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Investor's and Procurement Guide South Africa

Part 3: Manganese, Vanadium, Zinc

Deutsche Rohstoffagentur
Bundesanstalt für Geowissenschaften und Rohstoffe

Council for Geoscience
Leading Earth-Science Solutions

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Editors: Dr. Peter Buchholz,
Head of the German Mineral Resources Agency (DERA) within the
Federal Institute for Geosciences and Natural Resources (BGR)
Wilhelmstraße 25–30
13593 Berlin
Tel.: +49 30 36993 226
Fax: +49 30 36993 100
dera@bgr.de
www.deutsche-rohstoffagentur.de

Dr. Stewart Foya,
Head of the Department of Mineral Resources Development at the
Council for Geoscience (CGS)
280 Pretoria Street, Silverton
Pretoria, South Africa
Tel.: +27 12 841 1101
Fax: +27 86 679 8334
sfoya@geoscience.org.za

Authors: Herwig Marbler (DERA), Inga Osbahr (DERA),
Rehan Opperman (CGS), Katrin Kärner (DERA),
Abdul O. Kenan (CGS)

Project coordination: Dr. Herwig Marbler (DERA)
Rehan Opperman (CGS)

Contact BGR: Dr. Herwig Marbler: herwig.marbler@bgr.de

Contact CGS: Rehan Opperman: opperman@geoscience.org.za

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Part 3: Manganese, Vanadium, Zinc

Published jointly by the German Mineral Resources Agency (DERA) in the BGR and
the Council for Geoscience, South Africa (CGS)

Foreword

This is the third and final part of the "Investor's and Procurement Guide South Africa" – a handbook that is anticipated to aid potential investors into considering South Africa as an investment destination for raw materials as well as for related industries. This publication is considering and aggregating the many publications available on the economic geology and mineral wealth in South Africa as well as varied contacts to different mining companies in order to guide prospective and current investors, suppliers and mine equipment exporters through the process of doing business in South Africa.

The focus of this final part is on detailing the mineral raw materials manganese, vanadium and zinc while a short update is given on South Africa's infrastructure and the main economic, political and judicial changes within the South African mining industry since the publication of the second part in 2015. More detailed information and an overview of the economic geology is presented in part one of the investor's guide.

Beside the world's largest resources of PGMs, gold and chromite, South Africa has the world's largest manganese and vanadium resources and is a significant supplier of iron, coal and of numerous other minerals and metals. The South African minerals industry will continue to play a pivotal role in the growth of the economy in the foreseeable future.

South Africa is still one of the top destinations in Africa for foreign direct investments. South African head-quartered companies have been major investors into foreign direct investments on the African continent in the past decade. Investing into the South African mining sector would allow investors to gain foothold into the large emerging markets of Africa.

This handbook is a result of a cooperation project between the Council for Geoscience (CGS) of South Africa and the German Mineral Resources Agency (DERA) at the Federal Institute for Geoscience and Natural Resources (BGR) that started at the end of 2011 and is conducted by experts from DERA and the CGS. Studies on the different natural resources are compiled in this manual on evaluating new occurrences and deposits regarding investment and supply options for German investors and purchasers in South Africa.

Dr. Stewart Foya

Head of the Department of Mineral Resources
Development of the Council for Geoscience, South Africa

Dr. Peter Buchholz

Head of the German Mineral
Resources Agency (DERA), Germany

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1 Introduction

(A. O. Kenan, R. Opperman)

1.1 Economic, judicial and political framework of the South African mining industry

The present chapter specifies the latest changes in the economic, judicial and political framework of the South African mining industry since the publication of the second part of the Investor's and Procurement Guide South Africa in 2015. For general and detailed information about the economic, judicial and political framework please refer to the first part of the Guide (Buchholz & Foya 2014).

1.1.1 Implications of the new financial provisioning regulations on prospecting and mining projects in South Africa

Under the Government's One Environmental System, the requirements for financial provision for the environmental impacts of mining and prospecting operations are now regulated under the ambit of National Environmental Management Act 107 of 1998 (NEMA) and no longer Mineral and Petroleum Resources Development Act 28 of 2002 (MPRDA). On the 20th of November 2015, the Minister of Environmental Affairs published Regulations relating to the financial provision for prospecting, mining, exploration and production operations (the Financial Provisioning Regulations, 2015). These Regulations are applicable to applicants and holders of a Prospecting Right, Mining Right or Mining Permit.

The Financial Provisioning Regulation, 2015 are more onerous than the requirements previously under the MPRDA but if implemented correctly may save future costs. Failure to comply with these Regulations may result in a fine of up to R10 million and/or imprisonment. The most pertinent requirements are summarised below.

1.1.2 Determination, assessment and review of financial provision

The financial provision must be determined by specialist/s through detailed itemisation of all activities and costs associated with:

1. annual rehabilitation, as reflected in an annual rehabilitation plan;

2. final rehabilitation, decommissioning and closure, as reflected in a final rehabilitation, decommissioning and mine closure plan and

3. remediation of latent or residual environmental impacts, as reflected in an environmental risk assessment report.

The content of the specified plans and reports, as well as the financial vehicles to be used for financial provision, are set out in the Regulations. As part of a new application for environmental authorisation and an associated right or permit, an applicant must submit the financial provision and the specified plans to the Department of Mineral Resources (DMR) for consideration. The applicant must also provide proof of payment or arrangements to provide the financial provision prior to commencement of any prospecting or mining operation. A holder of a right or permit must ensure that the determined financial provision is reviewed and assessed by specialist/s and audited by an independent auditor within one year of commencement of the operation, or immediately after its financial year end, and annually thereafter.

Timeframes are included in the Regulations for the submission documents to the DMR as well as for where an adjustment to the financial provision is needed.

1.1.3 Responsibility of a holder of a right or permit

The holder of a right or permit must:

– Make the Environmental Management Programme available on a publically accessible website, at the relevant site office and to the public on request;

- Appoint a responsible person to implement the approved closure and rehabilitation plans and
- ensure that all required documentation submitted to the DMR is signed off by the Chief Executive Officer or person appointed in a similar position as well as an independent auditor.

1.1.4 Care and maintenance

A holder of a Right or Permit may now apply to the Minister of Mineral Resources to be placed under care and maintenance for a period not exceeding five years. A care and maintenance plan must be compiled and submitted to the Minister of Mineral Resources in line with the prescribed information.

The care and maintenance plan must be audited and updated annually.

1.1.5 Transitional arrangements

- The holder of a Right or Permit must within **three months** of its financial year end, or **within 15 months** of these Regulations coming into effect, apply these Regulations to its operation and submit the relevant documents to the DMR for approval.
- Financial provisions submitted in terms of sections 53 and 54 of the MPRDA Regulation, 2004 for which approval is pending at the time of these Regulations coming into effect, will be approved as if section 53 and 54 of the MPRDA Regulations were not repealed.

1.2 The Mining Charter of the Department of Mineral Resources (DMR) of the Republic of South Africa

Amendments to the new Mining Charter where published in June 2017 from the DMR (DMR 2017). The key points of the Charter are as follows:

Ownership:

- 30 % BEE for all mining rights: 8 % employees, 8 % mine communities, 14 % black entrepreneurs.
- Right-holders already at 30 % not required to apportion.
- Minimum 50 % plus 1 Black Person shareholding for all new prospecting rights; must include voting rights.
- Right-holder to pay 1 % of annual turnover to the 30 % BEE prior to any distributions to its shareholders. Provisions of Companies (Act 71, 2008) will apply.
- A holder who claims a Historical BEE Transaction (transaction that achieved 26 % prior to 2017 Charter) must top up to 30 % within 12 months. Applies even where the black person shareholding is no longer 26 % due to either a BEE partner exiting or the contract with the BEE partner lapsing or the transfer of shares by the BEE partner to non-BEE persons.
- A holder who has maintained 26 % black person shareholding is required to top up its black person shareholding to 30 % within 12 months of the 2017 Charter coming into effect.

Employment Equity:

- Board level: 50 % black; 2 % to be women
- Executive/Top management: 50 % black; 25 % to be women
- Senior management: 60 % black; 30 % to be women
- Middle management: 75 % black; 38 % to be women
- Junior management: 88 % black; 44 % to be women

Procurement:

- 70 % of all mining goods to be from BEE entities.
- 80 % of all services to be from BEE entities.
- 100 % of mineral samples to be analysed by SA-based firms.
- Foreign suppliers to pay 1 % of their annual turnover to the Mining Transformation and Development Agency.

Beneficiation:

A maximum offsetting of 11 % against BEE shareholding; must meet the following criteria:

1. Invested in beneficiation since 2004;
2. The beneficiation must be in line with the definition of beneficiation contained in the MPRDA;
3. The Department of Mineral Resources must approve such beneficiation;
4. 11 % offsetting will not apply to beneficiation that started after 2004 but has since ceased or that has been terminated; and
5. 11 % offsetting can only be claimed if the beneficiation is still ongoing.

Housing and living conditions:

Principles as set out in the Housing and Living Conditions Standards for the Mining and Minerals Industry developed in terms of section 100(1)(a) of the MPRDA which includes:

1. Decent standards of housing;
2. Centrality of home ownership;
3. Provision for social, physical and economic integrated human settlements;
4. Involvement of employees in the housing administrative system;
5. Affordable, equitable and sustainable health system; and
6. Proper nutrition requirements and standards.

Human resources development:

5 % investment of the Leviable Amount on skills development, apportioned as follows:

1. 2 % on essential skills development activities such as artisanal training, bursaries, literacy and numeracy skills for employees and non-employees (community members);
2. 1 % towards South African Historically Black Academic Institutions; and 2 % towards the Mining Transformation and Development Agency.

At the time of printing this study these amendments were proposed and due to issues raised by the mining industry some of the amendments might still be changed or altered.

1.3 References

Buchholz, P. & Foya, S. (2014) (eds.): Investor’s and Procurement Guide South Africa Part 1: Heavy Minerals, Rare Earth Elements, Antimony. – DERA Rohstoffinformationen 21: 136 pp.; Berlin.

DMR (2017): Department of Mineral Resources (DMR) of the Republic of South Africa: Broad-Based Black Socio-Economic Empowerment Charter for the South African mining and minerals industry, 2017. – URL: http://www.dmr.gov.za/gazetted-mining-charter-2016.html [As of 30.06.2017].

2 Manganese

(I. Osbahr, K. Kärner)

This chapter is dealing with the different properties of manganese, its application and use in the steelmaking process or batteries. The resource potential of manganese in South Africa will be discussed and evaluated based on information about currently operating mines, plants and exploration and prospecting projects.

2.1 Definition, mineralogy and sources

In the first part, manganese is going to be defined in terms of its properties, mineralogy, deposit types and a description of its worldwide reserves.

2.1.1 Definition

Manganese is a grey, hard and brittle transition metal which resembles iron in appearance and properties. It is the 25th element in the 7th Group of the periodic table between chromium and iron. Manganese comprises about 1,000 ppm of the Earth's crust and is therefore the 12th most abundant element (MATRICARDI & DOWNING 2012). Further physicochemical properties are listed in Tab. 2.1.

Tab. 2.1: Physicochemical properties of manganese (HESS et al. 1995).

Symbol	Mn
Atomic weight [amu]	54.94
Density [g/cm³]	7.43
Hardness [Mohs scale]	5
Melting point [°C]	1,244
Boiling point [°C]	2,150
Crystal system	cubic
Colour	grey, silver-white

2.1.2 Mineralogy

Manganese is known to be comprised in over 250 minerals, however only a few are of economic interest such as pyrolusite [MnO_2], braunite

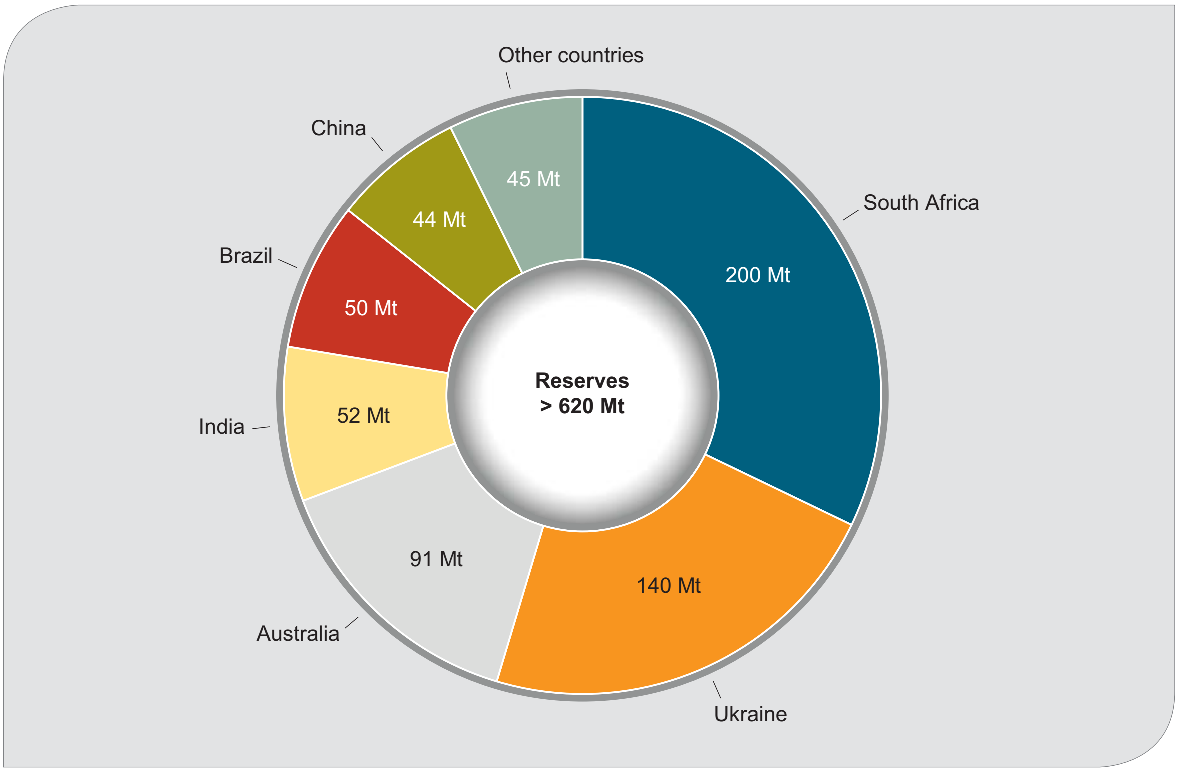

Fig. 2.1: World's manganese reserves distributed by the main countries in Mt (Mn contained) in 2015 (USGS 2016).

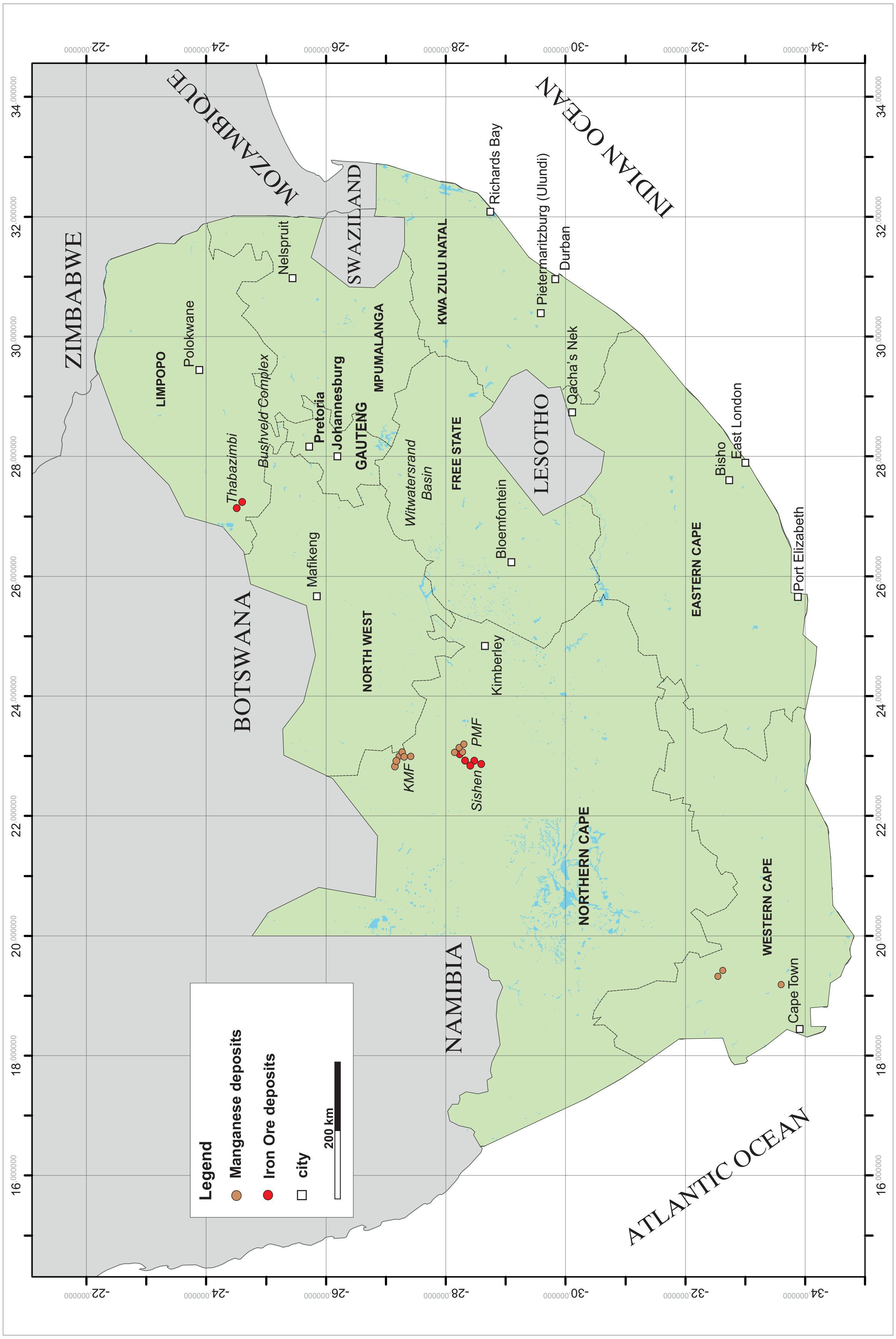

Fig. 2.2: Map of the South African manganese and iron ore deposits.

[$Mn^{2+}Mn^{3+}{}_6(O_8\backslash SiO_4)$] or manganite [$Mn_2O_3$•H2O], all containing between 60 and 63 wt.% of Mn (Wellbeloved et al. 2000). The main manganese ores are oxides and they generally occur in sedimentary deposits, residual accumulations, hydrothermal deposits or ocean floor nodules.

2.1.3 Sources

Land-based manganese resources are large but irregularly distributed. Total world resources of manganese metal are estimated at ca. 4,900 Mt (Grohmann 1995). South Africa accounts for about 75 % of the world's identified manganese resources, and Ukraine accounts for about 10 % (USGS 2016). The Kalahari Manganese Field (KMF) alone accounts for more than 9 bn t of manganese ore with a manganese content between 22 and 45 % and is the largest Mn resource of the world (Kleyenstüber 1984; Grobbelaar & Beukes 1986).

The world´s manganese reserves are around 620 Mt with South Africa and Ukraine accounting for more than 50 % of the world's manganese reserves (Fig. 2.1). Generally reserves for Australia, Brazil and Gabon have been revised downward and those for South Africa revised upward based on reported data by the governments of Australia and Brazil and the major manganese producers in Gabon and South Africa (USGS 2016).

2.1.4 Deposit types

Most of the manganese deposits are of sedimentary origin, with a few are hydrothermal ones. The sedimentary deposits comprise four types, namely banded iron formation (BIF)-hosted, black shale-hosted, karst-hosted and oolitic deposits (Beukes et al. 2016). The hydrothermal deposits are usually of minor economic importance and generally small in size. Sedimentary deposits are the main economic ore deposits and host most of the reserves worldwide (Astrup & Tsikos 1998). The KMF of South Africa is a BIF-hosted deposit (Fig. 2.2) while the supergene manganese ores of Gabon are black shale-hosted deposits. The Postmasburg Field (PMF) in South Africa (Fig. 2.2) is an example for a significant karst-hosted deposit (Beukes et al. 2016). Most production of manganese ore in Africa comes from the KMF and the deposits of Gabon, while a lot exploration is conducted in the PMF. In the past there was minor production coming from an oolitic deposit, called Tolwe, located in the Limpopo Province of South Africa (Beukes et al. 2016).

For the KMF, it can be distinguished between the Mamatwan-type ore and the Wessels-type ore, however there is a Hotazel supergrade-type located in a graben situation east of the KMF (Fig. 2.3). The Mamatwan-type ore is by far the most extensive. The average Mamatwan-type ore produced has 38 % Mn and 4.3 % Fe. The Wessels-type ore is a higher grade ore produced by hydrothermal alteration with 44 – 65 % Mn and 6 – 18 % Fe, but most deposits are now largely mined out (Astrup & Tsikos 1998).

Kalahari Manganese Field

The KMF in the Northern Cape Province is a world-class manganese ore deposit (Fig. 2.2 and 2.3). It occurs within the Proterozoic Transvaal Supergroup and comprises three laminated manganiferous units interbedded with Banded Iron Formation (Astrup & Tsikos 1998). The southern part of the KMF contains low-grade (< 44 % Mn, Mamatwan-type) carbonate-rich ore. The northern KFM hosts high-grade, carbonate-free, oxide-rich ore (generally > 44 % Mn, Wessels-type). Fault-controlled hydrothermal fluid flow and lateral infiltration away from faults into the Hotazel Formation as well as carbonate leaching and residual enrichment in manganese oxides at the expense of carbonate-rich protore are considered most critical to the development of the KFM (Tsikos et al. 2003).

Postmasburg Fe-Mn-Field

The PMF is located approximately 45 km to the south of the KMF (Fig. 2.2). It extends along strike for some 60 km in two distinct belts of deposits, the so-called Western and Eastern belts, from Sishen in the north to Postmasburg in the south. Mining of the manganese ores commenced in 1922 and was discontinued in the late 1980s, despite considerable remaining ore reserves, because of the more favourable composition and availability of high-grade manganese ore (> 44 % Mn) from the adjacent KMF. However, an increased demand for medium-grade manganese ore (34 – 44 % Mn)

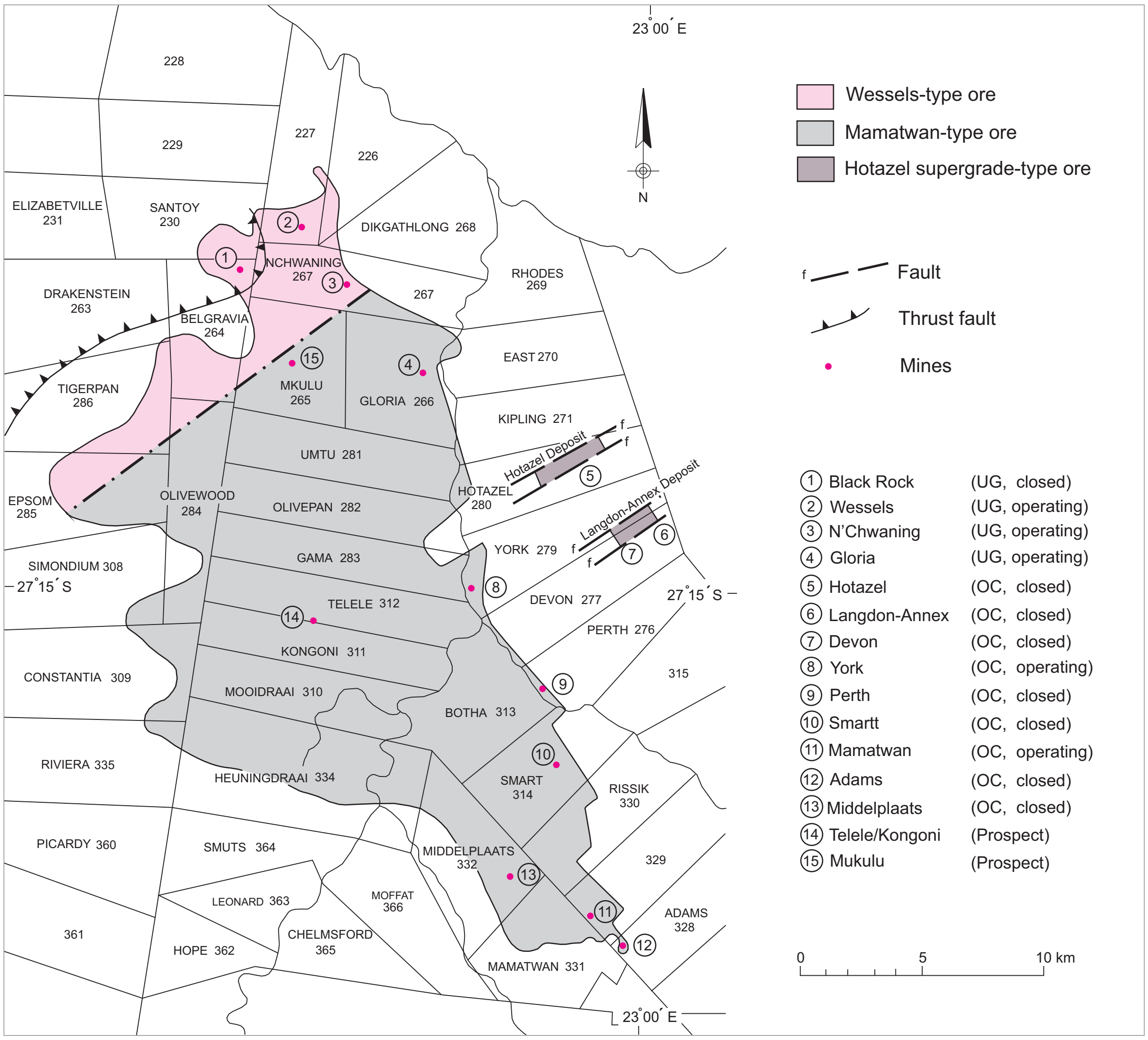

Fig. 2.3: Outline of the Kalahari Manganese Field showing the distribution of ore types and position of the more significant deposits (Wilson & Anhaeusser 1998).

has led to renewed exploration activity in the PMF. Several new manganese mines have commenced production or reviewed project potential from the PMF since 2010 (Segue Resources Ltd. 2012). Some of the manganese ores immediately underlie high-grade hematite iron ore deposits, e.g. at Sishen.

The manganese ores of the Postmasburg Field are subdivided into siliceous and ferruginous types. The latter form the bulk of the ore reserves. The ores are believed to have originated as karst-hosted wad deposits, which, subsequently, were overprinted by greenschist facies metamorphism and supergene alteration (Gutzmer & Beukes 1996).

2.2 Specifications and use

Approximately 90 % of all manganese is used in the manufacturing of steel, where it is added in the form of ferromanganese and serves as a sulphur fixing agent, as a deoxidant and, to a limited extent, as an alloying element. Eight percent is used in non-metallurgical application such as in dry cell batteries and the chemical industry. A small amount of manganese, in the form of manganese metal, is used in the manufacture of non-ferrous alloys, where it improves corrosion resistance. The ability of manganese to exist in six different oxidation states is used in the chemical industry, where manganese compounds are used as oxidants, colourants, fertiliser, animal feed and welding rods. Generally diagenetic minerals are processed to chemical or battery grade while metamorphic minerals are commonly used for metallurgical applications (ASTRUP & TSIKOS 1998). Manganese ores are classified after their area of application in metallurgical grade, chemical grade and battery grade (2). Besides the manganese content additional specific requirements are necessary. For the metallurgical grade, manganese ore with a general manganese content of 28–48 % can be used. The concentrations of P, Al_2O_3, SiO_2, CaO, MgO and S are important (e.g. phosphorous content should be preferably be below 0.1 %) as well as the manganese/iron ratio. A 7.5:1 ratio is required for a standard ferromanganese alloy with 78 % Mn (WELLBELOVED et al. 2000). The battery grade ore (44–54 % Mn) should contain less than 0.05 % of metals such as copper, nickel, cobalt or arsenic. For use in batteries additional factors are important as crystal structure, surface area, pore size distribution, particle shape and size, electrical conductivity, surface conditions, chemical composition or structure defects (WEISS 1977). Specifications for the chemical grade are considerably depending on the end use (WELLBELOVED et al. 2000).

Tab. 2.2: Manganese ores are classified as follows (ROSKILL 2015; WELLBELOVED et al. 2000).

Class	Mn in %
Metallurgical grade	28–48
Chemical grade	35–43
Battery grade	44–54

2.3 Mining and processing

There are several operating manganese mines in South Africa including underground operations as well as open-cast mining. Total manganese ore production in South Africa was approximately 16 Mt in 2015 which is a 15.3 % increase from 2014. From the years 2000 (3.6 Mt) to 2015 a steady increase was observed.

Beneficiation can be categorised into ore processing, primary manufacturing and downstream industries. Ore processing includes metallurgical and chemical processing.

Manganese alloys produced commercially can be divided into high-carbon ferromanganese (HCFeMn), refined medium- and low-carbon ferromanganese (MLCFeMn), silicomanganese (SiMn) and low-carbon silicomanganese (LCSiMn) (Tab. 2.3).

Ferromanganese constitutes as a chief manganese alloy used for steel production. Two alloys are produced from manganese ores, namely high-carbon ferromanganese (74–83 % Mn) and silicomanganese (59–67 % Mn and 14–31 % Si). In South Africa the producers of manganese ferroalloys are Metalloys and Assmang, and of silicomanganese Transalloys and Mogale Alloys (Tab. 2.4). In southern Africa there is only one other producer of manganese ferroalloys in Zambia, Match Corporation.

Submerged arc furnace (SAF) technology is utilised in the production of high-carbon ferromanganese (HCFeMn) and silicomanganese, applying the discard slag practice in both instances (STEENKAMP & BASSON 2013).

HCFeMn production using a rich slag practice, with subsequent SiMn production, sometimes referred to as the duplex process, is not applied in South Africa. Estimated figures (KAZADI et al. 2013) indicate that approximately 20 Mt of HCFeMn and

Tab. 2.3: Categories of manganese ferroalloys produced internationally and their typical chemical composition (from STEENKAMP & BASSON 2013 after OLSEN et al. 2007).

	Mn [%]	Si [%]	C [%]	P [%]	S [%]	B [ppm]
HCFeMn	74–78	0.3	7.5	0.2	–	–
Refined FeMn (MCFeMn)	80–83	0.6	0.5–1.5	0.2	–	–
SiMn	67	14–20	1.5–2.0	0.15–0.2	0.02	200
LCSiMn	59–63	26–31	0.05–0.5	0.1	0.01	100

Tab. 2.4: Manganese smelters in South Africa.

Company	Startup	Location	Capacity	Technology
Metalloys*	1937	Meyerton, Gauteng Province	410 kt/a	Closed SAF: 2 x 75 MVA, 2 x 81 MVA
			90 kt/a	30 t top-blown bottom-stirred converter
Assmang	1957	Cato Ridge, KwaZulu-Natal	200 – 240 kt/a HCFeMn	Semi-open SAF: 1 x 24 MVA, 2 x 22 MVA Closed SAF: 1 x 24 MVA, 2 x 12 MVA
	2011 (converted FeCr plant)	Machadodorp, Mpumalanga Province	130 kt/a (two furnace op) HCFeMn	Semi-open SAF: 1 x 24 MVA, 1 x 30 MVA, 1 x 24 MVA)
			270 kt/a (four furnace op) HCFeMn	(Closed SAF: 1 x 54 MVA)
			50 kt/a MCFeMn	30 t converter
Transalloys	1967 (converted FeCr plant)	eMalahleni, Mpumalanga Province	180 kt/a SiMn	Open SAF: 2 x 21 MVA, Semi-open SAF: 1 x 23 MVA, 2 x 48 MVA
			50 kt/a MCFeMn (currently not operational)	Open arc furnace: 2 x 7 MVA
Mogale Alloys	1963 (primarily FeCr plant)	Krugersdorp, Gauteng Province	55 kt/a SiMn	Semi-open SAF: 2 x 20 MVA
Kalahari Resources	Planned	Coega, Eastern Cape Province	320 kt/a HCFeMn	Closed SAF: 3 x 63 MVA or 4 x 48 MVA

** 60 % owned and operated Samancor Manganese Metalloys plant*

SiMn slag has accumulated over the years on dumps in South Africa, and that on average 0.5 Mt are added to these dumps each year. Interested and affected parties are looking into different ways to recycle the material and thus to reduce the slag volume. However, existing environmental legislation does not support the implementation of viable slag utilisation processes (Steenkamp & Basson 2013).

Samancor Manganese Metalloys alloy plant, located in Meyerton, is one of the largest manganese alloy producers in the world. Metalloys produces high- and medium-carbon ferromanganese. Production of manganese alloy in FY2014 was 377 kt (BHP Billiton 2015). Previous years' production was 374 and 404 kt for 2013 and 2012, respectively.

Metalloys is the largest producer of manganese ferroalloys in South Africa. In 2012, Metalloys decommissioned the five semi-closed furnaces producing SiMn, and replaced the production capacity of these by a single large furnace producing HCFeMn (Steenkamp & Basson 2013).

Assmang is the second largest producer of HCFeMn in South Africa with manganese alloys production increasing from 291 kt in 2010 to 350 kt in 2015. It has two underground manganese ore mines in the Kalahari Basin, Nchwaning and Gloria. Manganese alloys are produced at two operating smelters at Cato Ridge in KwaZulu-Natal and Machadodorp in Mpumalanga (Roskill 2015). The Machadodorp plant was originally commissioned as a ferrochrome (FeCr) plant but was converted to HCFeMn production in 2011. The Nchwaning Mine is a high-grade ore mine with the manganese content of ores ranging between 42 and 48 %. The Gloria Mine produces lower-grade semi-carbonate ore. Assmang exports 85 % of its manganese ore output and consumes 15 % at its own smelters (Steenkamp & Basson 2013; Roskill 2015). Specifications for different materials of ferromanganese lumpy produced by Assmang ore is listed in Table 2.5.

Tab. 2.5: Specifications of high and medium ferromanganese lumpy from Assmang (Assmang 2017).

Component	High-carbon ferromanganese lumpy (6–75 mm)	Medium-carbon ferromanganese lumpy (10–80 mm)
Mn	76.17–76.59 %	80.84–81.13 %
Si	0.08–0.305 %	0.32–0.37 %
P	0.08 %	0.056–0.06 %
S	0.007–0.009 %	0.006–0.007 %
C	6.48–6.67 %	1.43–1.47 %

Transalloys is the largest producer of SiMn with its smelter being located near eMalahleni in Mpumalanga Province. Transalloys was also commissioned as a FeCr plant in the 1960s but converted into to a SiMn plant in 1967 (Steenkamp & Basson 2013). Specifications of the silicomanganese produced by Transalloys are listed in Tab. 2.6.

Tab. 2.6: Specifications of silicomanganese from Transalloys (Transalloys 2017).

Component	Silicomanganese (LUMP)
Mn	66.7 %
Si	17.1 %
P	0.012 %
S	0.01 %
C	1.6 %

Mogale Alloys, which is situated near Krugersdorp, Gauteng Province produces primarily FeCr using DC arc furnace technology, but also produces SiMn since the 1990s (Steenkamp & Basson 2013). SAF technology is applied and the furnaces are rated from as low as 6 MVA to as high as 81 MVA. Medium- and low-carbon ferromanganese are produced using top-blown bottom-stirred converters and low-carbon SiMn using the Perrin process (Fig 2.4).

Fig. 2.4: Mogale Smelter (photo: DERA 2015).

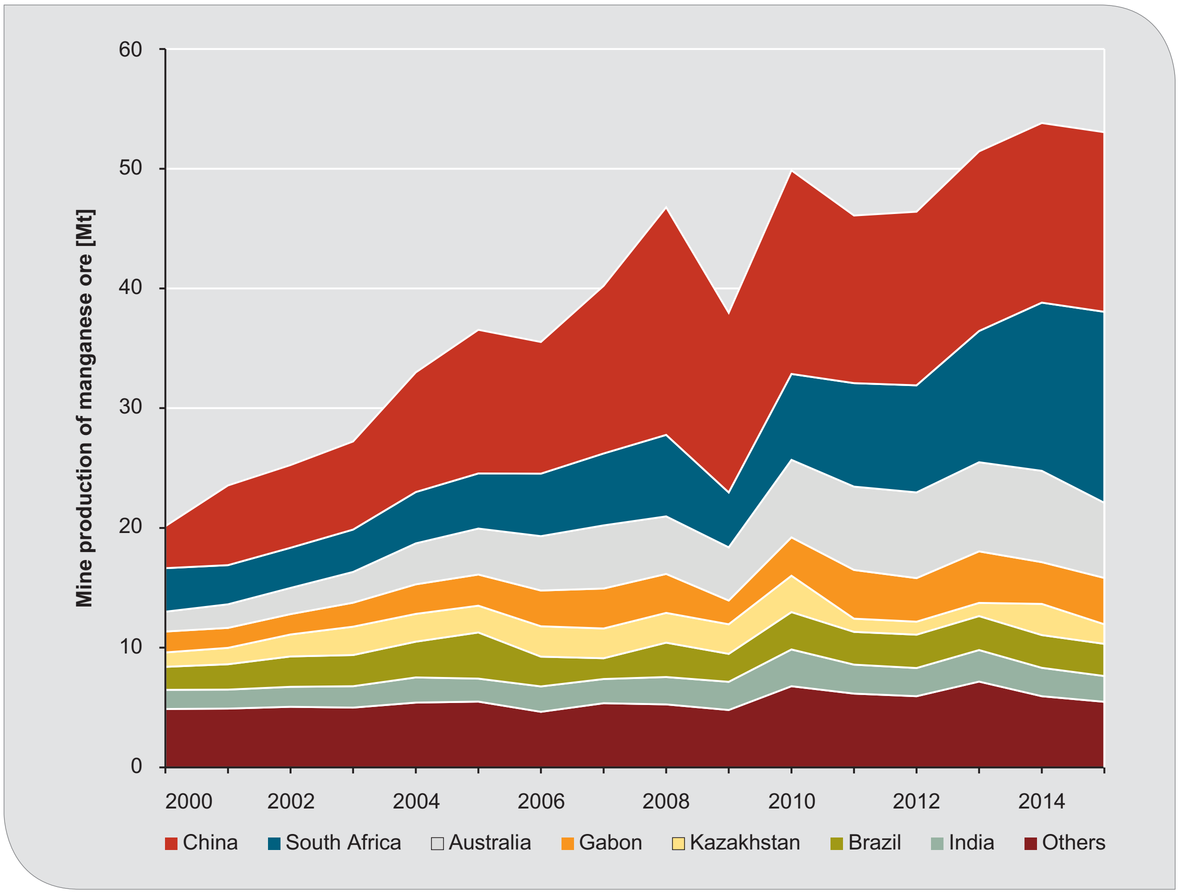

Fig. 2.5: Global trends in manganese ore (gross weight) production (BGR 2016).

The major challenges faced by the southern African (South Africa and Zambia) manganese ferroalloy producers are increasing electricity tariffs and the productivity of labour (Steenkamp & Basson 2013).

Smelter operators are working on solutions to increase energy efficiency through waste heat recovery, modifying furnace designs to closed furnaces only, and power generation using off-gas.

2.4 Supply and demand

Manganese resources are distributed worldwide and more than 20 countries are producing manganese. In the following the global situation of supply and demand as well as the German and South African perspectives are discussed.

2.4.1 Global situation

In the last decades global mine production steadily increased with a drop in 2009 because of the global

Tab. 2.7: Three top producers of manganese ore (BGR 2016).

Country	Production [Mt]		CAGR
	2014	2015	
South Africa	14.05	15.95	+ 13.52 %
China	15.00	15.00	+/– 0.00 %
Australia	7.62	6.28	– 17.59 %

Tab. 2.8: Top producing mines in 2016 (SNL Metals & Mining 2017).

Project	Location	Controlling company	Commodity	Mn production [Mt]	Reserves and resources [Mt]
Groote Eylandt	Australia	South32 Ltd., Anglo American Plc	Mn	5.12	174.0
Mamatwan/ Wessels (Hotazel)	South Africa	South32 Ltd., Anglo American Plc, NCAB, HMM Education Trust, Iziko, OM Holdings Ltd.	Mn, Fe	3.85	241.7
Moanda	Gabon	Eramet	Mn	3.41	258.6
Nchwaning/ Gloria (Black Rock)	South Africa	African Rainbow Minerals Ltd., Assore Ltd.	Mn, Fe, Mag	3.01	713.0
Nsuta	Ghana	Consolidated Minerals Ltd. (90 %), Government of Ghana (10 %)	Mn	2.00	105
Azul	Brazil	Vale S.A.	Mn	1.70	38
Tshipi Borwa	South Africa	Jupiter Mines Ltd., OM Holdings Ltd.	Mn, Fe	1.54	308.2

** E = Estimated*

financial crisis. Global mine production of manganese ore totalled approximately 53.1 Mt in 2015. This is a 1.42 % decrease from the previous year 2014 compared to a 4.6 % increase from 2013 to 2014 (Fig. 2.). In the year 2015, nearly 30 % of the manganese ore produced came from South Africa. China shows approximately the same proportion (28 %) of global production, followed by Australia, which produced about 12 % of manganese ore.

While South Africa`s manganese ore production increased by 13.5 %, China showed an unchanged production rate from 2014 to 2015, which was announced with 15 Mt in both years. Australia had a negative growth of 17.6 % from 2014 to 2015 (Tab. 2.7).

Three of the top seven producing mines in the world are located in South Africa (Hotazel, Nchwaning/ Gloria and Tshipi Borwa) producing between 1.8 and 3.8 Mt per year, however the top producers with ~5 Mt/a are Groote Eylandt in Australia and Hotazel in South Africa. The seven top producing mines make up at least 33 % share of the 2016 world production (Fig. 2.5 and Tab. 2.8).

The global production of ferromanganese (high-carbon and refined ferromanganese) decreases since 2013. While in 2013 the production totalled approximately 6.7 Mt, of which China produced about 3.6 Mt equalling a 53 % share. From 2014 to 2016, the global production decreases from 6.1 Mt to 4.9 Mt (IMnI 2017).

China as a main producer is followed by India and South Africa, producing 0.55 Mt (8.3 %) and 0.49 Mt (8.4 %) ferromanganese, respectively (Fig. 2.6). Except India all countries show a strong decrease of ferromanganese production in 2009 due to the global financial crisis. Only India's production increased from 386 kt in 2008 to 513 kt in 2009 (Fig. 2.6).

In 2015, there were some large production cuts especially in China, India, South Africa and Brazil, as output adjusted to the lower demand from the steel industry. The total Mn alloys (ferro- and silicomanganese) world output was 16.7 Mt which is a decrease of 15 % from 2014 (19.5 Mt; IMnI 2015 and 2016). China alone had a decrease of 20 % (total output 9 Mt) and the rest of the world of 9 % (total output 7.7 Mt). The main reasons were raised export taxes in China, increasing imports of steel reducing demand for locally produced Mn alloys or higher electricity prices as in Brazil and South Africa (IMnI 2016). However, there is a 13 % increase to 2016 where the global production reached 17.1 Mt (IMnI 2017a).

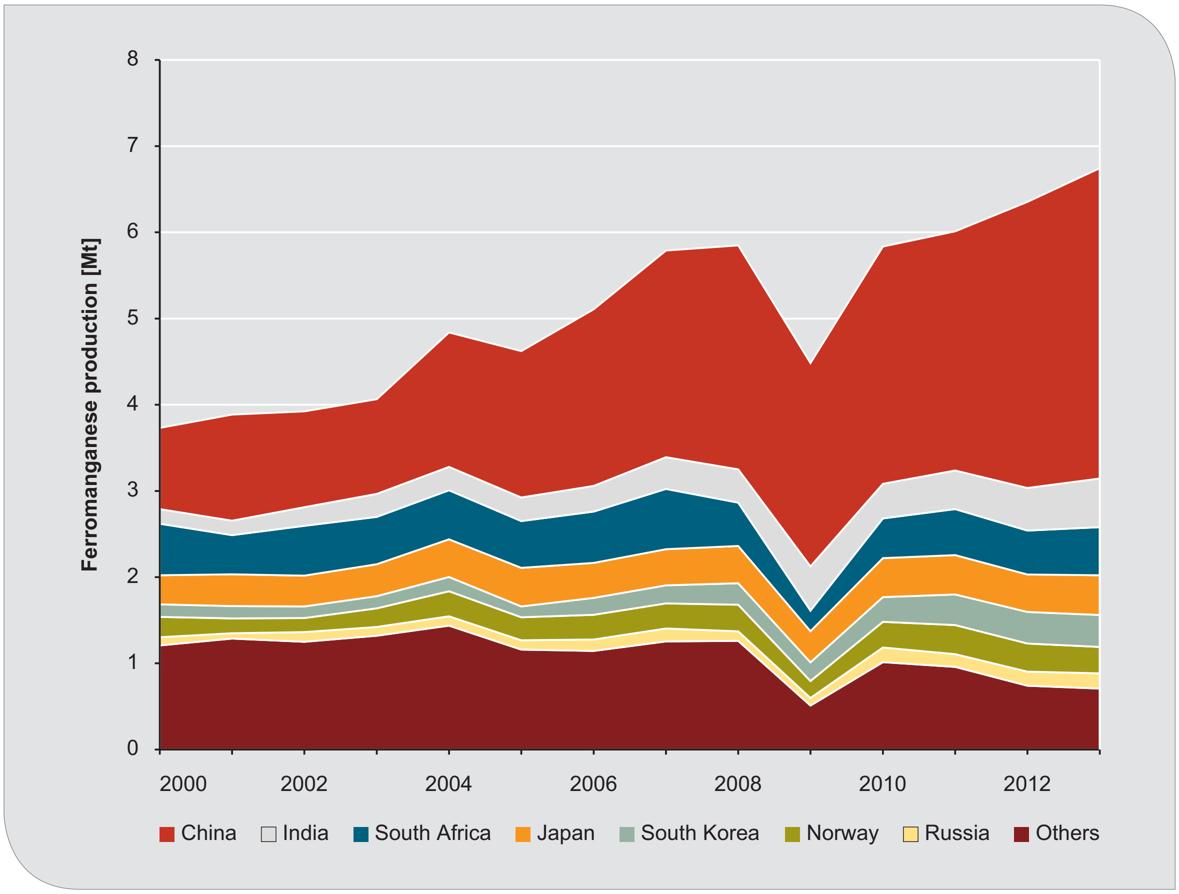

Fig. 2.6: Global trends in ferromanganese production (BGR 2016).

The development of global ferromanganese production in China showed an 8 % increase in 2013 compared to 2012. South Africa and India even recorded a 10 % and 14 % increase in production (Tab. 2.9).

2.4.2 Consumption

China is the world's leading producer of manganese alloys with a world share of approximately 50 % (Fig. 2.6 and Tab. 2.9) and consumes almost two third of the globally produced manganese ores and concentrates, followed by the Commonwealth of Independent States (CIS), India and Europe (Fig. 2.7).

Since 2008, the global consumption of manganese ore did not exceed (or only in small amounts < 100,000 t in 2011 and 2012) the production of manganese ore. One exception was the year 2009, when consumption exceeded production by 2,118 kt (Tab. 2.10). Similar trends exist for the different manganese products (SiMn, FeMn, electrolytic manganese metal (EMM) and electrolytic manganese dioxide (EMD); Tab. 2.10).

Tab. 2.9: Three top-producers of ferromanganese (BGR 2016).

Country	Production [t]		CAGR
	2012	2013	
China	3,320,000	3,600,000	+8 %
South Africa	509,800	558,300	+10 %
India	493,300	564,400	+14 %

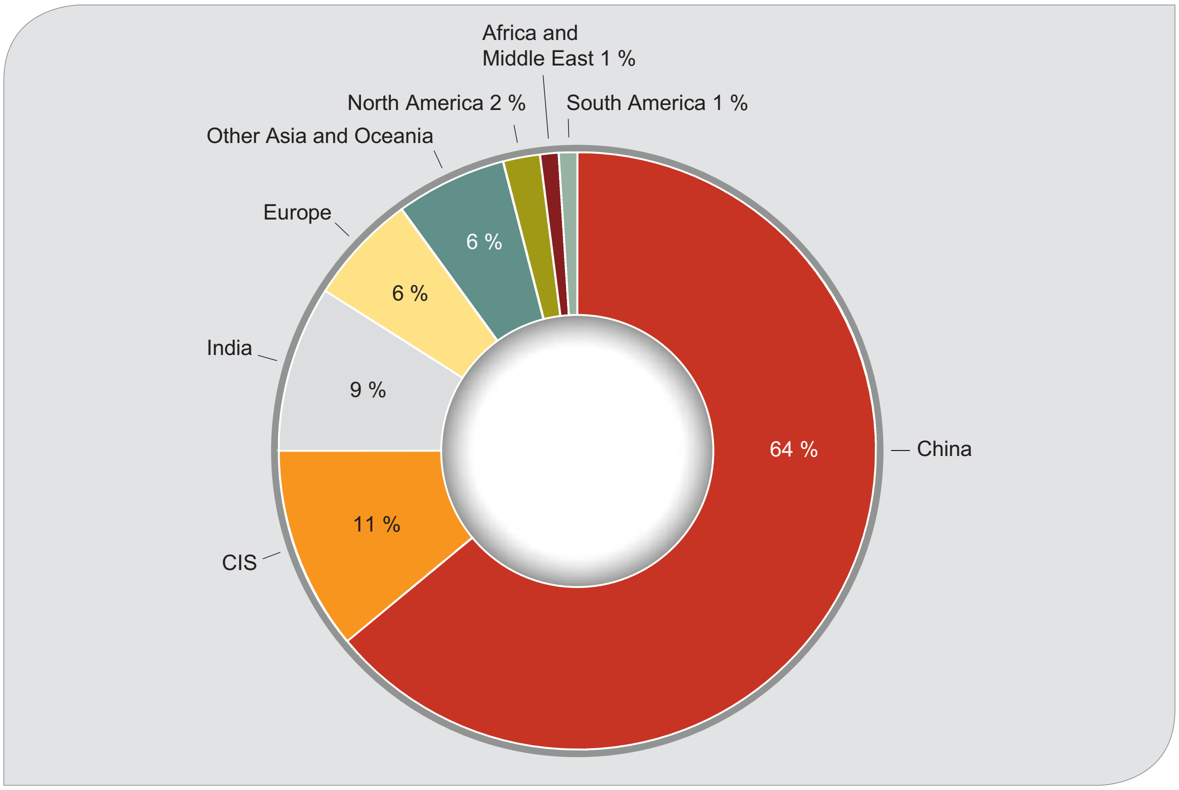

Fig. 2.7: World consumption of manganese ore by region 2014 (Roskill 2015).

Tab. 2.10: Balance of global production and consumption of manganese ore and different manganese production forms in '000 t (Roskill 2015).

	2008	2009	2010	2011	2012	2013
Manganese ore*	+1,611	–2,118	+0,085	–0,107	–0,001	+0,594
SiMn	+0,206	–0,557	+0,079	+0,246	+0,205	–0,085
HC FeMn	+0,358	–0,432	–0,002	+0,012	–0,019	–0,024
MLC FeMn	+0,139	–0,178	+0,021	+0,015	+0,020	–0,055
EMM	+0,033	–0,036	+0,061	+0,016	–0,019	–0,036
EMD	+0,010	–0,220	–0,07	–0,070	–0,040	+0,040

** Contained Mn*

2.4.3 Germany

Germany is an important manufacturer of steel with manganese playing an important role in that. Owing to the lack of domestic supply of manganese ore and manganese alloys, German steel producing companies are dependent on the import of manganese and its products. The majority of ferromanganese is sourced from South Africa (82,500 t in 2015; Fig. 2.8). Smaller amounts of ferromanganese (containing more than 2 % carbon) are imported from Norway, Spain, France and Luxembourg (Fig. 2.8). In 2015 Germany imported 255,000 t ferrosilicomanganese and 215,000 t ferromanganese, containing less than 2 % of carbon, in total, respectively. Germany imports manganese ore and concentrates from the Netherlands, Brazil and Australia, however, most of the Netherlands' manganese ores and concentrates are imported from South Africa.

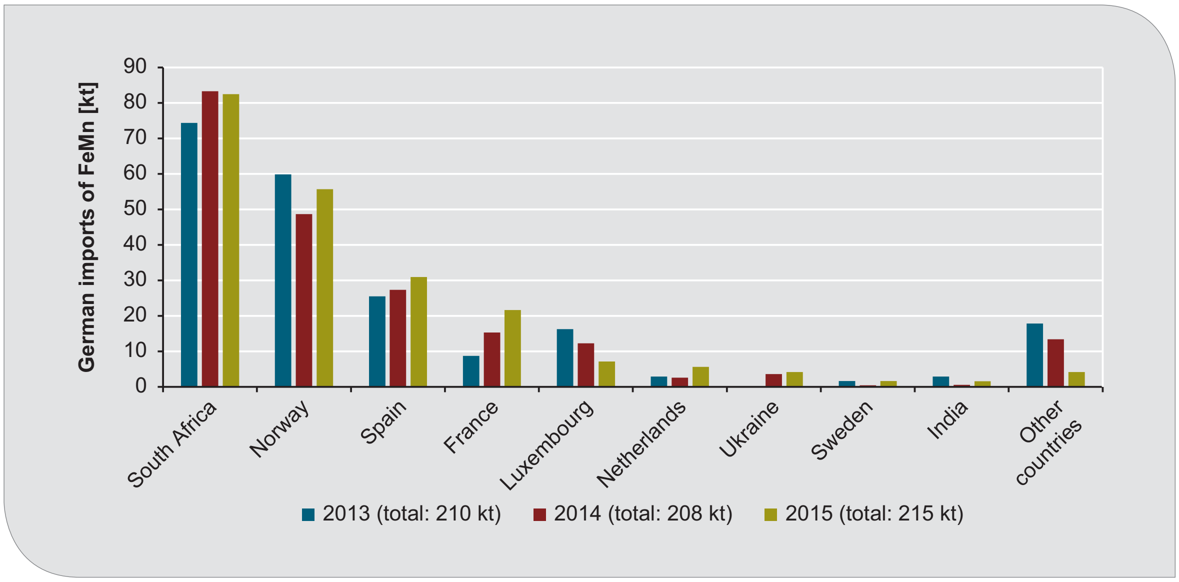

Fig. 2.8: German imports of ferromanganese, containing more than 2 % carbon, in (kt), from 2013–2015 (BGR 2016).

2.4.4 South Africa

Around 75 % of the world's manganese resources are located in South Africa and primary manganese production of 16 Mt in 2015 accounted for approximately 30 % of the world's total (Fig. 2.5). From the 16 Mt, 12.3 Mt have been manganese ore with 30–40 % Mn content; 2.5 Mt have been 40–45 % Mn content in the ore and 1.2 Mt have been 45–48 % Mn content in the ore (DMR 2016). There has been no production of manganese ore containing more than 48 % Mn. Exports of manganese ore and concentrates made up 12 Mt of which 50 % were exported to China and smaller amounts to India, Spain and South Korea. Less than 400 t were exported to Germany. In 2015 an amount of approximately 360 kt of ferromanganese (containing more than 2 % of carbon) was exported mostly to the USA, the Netherlands and Germany. Smaller amounts of ferromanganese, containing less than 2 % of carbon, were exported to China, Sweden and Austria (Fig. 2.9).

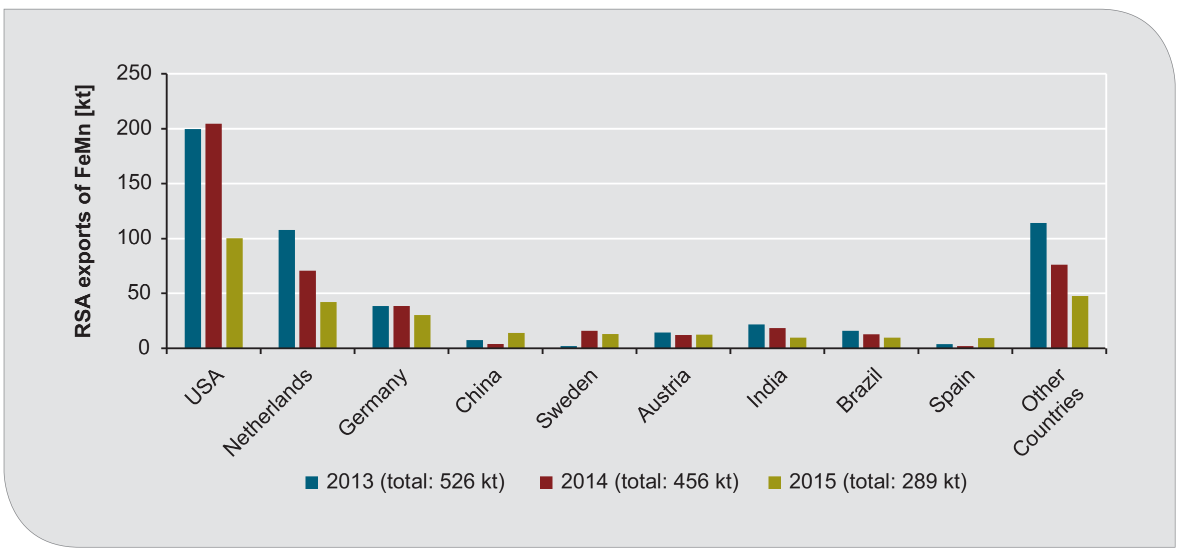

Fig. 2.9: South African exports of ferromanganese, containing more than 2 % carbon, in (kt), from 2013–2015 (GTIS 2016).

2.5 Operating mines

Manganese mining in South Africa began in the early 1900s. At that time manganese ore was mined at Hout Bay near Cape Town. In 1922 manganese occurrences were discovered near Postmasburg in the Northern Cape Province with production commencing in 1930. Subsequently, the KMF was discovered, where Black Rock Mine was eventually opened in 1940. At present, the KMF constitutes the principal production area. Current manganese deposits are labelled in the map (Fig. 2.3)

2.5.1 Kalahari Manganese Field

Three manganese mines (Black Rock, Hotazel and Tshipi Borwa) out of the seven top producing mines worldwide are located in the South African KFM. In total the current manganese projects of the operating mines show reserves of > 500 Mt and resources of > 750 Mt manganese with grades between 34 and > 40 % Mn. A detailed overview about the operating mines is given in Tab. 2.11.

2.5.1.1 Black Rock (Gloria/Nchwaning)

Location and ownership

The mines (Gloria and Nchwaning) are located in the Black Rock area of the Kalahari in the Northern Cape Province. The mining area is located approximately 80 km north-west of the town of Kuruman. The mine is owned by African Rainbow Minerals Ltd. (50 %) and Assore Ltd. (50 %) and is operated by Assmang Pty. Ltd.

Geology

The manganese ores of the KMF are contained within sediments of the Hotazel Formation of the Ghaap Group, Griqualand West Basin, a subdivision of the Proterozoic Transvaal Supergroup. The average thickness of the Hotazel Formation is approximately 40 m. The manganese ore bodies (Fig. 2.10) exhibit a complex mineralogy of more than 200 mineral species (mainly oxides and silicates) with braunite being the dominate mineral. The hydrothermal upgrading has resulted in a zoning of the orebody with regard to fault positions.

Fig. 2.10: Layering of banded iron formation (BIF) and manganese ore (photo: DERA 2015).

Tab. 2.11: Operating mines in the Kalahari Manganese Field (SNL Metals & Mining 2017).

Property	Owner	Coordinates	Mn [%]	Fe [%]	Mine type	Start-up	LOM	Mn production FY	Reserves and resources
Gloria	African Rainbow Minerals Ltd. (50%) Assore Ltd. (50%)	27°8'24"S 22°52'12"E	35.58	7.31	underground		> 30 years	3.1 Mt (FY 2015 combined Nchwaning and Gloria) 2.9 Mt (FY 2016)	713 Mt (combined Nchwaning and Gloria)
Nchwaning		See above	42.98	12.76	underground	1972	2033		
Black Rock*		See above	39.84	18.75	underground				
			Ø38.47	Ø10.82					
Hotazel: Wessels	South32 Ltd. (44.4 %), Anglo American Plc (29.6 %), NCAB (7 %), HMM Education Trust (5 %), Iziko (5 %), OM Holdings Ltd. (9 %)	27°12'35.668"S 22°58'35.67"E	42.3	16.41	underground	1973	2060** 46 years	5.1 Mt (FY 2015 combined Mamatwan and Wessels 3.8 Mt (FY 2016)	242 Mt (combined Wessels and Mamatwan)
Hotazel: Mamatwan		See above	35.9	4.88	open pit	1964	2032** (18 years)		
Tshipi (Borwa)	OM Holdings Ltd. (50.1 %), Jupiter Mines Ltd. (49.9 %)	27°22'44.4"S 22°58'1.2"E	37.10	/	open pit	2012	2072 (60 years)	1,828,630 t (FY 2015) 1,544,000 t (FY 2016)	Resources 308 Mt
United Manganese of Kalahari (UMK)	Majestic Silver Trading 40 (51 %), Renova Group (49 %)	27°19'30"S 22°59'6"E	37.5	/	open pit	2008	2038	2,550,000 t (FY 2015) 1,350,000 t (FY 2016)	Resources 282 Mt Reserves 41,3 Mt
Lomoteng	Guangxi N&H Metallurgy Dev Co (74 %), Unnamed owner (26 %)	28°1'58.8"S 22°59'20.4"E	25.8–34	25.4	open pit	n. a.	128 years	600 kt ore/a	Resources 118 Mt

** expansion project*
*** existing new order rights valid until 2035*

Mining and processing

Manganese ore mining operations today include the underground mining complexes Gloria and Nchwaning. The Nchwaning Mine is a high-grade ore mine with a manganese content of ores ranging between 42 and 48 %. Seam 1 shows Mn contents of around 45 % with a Fe-content between 8–10 %. Seam 2 has lower Mn contents of around 42 % with Fe contents of 15 %. The mining operations started with seam 1 as it shows better conditions for the processing because of the lower Fe contents. Mining at Nchwaning occurs at a depth of 200 m deepest, however excavations can be found at a depth of 519 m below surface. For the board and pillar mining method trackless equipment is used (African Rainbow 2007). Manganese ore is crushed underground before hoisted to a surface stockpile via a vertical shaft or a declined conveyor system, depending on originating from the Nchwaning No 2 or No 3 mine, respectively. Afterwards ore is forwarded to two stages of crushing, dry and wet screening to result in lumpy and fine products (African Rainbow 2007).

The Gloria Mine produces lower-grade semi-carbonate ore. Assmang exports 85 % of its manganese ore output and consumes 15 % at its own smelters (Steenkamp & Basson 2013; Roskill 2015). At Gloria Mine manganese is extracted at depths between 180 and 250 m below surface. The ore from Gloria passes the same procedure as from Nchwaning. At the plants finer portions of the ore are stockpiled while coarser parts are extracted from the respective product into road haulers, sampled, weighed and stored for despatch (African Rainbow 2007). Manganese ore production is around 3 Mt/a with an average Mn content of 45 % from which three-quarters are exported. The production in 2015 and 2016 was 3.08 and 2.93 Mt, respectively (SNL Metals & Mining 2017).

Black Rock Expansion Project

The project focuses on new mining opportunities at Black Rock Mine Operations in the Northern Cape to increase the output of high-grade manganese ore products. Project execution started in 2014, with project completion planned for December 2019/January 2020. Current production is at around 3.1 Mt/a and the expansion should increase production to 4.6 Mt/a.

2.5.1.2 Mamatwan and Wessels

Location and ownership

BHP Billiton (now South32 Ltd.) owns 60 % and Anglo American 40 % of Samancor Holdings (Pty.) Ltd. which operates the Metalloys division via its wholly owned subsidiary, Samancor Manganese (Pty.) Ltd. Samancor Manganese owns 74 % of Hotazel Manganese Mines (Pty) Ltd. (HMM), which gives South32 an effective interest of 44.4 % in HMM and Anglo American 29.6 %. The remaining 26 % of HMM is owned under the terms of the South African black-owned Broad-Based-Black-Economic-Empowerment (BBBEE) legislation (South32 Ltd. 2016a). Operator is Hotazel Manganese Mines (Pty.).

Geology

The manganese mineralisation at Mamatwan occurs as stratiform bodies interbedded with a banded iron formation. The formation is characterised by three manganese-rich horizons separated within the banded iron formation. The so-called Lower Horizon is exposed and under development at Mamatwan open pit. The Middle Horizon is poorly developed and carries no economic value. The Upper Horizon is considered to be potentially economic with manganese scattered throughout. The currently mined seam is 4 to 28 m thick (SNL Metals & Mining 2017).

Mining and processing

HMM operates the Wessels underground mine (Fig. 2.11) which is operational in shallow depth down to 500 m and the Mamatwan open-cut mine with a depth down to 100 m (Fig. 2.12). An expansion of the open-cut pit is planned to be mined down to 175 m. The first step for the mined ore is crushing down to < 150 mm in the "in-pit" primary crusher. In the ore processing plant it goes through a secondary crushing process (< 75 mm), washing and screening. The next step is crushing to < 15 mm. After sorting, the lumpy ore is being exported via road and rail through to Port Elizabeth (approximately 950 km) and Durban (approximately 1,100 km). Approximately 75 % of the ore is processed at the mine to an export saleable product, while the remaining ore is concentrated to alloys at the Metalloys plant (BHP Billiton 2015).

Fig. 2.11: Winding shaft at Hotazel mining area (photo: DERA 2015).

In fiscal year (FY) 2016, the total manganese ore production was 3.85 Mt at Wessels and Mamatwan (SNL Metals & Mining 2017). Mamatwan has reserves of ca. 62 Mt @ 36.7 % Mn, resulting in a reserve life of 17 years, and resources of 95 Mt @ 24.9 % Mn. Wessels has reserves of 90 Mt @ 42.2 % Mn, resulting in 67 years of reserve life until 2083, and resources of 147 Mt @ 42.4 % Mn (South32 2016a; BHP Billiton 2015). The production capacity of manganese ore for Mamatwan and Wessels is approximately 3.5 Mt/a and 1 Mt/a, respectively. Metallurgical recovery reaches 88 % for Wessels, 96 % for Mamatwan.

Wessels Central Block Expansion

The central block development project at the Wessels underground mine is being progressed in two phases. The first phase of the project comprises the construction of the ventilation shaft and development of the associated underground ventilation network. The second phase will complete infrastructure required to expand the mine to 1.5 Mt/a. The project comprises the development of a run of mine (ROM) infrastructure handling system for the central block, the development and equipping of underground workshops, including materials handling design, procurement and installation. The whole project at a cost of US$ 31 million was commissioned in March 2017 as planned (South32 2016b and 2017). A feasibility study was successfully completed in FY 2014 and was approved for execution in July 2014 at a cost of US$ 30.8 million.

2.5.1.3 Tshipi Borwa

Location and ownership

The project is located near the town of Hotazel in the Northern Cape Province. The project area is some 30 km north of Kathu, a town near Kumba's Sishen iron ore mine. Jupiter Mines Ltd. owns 49.9 % and Ntsimbintle NewCo 50.1 %. Ntsimbintle NewCo is owned by a Black Economic Empowerment (BEE) company Ntsimbintle Mining (74 %) and OM Holdings Ltd. (26 %; Tshipi é Ntle 2017).

Geology

The Tshipi Borwa Project is located on the south-western outer rim of the KMF making the ore resources shallower and amenable to open pit mining. Tshipi ore commences at a depth of

Fig. 2.12: Mamatwan open pit (photo courtesy SOUTH32, 2015).

70 m below surface and is contained within a 30 m to 45 m thick mineralised zone. The ore layer dips shallow to the north-west at approximately 5 degrees (JUPITER MINES LTD. 2017).

Mining and processing

Tshipi Borwa is one of the largest open pit mines based in South Africa (JUPITER MINES LTD. 2017). The mining area covers around 400 m^2 and is therefore one of the largest open pit mining projects in the KMF. Tshipi's strategy is to mine and process the lower 15–17 m of the mineralised zone, commonly known as the bottom cut, as it bears a higher grade ore. A portion of the upper 15 m mineralised zone, referred to as the top cut, is planned to be stockpiled for possible use later. Previous economic evaluations and mine plans have assumed the top cut to be an unsalable waste product (TSHIPI 2015).

The mine's production capacity is approximately 2.4 Mt per year manganese ore grading 37 %. The production will include two grades (20 % fines and 80 % lumpy). The manganese ore is simply mined using conventional open-pit excavation methods encompassing drilling, blasting, loading and hauling. The processing plant consists of crushing, screening, conveying and stockpiling operations to produce a carbonaceous direct shippable ore product (TSHIPI 2015). The life of mine is expected to be more than 60 years (JUPITER MINES LTD. 2017).

2.5.1.4 United Manganese of Kalahari (UMK)

Location and ownership

UMK mine is situated 13 km south of Hotazel and 42 km north of Kathu and is operated by United Manganese of Kalahari, a South African company. UMK has access to rail infrastructure, and has a state-of-the-art load-out station to enable rapid train loading. UMK sells its products in both the local and export markets. UMK's product is marketed by Kalahari Trading AG, a company incorporated in Switzerland and operating from offices in Zug, Switzerland. UMK is an unlisted, private company and is owned by Majestic Silver Trading 40 (Pty) Ltd. (51 %) and Renova Manganese Investments Ltd. (49 %). Majestic Silver Trading is a majority BBBEE business entity. Renova Manganese Investments is a fully owned subsidiary of the Russian-based Renova Group of Companies.

Mining and processing

UMK mine holds a manganese resource of 282 Mt and a reserve of 41.3 Mt. The life of mine is expected to be more than 30 years (to 2038) and beyond. In 2010 the production was ramped up to 1.5 Mt and in 2012 to 2.7 Mt, with a final production in 2016 of 1.35 Mt. Manganese grade in the ore is at 37.5 % (SNL Metals & Mining 2017).

2.5.2 Postmasburg Manganese Field (Lomoteng)

Location and ownership

Lomoteng is an iron and manganese mine located in the south-east region of South Africa in the Postmasburg District and is therefore the only operating mine in the PMF. The mining area is 50 km north of Kathu and 30 km south of Postmasburg. Guangxi N&H Metallurgy Development purchased the mining right of the Lomoteng mining area in July 2010 (Super Mayer investment Ltd. 2012).

Geology

Lomoteng is located in the mid-Postmasburg Anticline which is bound in the Postmasburg manganese metallogenic belt of the Kalahari iron and manganese metallogenic belt. The Postmasburg manganese metallogenic belt is divided into three ore belts, the east ore belt, the west ore belt and the south-west ore belt in the Wolhaarkop mining area. The Lomoteng mine is located in the middle of the west ore belt (Super Mayer investment Ltd. 2012).

Mining and processing

The mine is a large-scale open pit manganese mine with its own large transport fleet. This deposit has been proved for 135.58 Mt of iron ore and high-iron manganese ore after United Nations Framework Classification (UNFC). In particular, 17.62 Mt of iron ore resources and 117.96 Mt of high-iron manganese ore resources, with 86.84 Mt of high-iron resources are of indicated mineral resources and 31.12 Mt of inferred mineral resources. The grade for the high-iron manganese ore resource is between 25 % Mn up to 34 % in special areas of the deposit and 25.4 % of Fe (Super Mayer investment Ltd. 2012). The mine has an annual production capacity at 600 kt. The company exports 30–45 kt/m to China to satisfy the 40 to 50 kt of demand for the Chinese market (Strata Africa Resources 2017).

2.5.3 Exploration and prospection projects

Several exploration and prospection projects are currently in progress or have been in the last years. Tab. 2.12 shows a selection of promising projects. Some of these will be discussed in more detail in the following section.

One of the most promising projects in the KMF is the **Avontuur Project**. Aquila Resources Ltd. completed a Definitive Feasibility Study (DFS) for a medium- to high-grade manganese project at the Gravenhage deposit which is located approximately 30 km north of the KMF. The DFS proposes a 1.5 Mt/a run-of-mine open pit operation, with subsequent underground mining by decline access from the open pit. The DFS provides for oxide ore to be crushed and screened to produce 1.125 Mt/a of lump ore for export and 330 kt/a of fine ore for sale to domestic sinter plants. Blending stockpiles at the mine will allow for a consistent product to be prepared for transport to domestic and international customers. Marketing studies indicate Gravenhage's lump product should be able to attract similar Mn prices to those achieved by premium South African and Australian ores, due to relatively low contaminant levels that contribute to slag formation in ferroalloy furnaces (Aquila Resources 2015). The South African rail and port infrastructure is owned and managed by Transnet, a state-owned enterprise. Through its membership of the Manganese Industry Forum, Aquila has been working with Transnet, which is conducting a study into the expansion of the rail line to the port of Port Elizabeth, as well as the establishment of a new export terminal at the nearby deep-water port of Nggura (Aquila Resources 2015). The Gravenhage deposit has received almost all regulatory approvals. The only outstanding environmental license is a Water Use License. The Gravenhage deposit has total resources after JORC compliance of 118.9 Mt with 31.9 Mt of measured resources, 47.6 Mt of indicated resources and 28.3 Mt of

Tab. 2.12: Exploration and prospection projects (SNL Metals & Mining 2017).

Mine	Owner/Operator	Coordinates	Capacity	Mn [%]	Fe [%]	Resources	Status
Avontuur (KMF)	Aquila Resources Ltd. (74 %, operator), Rakana Mining (26 %)	26°51'0''S 22°52'12''E	/	39	/	161 Mt	Feasibility complete (temporarily inactive)
Tschipi Bokone (KMF)	Main Street 774 (Pty) Ltd. (50.1 %), Jupiter Kalahari S.A. (49.9 %), Tshipi é Ntle Manganese Mining (Operator)	27°4'48''S 22°51'21.6''E	/	/	/	Not determined	Exploration (temporarily on hold)
Kalagadi (KMF)	Arcelor Mittal (50 %), Kalagadi Manganese (Pty) Ltd. (40 %, operator), Industrial Development Corp. (10 %)		3 Mt/a	36–38	/	/	Construction started (active)
Kudumane (KMF)	Kudumane Manganese Resources		2.5 Mt/a	37	/	/	Preproduction – construction started (active)
Emang (PMF)	Emang Mmogo Mining (70 %), Segue Resources Limited (30 %)	28°4'58.8''S 23°1'37.2''E	500 kt/a	24.8	20.6	14 Mt (inferred resources)	Advanced exploration (temporarily inactive)
Kongoni (KMF)	Eurasian Resources Group B.V. (74 %), Amari Resources (26 %), Natural Resources Corp Ltd. (Operator)		/	35.8	/	150 Mt	Reserves development – prefeasibility (active)
Kareepan (PMF)	Gecko Africa (Pty) Ltd.	28°14'31.2''S 23°4'30''E	120–240 kt/a	/	/	/	Exploration
Autumn Skies Mine (PMF)	Strata Africa Resources		25–35 Mt/m	34–40	62–64	/	Prospection

inferred resources. Additional manganese mineralisations within the Avontuur prospecting right are the Haakdoorn and Eersbegint deposits which show total inferred resources after JORC compliance of 8.4 Mt and 1.8 Mt, respectively, with a Mn grade of 40.8 and 45.5 %, respectively (ASX Release 2012). The project is temporarily inactive, due to mining right uncertainties.

At **Tshipi Bokone** drilling and exploration work is currently being undertaking. Even though no resource has been determined yet, it is clear that there is a high potential for high-grade manganese ore as proved by drilling results. Several holes intersected various grade of manganese at a depth between 220 and 370 m. However, exploration at Tshipi Bokone is temporarily on hold as the focus is on bringing Tshipi Borwa (see chapter on operating mines) to optimum production (OM Holdings Ltd. 2016).

The **Kalagadi Manganese Project** has concluded an agreement with Arcelor Mittal to bring the Kalagadi project into production. The underground mine is expected to produce 3 Mt per annum of run of mine ore at a grade of 36 – 38 % Mn. An ore preparation facility and sinter plant is expected to beneficiate the ore into 2.4 Mt per annum of a high grade sinter (47 % Mn) (Kalagadi Manganese 2016).

The **Emang Manganese Project** covers 1,668 ha and with a maiden JORC-compliant inferred resource of 14 Mt with 25 % Mn and 12 % Fe including a high-grade component of 4 Mt with 34 % Mn and 11 % Fe. The project is planned to be an open pit project of 500,000 t/a of a saleable product with a grade of 36 – 38 % Mn and 12 – 15 % Fe. The project is located close to essential infrastructure including rail, water, power and roads (Segue Resources Ltd. 2012).

The **Kareepan Project** is a joint venture arrangement between Kaboko Mining Ltd. and Genet South Africa (Pty) Ltd. The project does not have a JORC-compliant resource but does have significant historical mining and drilling records as well as a current mining right enabling activity to commence mining. Preliminary processing test work has been undertaken on the ore-body and potential grade and recovery results have been established. The company considers the Kareepan dumps as an interim income stream until proposed exploration confirms an initial JORC-compliant resource statement which will then establish mining operations on the main ore body. An exploration drilling programme commenced in November 2013 to drill approximately 1,600 m to assess mineralisation on the project area followed by auger drilling of the detrital deposits. The drill programme will enable a report to be prepared identifying a JORC-compliant resource and a mine plan for production of saleable ore at between 10,000 and 20,000 t/m (ASX Announcement 2013).

At **Autumn Skies** the prospecting area is 2,339 ha. An extensive exploration programme and feasibility study are effective from mid-2013. It is believed that this extensive prospecting area will deliver at least a mining area with the potential of a 5 – 10 year life of mine. Autumn Skies Mine could produce iron ore and manganese ore. Currently, only a resource for minable iron ore is available (3.67 Mt). Further exploration work will be conducted to determine the total resource and reserve of both iron ore and manganese ore (Strata Africa Resources 2017).

2.6 Requirements and evaluation

South Africa hosts the world's largest manganese resources (75 %), followed by the Ukraine (10 %). The KMF in South Africa alone contains approximately 10 bn t of manganese resources with a grade of 20 – 48 %.

Tab. 2.13 shows reserves and resources of important manganese deposits in South Africa. The majority of the South African manganese deposits and occurrences are largely associated with the KMF or the PMF containing high-grade manganese ore (up to 44 %) ranging from metallurgical to battery grade ore (Fig. 2.13).

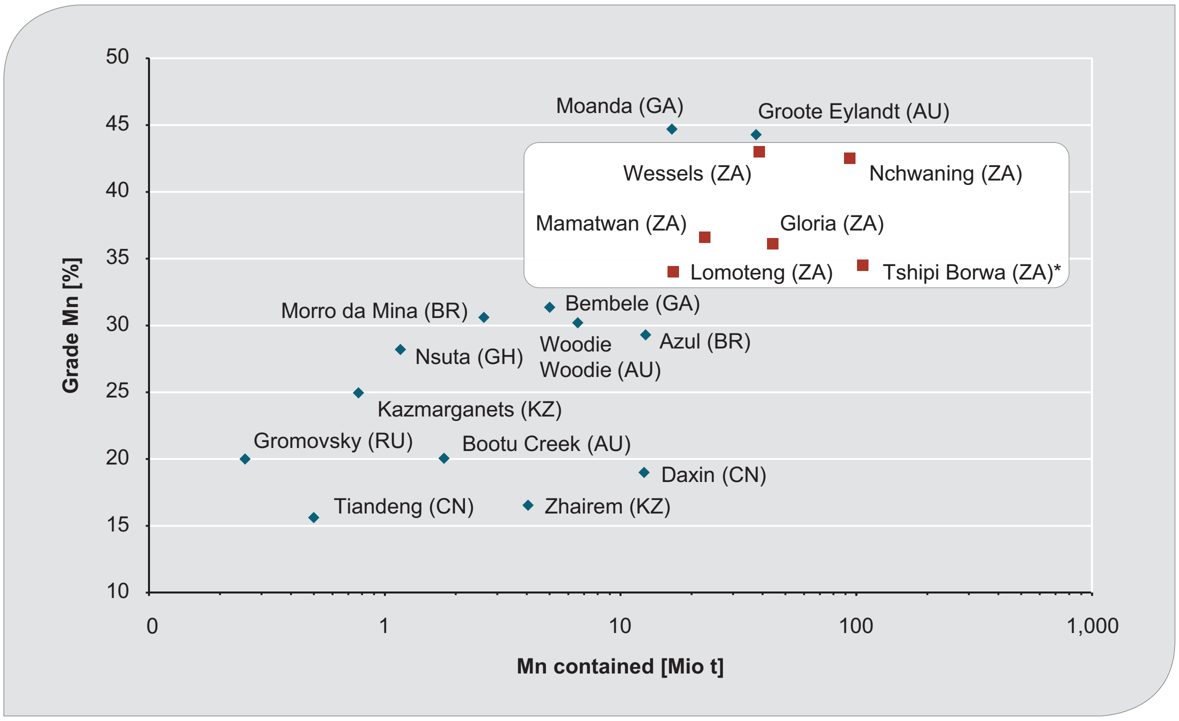

Fig. 2.13: Grade-tonnage-diagram of operating mines worldwide with proven reserves.
* only resources are announced for Tshipi Borwa, even though it is currently one of the top producing operating mines no reserves are indicated.

Tab. 2.13: Selected manganese deposits in South Africa with reserves (operating mines) and resources (exploration projects).

Deposit	Ore [Mt]	Grade [%]	Mn-contained [Mt]
Reserves			
Nchwaning/ Gloria	315.60	40.3	127.2
Tshipi Borwa	308.23	34.5	106.3
Hotazel	152.10	39.95	60.8
Lomoteng	49.26	34	16.7
Resources			
Avontuur	162.0	38.6	62.5
Kongoni	85.0	35.8	30.4

According to Petrow's mapping of the deposit size (Tab. 2.14) deposits from the KMF (e.g. Gloria/ Nchwaning, Tshipi Borwa or Hotazel) are classified as medium to very large deposits while deposits from the PMF (e.g. Avontuur or Kongoni) reach a medium size, however with lower grades than deposits in the KMF.

Tab. 2.14: Size classification of manganese deposits according to Petrow et al. 2008.

Tonnes (Mt)	Deposit size			
	Small	Medium	Large	Very Large
Mn	< 25	25–75	75–100	> 100

Compared to international standards, Gabon, Australia and South Africa are the world's largest producers of high-grade manganese ore. However, the deposits of Gabon and Australia and most of the other deposits worldwide are smaller compared to South Africa's reserves. Deposits comparable to the ones in South Africa are Groote Eylandt in Australia, a large deposit with average Mn contents of up to 44 %, (detailed information in Al Barazi et al. 2016; Fig. 2.13) or Moanda, a medium large deposit with an average grade of 45 % (Fig. 2.13). Deposits from China, Brazil or Kazakhstan have similar sizes but much lower grades between 10 and 30 %. However, Brazil, for example, offers deposits with inferred resources having a Mn grade of more than 50 %. Those mines/projects are currently inactive, in a reserve development status or

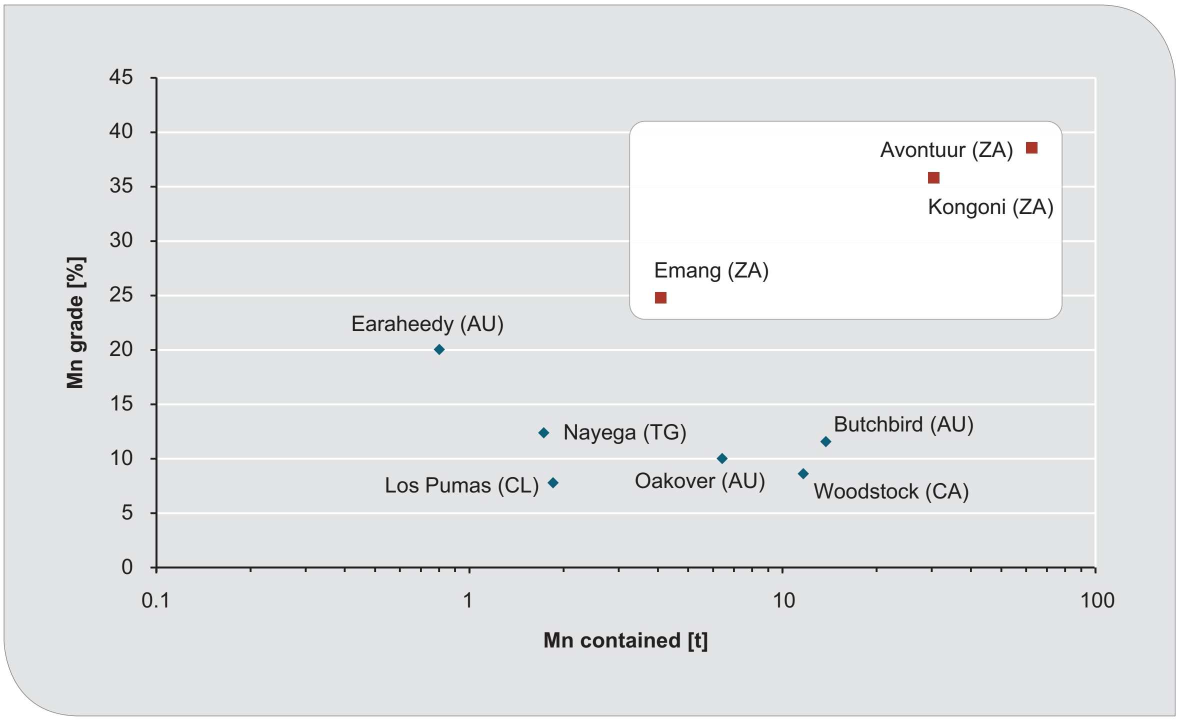

Fig. 2.14: Grade-tonnage-diagram of reserves and resources of worldwide manganese exploration projects.

do not have proven reserves and are therefore not described in this diagram.

Fig. 2.14 shows the exploration projects worldwide which are currently in an active, early to late stage development status. The different manganese exploration projects in South Africa, Kongoni, Emang and Avontuur are described in the diagram. However, there are several other small exploration projects which are briefly described above (Tab. 2.12), but are missing in the diagram because of lack of indicated either reserves or resources. Compared to other projects, the South African exploration projects are of much higher grade and are containing medium-grade ore (> 25 % Mn) while the projects that are currently under exploration in Togo, Chile, Canada and Australia are low-grade ores (< 20 % Mn).

The currently operating mines and associated projects (Hotazel, Black Rock and Tshipi Borwa) have huge amounts of reserves and resources (all in all more than 1 bn t). Therefore they alone can provide a great proportion of the manganese supply for the next decades. However, the South African exploration projects show a high potential concerning size and especially grade (e. g. Avontuur, Kongoni and Kalagadi > 35 % Mn). The exploration projects are currently located mostly in the PMF where significant potential is hosted for medium-grade ore

Tab. 2.15: Comparison of requirements concerning HC FeMn and SiMn.

Components	Requirements German industry (HC FeMn)	Assmang (HC FeMn)	Requirements German industry (SiMn)	Transalloys (SiMn)
Mn	75–79 %	76.4–76.59 %	65–75 %	66.7 %
Si	0.0–1.00 %	0.08–0.115 %	17–19 %	17.1 %
P	0.0–0.2 %	0.08 %	0.0–0.15 %	0.12 %
S	0.0–0.02 %	0.007–0.009 %	0.0–0.03 %	0.01 %
C	6–8 %	6.57–6.67 %	0.0–2.00 %	1.60 %

so that the increasing demand for medium-grade manganese ore can be met.

Furthermore, it should be noted that the specification of manganese alloys (described above) which are produced in the smelters of, for example, Assmang or Transalloys fulfil the requirements of the German steel industry concerning ferromanganese or silicomanganese (Tab. 2.15).

A slag utilisation process for returning manganese slag to the furnaces is resource potential which is currently under development. This process would add a huge number of unreduced manganese to the current reserves. Over the years approximately 20 Mt of HCFeMn and SiMn slag has accumulated on dumps in South Africa, constituting an environmental risk, and on average 0.5 Mt are added to these dumps each year. Even if existing environmental legislation does not support the implementation of viable slag utilisation processes right now (Steenkamp & Basson 2013), this could be a resource potential in the future.

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3 Vanadium

(H. Marbler, R. Opperman)

The following chapter gives a definition of vanadium as a raw material, describes active mines and exploration projects of vanadium in South Africa, analyses the global market situation and shows the overall potential of vanadium in South Africa in an international context.

3.1 Definition, mineralogy and sources

3.1.1 Definition

Vanadium is a grey white to silvery blue grey hard but ductile transition metal and the 23rd element in the 5th group of the periodic table with the symbol V. The element accounts for ~0.01 % of the total mass of the earth's crust with an average crustal abundance of 160 ppm (g/t; Goonan 2011). It occurs naturally as compounds with different valence states of +5, +4, +3, +2, +1 and –1 but mostly occurs in +3, as in V_2O_3, +4, as in VO_2 and +5, as in V_2O_5. In addition vanadium also occurs in a mixed (two) valence state for example V_3O_5, V_4O_7, V_6O_{11}, V_6O_{13}, V_7O_{13}, V_8O_{15}, etc.

Tab. 3.1: Physicochemical properties of vanadium (Chemistry Quick Facts 2017).

Symbol	V
Atomic weight [amu]	50.94
Density [g/cm³]	6.0
Hardness [Mohs scale]	6.7
Melting point [°C]	1,910
Boiling point [°C]	3,407
Crystal system	cubic
Colour	grey, silver grey, steel blue

3.1.2 Mineralogy

Vanadium is found in approximately 152 minerals with the most economical being patronite (VS_4), vanadinite [$Pb_5(VO_4)3Cl$] and carnotite [$K_2(UO_2)2(VO_4)2]\cdot 3H_2O$ (Hewett 1906; Goonan 2011), or as solid solution in magnetite.

The formation of vanadium minerals is dependent on V oxidation state, redox state and pH of the environment where it is formed. Vanadium minerals mostly occur as vanadium oxides, sulphides, secondary vanadates and as vanadium micas.

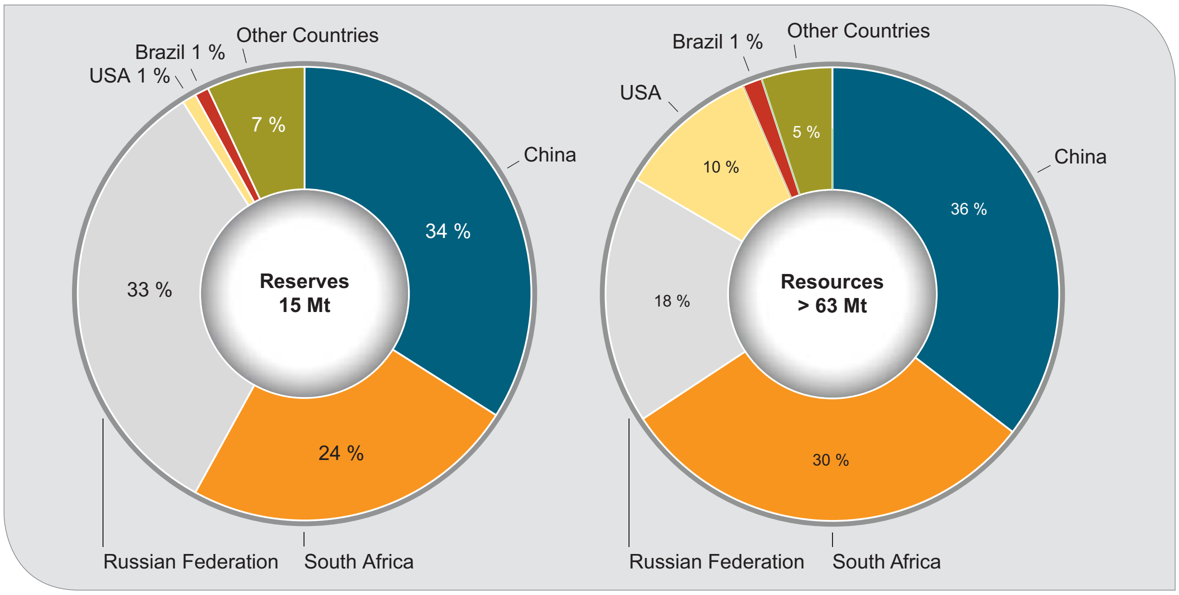

Fig. 3.1: Known (reported and announced) global reserves (left) and resources (right) of vanadium (in Mt V in total) in percentage distribution by the main countries (BGR 2016; USGS 2016).

Vanadium minerals form as:

- vanadium oxides within magnetite (titano-magnetite) and coulsonite, associated with titanium minerals (ilmenite, ulvöspinel), mostly in layered mafic and ultramafic intrusive bodies (as in the South African Bushveld Igneous Complex) subordinated in sandstone horizons,
- vanadium sulphide compounds with minerals including patrónite (VS_4), sulvanite (Cu_3VS_4) and colusite $Cu_{13}V(As,Sn,Sb)S_{16}$,
- secondary vanadate zones, above copper, lead or zinc ore,
- vanadium micas where vanadium (III) and some iron (II) replace aluminium in the octahedral layer of muscovite ($KAl_2(Si_3Al)O_{10}(OH)_2$) to form roscoelite ($KV_3$+2$(Si_3Al)O_{10}(OH)_2$

The vanadium in-situ content in commercially exploited deposits range between 0.2 and 1.6 % V_2O_5 (vanadium pentoxide), whereas the highest grades were found in the Brazilian Maracás Menchen deposit in Bahia with > 2 % V_2O_5. The South African Bushveld deposits contain around 1 % V_2O_5 in-situ.

3.1.3 Sources

The total world resources of vanadium exceed 63 Mt vanadium (contained metal) and the reserves announced, contain at least 15 Mt (USGS 2016). However, there are no official data from the USA, Brazil and other minor producers. The largest known reserves and resources are located in China, followed by South Africa, Russia and the USA (Fig. 3.1).

The world's most important vanadium deposits are vanadium-bearing titaniferous magnetites in mafic gabbro bodies in South Africa, north-western China, eastern Russia and north-east Brazil. Vanadium is also extracted from iron sands, phosphate and uranium ores and as a waste product in oil refinery (Fig. 3.2).

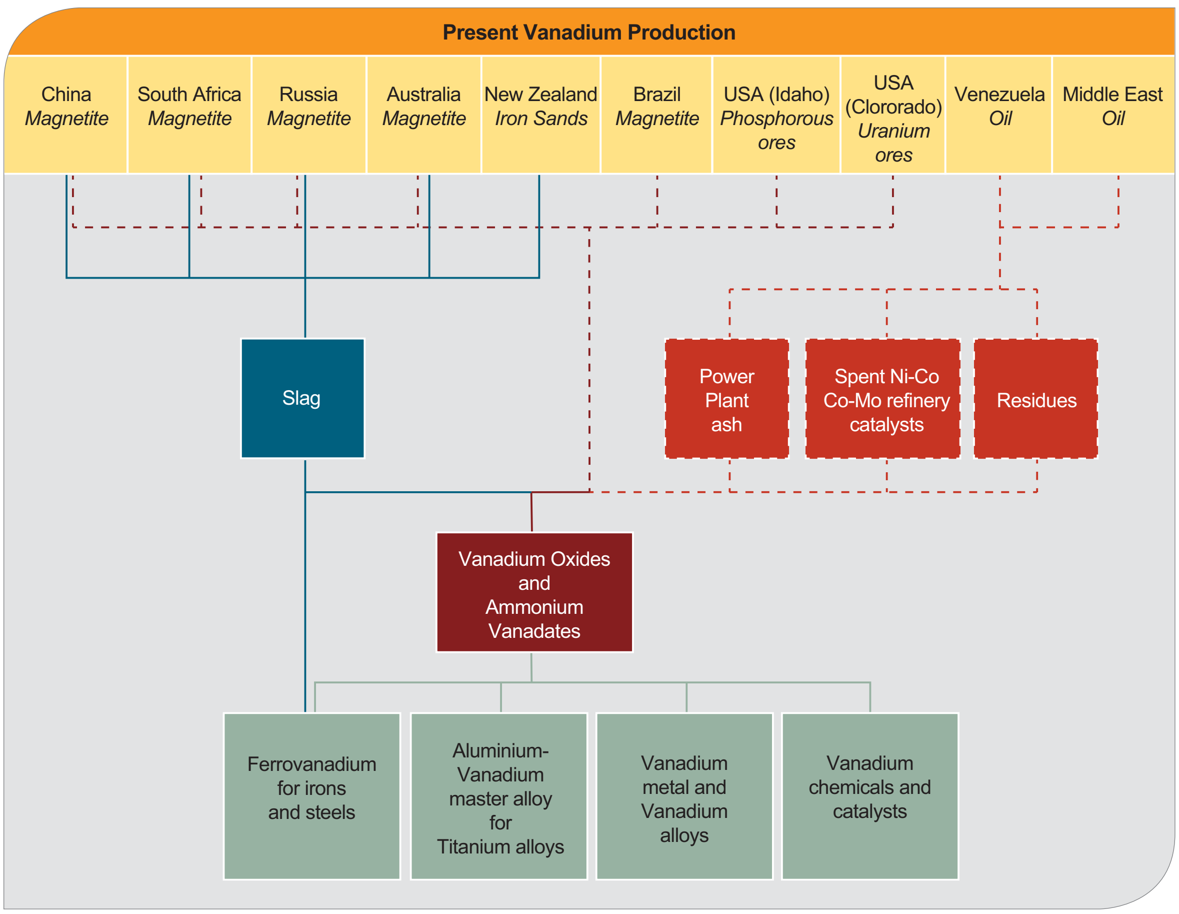

Fig. 3.2: World vanadium sources and final products (modified after Ocean Equities 2011).

3.2 Specification and use

The major part of vanadium, apparently 90 %, is utilised in steel production. A smaller percentage of consumption of about 4.5 % accounts for non-ferrous alloys (vanadium-aluminum master alloys), as titanium alloys, super alloys and magnetic alloys. The remaining 4.5 % are used in production of chemicals in catalyst and batteries (Fig. 3.3).

Vanadium use in steel can be further subdivided into HSLA steels (high-strength low-alloy steels), full alloy steels and carbon steels, with HSLA and full alloy steels together accounting for over three-quarters of all vanadium consumption in steels.

Steels containing vanadium have a much finer grain structure than steels of similar composition without vanadium. Vanadium decreases the rate of grain growth during heat treating processes and raises the temperature at which grain coarsening sets in thus improving the strength and toughness of hardened and tempered steels. Contents up to 0.05 % V increase hardenability while larger amounts tend to reduce hardenability due to the formation of carbide. Vanadium lessens softening on tempering and induces secondary hardness on high speed steels. The use of the special alloy nitride vanadium (see also chapter 3.5.4) strengthens steel more efficiently than ferrovanadium, allowing steelmakers to use less vanadium in high-strength steels and reducing vanadium costs by as much as 40 % (Evraz Vametco 2014).

Electrolyte properties of vanadium allow it to be very useful in batteries both for automotive use (vanadium-lithium) and for grid-scale storage of power in Vanadium Redox Batteries (VRB).

3.3 Mining and processing

3.3.1 Mining

The most economic vanadium deposits are vanadium-bearing titaniferous magnetite formations that are several metres in thickness, shallow-dipping and mostly outcropping layers, as in the South African Bushveld Igneous Complex. This geological situation is ideal for open-cast mining with conventional drilling, blasting, loading and hauling operations. Usually the total ore package with a sequence of mineralised layers is mined. After-

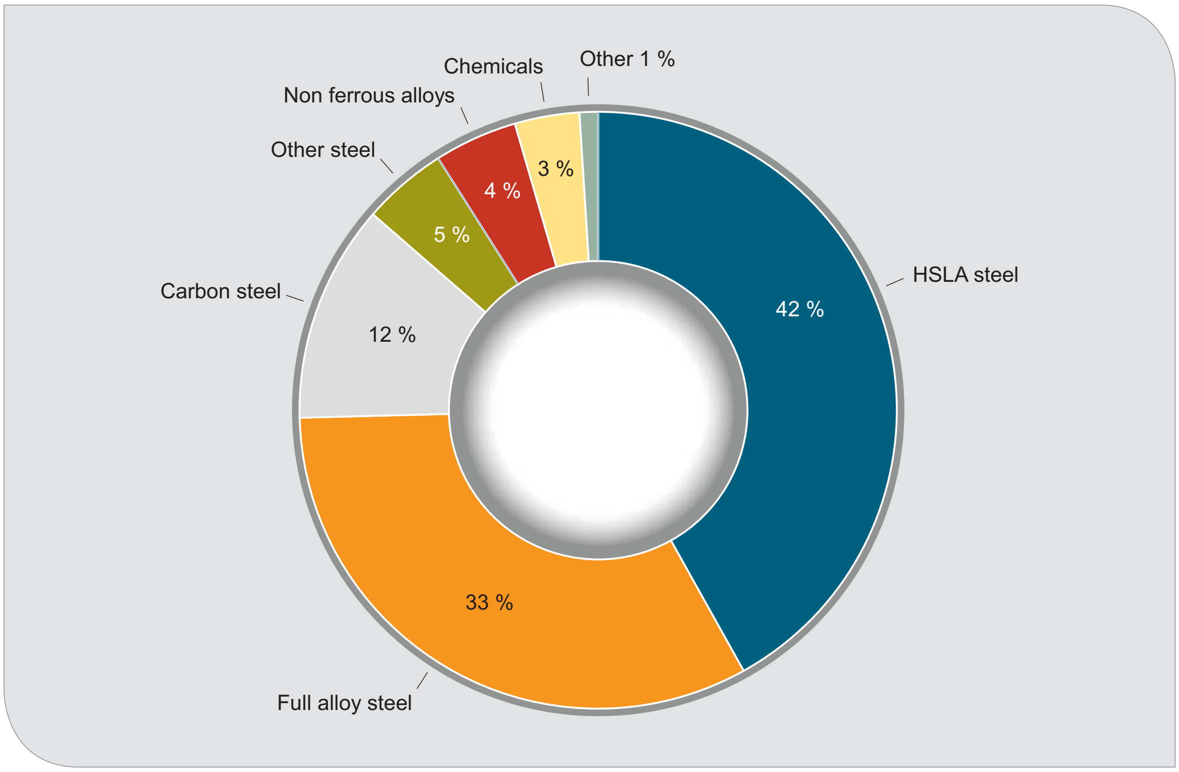

Fig. 3.3: Consumption of vanadium in end products (Roskill 2015).

wards the magnetite is separated from the gangue using magnetite separation.

3.3.2 Processing

Basic metallurgical processing of titaniferous magnetite for vanadium production

Vanadium extraction processes are similar in that they incorporate a liberation phase, a concentration phase, a conversion phase and a recovery phase. Two distinct processing flowsheet options are employed for the beneficiation of vanadium ore.

Option 1: A Salt Roast flow sheet is used to produce a primary vanadium product employed by Glencore Rhovan and the former Evraz Vametco (now Brits Plant) operations in South Africa;

Option 2: A Pig Iron flow sheet is used to produce pig iron and vanadium bearing slag and ferrovanadium products, formerly employed at the Evraz Highveld Steel and Vanadium plant in South Africa.

A Salt Roast flow sheet, employed by Glencore Rhovan and Vametco Brits plant

A typical Salt Roast flow sheet is shown in Fig. 3.4. The first stage in this processing route is the beneficiation of the ore to produce a magnetite-rich concentrate. The ore is passed through a three-stage crushing circuit and is milled with a conventional rodmill-ballmill combination to produce a product that is 80 % passing 53 microns. It is then passed through a three-stage low-intensity magnetic separation circuit to produce a concentrate product. The second stage involves the roasting of the concentrate with sodium carbonate and sodium sulphate in a rotary kiln at temperatures of up to 1,150 °C to

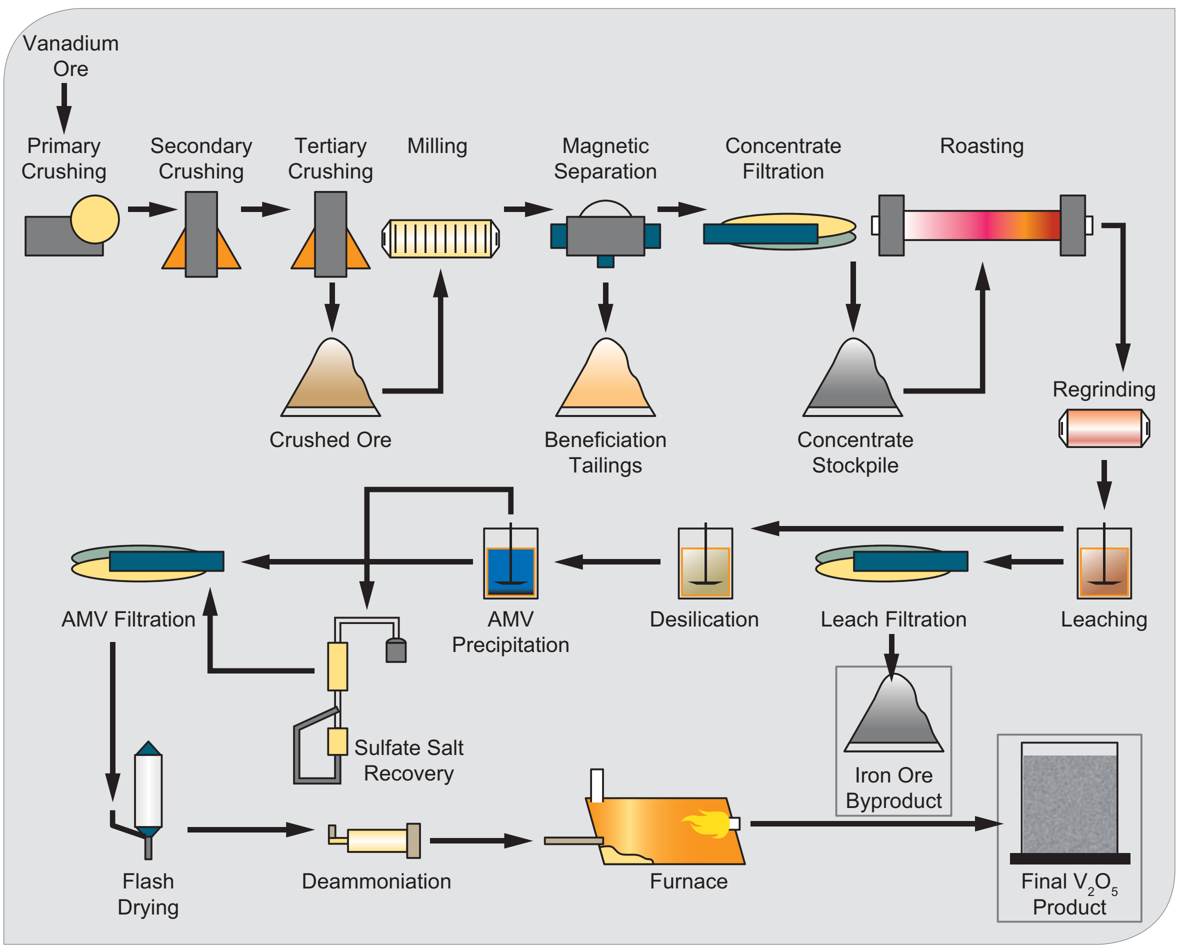

Fig. 3.4: High-level illustrative block flow diagram of the Salt Roast technique in the vanadium plant (after Waldeck et al. 2014).

form vanadates soluble in water. Solids existing in the rotary kiln are discharged directly into a rotary cooler that cools the solids to 350 °C (Moskalyk & Alfantazi 2003).

The cooled product, known as calcine, is fed to a wet ball mill, which grinds the agglomerated material for improved leaching and also acts as the first stage of leaching. The slurry from the mill is pumped to thickeners where desilication and concentration of the vanadium-bearing leach liquor take place. Thickened tailings are conveyed to the tailings disposal facility.

Ammonium sulphate (AMSUL) is added to the vanadium bearing leach liquor which allows for the precipitation of vanadium in the form of ammonium metavanadate (AMV). The AMV filter cake is dried in a diesel-fired flash dryer and calcined in a diesel-fired AMV calciner to produce V_2O_5. The calcined V_2O_5 powder is charged into a fusion furnace to form molten V_2O_5. The molten V_2O_5 is continuously tapped and flows onto water-cooled flaking wheels forming a thin layer of V_2O_5, which solidifies and is then scraped off as the final product of V_2O_5 flakes. The V_2O_5 product can be sold directly into the vanadium market or can be processed further mainly into a 80 % FeV (Ferrovanadium: FeV80) product through a simple process using an aluminothermic reactor. The addition of a ferrovanadium circuit either to convert vanadium pentoxide (V_2O_5) to ferrovanadium (FeV80) or generate it directly through a vanadium trioxide route, V_2O_3 as the final product or as part of a mixed product stream is becoming more common. Usually this will add significant value to the project because the ferrovanadium product achieves a price premium over vanadium pentoxide (Waldeck et al. 2014).

Production of pig iron and a vanadium bearing slag product employed at the Evraz Highveld Steel and Vanadium plant

Evraz Highveld Steel and Vanadium recovers vanadium as a by-product in its steel making production (Dworzanowski 2013; see also chapter 3.5.3). The vanadium-rich magnetite ore is crushed and mixed with coal, silica and limestone for fluxing, and is fed into a series of rotary kilns in which the ore receives a partial pre-reduction of about 37 to 45 % depending upon requirements (Steinberg et al. 2011). The high-titanium iron ore is then smelted in a submerged-arc furnace in which the temperatures are high enough to slag off all the titanium. The ferrotitanium melting point ranges from 1,070 – 1,135 °C, while ferrovanadium melts at 1,695 – 1,770 °C.

On leaving the smelting furnace the hot metal is passed to the shaking ladles which are top blown with oxygen. During this stage the vanadium is oxidised to V_2O_5 and forms as a slag, which is skimmed off. The vanadium content in the vanadium-rich slag is approximately 25 % V_2O_5, which is eminently suitable for the production of high purity V_2O_5 by the previously mentioned conventional sodium roast and leach process. This slag is sometimes crushed and cleaned by a magnetic separator for the removal of any metal that may have been carried over, and the rest of the pig iron follows the normal steel making process (Duke 1983; Dworzanowski 2013; Steinberg et al. 2011).

New processing techniques – hydrometallurgical

The alternative for processing titanomagnetites is a hydrometallurgical process. This has been explored in the past; however, the challenge has been to minimise the dissolution of iron in leaching without sacrificing the extraction efficiency of vanadium. The limiting factor in the process is being able to selectively separate the vanadium from the iron. The basic process involves acid leaching combined with solvent extraction and stripping to selectively recover units of vanadium, along with titanium and iron from the magnetite concentrate. Once the selective separation of the metals can be enhanced in this process, the technology has the potential to serve as a cost effective alternative to the more traditional pyrometallurgical process, also adding other valuable revenue streams from titanium and iron products.

Titanium recovery

Titanium recovery from vanadium ores in other parts of the world has been possible through basic physical beneficiation methods such as magnetic separation. The problem with the titaniferous magnetite ores of the Bushveld Complex is that titanium, occurring as ulvöspinel, is intergrown within the magnetite (which contains the vanadium) which makes it impossible to remove it to any significant degree by physical beneficiation methods. For this reason, Bushveld titaniferous magnetite ores undergo smelting, where the titanium is slagged off. The titanium slag contains the approximate equivalent of 37 % TiO_2. To date it has proved to be difficult to economically recover the titanium which mainly is in the form of lower oxides as TiO_2 and $CaTiO_4$. A small quantity of crushed titanium slag is sold for use as a flux and to protect the refractory linings of the blast furnaces.

3.4 Supply and demand

Vanadium price development reflects the supply situation. A negative growth of vanadium prices on the world market, commenced in Q3, 2014 until Q3, 2015 (Fig. 3.5), mainly caused by oversupply of V_2O_5 and FeV (Roskill 2015). Significant production cutbacks in vanadium slag at Evraz Highveld Steel and Vanadium and the closure of the Evraz Highveld’s Mapochs vanadium mine (see also chapters 3.5.2 and 3.5.3) had some positive pricing factors from Q4, 2015 until at least Q3, 2016, with prices climbing in USA, Europe and China. Also a reduced availability of ferrovanadium and vanadium slag following cutbacks in the steel production in China, namely by the Panzhihua Iron and Steel Group (Pangang), Chengde Iron and Steel and the Jianjiong Vanadium Industry resulted in a rise of the prices (Argus Metals International, April 2016). Furthermore, in December 2016 the state-owned Pangang declared that it will reduce its vanadium pentoxide output by 200 t per month (Argus Metals International, December 2016). These facts and the current situation in the vana-

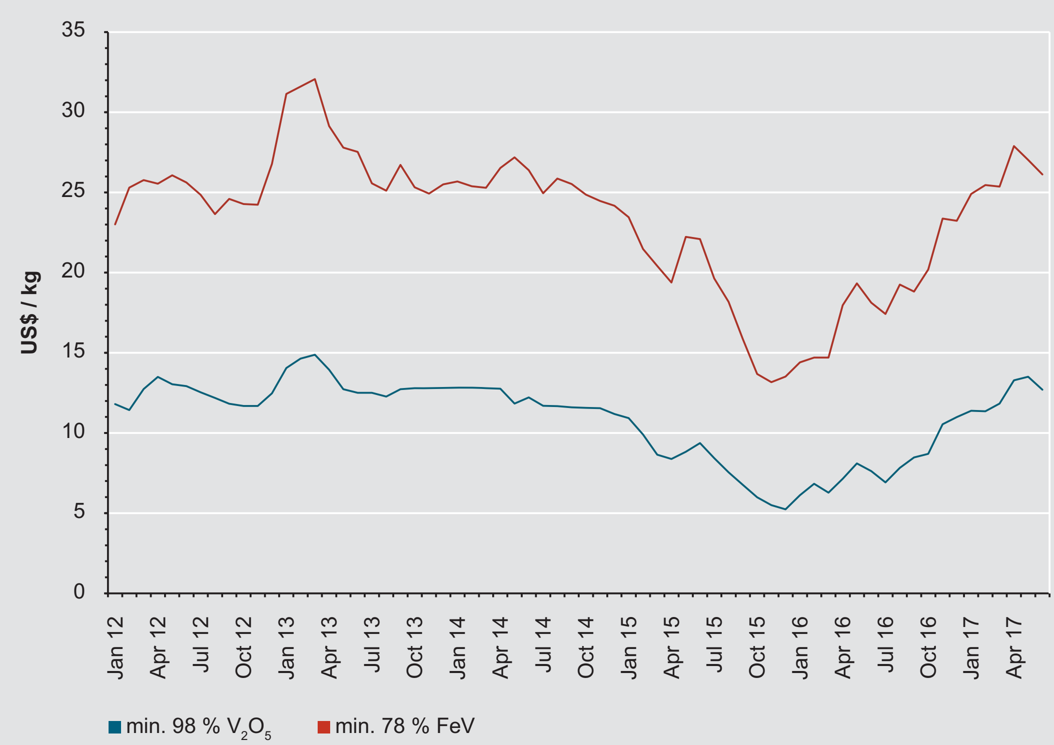

Fig. 3.5: Prices of ferrovanadium (FeV 78 % min.) and V pentoxide (V_2O_5 98 % min.) over five years (source: BGR 2016).

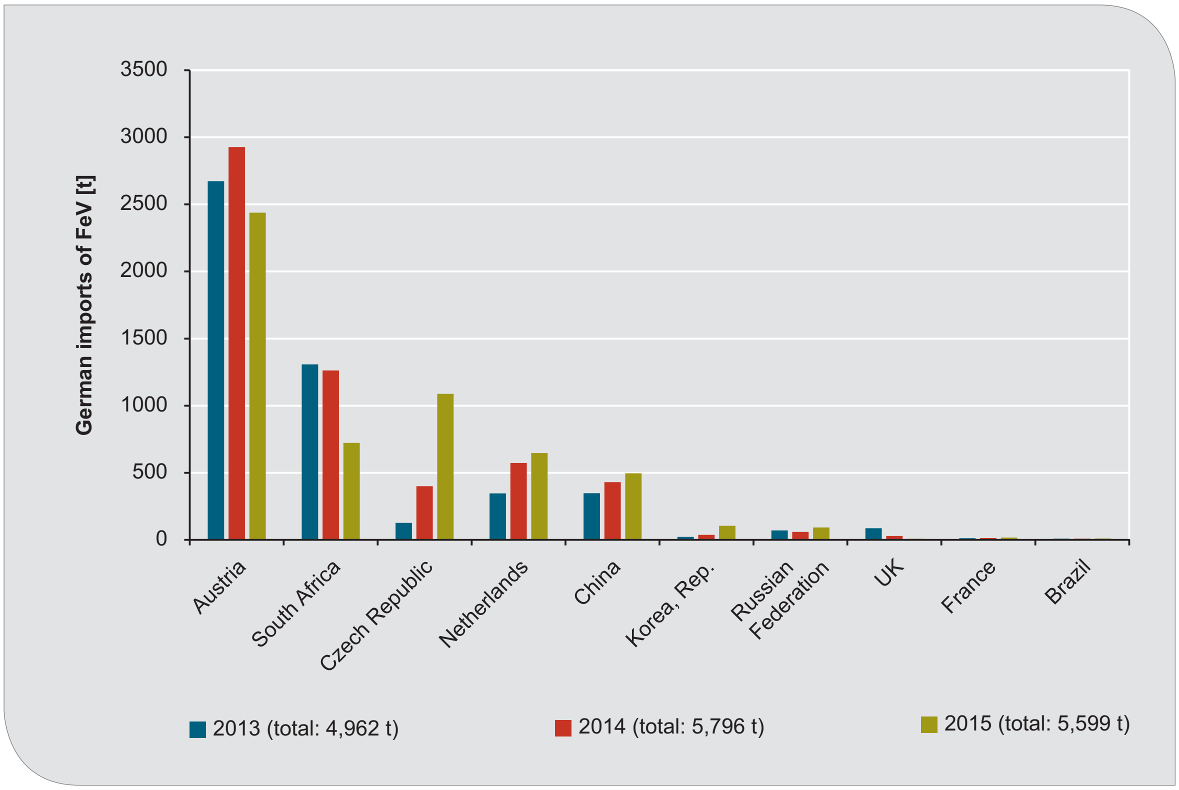

Fig. 3.6: Origin of German imports of ferrovanadium over three years by country (BGR 2016).

dium market appear to be having a significant effect on prices for ferrovanadium as well as for vanadium pentoxide.

3.4.1 Demand

Germany

Germany is by far the largest European steel-making country and therefore also the largest consumer of vanadium and vanadium alloys in the EU. Total imports of vanadium to Germany within the past three years amounted to around 15,000 t/a, wherein 98 to 99 % accounted for ferrovanadium. The most important supplier for ferrovanadium is Austria followed by South Africa, whereas the Czech Republic overstepped the South African ferrovanadium exports to Germany in 2015 (BGR 2016; Fig. 3.6).

The chemical composition of FeV is predetermined from German steelmakers with 78 to 82 % V. The upper limits of harmful accompanying by-products are commonly: 0.25 % C, 1.5 % Si, 2 % Al, 0.06 % P, 0.03 % S and 0.03 % Ti.

Other European countries

Until 2016 Austria imported vanadiferous slags mainly from Evraz in South Africa for further processing into vanadium products. The slags go via Hochvanadium Holding AG, a subsidiary of Evraz Highveld Steel and Vanadium Corp. Ltd., to Treibacher Industry AG for further processing primarily to ferrovanadium (FeV80 and FeV65), but also to chemical vanadium products such as vanadates and vanadium sulphates for catalysts, pigments and for the pharmaceutical industry. Treibacher Industry AG is the only producer of ferrovanadium in Austria, doing mostly high-grade ferrovanadium for European steelmakers and accounting for the majority of German ferrovanadium imports. In 2014 Austria exported a significant amount of 7,700 t of ferrovanadium (Roskill 2015). Furthermore Austria imported 1,200 t of vanadium pentoxide (V_2O_5) from the Russian Federation in 2014.

The ferrovanadium industry in the Czech Republic is based on vanadium pentoxide imports from the Russian Federation for conversion to ferrovanadium. Ferrovanadium from Netherlands is mainly of Chinese origin (Roskill 2015).

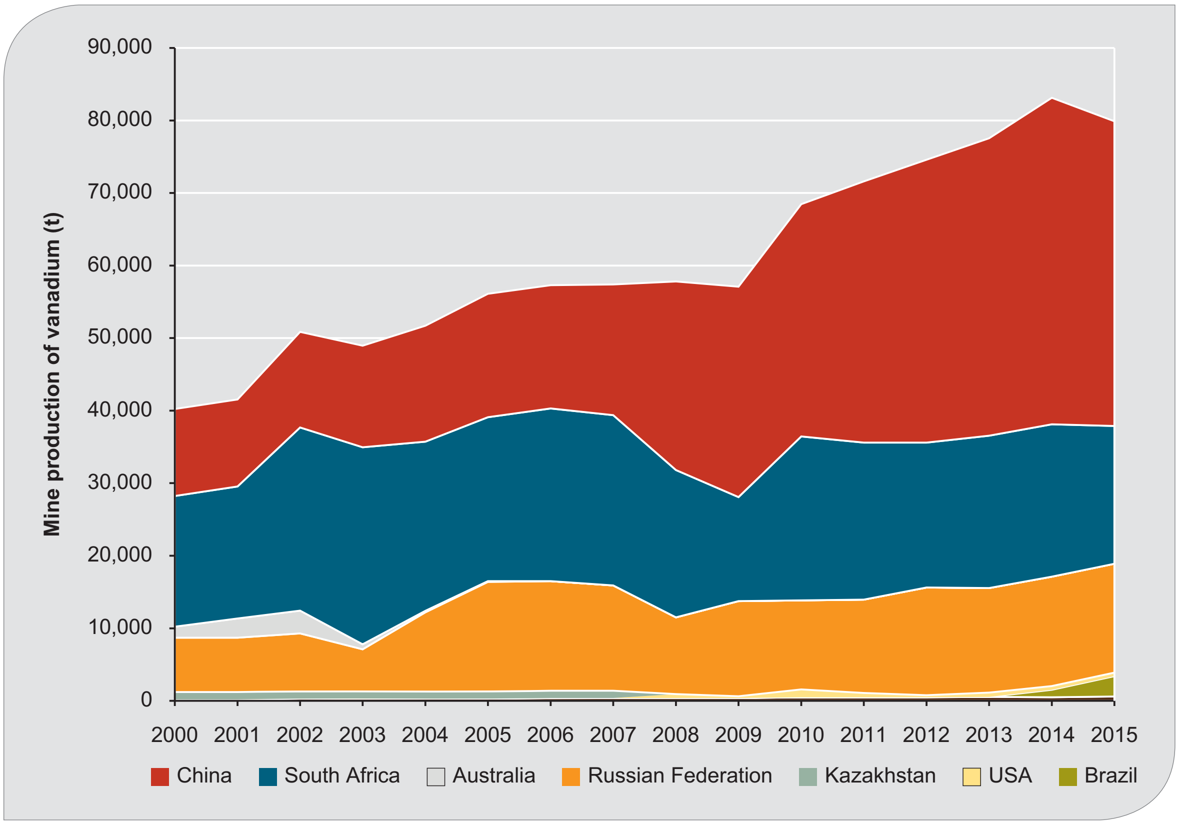

Fig. 3.7: World mine production of vanadium from 2000 to 2015 in metric tonnes (BGR 2016; USGS 2016).

3.4.2 Supply

The mine production of vanadium is mainly dominated by four countries – China, South Africa, Russia and, since 2014, Brazil. These countries collectively produce > 98 % of the world's vanadium. However, from 2014 to 2016, the vanadium market is in a state of oversupply (see also chapter 3.4), with the demand remaining sluggish since the global financial crisis leading to a drop in prices. The 2015 world vanadium production fell by 4.2 % to 79,400 t, after it grew in 2014 by 4 % to 82,700 t (USGS 2016), notably from expansion projects from existing Chinese producers but also the Brazilian newcomer, Largo Resources from its Maracás Menchen Mine in Bahia. South Africa was the largest vanadium producer for many years, until it was overtaken by China in 2007 (Fig. 3.7). The reduced production of vanadium slag at Evraz Highveld Steel and Vanadium Corp. Ltd. since 2015 caused a significant gap in the South African vanadium industry (chapter 3.4).

South Africa

Mine production of vanadium in South Africa amounted to 21,000 t V (metal content) for 2013 and 2014 and decreased to 19,000 t V in 2015 (Fig. 3.7). The main reason for this is a reduced production of vanadium at Evraz Highveld Steel and Vanadium Corp. Ltd. and its subsidiaries in South Africa caused by internal company problems (see also chapter 3.5.3).

Vanadium ores in South Africa show contents of vanadium pentoxide (V_2O_5) of between 0.2 % and a maximum of 2 %. Vanadium extraction in the Bushveld Complex occurs through a series of metallurgical processes, resulting in V_2O_5 flakes as the final sellable product (Fig. 3.8). South African producers follow different process routes according to the end product desired by the client. V_2O_5 is produced first in a refining process and then converted to FeV for use in steel (see chapter 3.3.2).

Fig. 3.8: Vanadium pentoxide flakes with a purity of > 99 % (photo: DERA 2015).

For use in batteries, vanadium is required to be in a 'high-purity' electrolyte form, typically 99.5 %. In the traditional pyrometallurgical processes the intermediate step to produce steel grade V_2O_5 is only 98.5 % purity. These products cannot be used in battery applications. High-purity battery grade vanadium requires further processing of steel grade V_2O_5 to remove contaminants in the electrolyte and therefore has additional capital and operating costs involved. Stratcor in Arkansas (Liddell 2011) and Maracás Menchen in Brazil are the only producers of battery grade V_2O_5 at the moment.

Currently, there are two operating mines producing vanadium in South Africa: Rhovan and Vametco and also two plants producing ferrovanadium and vanadium pentoxide (Rhovan and Vanchem) and additional five exploration projects: Bushveld Vanadium, Aurora, Nonnenwerth, Veremo and VanRes. However, only VanRes and Bushveld Vanadium (the Mokopane Project) which are in an advanced status (Tab. 3.2, Fig. 3.9) are described in detail in the following section.

Tab. 3.2: Vanadium operating mines, plants and projects in South Africa.

Property	Owner(s)	Development stage	Activity status	Coordinates	Commodity(s)	Reserves (Mt ore)	Total min. resources (Mt ore)	In-situ grade (% V_2O_5)
Bushveld	Bushveld Minerals Ltd., BEE	Pre-feasibility Scoping	Active	23°50'33.81"S / 28°47'1.80"E	Iron Ore, Vanadium, Titanium	28.5	284.8	1.41
Rhovan	Rhombus Vanadium (Pty) Ltd.	Operating	Active	25°34'34.00"S / 27°35'8.76"E	Vanadium, Ferrovanadium, Iron Ore, Titanium, Magnetite	39.6	182.6	0.8
Mapochs	(former) EVRAZ Highveld Steel	On care and maintanance	Temporarly inactive	25°10'28.42"S / 29°54'9.53"E	Vanadium, Iron Ore, Magnetite, Manganese, Titanium, Iron, Ferrotungsten, Ferronickel, Ferrotitanium, Ferrovanadium, Iron	NA	22.9	1.74
Aurora	Sylvania Platinum Ltd., Impala Platinum Ltd., Matlala-A-Thaba	Reserve Development	Active	23°34'14.02"S / 28°54'47.99"E	Platinum, Palladium, Nickel, Copper, Vanadium, Iron Ore, Titanium	NA	NA	
Brits Plant, Krokodilkraal	Vametco Min. Corp., Bushveld Minerals Ltd., Yellow Dragon	Operating	Active	25°34'10.25"S / 27°53'6.38"E	Vanadium	NA	NA	
Highveld	EVRAZ Highveld Steel	N.A.	Active	25°52'57.49"S / 29°5'39.01"E	Vanadium	NA	NA	
Highveld Smelter	EVRAZ Highveld Steel	N.A.	Active	25°52'58.00"S / 29°5'37.15"E	Ferrovanadium, Vanadium, Vanadium Slag	NA	NA	
Kennedy's Vale	Vanadium Technology (Pty) Ltd.	N.A.	Inactive	24°48'51.43"S / 30°06'23.27"E	Iron Ore, Vanadium	NA	NA	
Veremo	Petmin Ltd., Kermas Ltd.	Feasibility	Active	25°14'12.00"S / 29°47'53.00"E	Iron Ore, Titanium, Vanadium	NA	NA	
Steelpoortdrift (VanRes)	Vanadium Resources Ltd.	Pre-feasibility	Active	24°53'43.74"S / 30°1'4.33"E	Iron Ore, Titanium, Vanadium	NA	513	1.4

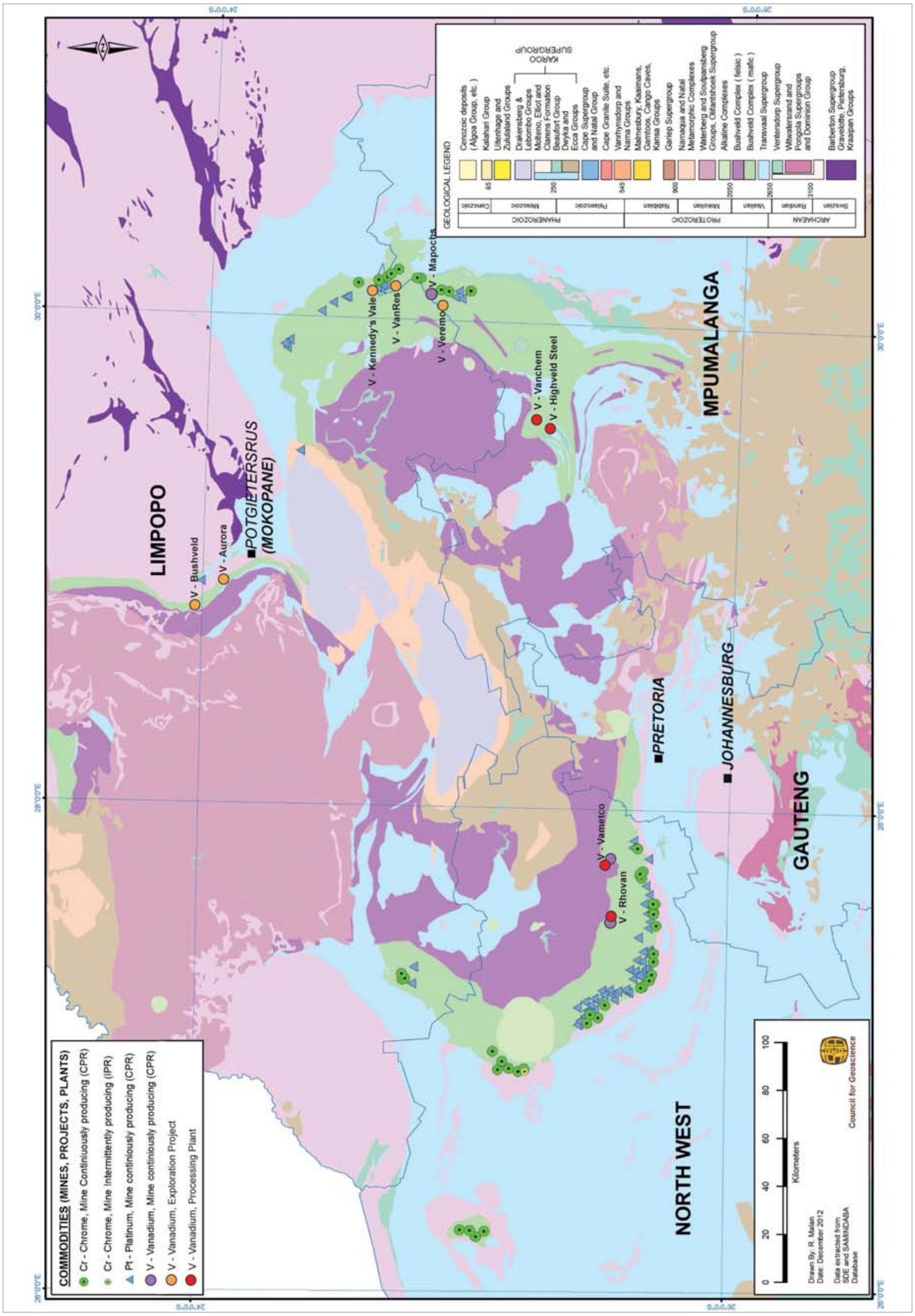

Fig. 3.9: Geological map of the Bushveld Igneous Complex with vanadium operating mines, plants and projects as well as chromite and platinum mines (updated after Council for Geoscience).

3.5 Operating mines and plants

Currently there are only two active and producing vanadium mines and plants in South Africa, which are Rhovan (see chapter 3.5.1) and Vametco with its Krokodilkraal Mine (see chapter 3.5.4). For an overview on the operating mines and exploration projects see Tab. 3.2 and Fig. 3.9.

3.5.1 Rhombus Vanadium ("Rhovan", Glencore plc.)

Location, ownership and project history

Rhovan is one of the world's leading producers of primary vanadium. The operation was officially opened in July 1991 by Rhombus Vanadium Holdings Ltd. Xstrata Alloys plc. took the mine over in 2004 and in 2013 Xstrata was merged with Glencore plc. Glencore is operating the mine and the plant and actually owns 74 % of the shares and the remainder 26 % of the shares are held by the BEE consortium Bakwena Ba Mogopa Traditional Community.

The vanadium mine and plant are located in the south-western limb of the Bushveld Complex about 22 km north-northwest of Brits on the R556 road in the Gauteng Province. The license area extends along the outcrop of the ore body from WNW to ESE over 17 km (Fig. 3.12).

Geology

The main magnetite layer and its associated layers are part of the main zone of the Bushveld Igneous Complex and are outcropping within the Rhovan license area. Of particular mining interest are the footwall zones with up to 2.2 % V_2O_5, as well as the boulder subzone, the lucky strike ore and the overlying main magnetite layer (Figs. 3.10, 3.11). Grades of Fe and TiO_2 range in general from 40 to 55 % Fe and from 12 to 19 % TiO_2. The dip angle varies between 6 and 25° (average of 15°) to the north.

The total resource is given with 143 Mt of ore and the total reserve with 39.6 Mt, totaling 182.6 Mt grading 0.9 % V_2O_5 (SNL Metals & Mining 2017).

Thickness (m)	1m	±9m	±6m	±15m	±9m	±25m	6->9m	±35m	2m
% Mangetite	75	35->40	15->20	±30	15->20	<15	±30	<15	75
% V_2O_5	2.20	2.15	2.10	1.95	1.90		2.00		1.75

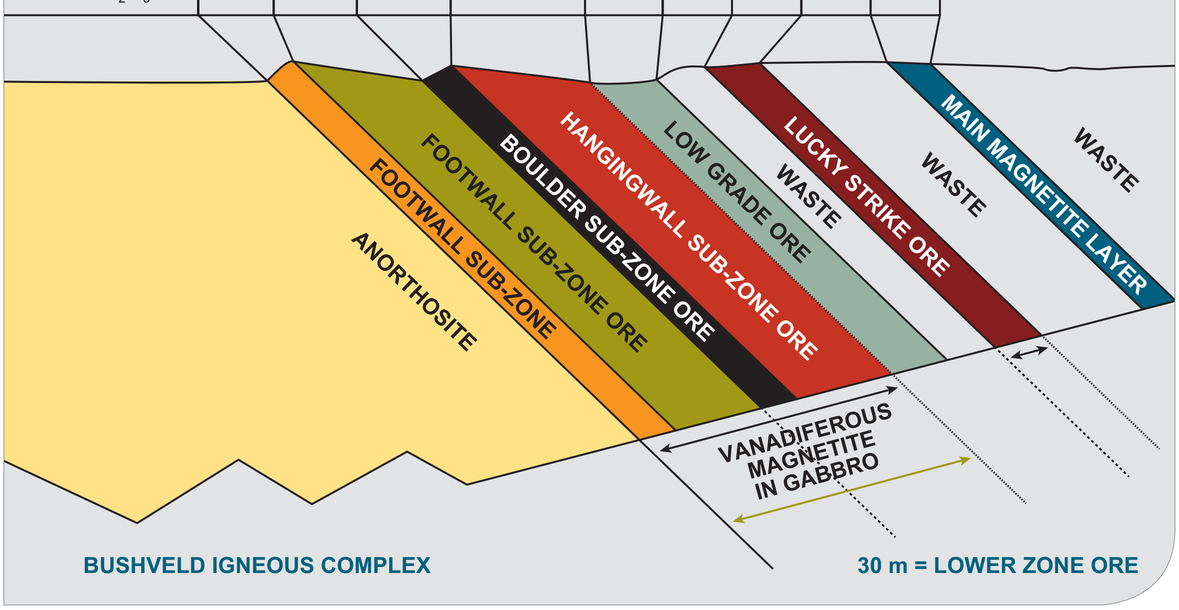

Fig. 3.10: Rhovan generalised cross-section of the geological contacts of the magnetite bearing ore layers with the contents of V_2O_5 (figure courtesy of Glencore 2015).

Fig. 3.11: Boulder of the main magnetite zone (photo: DERA 2015).

With the production of 8,500 t V_2O_5 and 6,600 t of ferrovanadium (80 % V) in 2015 the reserve situation of Rhovan gives a life of mine (LoM) of about 30 years.

Mining and processing

Mining at Rhovan is open cast in six pits (three of them currently active; Fig. 3.12). The oxidation depth within the ore body, caused by meteoric weathering, is about 5 m below the surface and a high content of silicate and hematite within the ore has to be avoided.

The processing plant (Fig. 3.13) is situated adjacent to the mine. After mining the ore, a two-stage crushing operation takes place, followed by milling. After milling, the ore is upgraded by magnetic separation, producing a 95 % magnetite concentrate containing approximately 2 % V_2O_5. The vanadium bearing titanomagnetite ore (VTM ore) is then fed into a rotary kiln (Fig 3.14) and fluxed in the presence of sodium salts (Salt Roast technique – see chapter 3.3.2). Vanadium oxide is then leached and ultimately precipitated and processed to produce a final vanadium pentoxide (V_2O_5) product of 99 % purity. Some of this product is sold while the balance is converted to vanadium trioxide (V_2O_3) in a reactor. Following this, the V_2O_3 is blended with aluminum, lime flux and scrap iron and fed into an electric arc furnace to produce ferrovanadium. The ferrovanadium is then tapped, cooled and broken down to meet the customers' size specifications. Vanadium pentoxide, trioxide and ferrovanadium are sold to a diversified international customer base (SNL METALS & MINING 2017).

Fig. 3.12: Satellite image of the Rhovan mine area south-west of Bethanie. The active pits are in the western section, while the south-eastern pits are currently inactive (image courtesy of SNL METALS & MINING 2017).

Fig. 3.13: Processing plant (crushing, milling) of the magnetite ore at the Rhovan plant (photo: DERA 2015).

Fig. 3.14: Rotary kiln to produce vanadium pentoxide at the Rhovan plant (photo: DERA 2015).

The daily production amounts to 14 t V_2O_5, 27.5 t V_2O_3 powder and 18.3 t of FeV. The cut-off grade is given at 1.95 % V_2O_5, but the in-situ grade in the entire ore horizon is about 0.5 % V_2O_5 (pers. comm. Adriaan Brugman).

Because of its comfortable reserve situation due to the relatively large license area over an ore body strike length of 17 km, the Rovan Mine has a very high potential as a future supplier of high quality vanadium ore as well as of vanadium intermediate products for several decades.

3.5.2 Mapochs Vanadium Mine

Location, ownership and project history

Mapochs Mine, one of the oldest vanadium mines in South Africa, is located in the Limpopo Province near Roossenekal on the R555 road, about 55 km south of Steelpoort (Fig. 3.9). The mine is owned by Evraz Highveld Steel and Vanadium Ltd. (74 %) and Umnotho weSizwe Group (Pty) Ltd. (Investment Holding, 23 %) and the other 3 % by the Mapochs Mine Community Trust. In August 2008 Evraz Highveld took over Mapochs Mine from Anglo American and transferred it into Mapochs Mine (Proprietary) Ltd. In April 2009 Evraz Highveld concluded an agreement to transfer 26 % of the ordinary equity interest in Mapochs Mine to local partners. Ore production decreased by more than 20 % in 2014 and a business rescue proceedings of Mapochs Mine Pty Ltd. were launched and commenced in April 2015. As a result of this ongoing business rescue plan, Evraz Plc. placed the mine on care and maintenance in September 2015. Up to date there has been no further production at Mapochs.

Geology, mining and processing

Mapochs Mine produced lumpy titaniferous magnetite ore from the Main Magnetite Layer of the Upper Zone of the Bushveld Complex with an average thickness of about 2 m in the license area. A magnetite concentrate was produced by magnetic separation. This concentrate was supplied exclusively to Highveld's steelworks in eMalahleni. Ore fines were also produced, which were supplied exclusively to Vanchem Vanadium Products (Proprietary) Ltd. for the production of a variety of vanadium products.

Total reserves and resources were announced in 2013 with 22.9 Mt of magnetite ore grading 1.74 % V_2O_5 (contained about 399.000 t vanadium pentoxide V_2O_5). The last information about production was in 2013 for about 2 Mt of iron ore and in 2010 for magnetite concentrate of about 2.28 Mt (SNL Metals & Mining 2017).

The open pit in Mapochs is, due to its restricted claim area, nearly mined out. The great potential of the mine lies in underground mining. This is mainly due to the extraordinary high in-situ contents of vanadium within the ores. Because of the current price development of V ores and intermediate products but also because of the open ownership conditions of the mine, the construction of an underground mine in Mapochs appears not economic to date.

3.5.3 Evraz Highveld Steel and Vanadium Ltd.

Location, ownership and project history

Evraz Highveld Steel and Vanadium Ltd. is a subsidiary of LSX-listed Evraz Plc., which is one of the world's top steel producers and is also active in the mining and vanadium businesses. In 2007, Evraz acquired 85 % stake in Highveld Steel and Vanadium Corporation, South Africa's second-largest steel maker and the world's leading vanadium-slag supplier, forming Evraz Highveld Steel and Vanadium Ltd. (name change in 2010). Evraz has its main operations in Russia, but also in the Ukraine, Canada, USA, Czech Republic, Italy, Kazakhstan and South Africa. In South Africa the company has operated the Mapochs vanadium mine near Roossenekal to produce VTM ore until 2015 (see chapter 3.5.2) and consists of Vametco Alloys Proprietary Ltd. (SNL Metals & Mining 2017).

Evraz Highveld Steelworks is based in eMalahleni in the Mpumalanga Province (Fig. 3.9) and is composed of the iron plant, the steel plant, the vanadium slag plant, the flat products mill and the structural products mill.

Processing

The iron plant treats the magnetite ore in a pre-reduction process in 13 rotary kilns. Once reduced, hot metal is produced in four open-slag bath furnaces and two submerged-arc furnaces. Vanadium slag is extracted in four shaking ladle emplacements

Fig. 3.15: The Evraz waste slag near eMalahleni (photo: DERA 2015).

in the steel plant and then is crushed, milled and packaged for sale to Hochvanadium Holding AG (USGS 2016; see also chapter 3.4.2). The waste slag is stored outside of the smelter (Fig. 3.15).

Until 2015 Highveld was supplied with VTM ore from the Mapochs Mine (see chapter 3.5.2). After the closure of Mapochs Highveld obtained the ore from the Krokodilkraal Mine (formerly Evraz Vametco – see below) near Brits for further processing into vanadium slag containing 22 to 24 % V_2O_5. The slag is delivered to Vametco Brits plant to produce nitrovan, a vanadium-nitrogen product that can significantly lower the strengthening costs of high-strength, low-alloy (HSLA) and other alloy steels. About 40,000 t of slag per year go to Hochvanadium Holding AG in Austria (see chapter 3.4.2) and Vanchem Vanadium Products (Pty) Ltd., a subsidiary of Duferco of Switzerland, also based in eMalahleni, annually takes some 40,000 t of slag. Vanchem produces V_2O_5 and ferrovanadium. The products are mainly shipped to Japan via South Africa Japan Vanadium – SAJV (Pty) Ltd.

Arcelor Mittal's South African unit (Amsa), along with state-owned Industrial Development Corporation and the business rescue practitioner of Evraz Highveld Steel and Vanadium Ltd., have been working on a plan to revive the latter's idled heavy-section steel plant since July 2016. Therefore, Amsa has agreed, in December 2016, to supply materials as blooms and slabs to a subsidiary of Evraz Highveld Steel, for processing into heavy structural steel (SNL Metals & Mining 2017). The agreement would be for two years at first, with an option to extend it for a year, and production should restart in 2017.

3.5.4 Vametco Brits plant and Krokodilkraal Mine

Location, ownership and project history

Vametco Mine and the Brits plant are located about 6 km east of the town of Brits, north of the R566 road, close to the village of Mothothlung on the Main Mothothlung Road (Fig. 3.9). The owner of the Vametco mine and plant is the Strategic Minerals Corporation (SMC) and until 2016 Evraz Plc. was the main stakeholder of SMC. In June 2016, Bushveld Minerals Ltd. acquired, together with Yellow Dragon, a private Chinese investment company, a 78.8 % stake in SMC Bushveld and Yellow Dragon has agreed to hold 45 % and 55 %, respectively, in Bushveld Vametco (SNL Metals & Mining 2017). The acquisition of the share was completed in May 2017.

Vametco is producing vanadium pentoxide and is the unique producer in the world of nitride vanadium (nitrovan; see also chapter 3.2). Vametco produces nitrovan from its own Krokodilkraal Mine, which is located about 800 m north of the Vametco plant and consists of three open pits over an E-W strike length of 3 km (Evraz Vametco 2014). In 2016, Vametco produced 2,850 t of vanadium, which corresponds to the full annual capacity of the mine. However, Bushveld Minerals announced already after the agreement in June 2016, that the mine's capacity could be expanded significantly within the next years.

3.6 Exploration projects

3.6.1 The Mokopane Vanadium Project (Bushveld Minerals Ltd.)

Location, ownership and project history

Mokopane Vanadium Project is a late stage exploration project and is situated approximately 45 km north-northwest of the town of Mokopane in the Limpopo Province (Fig. 3.9). The license area covers about 8,000 ha over five adjacent farms, namely Vogelstruisfontein 765LR, Vliegekraal 783LR, Vriesland 781LR, Schoonoord 786LR and Bellevue 808LR between the villages Malokong and Mosate. Another iron ore and titanium deposit, the so-called "PQ-Zone" is located about 2 km west in the license area. Both sites are easily accessible from paved national roads.

The majority of the project is owned by Bushveld Minerals Ltd. (AIMLSE: BMN) currently holding 64 % of the shares, and 36 % is owned by a BEE consortium.

During the pre-feasibility study, which was completed in 2016, 31 boreholes totaling 1,832 m were drilled and metallurgical test work including the extraction of titanium dioxide by pyrometallurgy and hydrometallurgy was carried out.

The mining right and the environmental impact assessment was applied in the beginning of 2015. Bushveld Minerals has received the environmental approval from the Department of Mineral Resources (DMR) in September 2016. The company anticipated the first constructions in 2017 and the projected startup with commercial production will be in 2019 (SNL Metals & Mining 2017).

Geology

The total mineral resource is given with 284.8 Mt of ore containing 0.68 % of V_2O_5, 24.4 % of Fe and 5.4 % of TiO_2 (MSA Group 2016). Bushveld Minerals reported a probable ore reserve of 28.5 Mt containing 1.41 % of V_2O_5 in 2016 (MSA Group 2016). This reserve is bound to the Main Magnetite Layer (MML and adjacent), which is near the base of the stratigraphic Upper Zone of the Bushveld Complex (Schürmann & March 1998) and has a consistent 5.5 km north-south strike length within the license area. The resource situation gives a thirty year LoM, mining 952,000 t of undiluted MML per annum (MSA Group 2016).

Three mineralised layers are associated with the MML: the MML, the MML Hanging Wall as well as the AB-Zone with a combined thickness of 70 m. The AB Zone is located stratigraphicaly around 100 m below the MML and hosts inferred resources of 12.5 Mt grading 0.7 % V_2O_5 (SNL Metals & Mining 2017). The MML ore body is divided into the MAG3 and the MAG4 unit, with a total thickness of about 10 m including a 2.2 m thick parting. In-situ contents of vanadium pentoxide (V_2O_5) in the MML ranges between 1.46 and 1.50 % and the Ti-magnetite concentrate grades in excess of 2 % V_2O_5, which represents a high-grade deposit, compared to other occurrences worldwide. TiO_2 grades of up to 10 %.

The dip direction of the layers is 18 to 22° to the west. The nearby PQ-Zone contains Fe grades of approximately 55 % and high TiO_2 contents of > 12 %. The MML and corresponding layers remain under a sediment cover within the area, only the PQ-Zone shows outcrops (Figs. 3.16, 3.17).

Mining and processing

A pre-feasibility study on the project, which was based on an operation targeting the MML, was completed in January 2016. The results envisaged an open-cast operation at a mining rate of 0.95 Mtpa down at a depth of 80 m.

The MML ore is planned to be mined in two pits, each following the dip of the MML (i. e. approximately 18°), one located to the north of the provincial road and one to the south. Each pit will utilise an access ramp excavated from the highwall (on the west) mined down at an angle of 8° to intersect the upper contact of the MML. Once the MML is intersected mining will follow it along strike on a

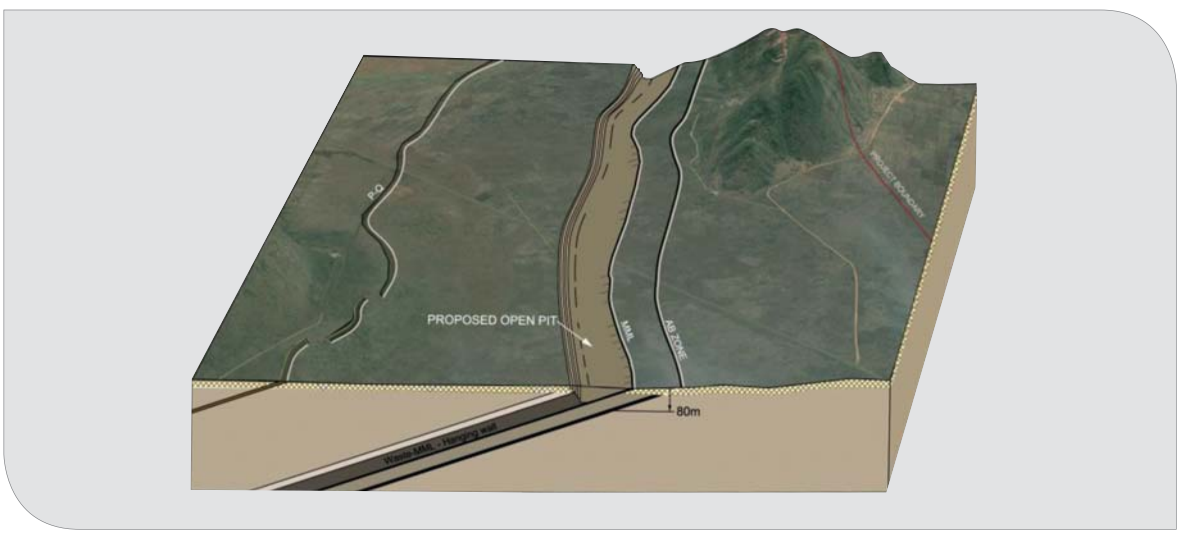

Fig. 3.16: Block diagram showing the proposed open-pit to extract the MML ore as well as the PQ-Zone in the west (with courtesy of Bushveld Minerals 2015).

Fig. 3.17: Outcrop of the PQ-Zone (photo: DERA 2014).

level gradient to create an open pit width of approximately 30 m. This open pit is planned to advance via working faces to the north and south utilising the central common ramp.

Conventional blasting, loading and hauling operations are planned for the ore extraction. The total package of the MML is expected to be mined and the MAG3 and MAG4 will be separated from the parting. The parting material is planned to be separated as low-grade stockpile. The initial production for 2018 is forecasted with 528,000 tpa run of mine material (ROM) to produce 5,000 tpa of V_2O_5 flakes (Waldeck et al. 2014).

The ore reserves will be depleted at a rate of 952,000 tpa with an allowance of an additional 5 % of non-MML included in the material delivered to the plant. At this rate the life of mine is expected to be just under 30 years.

For the metallurgic process to produce vanadium pentoxide, the Salt Roast technique will be applied. The individual steps of the total Salt Roast flowsheet are given in chapter 3.3.2 and in Fig. 3.4. Metallurgical testwork activities were carried out prior to the commencement of the PFS. The results of these previous testwork activities are used to determine various process parameters in the current plant design.

The V_2O_5 product will be sold directly to the vanadium market or can be processed into ferrovanadium (FeV80: 80 % V, 20 % Fe) by using an aluminothermic reactor. At a later stage, TiO_2 could be also produced as a by-product.

The announced total vanadium mineral reserve of 64.5 Mt of high grade ore (MML and AB-Zone) and the calculated LoM of more than 30 years show the great potential of this deposit. The Bushveld Mokopane Project will be a very important supplier of vanadium and vanadium intermediate products for the global industry.

3.6.2 Steelpoortdrift Vanadium Project (Vanadium Resources (Pty) Ltd. "VanRes")

Location, ownership and project history

The VanRes Project is an exploration project in the pre-feasibility stage and is owned by Vanadium Resources (Pty) Ltd., included 26 % of the shares of a BEE consortium and another 4 % of a Community Trust. The project is located 22 km southwest from Steelpoort (Fig. 3.9), at the farm Steelpoortdrift 365KT on the R555 road and covers an area of about 17 km^2. The prospecting rights were renewed in March 2012 by the DMR (pers. comm. with Nico van der Hoven).

Geology

Two layers within the license area are enriched in vanadium, the Lower Magnetite Unit (LMU) and the Upper Magnetite Unit (UMU). The LMU has an average thickness of 22 m, with a total resource of 329 Mt. The UMU is approximately 24 m thick and has a total resource of 184 Mt. Both layers dip between 10 and 12° to the west with a distance of about 32 m to one other. Additionally a number of magnetite pipes with in-situ grades of more than 2 % V_2O_5 and magnetite contents of about 80 % occur within the claim (pers. Comm. with Nico van der Hoven).

The SAMREC inferred resource is 513 Mt grading at 42 to 46 % magnetite, 41 to 43 % Fe and an in-situ V grade of 0.8 % (1.4 % V_2O_5). The V_2O_5 grade within the Ti-magnetite concentrate reaches 2.1 %.

Mining and processing

An open-cast mine is planned with a total V_2O_5 production of 4,493,500 t during a life-of-mine of

60+ years. A kiln is also planned with a feed grade of 2.1 % V_2O_5 within the ore concentrate.

Due to its exceptionally large resource, it is expected that the vanadium production at the VanRes Project will have a significant and long term impact on the vanadium market at the start of production.

3.7 Requirements and evaluations

South Africa hosts to the world-wide second largest vanadium resources after China. The currently identified vanadium resources of the total Bushveld Complex are estimated at approximately 1 bn t of ore with more than 100 Mt contained vanadium.

Tab. 3.3: Size classification of vanadium deposits after PETROW (2008).

Tonnes [t]	Deposit size			
Vanadium	Small	Medium	Large	Very large
	< 100	100 – 1,000	> 1,000	n. a.

In a worldwide comparison the South African vanadium mines and projects (late stage exploration projects such as the Bushveld and the Steelpoortdrift Vanadium Projects), according to their license areas, could be classified as medium to large deposits (after PETROW et al. 2008, Tab. 3.3).

South African deposits are characterised by relatively high in-situ grades of V_2O_5 (Fig. 3.18) within the entire mined ore package. The total V_2O_5 in-situ grade of the ore as well as the V_2O_5 grade of the Ti-magnetite concentrate are the critical factors for the economic feasibility of the deposit. Total ore resources are higher in the Australian and Russian deposits, but nevertheless, the mining and in particular the processing of the ore prove to be expensive in general, because of the relatively low V_2O_5 grades in those deposits.

According to the classification by PETROW et al. (2008) by regarding its total mineral resources of 52 Mt and in-situ V_2O_5 grades of about 1.5 %, the Bushveld Mokopane Project is classified as a very large and world class deposit with a long LoM (> 40 years). The key factor is the high V_2O_5 grade within the Ti-magnetite concentrate, which exceeds 2 %. As the first processing step, ores

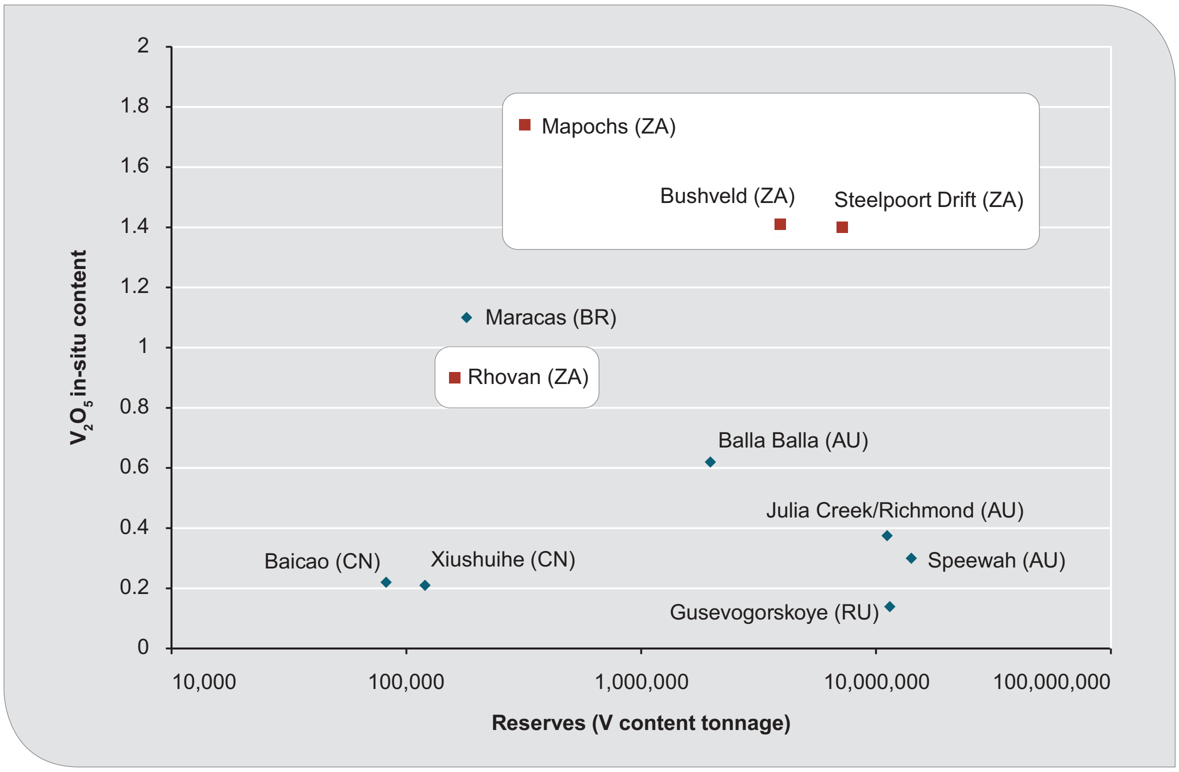

Fig. 3.18: Grade-tonnage comparison of worldwide vanadium deposits.

from the Bushveld Project therefore can be relatively quickly and economically magnetically separated to produce a Ti-magnetite concentrate to feed the kiln for further processing with the Salt Roast method.

Regarding the announced parameters, also the Steelpoortdrift Vanadium Project (which is in the exploration stage) with its announced significant mineral resources of 532 Mt, its in-situ grades of 0.8 % V_2O_5 and V_2O_5 grades of about 2 % within the Ti-magnetite concentrate could be classified as a very large and interesting vanadium project.

With increasing vanadium prices, as observed from the beginning of 2016, the development, in particular, of these two exploration projects could be characterised as economically highly feasible and profitable for the next years.

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4 Zinc

(R. Opperman, H. Marbler, I. Osbahr)

The following chapter gives an overview about zinc in terms of definition, mineralogy and deposit types. Zinc is not a major raw material in the South African mining industry at the moment, however ongoing exploration projects can be of significance in the near future. This chapter describes exploration projects and the potential of South African zinc deposits in an international comparison.

4.1 Definition, mineralogy and sources

The first part of this chapter is about the definition, mineralogy, deposit types and worldwide reserves of the raw material zinc.

4.1.1 Definition

Zinc is a silvery-white metal with a blue tinge, which tarnishes in air. It is the 30th element in the 12th group in the periodic table with the symbol Zn. The element makes up about 72 ppm of the Earth's crust. Zinc occurs naturally in several ores mostly associated with sulfur. A compilation of physico-chemical properties of zinc is listed in Tab. 4.1.

Tab. 4.1: Physicochemical properties of zinc (Hess et al. 1995).

Symbol	Zn
Atomic weight [amu]	65.38
Density [g/cm³]	7.1
Hardness [Mohs scale]	2.5
Melting point [°C]	420
Boiling point [°C]	907
Crystal system	hexagonal
Colour	silvery-white

4.1.2 Mineralogy

Zinc prefers to bond with sulphides and has a low affinity for oxides. Zinc occurs in approximately 66 minerals, however, the most commonly found and most economical being sphalerite (ZnS). Over 95 % of the world's zinc is produced from sphalerite. Minerals of lesser economic interest

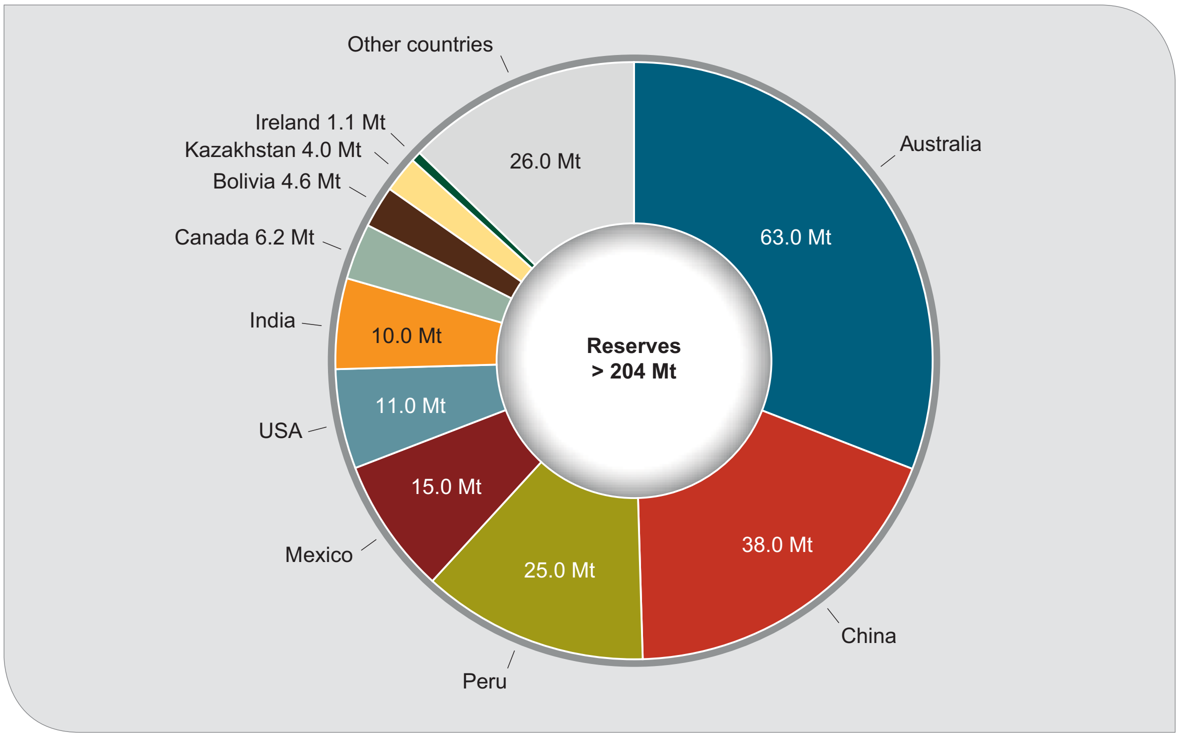

Fig. 4.1: World's zinc reserves distributed by the main countries in million tonnes contained Zn in 2015 (USGS 2016).

are for example, smithonite ($ZnCO_3$), hemimorphite ($Zn_4Si_2O_7(OH)_2{*}H_2O$), wurtzite (ZnS with low amounts of Fe) and sometimes hydrozincite $Zn_5(CO_3)_2(OH)_6$ (Emsley 2001). Sphalerite can also contain minor amounts of cadmium, significant amounts of iron and traces of indium, gallium and germanium of which it is a by-product. Iron and lead minerals, such as pyrite or galena, are often associated with zinc minerals in significant quantities (IZA 2017).

4.1.3 Sources

The identified total world resources of zinc are about 1.9 bn t and the reserves are announced with at least 200 Mt, contained Zn (Fig. 4.1; USGS 2016). The largest known reserves are located in Australia, China, Peru and Mexico.

South Africa hosts different zinc deposits in different genetic surroundings, distinguishing between volcanogenic massive sulphide (VMS) deposits, sedimentary exhalative type (SEDEX) and Mississippi valley type (MVT) deposits. Examples of VMS deposits are the Maranda Cu-Zn deposit, in felsic volcanics of the Murchison Greenstone Belt, and the Bien Venue Zn-Ba-Pb-Ag-Au deposit. Both are considered to originate from volcanic environments. VMS deposits usually consist of pyrite with subordinate chalcopyrite, sphalerite and galena arranged as stratiform lenses, or a series of lenses of massive sulphides (Lydon 1984).

The Gamsberg Zn-Pb and Broken Hill Zn-Pb-Ag deposits, both hosted in banded iron formations, are considered to have been derived from magmatically exhaled mineralised fluids in a sedimentary environment within restricted basins (Du Toit 1998). They belong to the sedimentary exhalative deposit type (SEDEX) which is generally located on ocean floors. Many SEDEX deposits contain zinc, lead, copper, barium and/or precious metals (Morganti 1988).

The Pering zinc-lead ore has many similarities with the MVT mineralisation in that saline ore-bearing fluids, probably generated during the leaching of carbonate rocks by basinal brines, moved up fractures and intergranular pore spaces. The other carbonate-hosted lead-zinc deposits, such as the Bushy Park deposit, as well as parts of the Pering deposit, occur associated with karst-fill breccias (Du Toit 1998).

4.2 Specification and use

Worldwide most of the zinc is used for galvanisation, die-casting alloys, copper-alloys as brasses and bronze, rolled zinc, zinc oxide or zinc dust (Fig. 4.2). Galvanisation has risen in the last ten years as an anti-corrosion protection for steel prolonging the service life of steel products significantly. Die-casting alloys are used where precision casting is required at a moderate cost but with significant strength. Brasses are mostly used in plumbing and electrical appliances. Rolled zinc is used in protective sheeting and zinc oxide in rubber manufacture, while zinc dust is used in protective coating applications and paints. These first-use suppliers then convert zinc into a broad range of products. The largest application area by far is the construction industry with 45 % of all first-use zinc products used in this area. The transportation sector is responsible for 25 % of the global zinc consumption and consumer goods – including electrical and electronic appliances – account for 23 %. The remaining 7 % is used for the manufacture of industrial machinery (IZA 2017).

Germany has a different distribution of uses showing a higher proportion for alloys and for chemicals and galvanisation (Fig. 4.2). Zinc metal is marked in three grades, Special High Grade (99.995 % Zn), High Grade (99.95 Zn) and Good Ordinary Brand (98.5 % Zn; BGS 2004).

4.3 Mining and processing

Most of the operating zinc mines worldwide (80 %) are underground mines and account for 64 % of overall zinc production. 8 % of these operation are open pits which account for 15 % of the overall zinc production while 12 % of the mines are a combination of underground and open pit supplying 21 % of the zinc production (IZA 2017). Usually the zinc ores contain 5–15 % zinc that can be used directly by smelters for further concentration. Therefore it first has to be crushed and then milled for separation from other minerals. The resulting concentrates comprise 55 % zinc with some copper, lead and iron and 25–30 % of sulphur. This is mostly

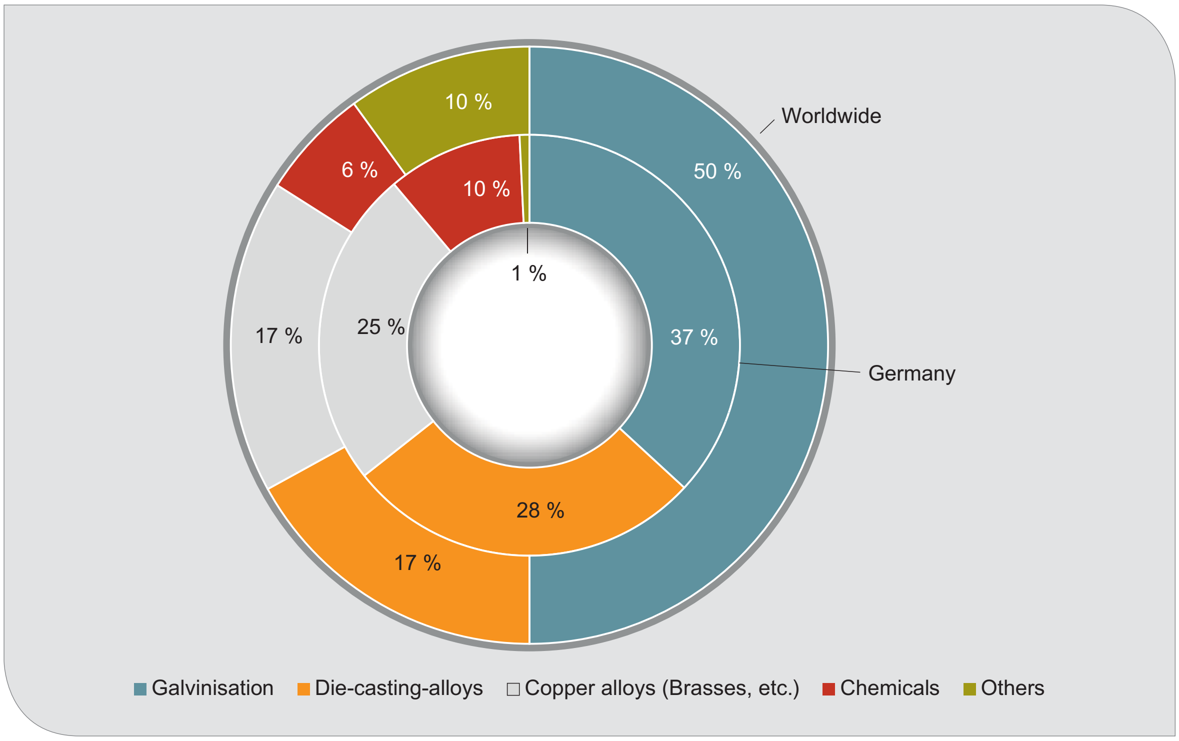

Fig. 4.2: Use of zinc worldwide and in Germany in 2015 (WVM 2016).

done directly at the mine site to keep costs as low as possible (IZA 2017).

Roasting and sintering

In order to recover metallic zinc from the concentrate by using metallurgical processes, sulphur has to be removed first. This can be done by roasting and sintering. During this process the concentrate is heated up to more than 900 °C where ZnS is transformed into ZnO. Additional sulfur dioxide is resulting from this process which is an important commercial by-product (IZA 2017).

The hydrometallurgical process

The hydrometallurgical process comprises the leaching of zinc oxide by using sulphuric acid in order to separate it from the other calcines. During this process the zinc becomes dissolved while the iron precipitates and lead and silver remain undissolved. To eliminate possible impurities from the dissolved solution zinc dust is added. During a cementation process all elements will be precipitated that lie below zinc in the electrochemical series. The purified solution then passes an electrolytic process and will be deposited during this process. Finally, it is stripped off, dried, melted and cast to ingots. Those can have different grades which are already mentioned above (IZA 2017).

The pyrometallurgical process

The pyrometallurgical process comprises the Imperial Smelting (IS) process. Here the zinc and lead are reduced into metal with carbon. IS furnaces are only in operation in China, India, Japan and Poland due to rising energy prices making this process very expensive (IZA 2017).

4.4 Supply and demand

This chapter includes an overview of the global supply and demand situation from the German as well from the South African point of view.

4.4.1 Supply

The global mine production of zinc ore was 13.5 Mt in 2015 with a nearly unchanged production rate compared to the previous year (Fig. 4.3).

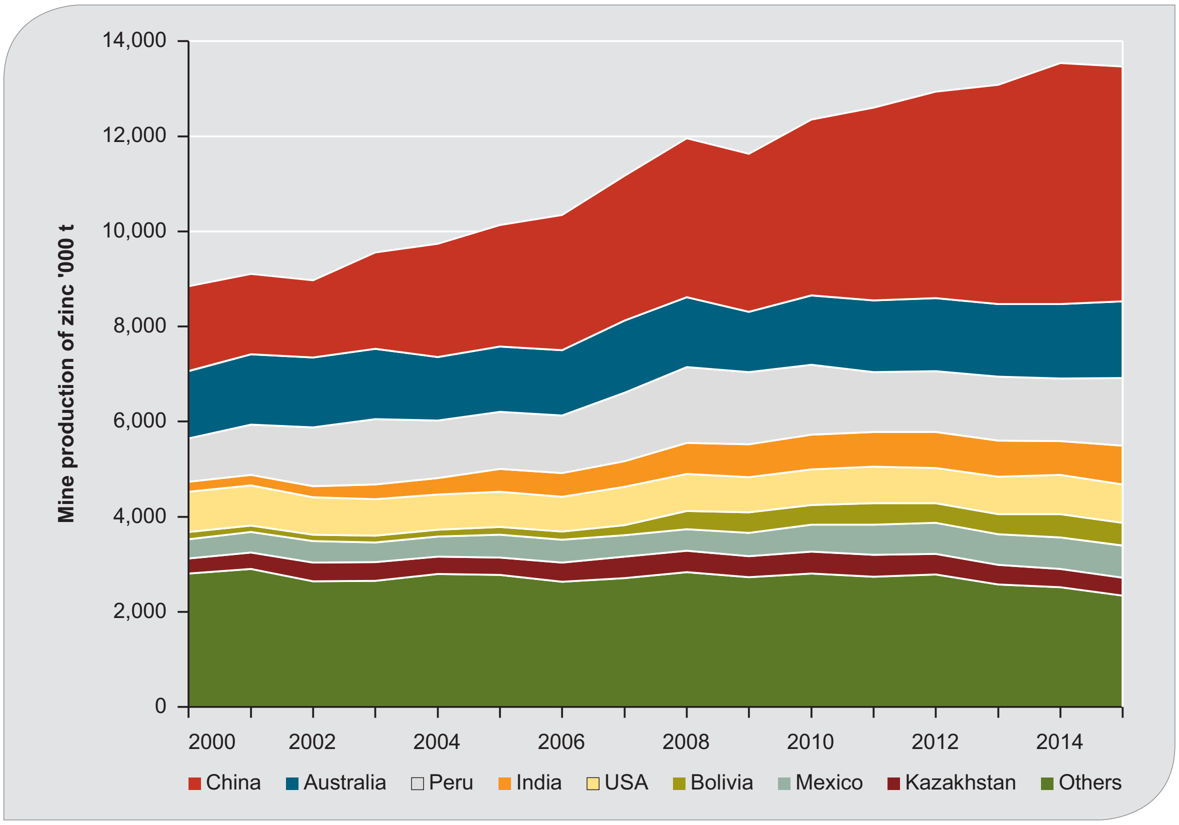

Fig. 4.3: Global top producers of zinc and the development in production from 2000 to 2015 (Source: BGR 2016).

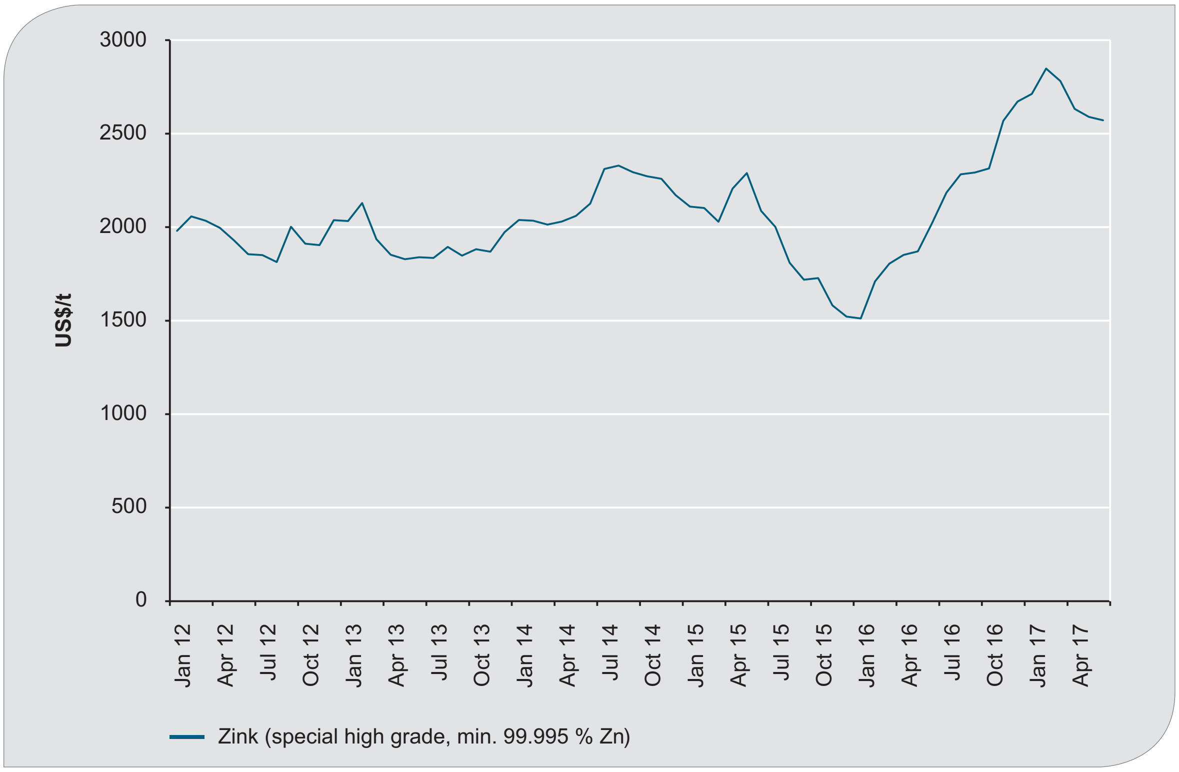

Fig. 4.4: Prices of special high grade zinc (99.995 % Zn) over the last five years (BGR 2016).

Tab. 4.2: Top 10 producing zinc mines (SNL Metals & Mining 2017).

Project	Location	Controlling company	Commodity	Production Zn [kt]	Share of world production [%]	Reserves and resources (kt contained Zn)
Rampura Agucha	India	Hindustan Zinc Ltd.	Zn, Pb, Ag, Cd	640 (E)	5.26	12,921
Red Dog	USA	Teck Resources Ltd.	Zn, Pb, Ag	583	4.79	12,491
Kazzinc Consolidated	Kazakh-stan	Glencore Plc.	Zn, Cu, Pb, Ag, Au, Mn	306	2.51	7,450
Mt Isa Zinc	Australia	Glencore Plc.	Zn, Pb, Ag	288	2.37	38,520
San Cristobal	Bolivia	Sumitomo Corp.	Zn, Pb, Ag	230 (E)	1.89	4,023
McArthur River	Australia	Glencore Plc.	Zn, Pb, Ag	200	1.65	17,900
Antamina	Peru	Glencore Plc, BHP Billiton Group, Teck Resources Ltd., Mitsubishi Corp.	Cu, Zn, Mo, Pb, Ag	198	1.63	16,100
Cerro Lindo	Peru	Compañía Minera Milpo SAA	Zn, Cu, Pb, Ag	174	1.43	1,915
Yauli	Peru	Volcan Minera Compañía S.A.A.	Zn, Ag, Cu, Co, Pb, Au, Ni	165	1.36	3,535
Vazante	Brazil	Votorantim S.A.	Zn, Ca	150 (E)	1.23	2,283

E = Estimated by SNL Metals & Mining 2017

China is the most important global zinc producer with almost 38 % share of global production, followed by Australia with 12 % share of global production and Peru with 10 %. However, the top producing mines belong to India, USA, Kazakhstan, Australia and Peru (Tab. 4.2). The largest three mines share 12.6 % of zinc in world production.

Since 2015 the prices for high grade zinc are rising to a current price of 2,570 US$/t (June 2017). From January 2016 to February 2017 this is an increase of 88.5 % (Fig. 4.4). However, since then the price has fallen again.

4.4.2 Demand

Currently, Germany does not import any zinc products directly from South Africa, neither zinc ore nor concentrates or any other zinc and products thereof. Germany is importing most of the zinc ore or concentrates from Australia, Sweden, the USA and Peru (BGR 2016). Zinc products of a higher value chain stage are mostly imported from European Countries (Dorner 2015).

South Africa is importing only a minor amount of zinc ore. It is mostly importing zinc products as oxides, alloys etc. However, South Africa is exporting around 65,000 t zinc ore per year, mostly to China, South Korea, the USA, Zimbabwe and Mozambique. Zinc metal and products thereof are mostly exported to Namibia (in total ca. 2,000 t out of 6,000 t). The rest is exported to Argentina, India, Peru, China, Zimbabwe and other countries (GTIS 2016).

4.5 Operating mines and exploration projects

Currently, there is only one operating mine, a lead mine, in South Africa which is producing zinc. However, quite interesting exploration projects have been evolving in the last years which will make South Africa an important zinc supplier in the near future. In this chapter, the operating mine and the potential of the exploration projects are described in detail.

4.5.1 Black Mountain

Location and ownership

Black Mountain mine is owned 74 % by Vedanta Ltd. and 26 % by Exxaro Resources, one of the largest black-owned mining companies in South Africa. It is located in the Northern Cape 99 km ENE of Springbok.

Geology

The SEDEX-type ore body has an average thickness of around 50 m and shows stratabound sulphide mineralisation with Pb, Zn, Cu and Ag in a magnetite and quartz rich host rock (Fig. 4.5). The dip angle of the ore body is about 15 to 20° to the south-east.

Mining and processing

Black Mountain Mining is actually a lead mine but is currently the only zinc producing mine in South Africa and comprises two operating shafts, Deeps (Fig. 4.6) and Swartberg. Deeps produces lead, copper and zinc with silver as a by-product. The minable underground at Deeps reserve is expected to be depleted by 2021. However, the planned Swartberg expansion proposed to replace Deeps production and extend LoM beyond 2021 (Vedanta 2017). Swartberg is primarily a copper and lead producer with silver as a by-product (Vedanta 2016). Black Mountain Mining has a capacity to produce 90,000 t/a of concentrate (Vedanta Ltd. 2017a). The calculated reserves and resources for Black Mountain are 49.9 Mt, of which 9.5 Mt are reserves and 37.1 Mt measured and indicated resources with grades of 2.57 % Pb, 1.3 % Zn and 0.5 % Cu. The deposit contains 1,284 kt of Pb (metal) and 649 kt of zinc (metal).

A great challenge of the Black Mountain mine as well as of the Gamsberg Project (see chapter 4.5.2)

Fig. 4.5: Sulphide mineralisation in the underground mine with galena, sphalerite and chalcopyrite; height of the image is 1.5 m (photo: DERA 2015).

Fig. 4.6: Head frame of the "Deeps" shaft at Black Mountain (photo: DERA 2015).

is the lack of infrastructure in the area, especially in the supply of water and electricity. The nearest electricity supplier is located 20 km from the mine and there is a water pipeline of about 40 km length from the Orange River as the next water source north of the mine.

4.5.2 Gamsberg exploration project

Location and ownership

The Gamsberg Project is owned 74 % by Vedanta Ltd. and 26 % by Exxaro Resources Ltd. Gamsberg is located approximately 20 km east from the Black Mountain mine in the Northern Cape.

Geology, mining and processing

Gamsberg is a metamorphosed volcanogenic massive sulphide deposit, hosted in a quartzite formation (Inselberg), from pre-tectonic supracrustal rocks. Both the Gamsberg and Black Mountain deposits are located in the Mid-Proterozoic Namaqua-Natal Belt. The mineralisation occurs as a stratabound metamorphosed SEDEX-type ore body. The mineralisation (Zn±Pb) is closely associated with banded iron formation. The ore mineral is mainly sphalerite, however, manganese within the crystal structure makes the ore more complex (Fig. 4.7).

A pre-feasibility study was conducted at Gamsberg in 2007 and a definite feasibility study in 2014 (Exxaro 2017). The open pit mine is expected to have a LoM of approximately 13 years with reserves of 50 Mt. The first ore production is scheduled for the middle of 2018. The ramp-up to full production is estimated to take 9 to 12 months (Vedanta 2017a). There is significant potential for further exploration at the north-east deposits, upside at Gamsberg South and West.

The Gamsberg Mine will be a 4.4 Mt/a run of mine open pit operation. A processing plant with the same capacity is planned to process the ore into concentrate with a final production of 250,000 t/a zinc. The mine has the potential for an expansion of the open pit to 10 Mt/a and the option of a

2.5 Mt/a underground mine later down the track (SNL Metals & Mining 2016). The LoM for the underground operation is expected to be more than 30 years.

The Gamsberg deposit contains about 200 Mt of zinc reserves and resources, which will provide future life extension options, depending on market conditions at the time. Gamsberg has medium grade ore (between 6 and 6.5 % Zn) to high grade ore (up to 10 % Zn in some parts). The company plans not only to mine and process the ore but also to market the concentrate. The mine will use mechanised truck and shovel mining methods and Gamsberg plans to create about 1,200 jobs during construction and 850 to 900 once the mine becomes operational (Vedanta 2016).

Vedanta will truck about 150,000 t/a of zinc metal in concentrate to its Skorpion Zinc refinery in Namibia, to process into metal. The Skorpion refinery can manage the manganese content of Gamsberg's concentrate, however, Vedanta will spend US$ 152 million on converting the Skorpion refinery to treat the sulphide concentrate coming from Gamsberg, about 360 km away (Vedanta 2016).

4.5.3 Kantienpan exploration project

Location and ownership

The Kantienpan deposit is located in the Northern Cape near the town of Upington and 315 km west of Kimberley. Kantienpan is owned by Orion Gold NL (73 %) and by private interest (27 %) (SNL Metals & Mining 2017).

Geology, mining and processing

The Kantienpan deposit is a VMS deposit, which lies in the Areachap Group, a volcano-sedimentary belt hosting other VMS deposits including Areachap, Boksputs, Kielder and Prieska (or Copperton) (Orion Gold 2016).

In 2016 a new zone of massive and disseminated sulphides was intersected during an ongoing drilling programme. Assay results from diamond drillings (end of 2016) confirm this new zone of high-grade zinc mineralisation with Zn and Cu grades up to 9.93 % and 0.34 %, respectively (Orion Gold 2017).

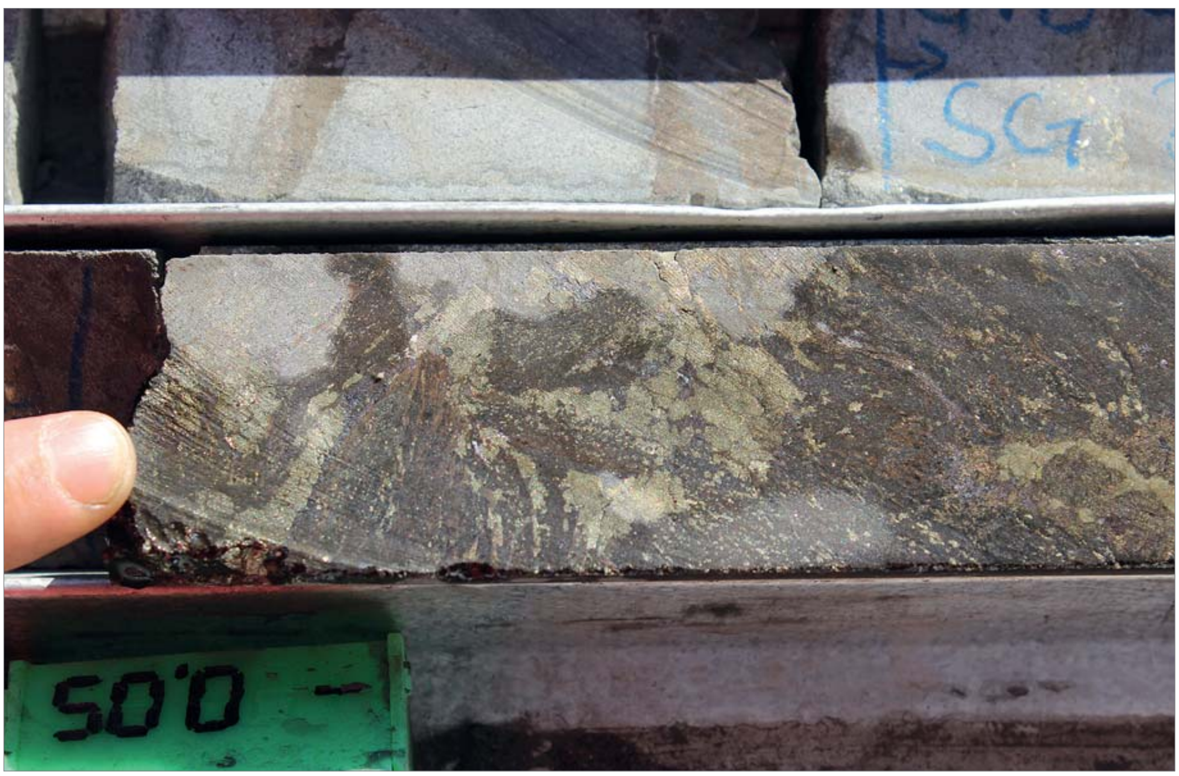

Fig. 4.7: Sphalerite mineralisation in a drillcore from Gamsberg (photo: DERA 2015).

4.5.4 Prieska Zn-Cu exploration project

Location and ownership

The Prieska Zn-Cu Project is also owned by Orion Gold NL (73.3 %) and is located in the Northern Cape 55 km south-west of the town of Prieska (Orion Gold 2017a).

The project covers the historical underground Prieska Copper Mine in the Northern Cape and is situated on the farm Vogelstruis Bult 104, 55 km southwest of the town of Prieska. The mine was operated by Anglovaal between 1971 and 1991. Since 1991, no further production and other activities have been recorded, however, to a re-opening by considering a feasibility study, drilling and geophysics is discussed (Orion Gold Annual Report 2016).

Geology and mining

Prieska is a VMS deposit with tabular, stratabound ore horizons, hosted within deformed gneisses of the 1,285 Ma old Copperton Formation as part of the Namaqualand Metamorphic Complex. The Prieska Mine produced more than 430.000 t copper and more than 1 Mt zinc. Mining ceased in 1989 and milling in 1991. Orion Gold are considering geophysics, in-fill drilling and feasibility studies in order to make a decision and are undertaking discussions with prospective investors interested in financing joint venture participation in the project. Exploration targets include near surface mineralisation comprising oxide, supergene and primary sulphide rock material to a depth of 100 m (open pit potential) and a target for deeper sulphide mineralisation identified by historic drilling, The initial resource to 840 m below surface is stated as 47 Mt grading approximately 7 % Zn (Orion Gold 2017).

4.5.5 Pering Mine (re-opening)

Location and ownership

Shell South Africa (Pty) Ltd. developed a lead and zinc mine near Reivilo called Pering, situated about 70 km south-west of Vryburg in the North West Province of South Africa. The Pering Mine was first mined in 1988 by both Shell South Africa (Pty) Limited's metals division (Shell) and BHP Billiton and was closed by BHP Billiton in early 2003 as a result of a corporate restructure, at a time when metal prices were at very low levels and prior to the boom that followed (BHP 2002). In 2008, it was sold to Minéro Mining Intl Ltd. (85 %). Minéro Zinc has invested in Pering Mine for the purposes of exploration and mining activities in respect of zinc and related base metals.

Geology, mining and processing

The Pering deposit is a prime example of Zn–Pb mineralisation hosted by stromatolitic dolostones of the Neoarchean to Paleoproterozoic Transvaal Supergroup. Sphalerite and galena are the main sulphide minerals with minor amounts of pyrite/marcasite and trace amounts of chalcopyrite. The Zn:Pb ratios within the deposit vary markedly but an average ratio of 5:1 is a good approximation (Du Toit 1998). Owing to pyrite/marcasite contamination, the zinc concentrate contains iron values of approximately 3 % despite the sphalerite having a relatively low iron composition of ~0.5 %.

The mine was operated as an open pit mine. The average annual output was 1.2 Mt of ore and over the LoM 20.4 Mt at a grade of 2.58 % Zn and 0.58 % Pb have been recovered. The ore was processed on site. The cut-off grade varied throughout the LoM, but in the 2002 Mineral Resource and Reserve Statement, a mining cut-off of 1.1 % was used by BHP Billiton. This cut-off resulted in a top of ramp grade of 1.8 % Zn. The mine produced approximately 39,000 t and 6,000 t of zinc and lead concentrate per annum, respectively (BHP 2002). These concentrates contained approximately 23,800 t and 5,500 t of zinc and lead metal, respectively. A total of 1.36 Mt of waste material was extracted from the pits during 2001, representing a stripping ratio of approximately 1:1.

Minéro Zinc was planning to re-open Pering Mine and was planning the construction of a 5 Mt/a Dense Media Separation (DMS) plant as well as a 1.5 Mt/a concentrator plant. The results of the Competent Persons Report (from February 2009) which was issued by Venmyn concluded that Pering is an economically viable lead and zinc project. The study completed at the end of May 2009 indicated a return of 33 % based on a capital amount of R800m required to re-establish the mine, process plant and related infrastructure. Commissioning of the mine was planned to have occurred during mid-2011 with the first delivery of concentrates in the same year.

METMAR (2012) stated that this project includes reserves of 51 Mt at 1.1 % Zn and 0.3 % Pb grade. The intention is to develop Pering as a low-cost producer using DMS technology, producing 544,310 t of zinc and lead over a 13-year life of mine. Significant effort was expended in FY2012 under new management to produce a revised bankable feasibility study. In METMAR (2013) it was indicated that the investment in Pering Base Metals is held-for-sale.

4.6 Requirements and evaluation

In a global comparison South Africa is not among the major zinc producers. However, the largest potential to become a big player is the Gamsberg zinc project in the Northern Cape Province (see chapter 4.5.2). Currently Gamsberg is in a preproduction development stage. Compared to other exploration projects at this stage it is the most promising zinc project worldwide. In a grade-tonnage diagram (Fig. 4.8) the Gamsberg Project as well as other zinc projects outside of China in a similar development stage are compared, regarding the Zn-contained equivalent based on their reserves and resources versus the Zn grade equivalent. The Zn equivalent was chosen instead of using the pure zinc grade in order to consider other valuable metal as lead and silver. Lead and silver were chosen, because the most information has been available for those metals. Therefore, Gamsberg includes almost 16 Mt of zinc equivalent reserves and resources grading 7.5 % Zn. The Russian project Ozernoye has a similar Zn grade (8.5 %) but less reserves and resources than Gamsberg (< 12 Mt), while the Australian Dugald River is a high grade deposit with 14 % Zn, but with comparatively small reserves and resources (< 10 Mt). Projects such as Baiganhu in China, Thalanga in Australia or Rey de Plata in Mexico are rather minor deposits (< 2 Mt) compared to Gamsberg, even with their slightly higher grades (up to 10 % Zn).

Vedanta announced that the first production in Gamsberg is planned in the middle of 2018. The

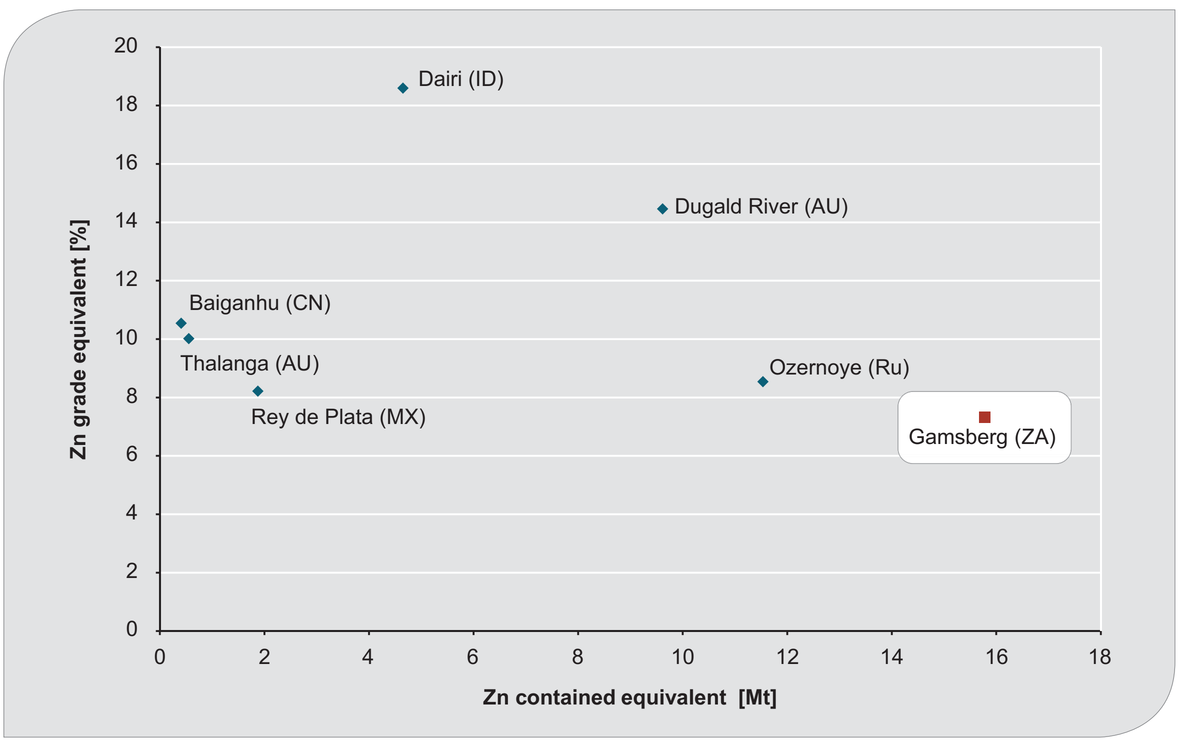

Fig. 4.8: Grade-tonnage comparison of worldwide zinc exploration projects in a pre-production state. Please note that for comparison between the different projects, the Zn equivalent was taken from the reserves and resources.

Table 4.3: Top producing zinc mines worldwide outside of China in 2016, including the Gamsberg Project in South Africa (SNL Metals & Mining 2017).

Mine	Country	Annual production (kt contained Zn)	Reserves and resources (kt contained Zn)
Rampura Agucha	India	640	12,921
Red Dog	USA	583	12,491
Kazzinc Consolidated	Kazakhstan	306	7,450
Mount Isa	Australia	288	38,520
Gamsberg (project)	South Africa	250	14,638
McArthur River	Australia	200	17,900

expected annual production will be 250,000 t of zinc. With this production rate Gamsberg will be under the top six zinc producing mines worldwide outside of China. However, the production rate can be increased to around 400,000 t/a so that Gamsberg will keep up with the Australian mines Century and Mount Isa (Tab. 4.3).

Zinc exploration projects, especially the Gamsberg Project, can currently be characterised as highly feasible considering the current zinc price of 2,713 US$/t (Fig. 4.4). Assuming a probable future trend of further increase which is the opinion of several market analysts (DERA 2017), they would be profitable within the next years.

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Deutsche
Rohstoffagentur
Bundesanstalt für Geowissenschaften und Rohstoffe

Deutsche Rohstoffagentur (DERA) in der
Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)

Wilhelmstraße 25 – 30
13593 Berlin
Tel.: +49 30 36993 226
dera@bgr.de
www.deutsche-rohstoffagentur.de

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