thins towards the north (Fig. 2.10) and thickens to the east (Fig. 2.11).

For the purpose of this investigation, only samples from the M, C and N-zones (Fig. 2.12) that represent the economic zones of the Lower manganese bed, were examined in detail. The M-zone (Fig. 2.12A) has a unique mottled mesoscopic appearance with medium size (1-3mm) carbonate ovoids and only few thin carbonate lenses and laminae (1mm). The unaltered C-zone (Fig. 2.12D) has very characteristic cloudy accretions of small Mn-calcite pseudospar ovoids and few thin calcite and Mn-calcite laminae that result in a distinctly banded appearance. The unaltered N-zone (Fig. 2.12G) is characterized by a distinct decrease in ovoid size (> 1mm) and an abundance of unusually thick carbonate laminae (1-3mm).

Immediately below the erosional contact to the Kalahari Formation all lithologies of the Hotazel Formation appear distinctly altered. Along the pre-Kalahari unconformity, oxdised BIF has a friable and very goethitic appearance and hematite lutite appear friable, very porous with a red to ochre colour and abundant Mn-oxyhydroxide dendrites. Typical examples of incipiently altered braunite lutite from the M (Fig. 2.12B), C (Fig. 2.12E) and N (Fig. 2.12H)-zones are illustrated in fig. 2.12. Most importantly carbonate appears to become replaced by Mn^{4+}-oxyhydroxide minerals during the supergene alteration process. Fig's. 2.12 C, F and I illustrate the appearance of strongly supergene altered manganese ore that typically has a submetallic to dull black colour and microcrystalline, dense to earthy consistency. In these altered ores former carbonate ovoids and laminae can still be recognized but they are replaced by porous Mn^{4+}-oxyhydroxides. Distinct fracturing (Fig. 2.13) marks the manganese ore present on the contact with the Kalahari Formation. Fractures are filled by secondary calcite and/or carbonate. Ore reserves of the supergene ores in the study area are estimated at about 36.9 million metric tons. This represents 0.3% of the total ore resource present in the KMF. There appears to be a definite correlation between the degree of supergene alteration and position of faults and dykes in the area. Supergene alteration is most intense and best developed next to faults and dykes.

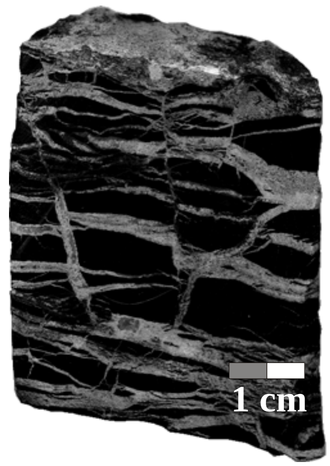

Figure 2.13. Strongly supergene altered M-zone dissected by stockwork of veinlets filled by calcite. This is characteristic of the immediate contact between Mn ore of the Hotazel Formation and the Kalahari Formation.