Chapter 1
Introduction

1.1 General

The giant Kalahari manganese field (KMF) is located 60km northwest of Kuruman in the Northern Cape Province of South Africa (Cairncross et al., 1997) (Fig. 1.1). It is the largest known land-based manganese deposit in the world (Taljaardt, 1982). The KMF is comprised of five erosional relicts of the manganese bearing Hotazel Formation of the Paleoproterozoic Transvaal Supergroup. The Kalahari deposit is the largest of the five deposits (Fig. 1.1) and has a NS dimension of 41km and an EW dimension of 5-20km (Samancor, 1994). To the east of the Kalahari deposit are the previously mined hydrothermally enriched Hotazel and Langdon-Annex deposits (Fig 1.1) (De Villiers, 1970). The Leinster and Avontuur deposits to the north of the Kalahari deposit are jacobsitic in composition and the manganese grade is too low to be of economic value at present (Gutzmer, 1996). The manganese ore is of sedimentary origin. Three beds of manganese ore are interbedded with iron-formation of the Hotazel Formation. The lowermost of the three beds is thickest and currently the only bed mined in the Kalahari manganese field.

South Africa, with more than 80% of the World's manganese ore reserves, produces about 20 percent of the worlds manganese ore per year, with a production of 3.635 million tons in 2000 (Fig. 1.2 and Table 1.1). The two major producers of manganese in South Africa are Samancor Manganese and Assmang (Associated Manganese Mines of South Africa). This study was conducted on property of Samancor Manganese. There are two current mining operations managed by Samancor Manganese in the KMF. The open pit operation at Mamatwan in the southernmost part of the KMF produces 150 000 tons of low-grade (38 wt%) manganese ore a month (1.8 Mt annually), while the underground operations at Wessels Mine in the northwestern corner of the KMF produces 110 000 tons of high-grade (+42 wt%) manganese ore per month (1.32 Mt annually).

Table1.1 World manganese ore reserves, production and exports in 2000 (after Mottie, 2001).

Country	Reserve base			Production			Exports		
	Mt	%	Rank	kt	%	Rank	kt	%	Rank
South Africa	4000	80	1	3635	19.5	1	1845	25.4	2
China*	100	2	4	3143	16.9	2	=	=	-
CIS*	560	11.2	2	2571	13.8	3	=	=	-
Gabon	150	3	3	2410	12.9	4	2102	28.9	1
Australia	75	1.5	5	2108	11.3	5	1360	18.7	3
Brazil	56	1.1	6	1590	8.5	6	698	9.6	4
India	36	0.7	7	1398	7.5	7	385	5.3	6
Mexico	9	0.2	8	574	3.1	8	=	=	-
Ghana	=	=	-	560	3	9	475	6.5	5
Iran	=	=	-	210	1.1	10	=	=	-
Other	14	0.3		443	2.4		410	5.6	
Total	5000	100		18642	100		7275	100	

Notes: = Include under 'Other', * = Low grade ores

1.2 Market for Manganese

Manganese has several uses. Steel output is crucial for manganese demand, consuming 95% of the world's manganese production. The continuous casting of steels, replacing traditional ingot casting, has reduced the need for, and consumption of manganese in the world in the early 1990's (Fig. 1.3). However, in the last few years the demand for manganese has grown (Fig. 1.3) as a result of the growth of several other industries dependent on manganese beneficiation. In the non-ferrous metallurgical industries, manganese is used as an alloying element with aluminium, where it acts as a strengthening agent in hot-working, and with copper to produce a wide range of manganese bronzes (Mottie, 2001). Another important use for high grade manganese is the production of electrolytic manganese dioxide (EMD); a major component of alkaline batteries. The price of manganese (per unit Mn) has steadily increased through the years in real terms but also due to the devaluation of the Rand against the US dollar (Roux, 2001).

Better market prices and lower production costs motivate the exploration for high-grade manganese ore that needs little beneficiation before being introduced to the competitive world manganese market. This is one of the main reasons why Samancor Manganese commenced an exploration project on high-grade supergene enriched ore along the suboutcrop of manganese beds below the unconformity at the base of the Cenozoic Kalahari Formation to the north of Mamatwan Mine (Fig. 1.1) on the farms

Rissik and Smartt. This study aims at providing detailed mineralogical and geochemical data on the supergene enriched manganese ore in this area. Samancor Manganese made drill core available from the prospect for this study.

1.3 Problem statement

Most of the manganese ore present in the Kalahari manganese field, which comprises 80% of the world reserves (Table 1.1) is of rather low grade (35-38 wt% Mn). The market for this low grade ores is limited and forces Samancor to upgrade the ore by heavy media separation and sintering at Mamatwan. The latter processes are very costly. Of the total reserve of about 4.5 billion tons of manganese ore in the Kalahari manganese field, only about 350 Mt has been altered to high-grade ore containing more than 42wt% Mn. This focused Samancor on the search for primary (in situ) high-grade ores. Earlier studies (Kleyenstüber (1993), Nel et al. (1986), Gutzmer & Beukes (1996) and Preston (2001)) have indicated the presence of supergene enriched manganese ores along the suboutcrop of the Mn ore beds against the Cenozoic Kalahari Formation. In this supergene enrichment zone carbonates are leached and Mn^{2+}/Mn^{3+}-bearing minerals are altered to supergene Mn^{4+} -bearing mineral phases. By this process, ore is upgraded from 38% wt% Mn to ore with more than 40 wt% Mn. Samancor started an exploration project for such ores in the Smartt-Rissik area immediately north of Mamatwan mine (Fig. 1.1). Drill core from this project was made available for this study to evaluate the mineralogical and geochemical changes brought about by supergene alteration processes. The study was required because previously no detailed work had been undertaken on the nature and composition of the pre-Kalahari supergene altered ores in the Kalahari manganese field.

Based on the above the objectives of this study can be defined as follows:

- To provide an accurate 3-dimensional model for the distribution, thickness and grade of the economic zone (altered and unaltered) of the Lower manganese ore bed in the southeastern part of the KMF, south of the border between the farm Rissik and Smartt (Fig. 1.1).

- To document mineralogical and geochemical changes attributable to supergene alteration of Mamatwan-type braunite lutite along the Kalahari unconformity in the Rissik portion of the Smartt-Rissik exploration area.

- To determine the timing and duration of supergene alteration.

1.4 Previous work

Much work has been done on the composition of the primary Mamatwan-type ore (Kleyenstüber, 1985 and Nel et al., 1986) and hydrothermally altered Wessels-type ore (Gutzmer, 1996). However, very little information is available for supergene altered ores. Supergene alteration is an ongoing process that affects the manganese ores of the Hotazel Formation where they are exposed to the interaction with meteoric water at or near the surface. The nature of the supergene ore was only briefly touched by previous studies (De Villiers (1970); Kleyenstüber (1993); Nel et al. (1986). Kleyenstüber (1993) described the influence of three erosional unconformities on the sedimentary rocks of the Hotazel Formation. He illustrated that the Kalahari unconformity is the only of the three unconformities that had a noticeable effect on the manganese ore. These effects were briefly described. The influence of descending meteoric water on manganese ore along the eastern suboutcrop perimeter of the Kalahari deposit was also stressed by Gutzmer and Beukes, 1996, and Nel et al. (1986) reported that a supergene crust of cryptomelane is often developed below the pre-Kalahari Unconformity (Nel et al., 1986).

1.5 Analytical methods

Twenty-two boreholes intersecting the Lower manganese bed of the Hotazel Formation were selected to cover the entire Rissik area, and to allow the construction of a descriptive geochemical and mineralogical model of the supergene alteration below the Kalahari unconformity in the area. Of the 22 boreholes 8 were selected to be representative of all the ore types present in the study area and for detailed chemical and mineralogical analytical studies. These cores were Rex 44, 16 and 85 for the unaltered ore; Rex 70, 71 and 74 for weakly supergene altered ore, and Rex 2 and 24 for strongly supergene altered ore (Fig. 1.4).

The eight representative drill cores were halved using a diamond saw, leaving half of the core at the Hotazel core shed. The cores were quartered with a diamond saw at Rand Afrikaans University (RAU) and one quarter was used for mineralogical and geochemical analyses, while polished thin sections were prepared for petrograpical studies from the remaining quarter. Small blocks of the second quarter were selected for density measurements.

Samples for polished thin sections were carefully selected from the eight representative boreholes to be representative of all the lithostratigraphic zones and ore types. The thin sections were studied for mineralogy using reflected light microscopy on a Leica DMLP research microscope at the Department of Geology at RAU. The mineralogy was also studied using a JEOL JSM 5600 Scanning Electron Microscope in the Central Analytical Facility at RAU (Chapter 3).

For the purpose of XRD and geochemical analyses, representative samples of each lithostratigraphic zone were crushed to <1.5cm chips using a jaw crusher. These chips were then milled in a SiebTechnik disc swing mill using a Cr-steel body and rings. The large amount of milled material produced for each lithostratigraphic zone was homogenized by quartering, before being sumitted for X-ray powder diffraction and whole rock geochemical analyses. Geochemical analyses were undertaken by MINTEK laboratories in Randburg for whole rock geochemical analyses using suitable techniques (ICP-MS, ICP-OES, AAS). X-ray powder diffractometry was undertaken at the Central Analytical Facility at RAU with a PHILIPS PW 1710 diffractometer.

The XRD measurements for the unaltered samples were carried out with the following diffractometer settings: Tube anode material: Co-Kα radiation (wavelength Kα-1.789Å); Generator current: 30mA; Voltage: 40kV; Angle range: 3-80° 2Θ; Step size: 0.02 deg/step; Scan rate: 1.00 sec per step; Scan type: step. XRD measurements for the altered samples were carried out with the following diffractometer settings: Tube anode material [Co-Kα radiation]; generator current (30mA); voltage (40kV); angle range (3-80° 2Θ); step size (0.04 deg/step); scan rate (20.00 sec per step); scan type (step). The scan interval was made bigger for the altered ore to increase the time of data collection per step in order to improve peak-to-background ratios.

Microprobe analyses, using the CAMECA 355 microprobe, were performed on representative samples. Some of the samples were submitted for $^{40}Ar/^{39}Ar$ geochronology, details of which are provided in Chapter 5.

Whole rock density measurement were conducted of unaltered, weakly supergene altered and strongly supergene altered ore on sample blocks in the Department of Geology at RAU, using a Sartorius laboratory scale. Details of the method are presented in Chapter 4.

A database containing all the required information was generated in Sable Data Works and different logs were created to integrate field geological observations with mineralogical and geochemical data. Sable View(1) was used to create three types of logs namely a geological log, a geochemical log and an alteration log (see Appendices 3 and 4). Contour maps of ore grade were generated using Surfer 7(2).

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2© Surfer 7, Golden Software, Inc., 1999