Deutsche Rohstoffagentur
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22

DERA Rohstoffinformationen

Investor's and Procurement Guide South Africa

Part 2: Fluorspar, Chromite, Platinum Group Elements

Deutsche Rohstoffagentur
Bundesanstalt für Geowissenschaften und Rohstoffe

Council for Geoscience
Leading Earth-Science Solutions

Impressum

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

Foreword

This is the second part of the "Investor's and Procurement Guide South Africa", a handbook for investing, procuring raw mineral materials and doing business in South Africa's mineral industry. It is anticipated that this publication will aid potential investors and buyers in considering South Africa as a business destination, not only for raw materials, but also for related industries. This manual supplements the many publications available on the economic geology and mineral wealth in South Africa and has been designed to guide prospective and current investors, buyers, suppliers and mine equipment exporters through the process of doing business in Africa's biggest and most dynamic economy. As well as detailing the mineral raw materials Fluorspar, Chromite and Platinum Group Elements, this second part of the handbook provides information regarding recent changes and developments in the economic and judicial framework of the South African mining industry since the release of Part 1 in 2014.

South Africa has a long and complex geological history dating back in excess of 3.6 billion years. The country has a vast mineral wealth, undoubtedly due to the fact that a significant proportion of the Archaean and younger rocks have been preserved. The mining of the enormous Witwatersrand gold deposits, commencing in 1886, led to the establishment of South Africa's well-developed infrastructure and to the sustained growth of an industrial and service sector in the country. With the world's largest resources of PGMs, gold, chromite, vanadium and manganese and significant resources of iron, coal and numerous other minerals and metals, the minerals industry will continue to play a pivotal role in the growth of South Africa's economy for the foreseeable future. South Africa is one of the top destinations in Africa for direct foreign investments. South African headquartered companies have been major investors into foreign direct investments on the African continent in the past decade.

Despite production disruptions in South African (SA) mines due to labour unrests, global platinum group element (PGE) supplies were largely unaffected in 2013. According to Johnson Matthey's PGE Review of 2014 (Platinum 2014), platinum supplies increased by a modest 2.5 percent to 181 metric tonnes, with RSA accounting for just over 72 percent of world production. Newly committed investment in primary minerals related projects in South Africa in 2012 was dominated by platinum projects accounting for 54.8 percent followed by other minerals (38.9 percent) and gold (5.4 percent). At least six projects involving these commodities are expected to commence production in 2015.

Global chromite reserves were estimated at 9,106 million tonnes (Mt) in 2013, with South Africa accounting for 74.1 percent of this value. South Africa remains the leading producer of chrome, accounting for 48.8 percent of the total world output of chrome ore. The fluorspar industry in South Africa is still developing, with South Africa currently accounting for only 3 percent of total world production. However, there is major potential for fluorspar deposits in and around the Bushveld Complex.

Investing in South African companies would allow investors and buyers to gain a foothold in 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 Geosciences and Natural Resources (BGR) that started at the end of 2011 and has been conducted by experts from BGR/DERA and the CGS. The different natural resources are evaluated in this manual on new occurrences and deposits with investment and supply options for German investors and purchasers in South Africa.

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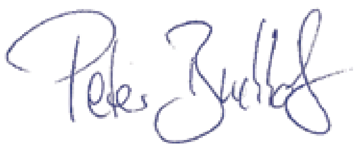

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1 Introduction (R. Opperman, A. O. Kenan)

Aim of the study, background and comments

South Africa is not only the world's largest supplier of platinum but also one of the biggest chrome producers. The world's largest resources of chrome and platinum are deposited in the South African Bushveld Complex. Platinum mining in particular has a long history in South Africa since Hans Merensky discovered platinum group metal bearing chromitite and pyroxenite layers in the eastern, western and also in the northern margins ("limbs") of the Bushveld Igneous Complex in the 1920s.

Despite the long history of mining in South Africa, there is still a high potential for mining, particularly of platinum metals, chrome and fluorspar. Therefore it is obvious that a new evaluation of deposits of these raw materials represents a great challenge, and is of great interest as well. The industrial demand for platinum, chrome and fluorspar, and in particular acidspar, is consistently ongoing in the German industry. With this background, the study should provide an invaluable overview of operating mines as well as newly evaluated resources for the purposes of informing and supporting German companies and investors and for identifying new supply sources.

Due to the broad information base about the Republic of South Africa with respect to the country profile, the regional and economic geology, the political, economic and judicial framework within the first part of the Investor's and Procurements Guide South Africa (Buchholz and Foya 2014), we only present a brief introduction here regarding the latest developments. For any other information in this regard, we refer the reader to the first part of the manual.

1.1 Economic, judicial and political frame of the South African mining industry (latest developments since 2013)

1.1.1 Key government legislation and policies regarding the mineral industry in South Africa

As an addendum to the first part of the Investor's and Procurement Guide South Africa (Buchholz & Foya 2014), we complement recent developments of the governmental legislation and policies in the South African mineral sector. In the following, the latest changes and additions since 2013 are presented. As for the current legal situation and regulatory framework of the South African mining sector, we refer to the first part of the Investor's Guide.

1.1.2 Mineral and petroleum resources development amendment bill (MPRDA) of 2013

Some of the amendments in the Mineral and Petroleum Resources Development Amendment Bill (2013) are highlighted below, wherein we refer to extracts from the Bill. The purpose of the MPRDA as outlined in the Bill is:

- to provide for strengthening of existing provisions relating to the implementation of Social and Labour Plans (SLPs) to augment and substantially increase the socio-economic development impact through mining;
- to enhance the provision relating to the beneficiation of minerals as outlined in the approved beneficiation strategy;
- to stream and integrate administrative processes relating to the licensing of rights to provide regulatory certainty;
- to promote national energy security;
- to align the MPRDA with the Geoscience Act, 1993 (Act No. 100 of 1993), as amended by the Geoscience Amendment Act, 2010 (Act No. 16 of 2010) to remove ambiguities that may exist in the principal Act by amending certain definitions;
- to provide for enhanced sanctions;

- to improve the regulatory system;
- to provide for matters connected therewith.

The Bill enhances integrated licensing with respect to mining rights, environmental authorisations and licenses for the use of water currently resident in various government departments and provides for optimal contribution of the mining industry towards national development priorities, such as energy security. It further enhances provisions that promote mineral and petroleum resources development in a sustainable and equitable manner for the benefit of all South Africans. The Bill furthermore aims to improve the efficiency and efficacy of the legislation in achieving the primary object of creating a mining and minerals regulation regime that conforms to regulatory best practice.

Section 9 of the Act, which deals with the order of processing applications, is amended by substituting the first-come, first-served application process with a process in terms whereby the Minister of Mineral Resources reserves a right to periodically invite applications by publishing notices in the Gazette. This invitation process will ensure coordinated quality approvals by the Department that meaningfully contribute towards the fulfilment of the objects of the Act. It will improve certainty and transparency and further enhance the optimal development of the nation's mineral and petroleum resources.

A Regional Mining Development and Environmental Committee (RMDEC) is established as a statutory body by the insertion of clauses 10A to G dealing with the composition, functions and management of the RMDEC after section 10 of the Act.

Beneficiation has been redefined in the Amendment Bill as transformation, value addition or downstream beneficiation of a mineral and petroleum resource (or a combination of minerals) to a higher value product, over baselines to be determined by the Minister of Mineral Resources, which can either be consumed locally or exported. Section 26 of the MPRDA Act is amended:

- to subject any export of minerals and petroleum resources to Minister's written consent and relevant conditions
- to place an obligation on producers to offer a percentage of minerals, or form of petroleum, resource to local beneficiators
- to empower the Minister of Mineral Resources through a Gazette to determine both such percentage of production and the developmental pricing conditions at which it should be disposed of after taking into account national interests.

Regulations and guidelines will be developed outlining the criteria to be used by the Minister of Mineral Resources in determining the levels of beneficiation, relevant percentages and developmental pricing conditions in respect of local beneficiation as provided for in this clause.

Any historic residue stockpiles and residue deposits currently not regulated under this MPRDA Act continue in force for a period of two years from the date on which this Act is promulgated. The holder of an old order right or converted right to which the historic residue stockpile or residue deposits relates has the exclusive right to apply for a reclamation permit at the office of the Regional Manager in whose region the residue stockpile or residue deposit is situated.

Sections 80 and 84 of the MPRDA are amended to provide for State participation in petroleum development. The State has a right to a free carried interest in all new exploration and production rights. Section 84 defines a State board participation in the holders of production rights. State participation is not a new concept and is already practiced in other jurisdictions in various forms.

Section 99 is amended to provide for improved sanctions in respect of offences committed under the Act. The offences are now linked to a percentage of a person or right holder's annual turnover and exports during the preceding financial year. Furthermore, the amount in respect of penalties that may be imposed by court is increased. Provision is also made for administrative fines. The basis for these improvements is to deter non-compliance with the Act.

Subsection 3 of Section 102 of the Act deals with the regulation of exploitation of associated minerals. The right holders are required to declare and account for the associated mineral(s) discovered in the mining process.

The Minister of Mineral Resources is the competent authority to implement mine environmental management in terms of the National Environmental Management Act (NEMA) whereas the Minister of Environmental Affairs is the competent authority to develop, review and amend legislation, regulations and policies relating to mine environmental management. Processes are under way to give effect to this arrangement between the two departments regarding the mine environmental management function which includes further refinement of both pieces of legislation to ensure that there is no duplication of mandates.

The holder of a prospecting right, mining right, retention permit, mining permit or previous holder of an old order right or previous owner of works that has ceased to exist, remains responsible for any environmental liability, pollution, ecological degradation, the pumping and treatment of extraneous water, compliance with the conditions of the environmental authorisation and the management and sustainable closure thereof, notwithstanding the issuing of a closure certificate by the Minister of Mineral Resources in terms of this Act to the holder or owner concerned.

No closure certificate may be issued unless the Chief Inspectors of Mines and the Department of Water and Environmental Affairs have confirmed in writing that the provisions pertaining to health and safety and management of pollution to water resources, the pumping and treatment of extraneous water and compliance to the conditions of the environmental authorisation have been addressed. When the Minister of Mineral Resources issues a certificate he or she may retain any portion of a financial provision for latent and residual safety, health or environmental impact which may become known in the future for a period of 20 years after issuing a closure certificate.

With respect to the Broad-Based Socio-Economic Empowerment Charter for the South African Mining and Minerals Industry within the Mineral and Petroleum Resources Development Amendment Bill, the Minister of Mineral Resources must, when granting applications in terms of section 17 and 23, impose the provisions of the housing and living conditions standard for the minerals industry, codes of good practice for the minerals industry and the broad-based socio-economic empowerment charter. The Minister shall, as and when the need arises, amend or repeal the housing and living conditions standard for the minerals industry, codes of good practice for the minerals industry and the broad-based socio-economic empowerment charter.

The DMR released the findings of the Broad-based Socio-Economic Empowerment Charter for the South African Mining and Minerals Industry at the beginning of April 2015 (the targets of the 2014 Mining Charter) that 90 percent of the mining companies in South Africa have achieved the 26 percent of the HDSA ownership target (interpretations were on an employment weighted basis), with an average of 32.5 percent HDSA ownership. However, only 20 percent of the companies (weighted for the number of people employed) that had concluded empowerment transactions fulfilled the full requirements of meaningful economic participations as inscribed in the charter.

The amendments of the MPRDA Bill were gazetted towards the end of 2012 for comments. It was approved by the Cabinet for tabling in parliament in mid-2013. The Bill was passed by the National Assembly and sent to the National Council of Provinces for concurrence in March 2014. The Bill was subsequently sent to the President of the Republic of South Africa for assent. However, the office of the presidency declared that the Bill has been returned to parliament for reconsiderations due to doubts over whether, once signed, it would pass constitutional muster. It is still not known when the Bill will be ready to be re-sent to the President for assent.

Since 2013, no significant changes and additions to the acts and amendments regarding environmental issues related to mining activities were enacted in South Africa. Regarding the situation in this legislation as also in the taxation policy as well as in the beneficiation strategy, we refer also to the first part of the Investor's and Procurement Guide South Africa (Buchholz & Foya 2014).

1.1.3 References

MPRDA: Act No. 28 of 2002. – Mineral and Petroleum Resources Development Act of 2002.

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.

2 Fluorspar (S. Röhling, R. Opperman)

2.1 Definition, Mineralogy and Sources

2.1.1 Definition

Fluorspar is the name of the mineral fluorite, which is a calcium fluoride with the chemical formula CaF_2. It is the most common and important fluorine mineral and the most dominant source of fluorine and fluorine-based chemicals. Fluorine represents around 0.06 to 0.09 % of the earth’s crust. It is also found in small amounts in a wide variety of other minerals, such as apatite, kryolite, sellaite, villiaumite and phlogopite.

Commercial fluorspar is graded according to quality and specification into acid-grade (97 % or more CaF_2 content) and metallurgical-grade (97 % or less CaF_2 content). In addition, fluorspar is used for optical applications (optical-grade fluorspar).

2.1.2 Mineralogy

Theoretically, pure fluorite contains 51.33 % calcium and 48.67 % fluorine. In nature substitutions of small amounts of iron, magnesium, manganese, rare earth, strontium and uranium for calcium and oxygen for fluorine have been noted. These impurities give the mineral a variety of colors, from white to nearly black. Fluorite can also be colorless and water clear. Color zoning or banding is commonly present. Fluorite has an excellent mineral cleavage, but fracture is conchoidal to uneven and brittle. It is an isometric mineral, forming cubes and octahedrons, and it also occurs in both massive and earthy forms, occasionally with columnar crystals, and as crusts or globular aggregates with a radial fibrous texture. The mineral has a hardness of 4 (Mohs scale) and its specific gravity is 3.18 g/cm^3. Some varieties fluoresce blue, violet, green, yellow or red under ultraviolet light. Some specimens phosphoresce, thermoluminesce or triboluminesce (Tab. 2.1).

2.1.3 Sources

Fluorspar is found in a variety of geological environments ranging from hydrothermal to sedimentary. Most commonly fluorspar occurs as veins deposited from hydrothermal fluids, and in related replacement deposits. After Fulton and Miller (2006) the most important modes of occurrences are:

- Fissure veins in igneous, metamorphic, and sedimentary rocks
- Stratiform replacement deposits in carbonate rocks
- Replacements in carbonate rocks along contacts with acidigneous intrusives
- Stockworks and fillings in shattered zones
- Deposits in association with carbonatite and alkalic rock complexes
- Residual concentrations resulting from the weathering of primary deposits
- Occurrences as recoverable gangue in base metal deposits.
- Fluorspar is often associated with barite, galenite, sphalerite and other minerals.

Tab. 2.1: Physicochemical properties of fluorite.

Symbol	CaF_2
Density	3.181 g/cm^3
Hardness (Mohs scale)	4
Melting point	1,360 °C
Boiling point	2,500 °C
Crystal system	isometric
Color	various: colorless, purple, blue, green, yellow, pink, red, white, brown, black, and nearly every shade in between

2.2 Specifications and Use

Fluorspar is used in the steel, chemical, aluminium, glass, ceramics, and optical industries. According to these main applications metallurgical-grade fluorspar (metspar), acid-grade fluorspar (acidspar), ceramic-grade fluorspar, and optical-grade fluorspar can be differentiated. These grades are based on the fluorite content and the amount of impurities (e.g. quartz, calcite, sulphur, arsenic and lead).

Metallurgical-grade fluorspar is used as a flux, especially in steelmaking, in iron and steel casting to improve the characteristics of the slag, specifically to reduce the melting point and the surface tension, to minimise variations in viscosity and improve the fluidity. It contains less than 97 % CaF_2 (minimum 80 % CaF_2). A maximum of 15 % SiO_2, 0.3 % S and 0.5 % Pb is set (Fig. 2.1).

Acid-grade fluorspar is required in the chemical and aluminium industries especially as a feedstock in the manufacture of hydrofluoric acid (HF), which is the basis for a wide range of fluorine chemicals, including fluorocarbons. These fluorine containing chemicals are used as refrigerants, non-stick coatings, agrochemicals, medical propellants, anaesthetics and in the production of electronics. Small amounts of hydrofluoric acid are also used in petroleum alkylation and stainless steel pickling. Specifications are set at a minimum of 97 % CaF_2 and a maximum of 1.0 % SiO_2, 1.5 % $CaCO_3$, 0.1 % S, 0.4 % heavy metals, 12 ppm As and 550 ppm Pb. Acid-grade fluorspar is also used in the production of aluminum fluoride (AlF_3) and synthetic cryolite (Na_3AlF_6), which are the main fluorine compounds used in primary aluminium smelting (Fig. 2.1).

Ceramic-grade fluorspar is used as opacifier and flux in the manufacture of frits, enamels and coloured, opalescent and opaque glasses (Fig. 2.1). In smaller quantities fluorspar is an ingredient in the manufacture of magnesium and calcium metals, manganese chemicals and welding rod coatings. The CaF_2-content of ceramic-grade fluorspar varies between 85 and 96 %. It should contain less

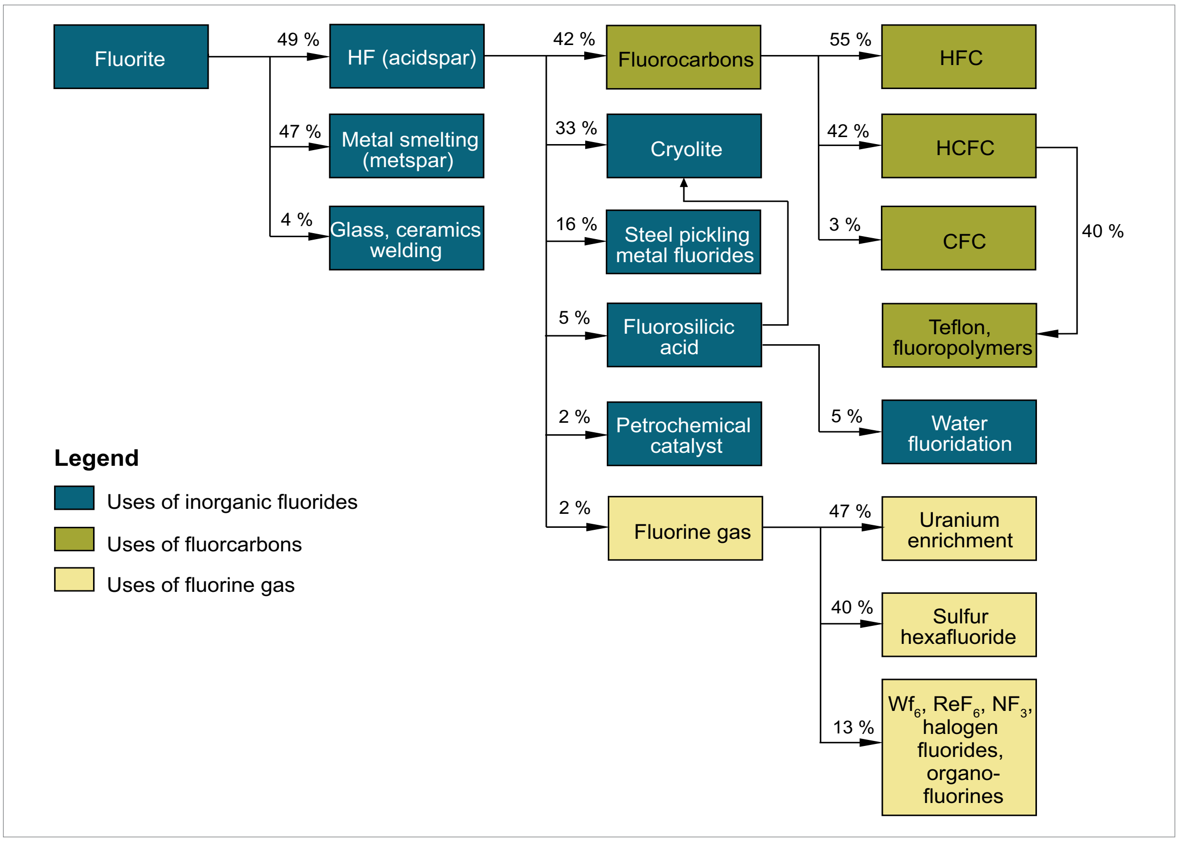


Fig. 2.1: Fluorspar value chain: sources, uses and conversion pathways of commercial fluorine (after VILLALBA et al. 2008).

than 3.0 % SiO_2, 1.0 % $CaCO_3$ and 0.1 % Fe_2O_3 and be free of Pb, Zn, Mn, S, and Ba.

Optical-grade fluorspar is used in the manufacture of high quality optics, because of its low index of refraction, low dispersion isotropic nature and transparency to a wide range of wave lengths, for example for spectroscopic applications or for high energy laser systems. The fluorspar must be water clear, transparent and free of cracks, striations and inclusions.

Acid-grade fluorspar as raw material for the production of hydrofluoric acid is the most sought-after quality.

2.3 Supply and Demand

2.3.1 Global Situation

In 2013, the total world fluorspar production was around 7 Mt, of which nearly two thirds is in the form of acidspar. China dominates the world production of fluorspar accounting for 63 %. The next-largest producers – Mexico, Mongolia, South Africa, Italy, Russia and Spain – together contributed an additional 29 % of world production in 2013. Each of them produced more than 100,000 tpy of fluorspar. However, beyond that there are many smaller suppliers (Fig. 2.2).

Fluorspar reserves are estimated at 240 Mt but there is no information for several producing countries such as the Russian Federation, the USA and Morocco.

The production of hydrofluoric acid is by far the largest market for fluorspar supply, accounting for about 52 % of total world production. Another major market outside the HF sector is the iron and steel industry, were 25 % of the total fluorspar production is used. 18 % was used in the manufacture of aluminium. The aluminium fluoride production has increased in volume over the last ten years mirroring the growth in global aluminium output.

It is estimated that China is the world's largest consumer of fluorspar, with nearly half of the worldwide consumption totaling 6.4 Mt in 2011 (Roskill Information Services 2013). Between 2000 and 2012 the Chinese domestic consumption has grown at 9 % CAGR, compared with an average global growth rate of 3.4 %. Other key consumers are North America and Western Europe (Fig. 2.3).

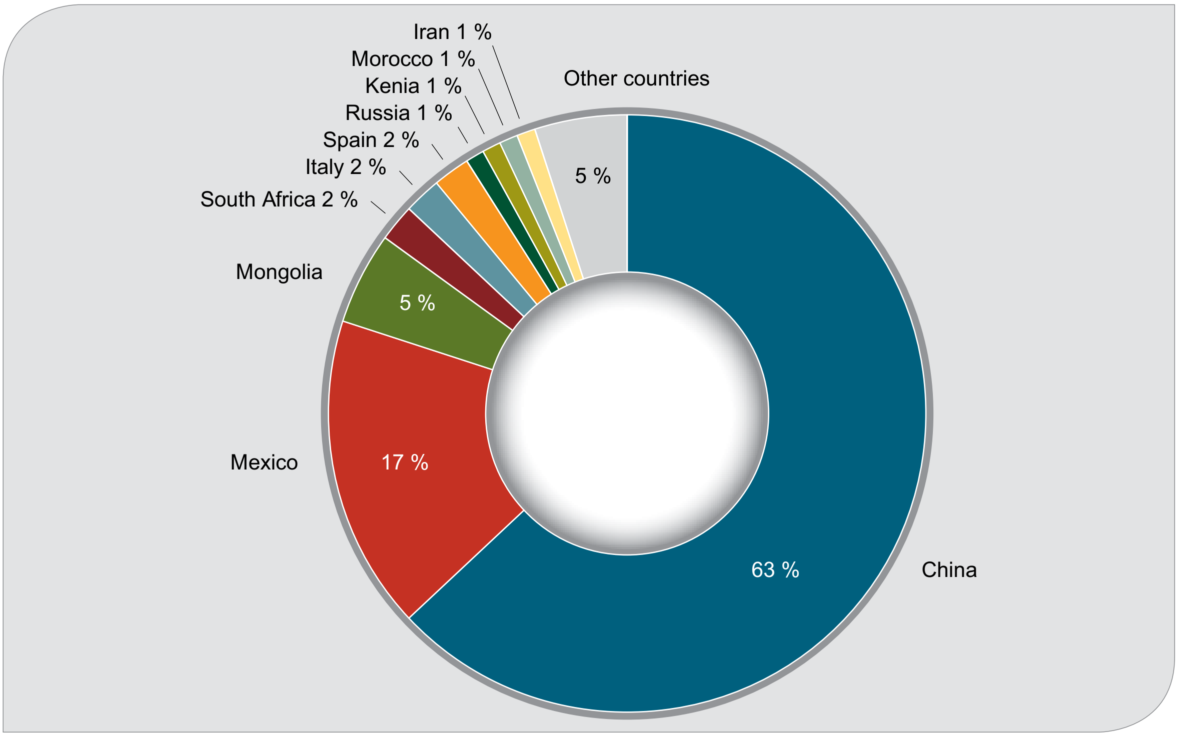


Fig. 2.2: World mine production of fluorspar by country in 2013 (7 Mt in 2013).

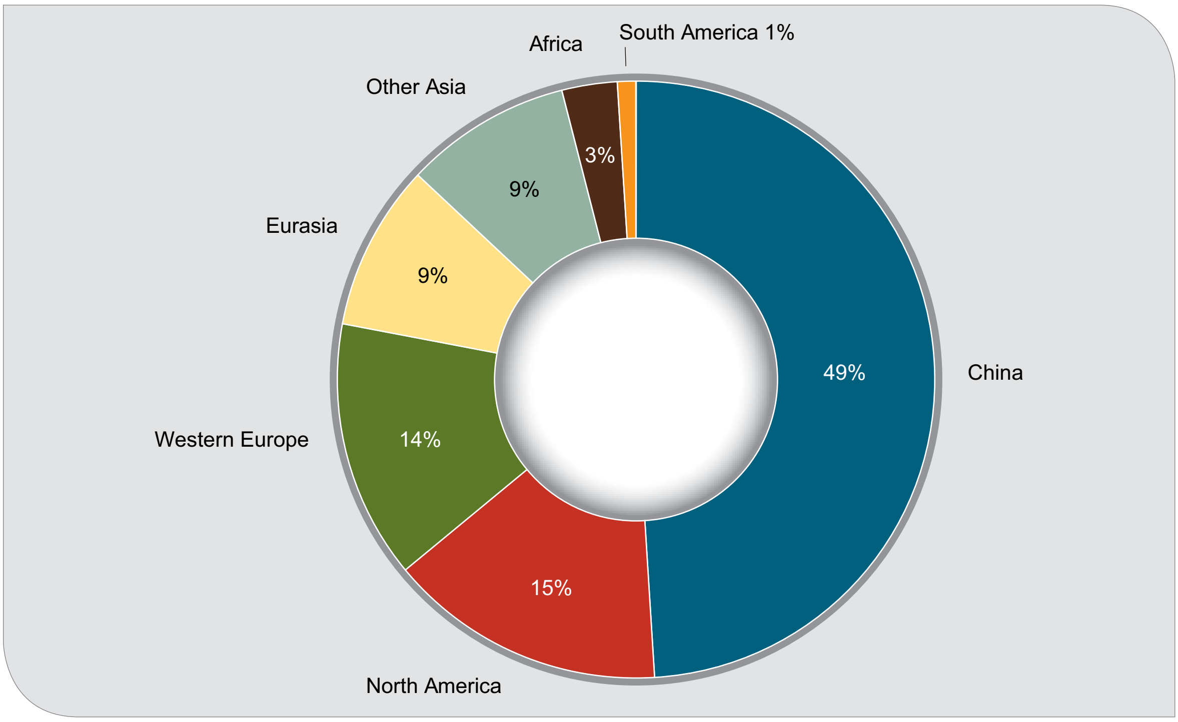


Fig. 2.3: World fluorspar consumption in 2011 by geographic regions (6.4 Mt, Roskill Information Services 2013).

2.3.2 Germany

Germany is the main importer of fluorspar in Europe (Figs. 2.4, 2.5, 2.6). Only 20 % of domestic consumption is produced in the country, and there is only one mine near Wolfach in the Black Forest. On average, 250,000–350,000 t of fluorspar is imported annually. In 2013, the majority was sourced from China (32 %), South Africa (25 %), Great Britain (16 %) and Namibia (13 %). Smaller amounts are also imported from Kenia, Bulgaria, Belgium, Mongolia, Mexico and Sweden. Fluorspar is used in the chemical, steel and aluminium industries.

2.3.3 Resources in South Africa

In South Africa the production of fluorspar started in 1917 near Zeerust (North West Province). Since that time, a number of deposits of different geology and size have been discovered. From 1977 onwards South Africa has belonged to the top five world producers of fluorspar. In 2012 it was the fourth largest world producer. Output grew rapidly from the 1950s and peaked at over 500,000 t in 1980. It fell to 175,000 t in 1993 and increased to nearly 300,000 t in 2008. Since that time it has fluctuated between 200,000 and 157,000 tpy (Fig. 2.10). There is now only one main producer in the country. Production consists primarily of acid-grade fluorspar for the export market. Around 10 % of the production is for the local market.

The total exports of acidspar (> 97 % CaF_2) from South Africa in 2014 was 255,769 tonnes. The largest portion of 215,914 t was exported to the European Union, 39,800 t to USA and 54 t to Asia (the dti 2015).

In South Africa one fluorspar mine is currently in operation: Vergenoeg Mine in Gauteng. Two other mines had been shut down; the Buffalo Mine in the Limpopo Province in 1994 and the Witkop Mine in North West in 2013.

In addition to the producing mine several fluorspar projects are being developed and are at various stages.

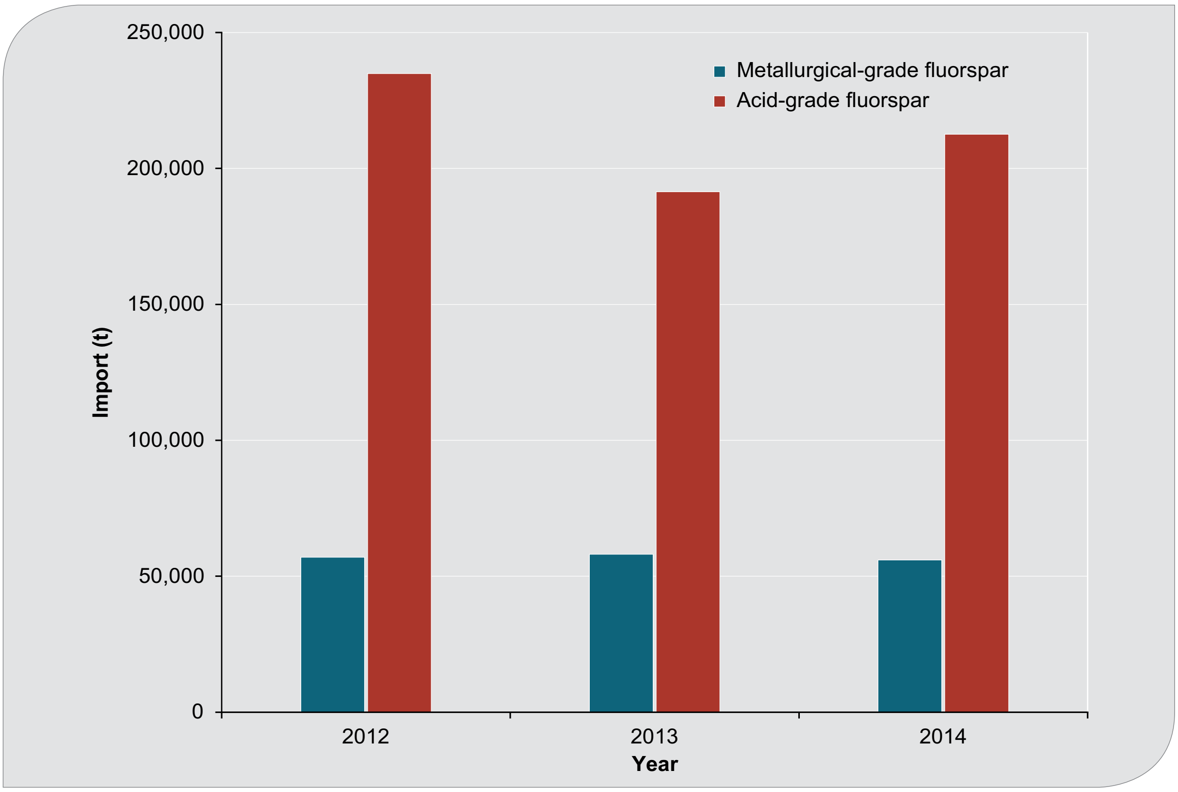


Fig. 2.4: German total import of fluorspar – metallurgical-grade and acid-grade – from 2012 to 2014.

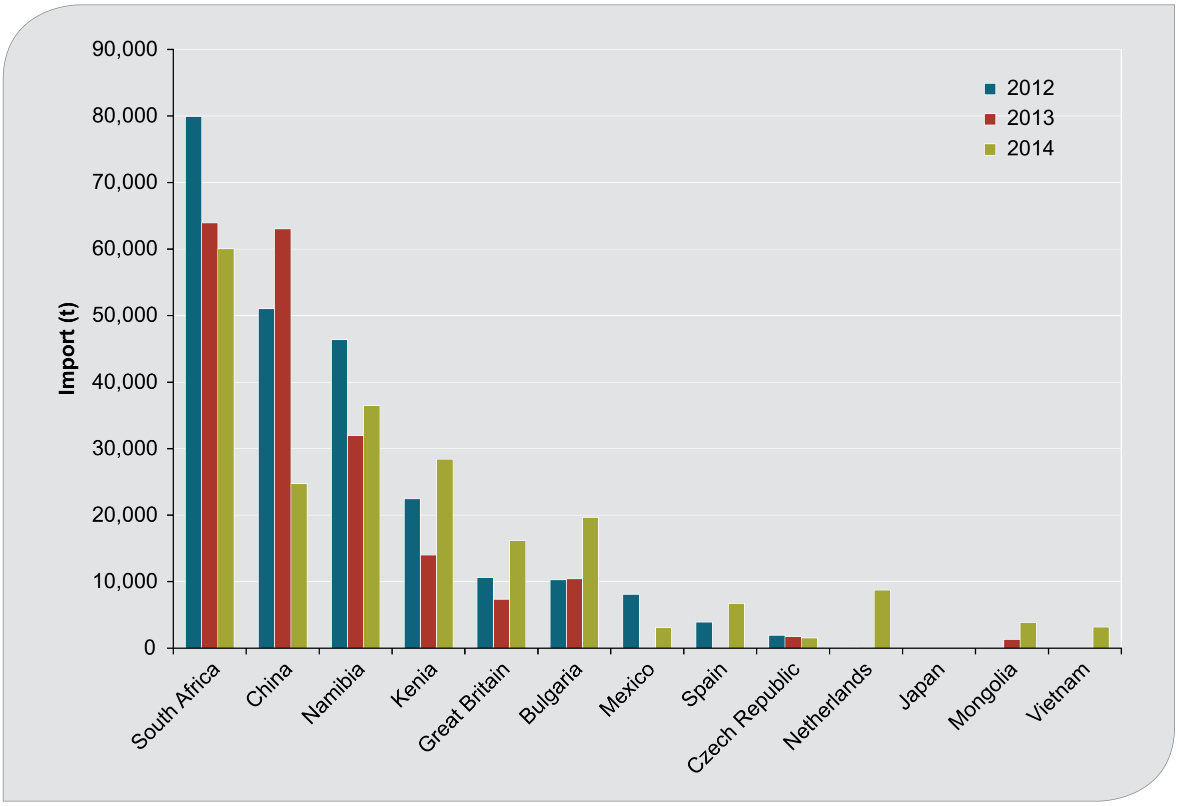


Fig. 2.5: German import of acid-grade fluorspar (acidspar) from 2012 to 2014.

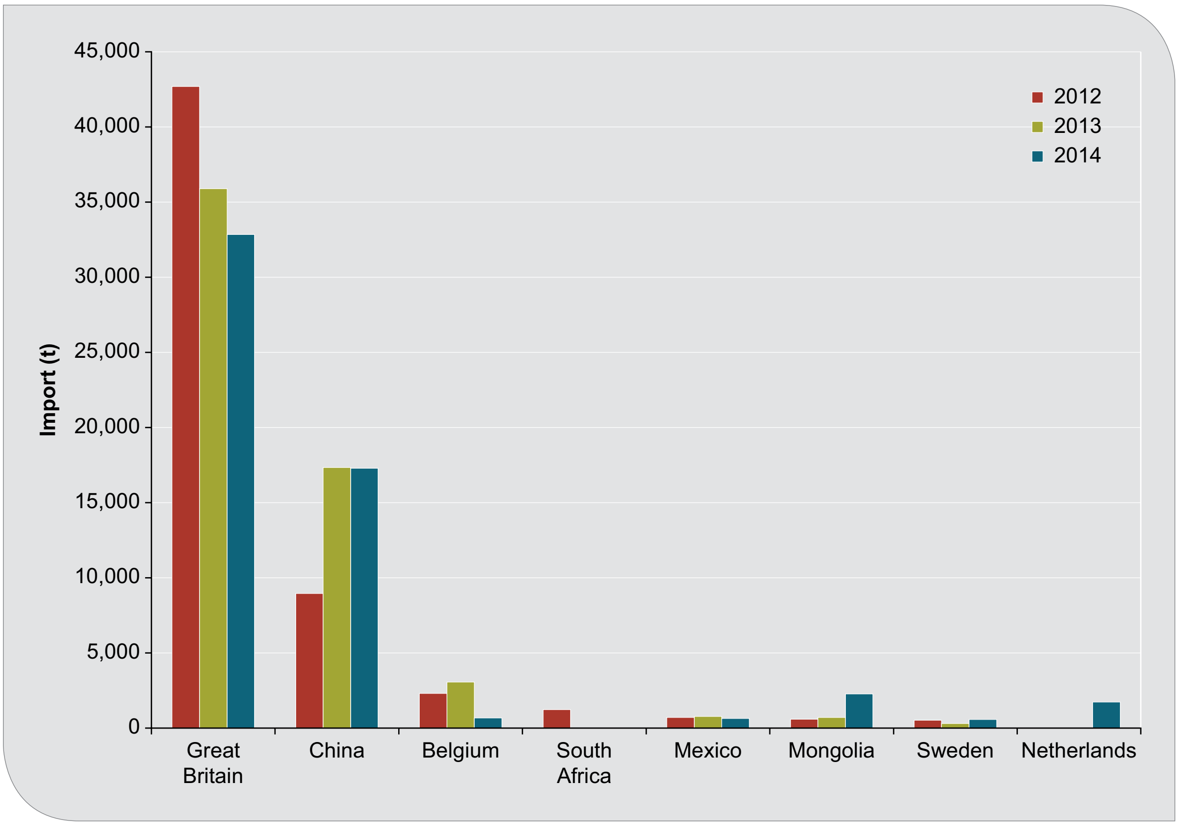


Fig. 2.6: German import of metallurgical-grade fluorspar (metspar) from 2012 to 2014.

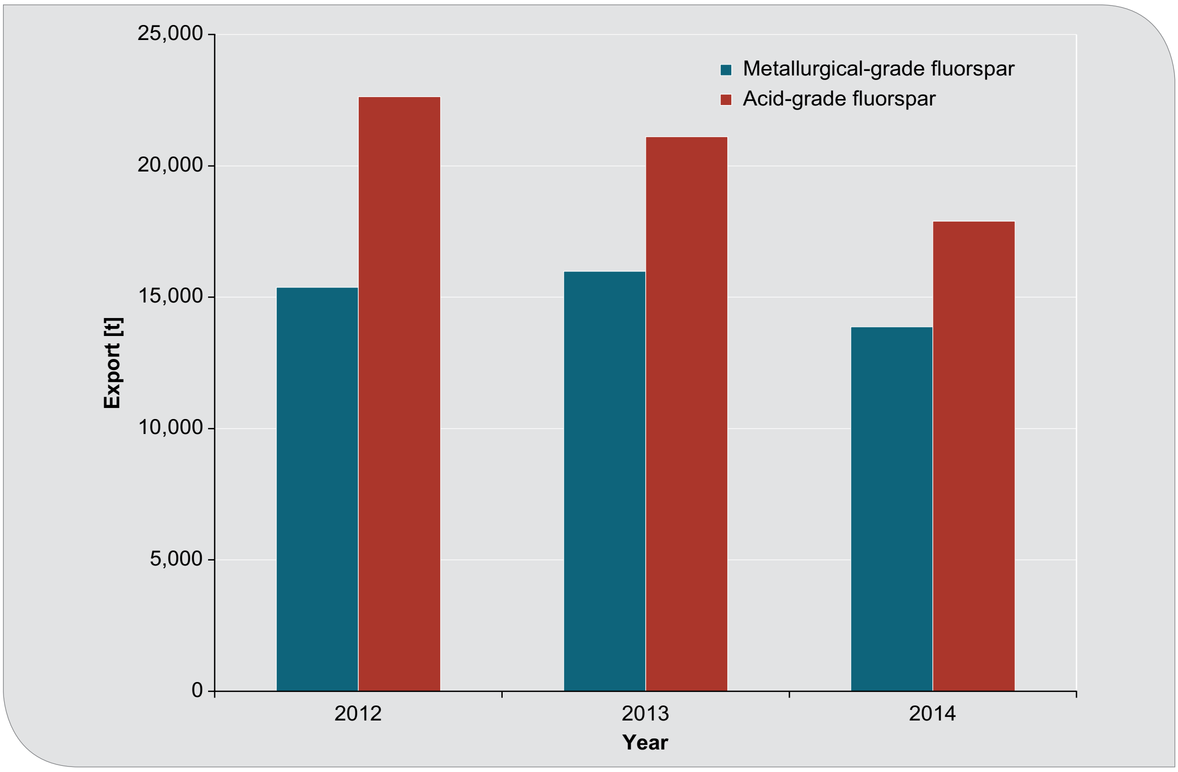


Fig. 2.7: German total export of fluorspar – metallurgical-grade and acid-grade – from 2012 to 2014.

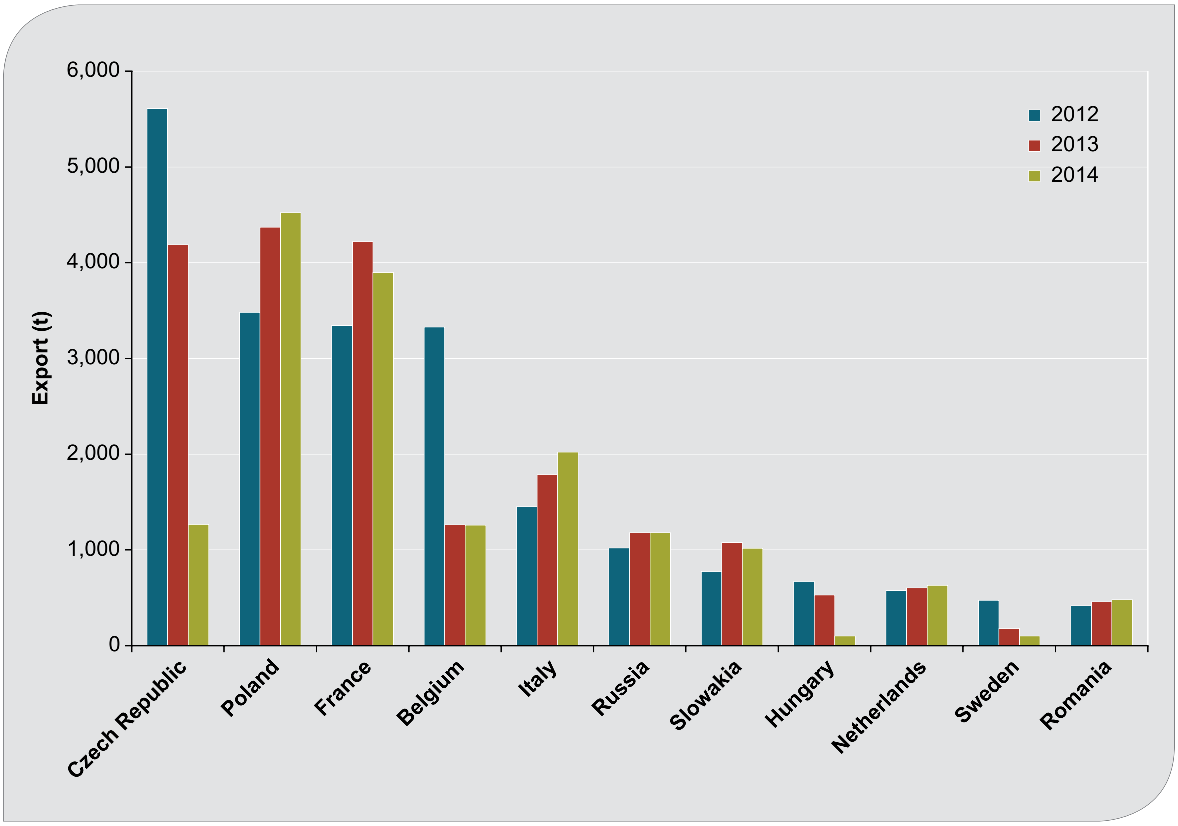


Fig. 2.8: German export of acid-grade fluorspar (acidspar) from 2012 to 2014.

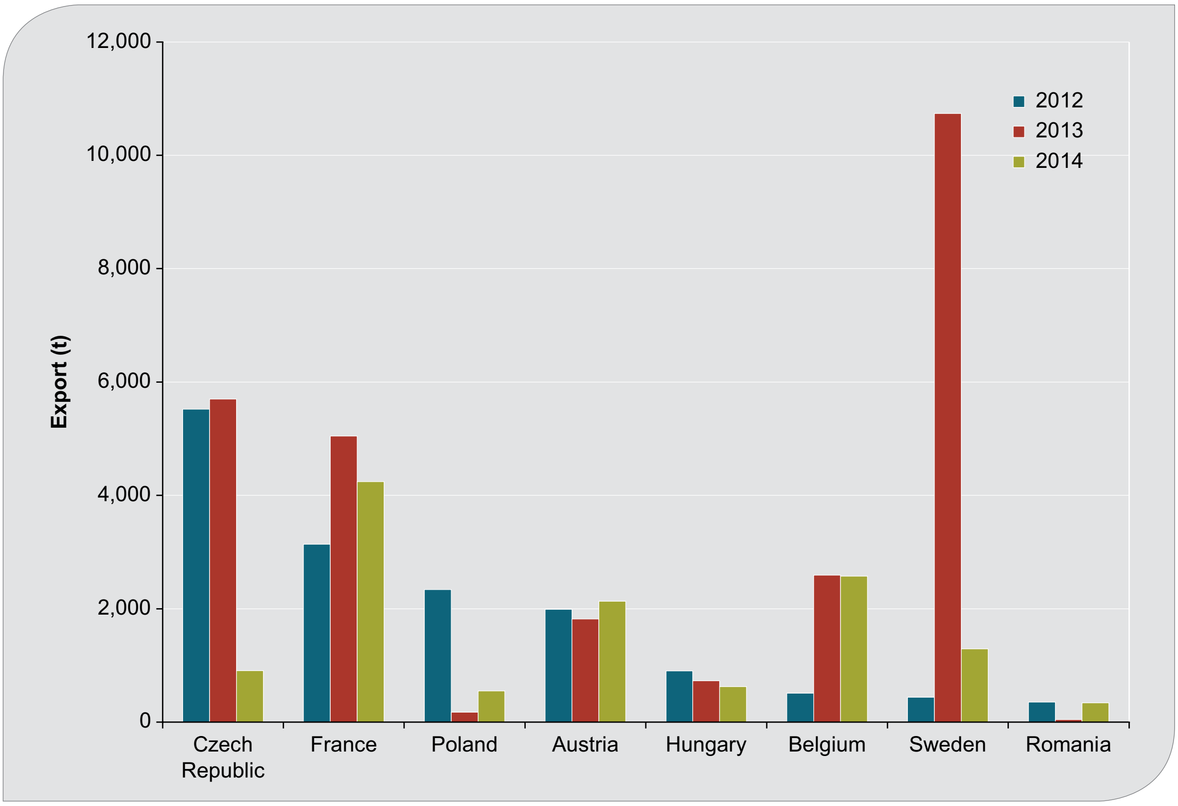


Fig. 2.9: German export of metallurgical-grade fluorspar (metspar) from 2012 to 2014.

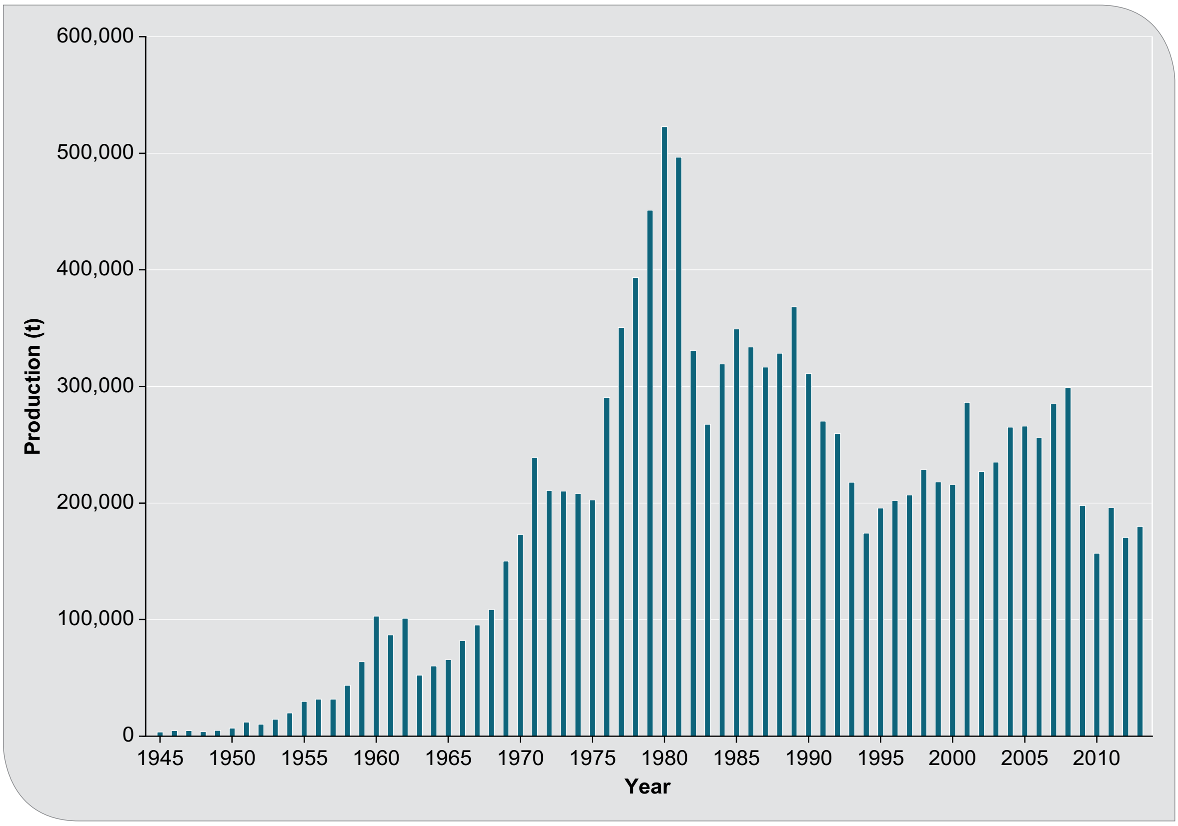


Fig. 2.10: South Africa production of fluorspar from 1945 to 2013.

2.3.4 Vergenoeg Fluorspar Mine (Gauteng)

Location and owner

Coordinates: (Centre of open pit of the mine)
25°15'19.65"S, 28°34'51.62"E

The Vergenoeg Fluorspar Mine is situated approximately 125 km northeast of Johannesburg and 55 km southeast of Bela-Bela on the remainder of farm Kromdaai 209 JR on the border of the Limpopo Province. The mine is operated by Vergenoeg Mining Company (Pty) Limited. The company was incorporated in 1951 and is presently (since 2009) owned by Minerales Y Productos Derivados S.A. (Minersa) which holds 85 % of the issued ordinary share capital of Vergenoeg. All data summarised in this chapter are sourced from publicly avalable scientific publications and reports.

Local infrastructure

The Rust de Winter settlement close to the Vergenoeg Mine site is connected with the N1 national highway (Pretoria–Bela-Bela; exit: Pienaarsrivier) by a paved road. The Vergenoeg fluorspar deposit is easily accessible via the D567 paved road connecting the towns of Moloto (south of Vergenoeg) and Rust de Winter (north of Vergenoeg; distance from N1 to Vergenoeg: ~35 km). The Elands River is approximately 4.3 km north and the Enkeldoring Spruit is about 7.4 km east of the site; they are the closest perennial rivers. The mine makes use of groundwater and has a pipeline to supplement the groundwater from the Rust de Winter Dam. Two dams are constructed in the watercourse of the Rhenoster Spruit (on the property; no constant flow of water) named the Red Industrial Water Dam (built in 1964; capacity: 1,136,000 m^3) and the Flood Diversion Dam (built in 1975; storage capacity: 1,065,865 m^3; Shangoni Management Services 2011). The mine entered into a power supply agreement with the Bela-Bela Municipality and built a private power line. The power supply and line were later taken over by Eskom and the grid was extended in order to include the farms and settlement of Rust de Winter (Shangoni Management Services 2011).

Geology

The Vergenoeg Igneous Complex (Fig. 2.11) is located in the Rooiberg Group, an unusually thick and extensive sequence of acid volcanic rocks, which forms the top of the Bushveld Complex. The main ore body at Vergenoeg forms a roughly vertical, discordant pipe that cuts felsic volcanic rocks of the Selonsrivier Formation of the Rooiberg Group (Fig. 2.12), 2,061 ± 2 Ma (Walraven 1997). The last-mentioned formation overlies the intracratonic Transvaal Supergroup. The Vergenoeg pipe is oval in shape and stretches some 900 m north-to-south, and about 600 m east-to-west. At 600 m depth, it is a tapering funnel-like body with a diameter of about 200 m. The shape of the ore body was defined by geophysical methods, in particular a gravity survey, surface mapping and borehole information (Fourie 2000). The pipe is roughly horizontally zoned and consists of four units; the units are, from top to bottom: (i) a hematite-fluorite unit (gossan), (ii) a magnetite-fluorite unit, (iii) a magnetite-fayalite unit, and (iv) a fayalite unit. The contacts between the units are mainly gradual and uneven (Fourie 2000). Both massive and disseminated fluorite occurs throughout the pipe, but the fluorite content decreases with depth. Most of the fluorite is colorless, but white, purple and green varieties also occur.

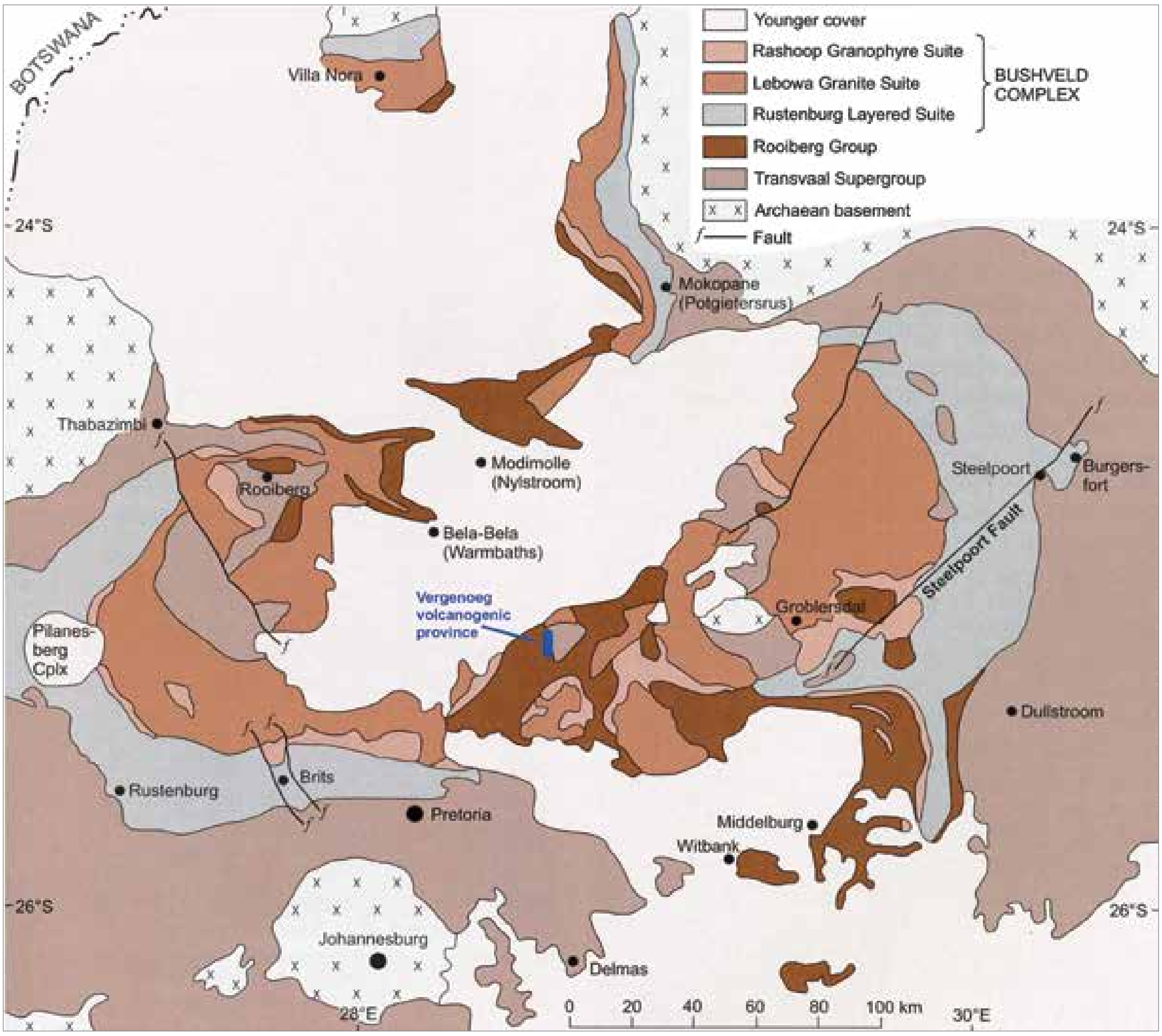


Fig. 2.11: Simplified geological map of the Bushveld Complex indicating the position of the Vergenoeg volcanogenic province (Graupner et al. 2014, modified after Buchanan 2006).

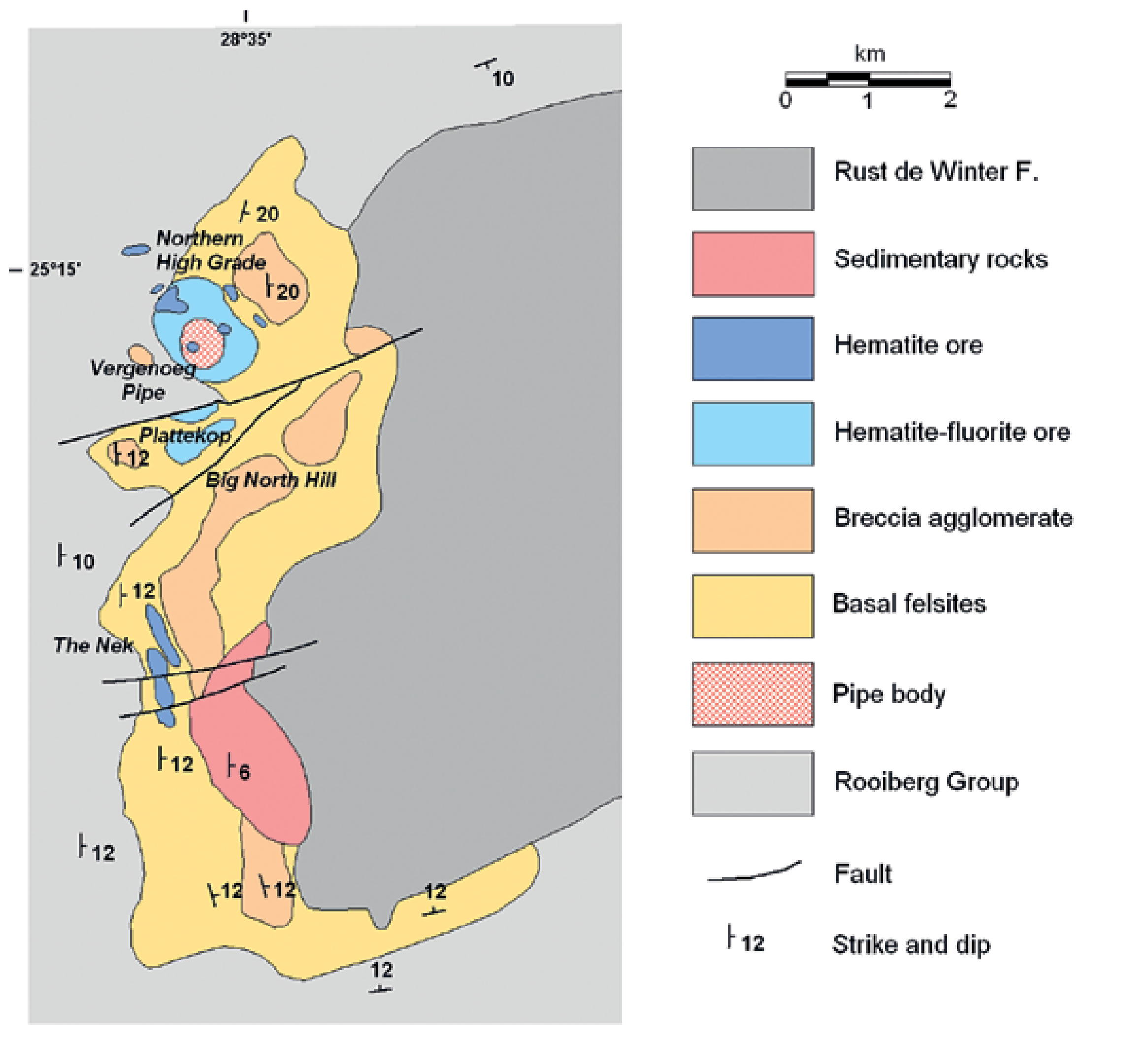


Fig. 2.12: Geological map of the Vergenoeg volcanogenic province (Schütte 2005, modified after Fourie 2000, Crocker et al. 2001).

Furthermore, siderite lenses and pods are common throughout the pipe in all rock types. According to Goff et al. (2004), the Vergenoeg pipe units have unusually high REE contents. An excellent potential of REE is supposed by Watanabe et al. (2009).

The genesis of the Vergenoeg deposit is still a matter of debate (e.g. Crocker et al. 1985, Borrok et al. 1998, Goff et al. 2004).

Mining and processing

History of exploration and mining: The fluorite deposit was discovered in 1928, although mining only started in 1956, when Watercress Mining Company began operations (Cairncross et al. 2008). Bayer AG bought the mine in 1969. Vergenoeg was then bought by a joint venture of Metorex (70 %) and Minerales Y Productos Derivados S.A. (Minersa, 30 %) in 1999. In 2010 Minersa acquired a majority share of Vergenoeg. Currently, Vergenoeg Mining Company (Pty) Limited operates as a subsidiary of Minerales y Productos Derivados, S.A. (Minersa 85 %, Medu Capital, a local black investment company 15 %).

Operations: Vergenoeg Mine is fully self-contained with housing, workshops, the processing plant equipped with advanced processing and control means, a modern laboratory, drying and bagging facilities, a briquetting plant, a clinic, etc. situated on the mine property.

Fig. 2.13: View of the Vergenoeg Fluorspar Mine (photo: DERA 2012).

Mining is undertaken at a large dimension open pit mine with an N-S extension of 200 m and an E-W extension of 650 m (Figs. 2.13, 2.15). Currently mining is taking place to the north with 11 m benches and 15 m berms. The ore averages from 20–40 % CaF_2 and 50–60 % Fe_2O_3, but locally purer zones with up to 60 % CaF_2 are present (Fig. 2.14). Fluorspar pegmatoide, also called metspar plugs, are of particular importance. They are concentrated in the center of the pipe with a CaF_2 content up to 90 %. In many cases they are brecciated.

Processing is carried out by means of crushing, milling, upgrading by a preliminary cyclone, a flotation circuit and final filtration to an acid-grade fluorspar with 97 % purity. Debottlenecking of the existing plant, and flotation recovery and concentrate grade improvements have been conducted over the past years.

Fig. 2.14: Rock sample from Vergenoeg mine with fluorspar in a magnetitic matrix (photo: DERA 2012).

Resources: Fluorite occurs in variable amounts and parageneses in all facies types of the Vergenoeg deposit except for the mafic dyke and the felsites. Massive lenses of metspar are present throughout the pipe and the gossan. Presently, mining of fluorite is mainly restricted to the hematite-fluorite gossan (open pit; Fig. 2.14), which has formed due to weathering of the magnetite-fluorite unit. Three types of ore can be distinguished within the gossan: fluorite ore, mixed fluorite-hematite/goethite ore and high-grade and massive spicultar hematite iron ore (60 % Fe_2O_3). The fluorite ore occurs in both massive (fluorite plugs with 60 % CaF_2) and disseminated form (Borrok et al. 1998). For the geochemical composition see Table 2.2.

The underlying magnetite-fluorite unit is the major fluorite ore resource at Vergenoeg (Goff et al. 2004). Fluorite content decreases from 32 % at the top to 20 % at the bottom (Fourie 2000). Coarse-grained fluorite and magnetite crystals are set in a groundmass of magnetite, fluorite and siderite with accessory REE minerals (Goff et al. 2004). The magnetite-fluorite unit grades into the magnetite-fayalite unit at around 250 m. In the fayalite unit the fluorite grade is 10 % (Goff et al. 2004), however, fluorite resources are present to a depth of 600 m below the surface (Tab. 2.2).

Vergenoeg is the present active fluorspar producer (170,300 t in 2012) in South Africa with a growing production capacity of 240,000 t. Currently, around 95 % of fluorspar is being exported and the remaining 5 % beneficiated to crude and pure HF and

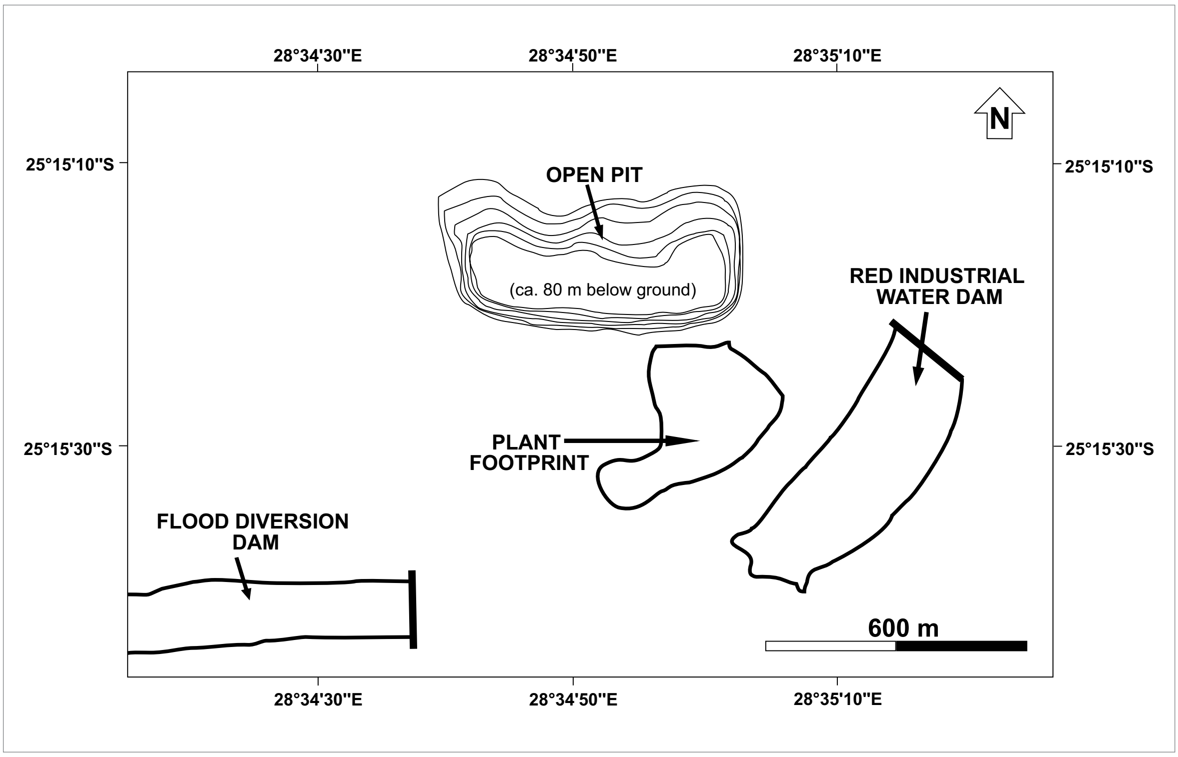


Fig. 2.15: Simplified map of the Vergenoeg Fluorspar mine site with the open pit, the processing plant and the water dams (Graupner et al. 2014).

other fluorochemical products (DMR 2012). The fluorspar concentrate (acidspar) grades over 97 % CaF_2 with a maximum of 0.03 % SiO_2. Metspar is produced for local consumption from lower grade flotation concentrates. A new 30,000 tpa metspar powder and briquette plant was installed in 2012 (Roskill 2013).

Vergenoeg Mine represents one of the largest fluorite deposits globally with a total fluorite resource in excess of 122 Mt at 22.5 % CaF_2 in 2012 (Roskill 2013). The life of mine is expected to be more than 125 year (Shangoni 2013). According to data of ISCOR (1999), Vergenoeg also contains an iron resource in the order of about 195 Mt at 42 % Fe.

The expansion of the Vergenoeg Mine plant capacity in Rust de Winter in the Gauteng Province, which was commissioned in 2012, is now complete. The plant can now produce 200–250 kt/pa with a potential of 300 kt/pa with minimal additions to design. Also, the new processing plant commissioned for production of metspar powder and briquettes can now produce 30 kt/pa.

The Fluorochemical Expansion Initiative (FEI), which is driven by the Department of Science and Technology (DST) and the Department of Trade and Industry (DTI), is aimed at developing South Africa's fluorochemical industry through increased local beneficiation of the country's fluorspar reserves. Whilst South Africa has had success in the establishment of its existing fluorochemical industry (Pelchem's FEI), significant efforts need to be made in accelerating development and growth in skills, technologies, manufacturing capacities and mineral beneficiation and improving the trade deficit in the chemical sector and reliance on imports. The Industrial Policy Support Fund (IPSF), administered by the Industrial Development Corporation (IDC) on behalf of the DTI, is pursuing the commissioning of an investigation into the commercial viability of the potential downstream opportunities of fluorocarbons and fluoropolymers in South Africa. Beneficiation of current fluorspar resources is expected to promote industrial development, investment, competitiveness, employment creation and diversification of the industrial base of the economy.

Tab. 2.2: Vergenoeg fluorspar mining operation; general geochemical compositions of whole-rock ore samples. Data are from (1) Goff et al. (2004) and (2) Schütte (2005) (data from drill core).

Species	Units	Vein fluorite			Hematite-fluorite unit (Gossan)			Magnetite-fluorite unit			Magnetite-fayalite unit		
		26	27		21	7		15	16		18	19	
Data source		1	1	2	1	1	2	1	1	2	1	1	2
SiO_2	%	5.70	0.51	0.56[1] (0.45 – 0.72)	15.60	6.80	10.13[1] (0.8 – 30.15)	14.60	6.55	11.08[1] (1.36 – 16.37)	6.50	18.00	10.82[1] (1.39 – 24.76)
TiO_2	%	0.11	bdl	0.01[1]	0.005	0.045	0.07[1]	0.010	0.075	0.11[1]	0.100	0.090	0.65[1]
Al_2O_2	%	1.91	0.17	0.29[1]	0.10	0.36	0.31[1]	0.14	0.11	0.23 [1]	0.18	0.07	0.49[1]
Fe_2O_3	%	2.1	0.2	7.83[1]	52.0	54.6	59.98[1] (10.42 – 94.88)	41.4	55.6	65.31[1] (55.89– 70.47)	57.2	66.6	72.91[1] (45.31 – 87.91)
MnO	%	0.03	bdl	0.1[1]	0.02	0.02	0.21[1]	0.32	0.68	0.97[1]	0.10	1.27	0.57[1]
MgO	%	0.65	0.07	0.06[1]	0.02	0.02	0.01[1]	0.18	0.24	0.24[1]	0.12	0.85	0.32[1]
CaO	%	63.8	72.4	45.1[1, 2]	23.0	26.0	13.4[1, 2]	25.2	15.0	5.63[1, 2]	25.4	6.8	7.04[1, 2]
CaF_2	%	88.8	100.8	87.98[1] (74.00 – 95.97)	32.0	36.2	26.17[1] (0.22 – 86.86)	35.1	20.9	10.98[1] (1.07 – 24.52)	35.4	9.5	13.73[1] (0.21 – 40.31)
Na_2O	%	0.29	0.06	0.05[1]	0.01	0.02	0.01[1]	0.02	0.02	< 0.01[1]	0.02	bdl	0.02[1]
K_2O	%	0.17	0.08	0.05[1]	0.09	0.10	0.02[1]	0.09	0.09	0.01[1]	0.05	0.06	0.04[1]
P_2O_5	%	0.03	bdl	0.02[1]	0.17	0.55	0.71[1]	0.31	2.26	0.06[1]	0.66	0.02	0.26[1]
LOI	%	0.00	0.00		1.20	2.00		6.60	6.80	11.15[1]	0.20	4.20	
Total Oxides	%	**74.76**	**73.47**		**92.22**	**90.52**		**88.87**	**87.43**		**90.53**	**97.96**	
Total Oxides[3]	%	**99.79**	**101.88**		**101.24**	**100.72**		**98.76**	**93.31**		**100.50**	**100.63**	
Be	ppm	bdl	bdl		3	4		395	1540		220	22	
Cu	ppm	bdl	bdl		105.9	56.9		279.9	240.6		bdl	bdl	
Zn	ppm	34.9	bdl		bdl	43.4		89.3	280.3		76.0	90.4	
As	ppm	7.2	bdl		182.4	97.3		92.3	350.0	18 – 841	160.6	942.8	
Ba	ppm	30.3	5.7		19.1	69.1		92.3	34.5		3.4	bdl	
Pb	ppm	bdl	bdl		22.0	176.3		45.6	189.2		27.5	15.9	
Th	ppm	3.5	0.2		15.9	113.1		71.2	379.7		81.4	1.8	
U	ppm	2.2	0.4		7.9	81.8		95.0	438.7		79.5	4.5	
Total	%	**75.4**	**73.8**		**92.6**	**92.4**		**89.8**	**91.5**		**91.5**	**98.2**	
Total[3]	%	**100.4**	**102.2**		**101.6**	**102.6**		**99.7**	**97.4**		**101.4**	**100.8**	

[1] average content, [2] Ca-content, [3] includes Ca as CaF_2

2.3.5 Nokeng Fluorspar Mining Project (Sepfluor Ltd.)

Location and owner

Coordinates: (exploration facilities)
25°17'58.4"S, 28°35'28.6"E

The Nokeng fluorspar mining project is situated approximately 120 km northeast of Johannesburg and around 60 km southeast of Bela-Bela on farm Kromdaai 209 JR and Naaupoort 208 JR on the border of the Limpopo Province. The project is directly situated south of the Vergenoeg fluorspar deposit and is developed by Sepflour Ltd., a HDSA-compliant company that was founded in 2006.

Local infrastructure

The Rust de Winter settlement north of the Nokeng project is connected with the N1 national highway (Pretoria – Bela-Bela; exit: Pienaarsrivier) by a paved road. The Nokeng project is easily accessible via the D567 paved road connecting the towns of Moloto (south of Nokeng) and Rust de Winter (north of Nokeng; distance from N1 to Nokeng: ~40 km). The Elands River is approximately 10 km north and the Enkeldoring Spruit is ~6 km east of the site; they are the closest perennial rivers. The Rust De Winter Dam is situated approximately 12 km northwest of the project. Power is also available.

Geology

The Nokeng fluorspar mining project is situated within the Vergenoeg igneous complex, which constitutes a volcanic pipe (see Vergenoeg mine) and an associated suite of volcano genetically derived pyroclastic and sedimentary rocks. The Vergenoeg suite consists of an uppermost stratiform sedimentary unit, followed by a fragmental conformable stratified hematite and hematite-fluorite unit, a breccia agglomerate and then by a basal unit of ignimbrite. Within these units the deposits of the Nokeng project were found, situated south of the Vergenoeg pipe.

There are three deposits, from north to south the Plattekop deposit (within the hematite-fluorite unit), the Wiltin deposit (breccia agglomerate) and, within the sedimentary unit, the Outwash Fan deposit (Fig. 2.16).

The Plattekop deposit is located about 1,000 m south of the volcanic Vergenoeg pipe, is approximately 30 m to 40 m thick, and dips 10° southeast and represents a channel of the main vent from the Vergenoeg pipe. It covers an area of about 100,000 m² (250 m x 400 m). The deposit consists of red to greyish massive hematite containing phenocrusts of predominatly euhedral fluorite crystals. Bedding is caused by an enrichment of fluorite crystals. The fluorite content (CaF_2) is about 40 – 42 %, with about 10 % quartz and the balance iron oxides (Fourie 2000).

The Outwash deposit extends over 1000 m by 1000 m with a thickness down to 9 m and consists entirely of fragmental pyroclastic rocks. Rounded hematite and felsitic and fluorite clasts in a ferruginous matrix are typical. These rocks are viewed as erosion remnants of the Vergenoeg volcanic cone (Fourie 2000).

The Wiltin deposit is at an early exploration stage.

Mining and processing

In 2014 only the Plattekop and the Outwash Fan deposits were prioritised for development and mining (personal communication with Wilson Hlangwane, Project Geologist, Sepfluor Ltd.).

In 2013, Nokeng received all final approvals, and a mining right was granted.

The Nokeng fluorspar deposit has been developed as a low cost open pit operation. There is virtually no overburden. Cost of production is expected to be low; < USD 200/ton fob Durban.

Resources: Total reserves stood at 11.2 Mt in 2014. Fluorite is estimated at 42 % for Plattekop and 27 % CaF_2 overall (Tab. 2.3). At an average annual mining production of 600,000 t a 20 year life of mine is estimated. The production of 180,000 tpa of acidspar and 30,000 tpa of metspar is targeted. Acidspar is used for internal benefication at the planned fluorochemical beneficiation plant at Ekandustria, Bronkhorstspruit, and metspar is for local and export steel markets.

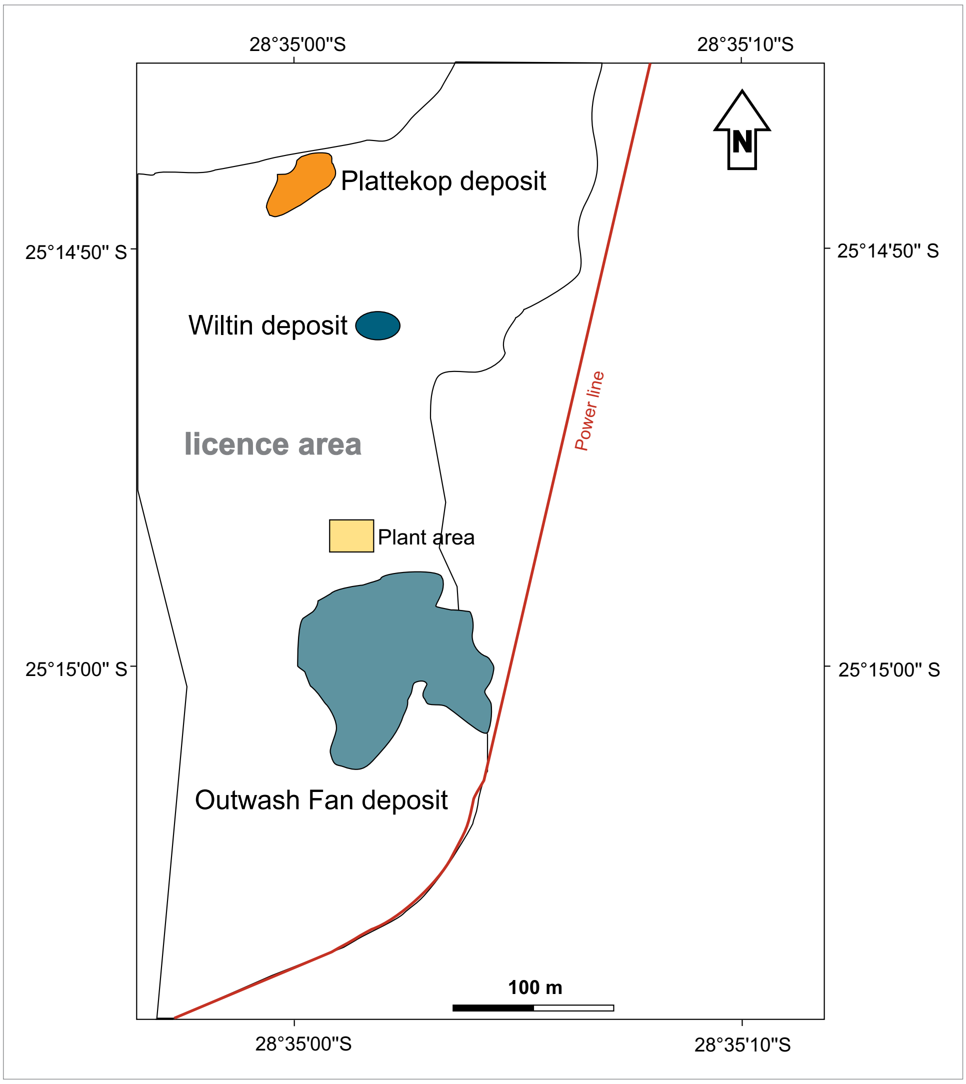


Fig. 2.16: Map of the Nokeng license area, with the Plattekop, Wiltin and the Outwash Fan fluorspar deposits (with courtesy of Sepfluor Ltd.).

Tab. 2.3: Reserve statement for Nokeng fluorspar deposit (Sepflour 2014).

Deposit	Category	Tonnes ('000)	Contained CaF_2 ('000)	CaF_2 (%)
Plattekop	Proven	-	-	-
Outwash Fan	Proven	9,065.1	2,055.1	22.7
Proven		**9,065.1**	**2,055.1**	**22.7**
Plattekop	Probable	3,129.6	1,259.1	42.4
Outwash Fan	Probable	-	-	-
Probable		**3,129.6**	**1,259.1**	**42.4**
Total mineral reserves		**12,194.7**	**3,314.2**	**27.2**

2.3.6 Buffalo Fluorspar Mine (Rooiberg Stone Pty Ltd.)

Location and owner

Coordinates: (North Kloof) 24°28'29"S, 28°39'19"E

The 100 % Rooiberg Stone Ltd. owned Buffalo Mine is situated on the farm Buffelsfontein 347 KR about 5 km northwest from the town of Mookgopong (prior name: Naboomspruit) in the Limpopo Province. Buffalo had been closed for maintenance since 2008 with no plans to re-open. The mine comprises three open pits (Fig. 2.17; for the northern pit "North Kloof" see Fig. 2.18), with two of them closed and one still open for aggregate production. Additionally, Rooiberg Stone is currently processing the stockpiles for aggregates. The deposit is not exhausted.

Infrastructure

The Buffalo mine sight can be accessed via the R520 paved route from Mookgophong. Power and water are available.

Geology

The geology of the farm Buffelsfontein 347 KR consists of granite in the northwestern parts, a sandstone plateau to the southwest and a sandstone flats to the southeast. It is further intruded by quartz and diabase veins with leptite forming around the central part of the farm (Fig. 2.17). The granite is red to grey in colour, coarse-grained, miarolitic and grades to a medium-grained facies with a grain size less than 3.5 mm. It consists of 63 % perthitic feldspar, 35 % quartz with minor chlorite, sericite, fluorite and magnetite and trace

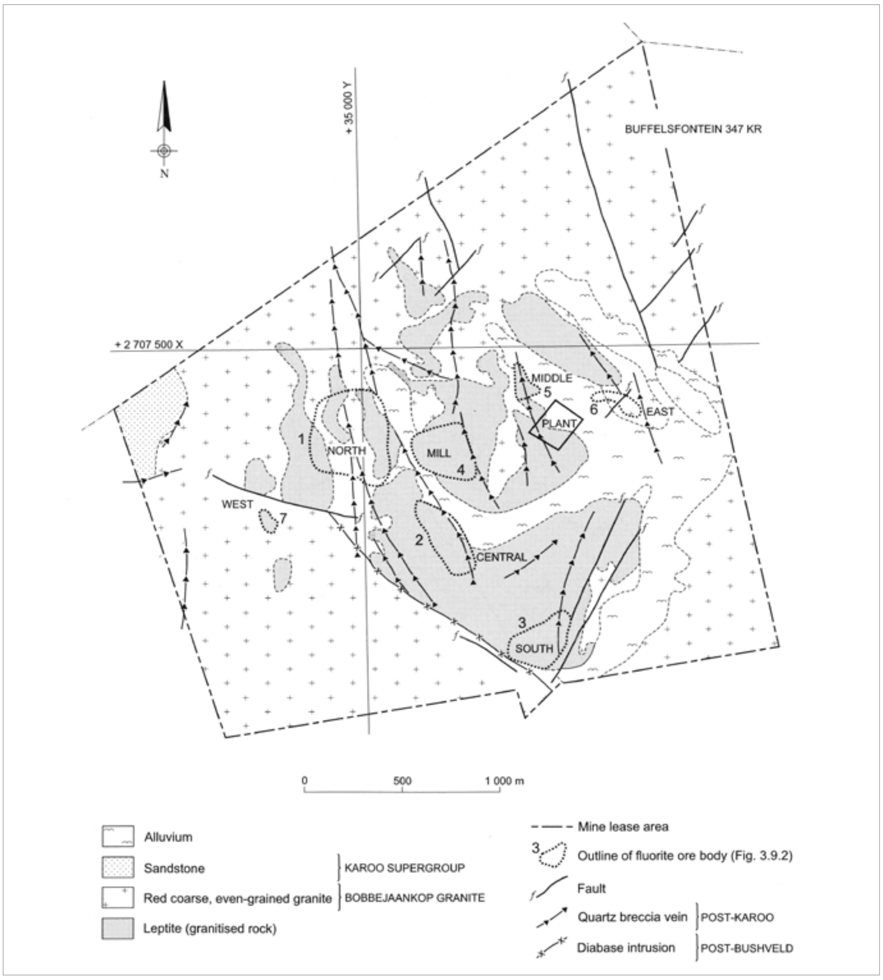


Fig. 2.17: Simplified geological map of the Buffalo area with its seven ore bodies within the leptite xenoliths (Crocker et. al 2001).

Fig. 2.18: The northern pit (the North Kloof, closed since 1994) of the three open pits from the Buffalo Mine with an N-S extension of about 320 m and a depth of 100 m (photo: DERA 2013).

minerals zircon, thorite, monazite and apatite. Leptite consists of rounded feldspar and quartz grains and occurs as xenoliths in granites (Absalom 1986, Crocker et. al 2001).

The granites belong to the north-central part of the Bushveld Complex. Buffalo Mine is the largest fluorite mine in acid rocks of the complex. The fluor-spar mineralisation belongs to high temperature hydrothermal deposits. The fluorspar varies from dark purple to pale green with a grain size ranging from less than 1 mm to 100 mm. It occurs as stockwork mineralization, ranging from a few millimetres to about 60 cm, subparallel and parallel to the relic bedding planes, fractures and certain joints within xenoliths of Transvaal Supergroup metasediments (known as leptite) in the upper part of the Nebo Granite (Kinnaird et al 2004). There are seven ore bodies within the leptite xenoliths, which are enclosed by granite (Fig. 2.19). Fluorspar also occurs in the granite and at the contact between granite and metasediment along joints. Besides fluorspar, monazite is present, giving a P_2O_5 contamination of about 700 to 1,500 ppm (personal communication with Hennie du Plessis, Rooiberg Stone Ltd.). It is possible, however, to reduce the P-content by separation.

Due to the irregular distribution of the fluorspar mineralisation within the granite, the calculation of the total remaining resources and reserves is difficult and no actual fluorspar data are available from Rooiberg Stone. Originally, the ore reserves amounted to 60 Mt at 16 % CaF_2, which was the approximate cut-off (Martini et al. 1998). Acid-grade, metallurgical-grade as well as ce-

Fig. 2.19: Fluorspar veins within the granite at Buffalo (photo: DERA 2013).

ramic-grade fluorspar were produced until 1994. A reactivation of the mine is planned with an annual production of 60,000 t fluorspar.

About 300 Mt of tailings material from previous mining operations is available on the mine site with a fluorspar content of 13 to 14 % (CaF_2) within the < 500 µm grain fraction (personal communication with Hennie du Plessis, Rooiberg Stone Ltd.).

2.3.7 Witkop Fluorspar (Coffey mining)

Location and owner

Coordinates: 25°43’4”S, 26°5’36”E

The abandoned Witkop Fluorspar Mine is situated approximately 18 km south of the town of Zeerust, Ngaka Modiri Molema District, North West Province. It lies approximately 240 km northwest of Johannesburg on the N4 road, the main road link between South Africa and Botswana.

History

At the end of the 19th century, fluorspar was discovered southwest of Zeerust, but virtually no mining took place until 1917. From 1917 to 1936 around 50,000 t of high-grade ore was mined mainly for export to the United States (Ryan 1986). Witkop Fluorspar Mine was established as a major acidspar producer by the wholly-owned South African Phelps Dodge Corporation commencing in 1971. Intensive exploration was undertaken in the early 1970s in the area, with a total of 97 diamond and 350 percussion boreholes. The mine was sold to Sallies in 1999 and in 2011 to Fluormin Plc (London, United Kingdom). Fluormin placed the Witkop Mine under care-and-maintenance, effective from October 2012. The mine faced operational and cost pressures, which were further exacerbated due to declining fluorspar prices. Despite efforts to keep operations running, the company reported that the prevailing fluorspar price fell below current operating costs.

On 17 May 2013, Fluormin Plc was sold to Vanoil Energy, a Canadian oil and gas company. It is unclear what Vanoil intends to do with Fluormin’s Witkop asset.

Several companies are currently conducting exploration works to identify near term higher grade ore to mitigate the higher costs that the industry is currently experiencing.

Infrastructure

The mine is well served with paved and gravel roads. The main railway line from Johannesburg to Botswana is located about 7 km to the west of the mine. The area is bush covered and hilly with elevations ranging between 1,300 and 1,550 m above sea level. Water and power is available.

Geology

The fluorspar deposits occur as large stratabound bodies in a well-defined dolomitic limestone unit (Frisco Formation) of the Transvaal Supergroup. The Frisco Formation consists of dark, well-bedded dolomite with minor shale and limestone at the base, followed by massive stromatolitic dolomite and dark micritic, well-bedded shaly dolomite on top. It is covered by a continuous thin layer of banded chert (Penge Formation). At Witkop Mine, so-called “algal” ore is developed in stromatolitic beds of the middle Frisco Formation. The main body of fluorspar mineralisation varies in width from 300 to 600 m with thicknesses from 2 to 30 m, with an average of 6 m (Rayn 1986). Three ore types have been distinguished, namely dolomitic ore, the most abundant ore type at the mine, rockspar ore and residual ore. The ore types differ in grade, ranging from 8 to 40 % CaF_2 (dolomitic ore) and from 40 to 75 % CaF_2 (rockspar ore). The fluorspar is granular and colorless and mostly occurs in small irregular lumps to that effect that the dolomite is completely replaced by fluorspar. Minor amounts of pyrite, pyrrhotite, sphalerite, galena and chalcopyrite occur within the ore, but it also contains negligible amounts of rare earths, beryllium, niobium and titanium.

2.3.8 Doornhoek Fluorspar Project

Location and owner

Coordinates: 25°43'4"S, 26°5'36"E

The Doornhoek fluorspar project is situated in the Marico District of the North West Province approximately 25 km south of the town of Zeerust. It lies approximately 240 km northwest of Johannesburg and is connected with the N4 road, the main road link between South Africa and Botswana. The project area spans an area of around 23,000 hectares on different farms. It is situated southeast of the abandoned Witkop Mine.

The project is developed by the Eurasian Natural Resources Corporation Ltd. (ENRC), a company which was acquired by Eurasian Resources Group S.à r.l. (ERG) in 2013.

Infrastructure

The Doornhoek project is well served with paved and gravel roads. The main railway line from Johannesburg to Botswana is located about 20 km north the project area. There is a railway station with all infrastructures in Zeerust. The connection to harbours is given. The area is bush covered and hilly with elevations ranging between 1,300 and 1,550 m above sea level. Water and power is available. Because of the neighbouring abandoned Witkop Mine the relevant infrastructure is already in place.

History

At the end of the 19th century fluorspar was discovered southwest of Zeerust. In the 20th century several companies started exploration. In the late 1970s Esso, a subsidiary of Exxon Mobil Corp., drilled 108 boreholes that was followed by further drilling of 212 boreholes in the early 1980s. A bulk sample for metallurgical testing was extracted from a new installed 90 metre shaft (Industrial Minerals 2009). Further boreholes were drilled by Samancor, a South African chromite producer, until 2004. After that time the project was acquired by CAMEC (Central African Mining Exploration Company), including the analytical results and the core for 154 boreholes for the vast majority of borehole logs. In December 2009 ENRC acquired 95.40 % of the shares of CAMEC.

Geology

Fluorspar is bounded to dolomite of the Frisco Formation of the Transvaal Supergroup. The Frisco Formation consists of dark, well-bedded dolomite with minor shale and limestone at the base, followed by massive stromatolitic dolomite and dark micritic, well-bedded shaly dolomite on top (Fig. 2.20) with a thickness of around 190 m. The top of the Frisco Formation is characterised by an unconformity, followed by a continuous thin layer of banded chert (Penge Formation). The main mineralisation, sometimes 40 %, is bounded to the stromatolitic beds, where the calcite is replaced by fluorite (Fig. 2.21). This ore type is named algal ore and it is typically confined to a sparry, cryptalgal laminated dolomite zone with a thickness of 20 to 50 m in the upper part of the Frisco Formation. In the dolomite the fluorspar forms irregular nodules with a few centimetres in diameter, fine grains and thin layers following the lamination with cryptalgal structure. The fluorspar is colorless and is associated with variable quantities of quartz, calcite, dolomite, talc, pyrite and, in places, sphalerite (Martini 1986). The second important ore type is so-called blockspar, finely crystalised and mostly of very dark color due to the presence of organic inclusions. There are also white fluorspar grains. Blockspar occurs in the lower Frisco Formation.

Other ore types are banded spar below the Frisco Formation, breccia spar and also massive cave fills, most of which are already mined out. The fluorspar is frequently associated with tremolite, but the fluorspar in general is not affected by metamorphism.

Project

At Doornhoek there has been an exploration license beginning in 2008 and which is valid until the end of 2017. The fluorspar occurrences are well investigated by around 600 boreholes. In general the ore contains > 9 % CaF_2, with high-grade pods commonly exceeding 30 % CaF_2. The extraction of fluorspar is though in the form of underground mining in the eastern part of the exploration area,

Fig. 2.20: Massive stromatolitic dolomitic bedding within the Frisco Formation at quarry “R7” (active from 1974 to 1984) in the Doornhoek license area (photo: DERA 2014).

Fig. 2.21: Stromatolite sample from “R7” with layers of fluorite, which has replaced the original calcite (photo: DERA 2014).

Tab. 2.4: Calculated mineral resources of the Doornhoek project in 2009 (ENRC 2009).

Classification	Tonnages (Mt)	Grade (CaF_2 %)
Indicated	15.8	20.8
Inferred	16.5	19.6

Tab. 2.5: Doornhoek mineral resources, calculated by Esso at 20 % and 25 % CaF_2 cut-off grades, grade cut off vs minimum mining (Industrial Minerals 2009, Source: CAMEC).

Grade cut-off	Minimum mining height			
	2 m	2.6 m	3.3 m	4 m
20 % CaF_2	39.00 Mt @ 26.18 % CaF_2	36.02 Mt @ 25.87 % CaF_2	36.43 Mt @ 24.99 % CaF_2	33.36 Mt @ 25.24 % CaF_2
25 % CaF_2	21.83 Mt @ 30.21 % CaF_2	18.94 Mt @ 30.36 % CaF_2	14.74 Mt @ 30.36 % CaF_2	12.40 Mt @ 30.71 % CaF_2

whereas in the western part opencast mining is possible.

Available resource data are to be seen in Table 2.4 and 2.5.

2.4 Requirements and Evaluation

The reference value specified in Table 2.6 can be applied to the size assessment of deposits that are predominantly mined for fluorite.

In a global comparison of the three largest primary deposits of South Africa, Vergenoeg, Doornhoek and Nokeng, these are large deposits after Lorenz (1991) and Orris & Bliss (1992) (Tab. 2.6).

By taking into account the total ore resources and its CaF_2 grades, the investigated deposits would form a highly lucrative economical potential in a worldwide comparison (Fig. 2.22).

According to the chemical composition of fluorspar, the raw material is used for different applications, and is distinguished into metallurgical-grade fluorspar (metspar), acid-grade fluorspar (acidspar), ceramic-grade fluorspar, and optical-grade fluorspar with corresponding requirements (see chapter 2.2). Most of South African fluorspar can be used as acidspar.

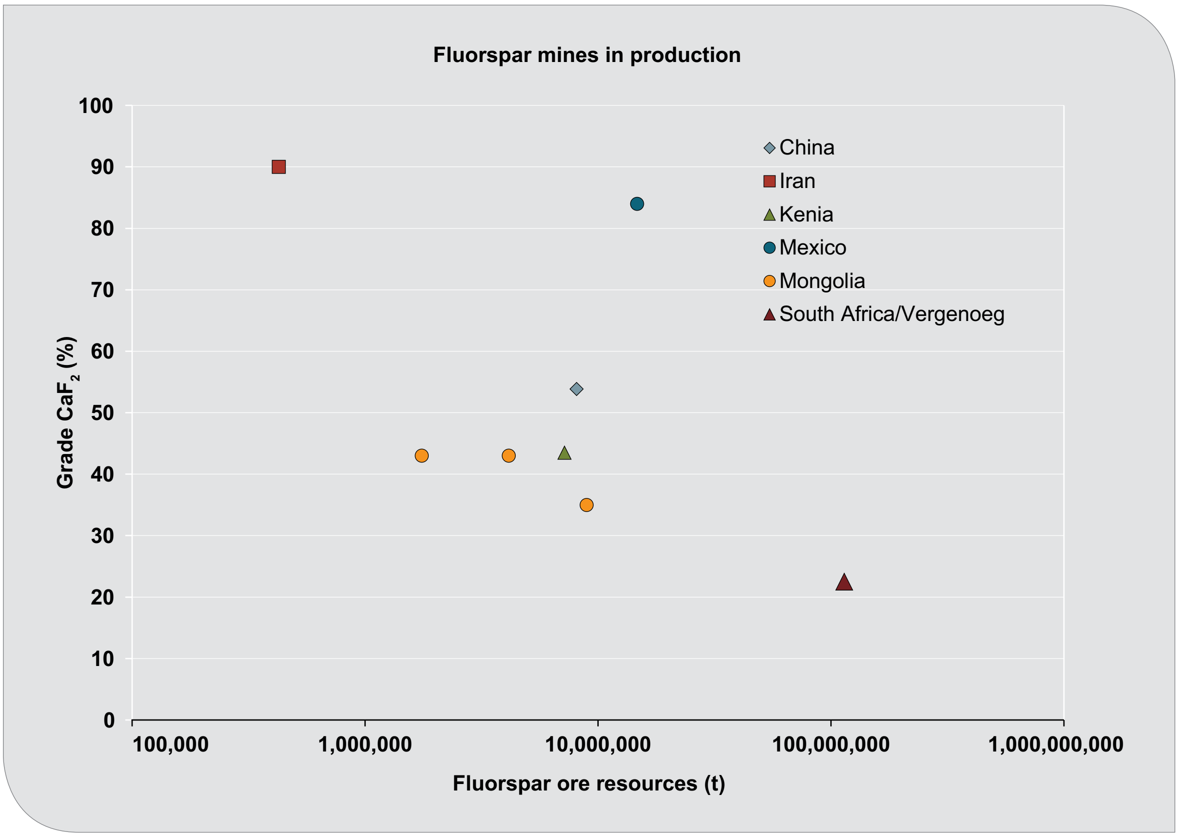
South Africa accounts with 41 Mt (Salwan 2015) for the largest primary reserves worldwide (18 %) followed by Mexico (14 %) and China (9 %). Regarding additionally unofficially secondary resources and reserves within the tailings of the Buffalo fluorspar mine (see chapter 2.3.7) this number would increase to several million tones.

South African reserves and resources can sustain fluorspar production for many years to come. The deposits are well known and understood. The ore is metallurgicaly simple and high-grade ore can be delivered. Scope exists for finding more deposits of fluorspar. Current and past fluorspar

Tab. 2.6: Size classification of fluorite deposits according to Lorenz (1991) and Orris & Bliss (1992).

	All deposits[1)]	Vein deposits[2)]
	CaF_2-content	CaF_2-content
Small	< 50,000 – 100,000 t	< 200,000 t
Medium	100,000 – 2 Mt	200,000 – 2 Mt
Large	2 – > 15 Mt	> 2 Mt

[1)] LORENZ (1991), [2)] ORRIS & BLISS (1992)



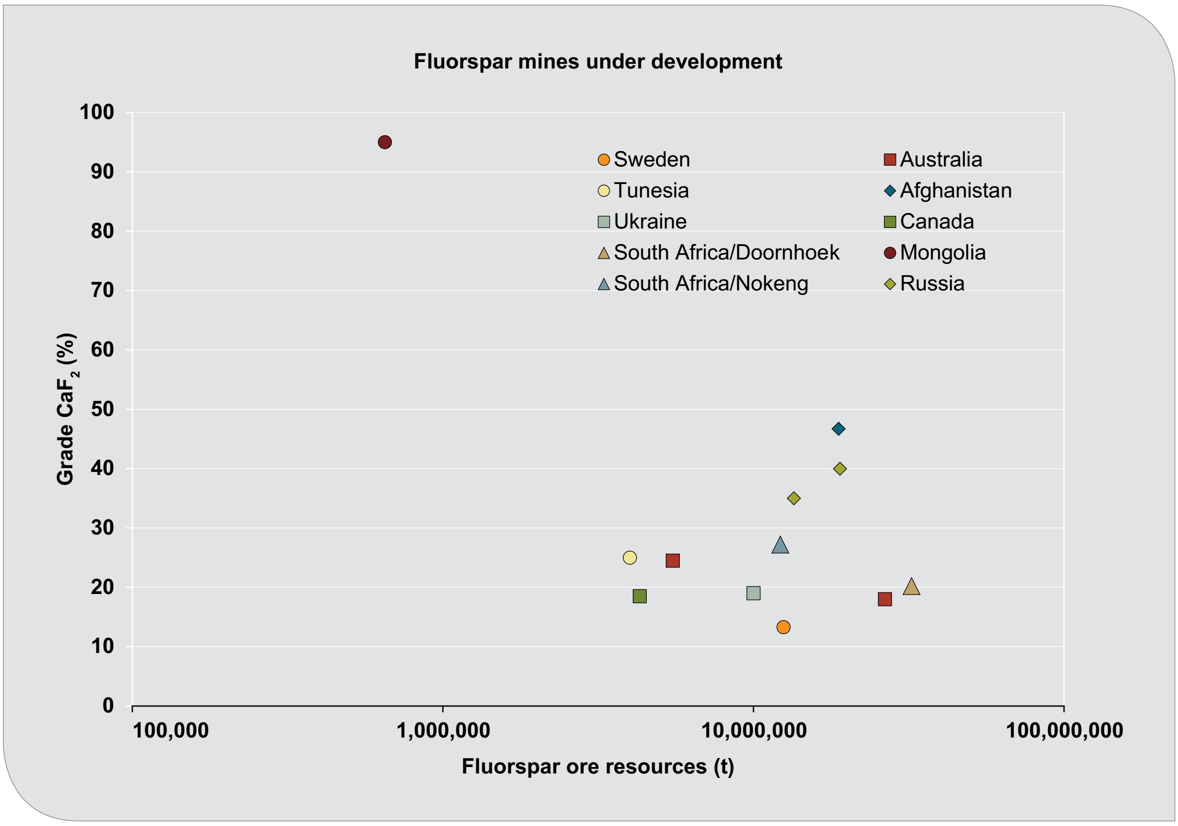


Fig. 2.22: Global grade-tonnage-comparison of active fluorspar mines (above) and fluorspar mines under development (below).

operations have strong management teams with sound technical financial backing and often are owned or have a strong European shareholder base. Operations like Vergenoeg keeps one of the largest customer bases in the world, with customers located in all continents and market niches. Further devaluation of the South African Rand will also help to keep costs down for local producers of fluorspar. South Africa is also located on a busy shipping route.

Fluorspar is one of the many mineral resources that are abundant in South Africa on which the country has never truly capitalised. Yet there has been a reluctance to invest in the technology and infrastructure required for its beneficiation. This presents an opportunity for manufacturers to venture into the downstream value addition market on raw materials.

The Fluorochemical Expansion Initiative (FEI), driven by the Department of Science and Technology (DST) and the Department of Trade and Industry (the dti), is aimed at developing South Africa's fluorochemical industry through increased local beneficiation of the country's fluorspar reserves. The FEI is aligned to broader national programmes, including the National Industry Policy Framework, the Advanced Manufacturing Technology Strategy and the Beneficiation Strategy for Minerals in South Africa.

South Africa has the opportunity to challenge the market by providing an alternative stream of beneficiated supply. The jobs created directly and indirectly are likely to have the greatest impact on South African communities, and will be supported by deliberate programmes for training and development, corporate social investment and local economic development (Pelchem 2015).

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3 Chromite (K. Kärner, H. Marbler)

3.1 Definition, Mineralogy and Sources

3.1.1 Definition

Chromium is a steely-grey transition metal in group 6 of the periodic table, assigned the atomic number 24. This hard and brittle metal has a very high melting point (Tab 3.1) and is the 22nd most abundant element in the earth's crust.

Tab. 3.1: Physical properties of chromium.

Atomic weight [amu]	52.0
Density [g/cm³]	7.19
Melting point [°C]	1,907
Boiling point [°C]	2,671
Crystal system (chromite)	Isometric
Atomic radius [pm]	128
Hardness (chromite) [Mohs]	5.5

3.1.2 Mineralogy and Sources

Chromium occurs naturally as the oxide mineral chromite ([Mg, Fe^{2+}][Cr, Al, Fe^{3+}]$_2O_4$). Typical trace elements in chromite are titanium, vanadium, manganese, nickel, cobalt and zinc. Based on its Cr_2O_3 content and its chromium to iron ratio, chromite is subdivided into high-chromium, high-iron and high-aluminium chromites (Tab. 3.2).

3.2 Specifications and Use

The areas of application of chromite depend on the content of minor components, such as magnesium and aluminium, as well as the chromium/iron ratio (Tab. 3.3).

The largest proportion of globally produced chromite is used in the metallurgical industry (Fig. 3.1). High-chromium chromite is an important raw material for the production of ferrochrome, an alloying material used in steel manufacturing. Unalloyed chromium is also used as a surface coating for a range of appliances due to its relative hardness, as well as corrosion resistance, hence its durabil-

Tab. 3.2: Classification of chromite after Maliotis (1996).

Type of chromite	Cr_2O_3-content	Cr/Fe-ratio	Al_2O_3-content
High-chromium	46 – 55	> 2.1	-
High-iron	40 – 46	1.5 – 2.0	-
High-aluminium	33 – 38	2.0 – 2.5	22 – 34

Tab. 3.3: Specifications for chromite concentrates as a function of the intended use after Elsner (2010).

Formula	Refractory Industry		Chemical Industry	Steel Industry
	(refractory-grade)	*(foundry-grade)*	*(chemical-grade)*	*(metallurgical-grade)*
Cr_2O_3 (%)	> 30	> 44	> 40 – 46	≥ 46
FeO (%)	≤ 16	≤ 26	< 20	n/a
Cr/Fe	2 – 2.5	2 – 2.5	1.5–2.0	≥ 1.5
SiO_2 (%)	≤ 1.5 – 4	< 3.5	2.5	≤ 3
Al_2O_3+Cr_2O_3 (%)	≥ 57	n/a	n/a	n/a
Al_2O_3 (%)	> 20	~ 26 – 28	as low as possible	3 – 10
MgO (%)	~ 15 – 20			as high as possible
CaO (%)	≤ 0.5–1	≤ 0.5	≤ 3	n/a
S (%)	n/a	n/a	n/a	≤ 0.05
P (%)	n/a	n/a	n/a	< 0.04

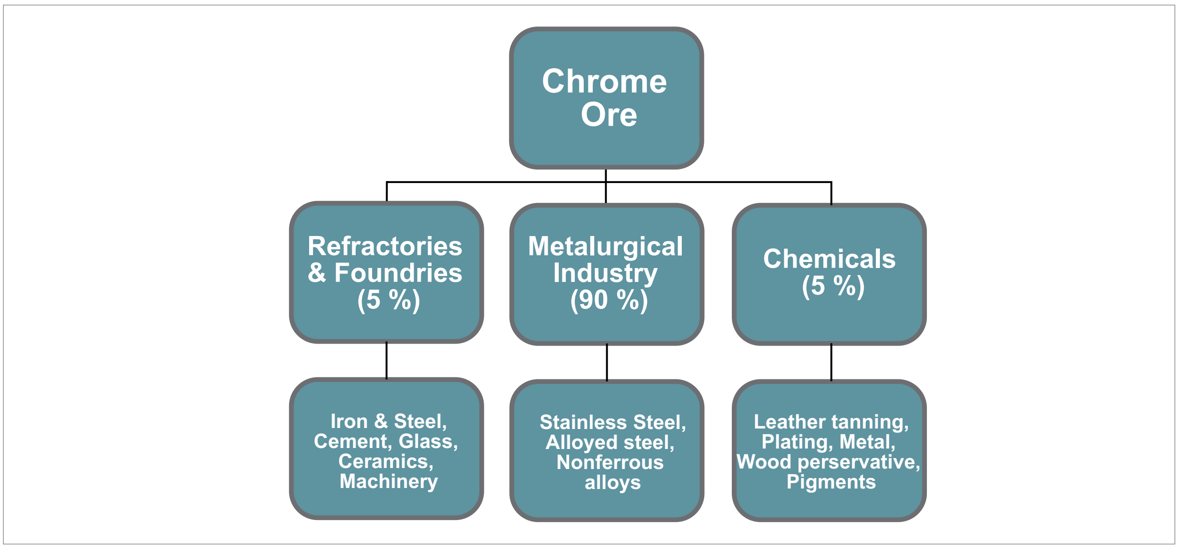

Fig. 3.1: Uses of chromium, according to the International Chromium Development Association (2013).

ity. High-iron chromite is widely used to produce chemicals and pigments. Certain chromium salts are used for the tanning of leather and for timber preservation. The high heat resistance and high melting point makes high-aluminium chromite a material suitable for high temperature refractory applications, such as blast furnaces.

3.3 Supply and Demand

3.3.1 Global Situation

In 2013, a total of 18 countries contributed to the primary mine production of approximately 28.8 Mt of chromite worldwide with South Africa being the world's largest chromite producer, accounting for 13.64 Mt (47 %) of global output (Figs. 3.2 and 3.3). The decrease in chromite production between 2009 and 2010 was the result of the global financial crisis. This also applies to the ferrochrome production (see Fig. 3.4).

The ferrochrome market accounts for over 90 % of the world's demand for chromium. Ferrochrome is an alloy of chromium and iron, containing between 50 and 70 % chromium. Ferrochrome with a chromium content below 56 % is known as "charge chrome" and is produced from low-grade chromite ore (Tab. 3.4). High carbon ferrochrome produced from higher grade ore is more commonly used in specialist applications such as engineering steels where a high chromium to iron ratio and minimum levels of other elements such as sulfur, phosphorus and titanium are important. Low carbon ferrochrome is used during steel production to correct chromium percentages without causing undesirable variations in carbon or trace element contents. It is also a low cost alternative to metallic chrome for use in super alloys and other special applications (Fondel 2014).

Of the three different forms of ferrochrome, high carbon ferrochrome/charge chrome is by far the most important one, representing approximately

Tab. 3.4: Ferrochrome specifications after Fondel (2014).

	Cr (% min)	C (% max)	Si (% max)	P (% max)	S (% max)
Charge chrome	49 – 55	9	5	0.035	0.05
High carbon ferrochrome	60 – 68	9	1 – 3	0.03	0.05
Low carbon ferrochrome	58 – 65	0.05 – 0.25	1.5	0.03	0.03

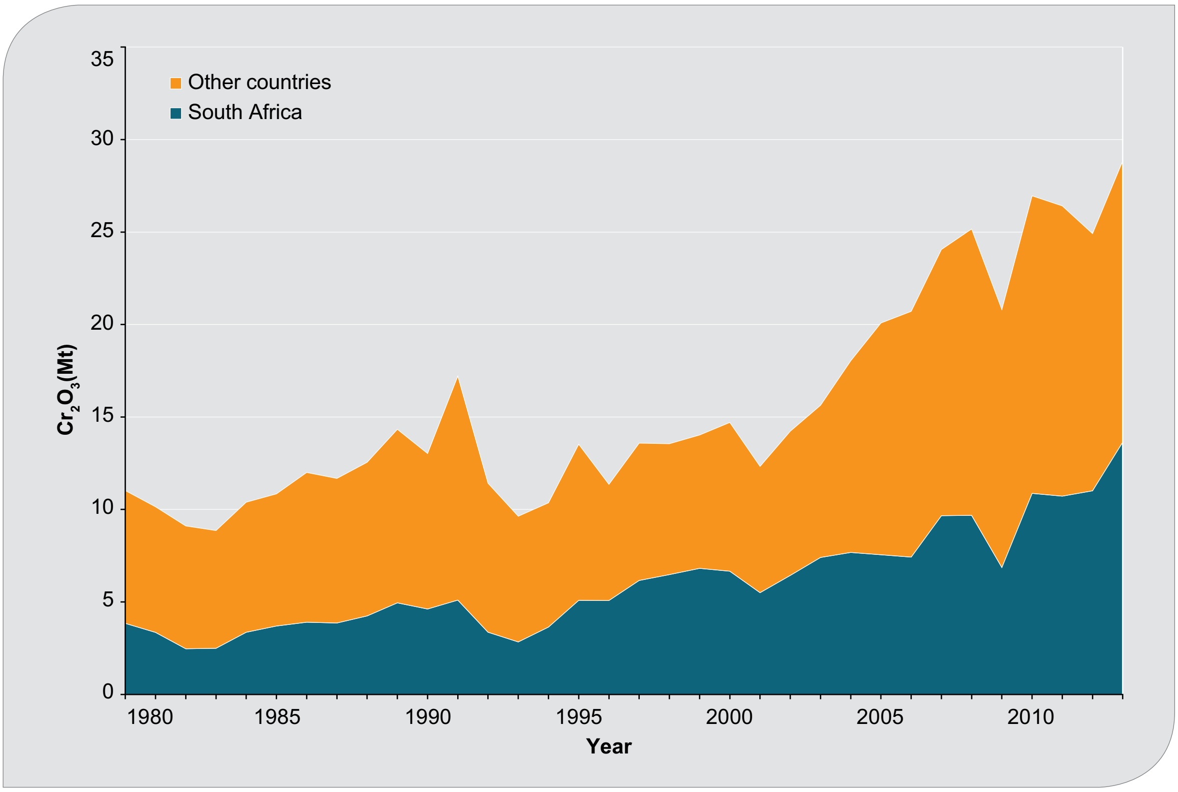

Fig. 3.2: Global primary mine chromite production from 1980 to 2013 (BGR 2013).

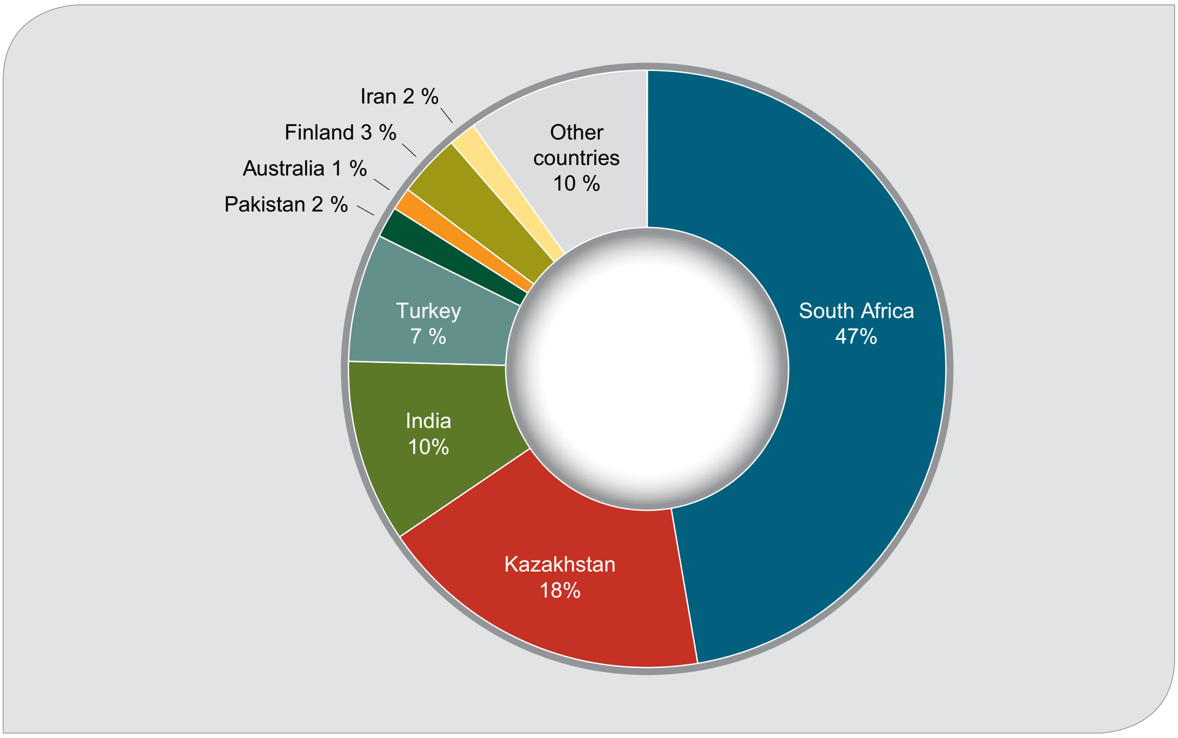

Fig. 3.3: Share of global chromite production in 2013 (BGR 2014).

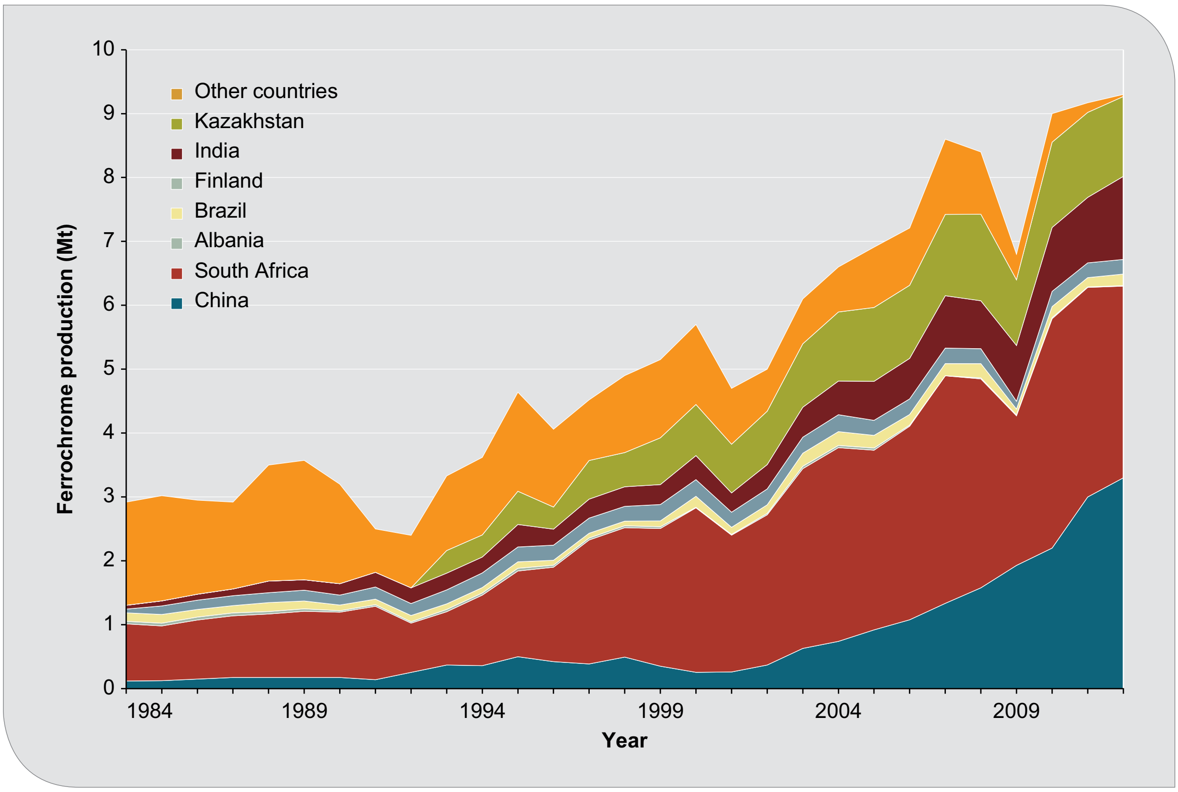

Fig. 3.4: Ferrochrome production by country from 1984 to 2012 (Raw Materials Group, 2014).

93 % of global ferrochrome production (Roskill Information Services Ltd. 2014). High-carbon ferrochrome/charge chrome is mostly used to manufacture stainless steel.

In 2013 global ferrochrome production reached a new record high at 10.8 Mt (Roskill Information Services Ltd. 2014), up 10 % from 2012. The recovering global stainless steel industry, which also reached a new record high in 2013, at 38.1 Mt (stainless melt shop production), up 7.8 % from the previous year (Stainless Steel Forum 2014) is likely to have triggered the increased production of ferrochrome.

After outpacing South Africa in 2012 (Fig. 3.4 and 3.5), China consolidated its position as the world's largest ferrochrome producer in 2013. China's 2013 output volume totaled 4 Mt, representing more than a third of global ferrochrome production (d'Harambure, 2014). By comparison, South Africa produced 3.2 Mt of ferrochrome in 2013, up some 7 % from the previous year. China and South Africa are followed by Kazakhstan and India, where ferrochrome production in 2013 was 1.2 Mt and 1 Mt respectively.

In 2012 the world production of ferrochrome (9.3 Mt) met the demand (9.1 Mt, Fig. 3.6). However, the world demand for ferrochrome is expected to increase by approximately 23 % by 2017 due to the forecast increase in stainless steel production. In addition to the current production, more than 5 Mt of high-grade chromite ore per year will be required in five years to produce the additional volumes of ferrochrome (International Ferro Metals 2013). Roskill (Roskill Information Services Ltd. 2014) estimates the potential expansion in primary ore production capacity through 2018 will exceed 6 Mt per year, which would be sufficient to meet the demand.

3.3.2 Germany

Germany is an important manufacturer of stainless steel. The stainless steel industry is the major consumer of chromium ore and ferrochrome. Due to the lack of domestic supply, Germany is dependent on importing chromium ore and its alloys.

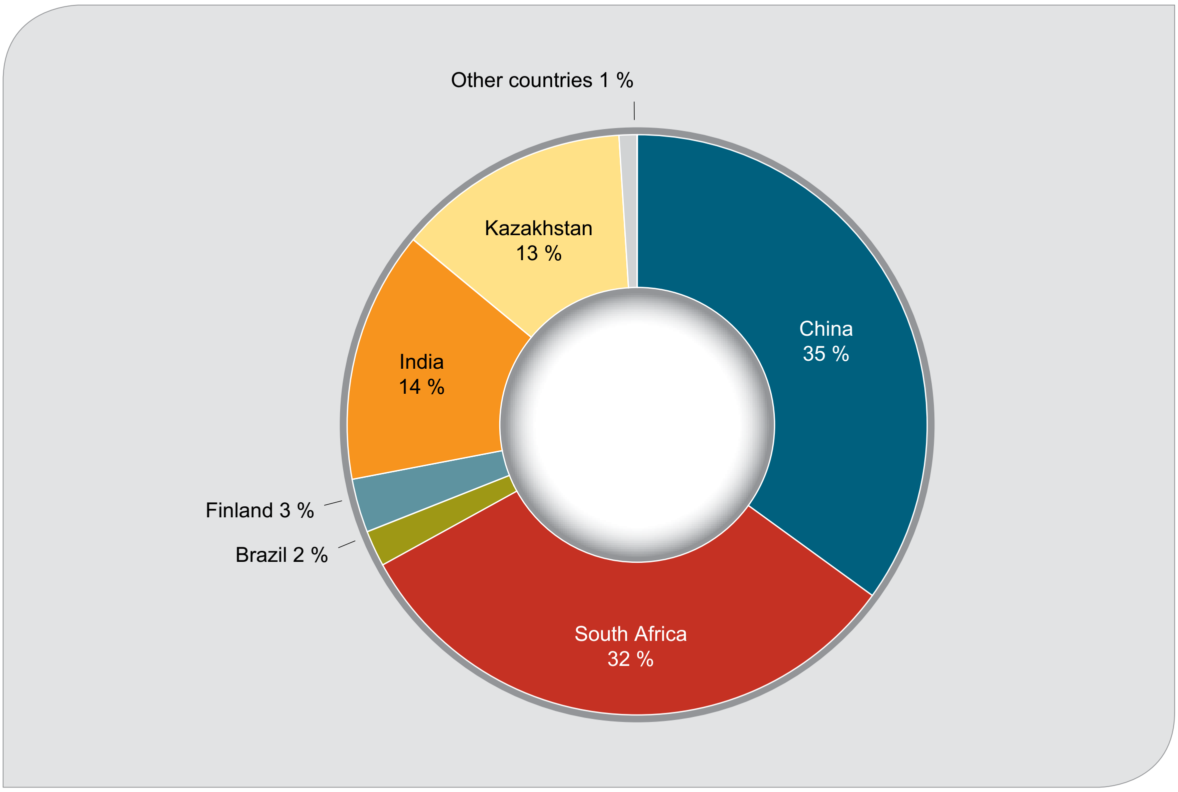

Fig. 3.5: Share of global ferrochrome production in 2012 (Raw Materials Group 2014).

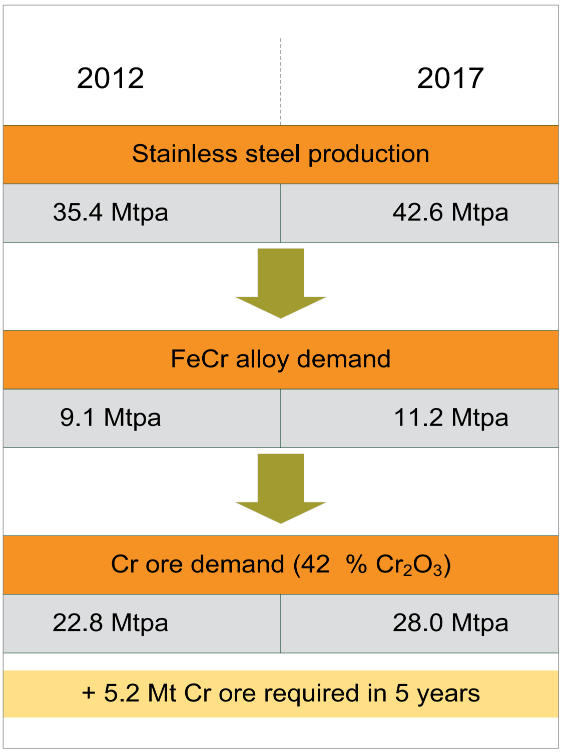

Fig. 3.6: Ferrochrome demand forecast, according to International Ferro Metals (2013).

The majority of chromium ore and ferrochrome is sourced from South Africa. Smaller amounts of chromium ore are also imported from Turkey and via the Netherlands. In addition, Finland and the Netherlands supply some minor amounts of high-carbon ferrochrome to Germany (Fig. 3.7). The falling import rates in 2009 were caused by the global financial crisis.

The import of (high-carbon) ferrochrome diminished by approximately 30 % between 2011 and 2013. The significant decrease is likely to reflect the change within the German steel industry. ThyssenKrupp, one of Germany's major steel manufacturers, divested its stainless steel business in 2012 (RP Online 2013). However, the sale was unwound in late 2013, and ThyssenKrupp has recently re-entered the stainless steel business, which resulted in increased chromium import figures in 2014.

A leading German manufacturer of chromium products is Gesellschaft für Elektrometallurgie mbH (GfE). GfE is a subsidiary of AMG Advanced Metallurgical Group N.V., Netherlands. The Nürnberg-based enterprise was founded in 1911 and is one of the world's leading manufacturers and sup-

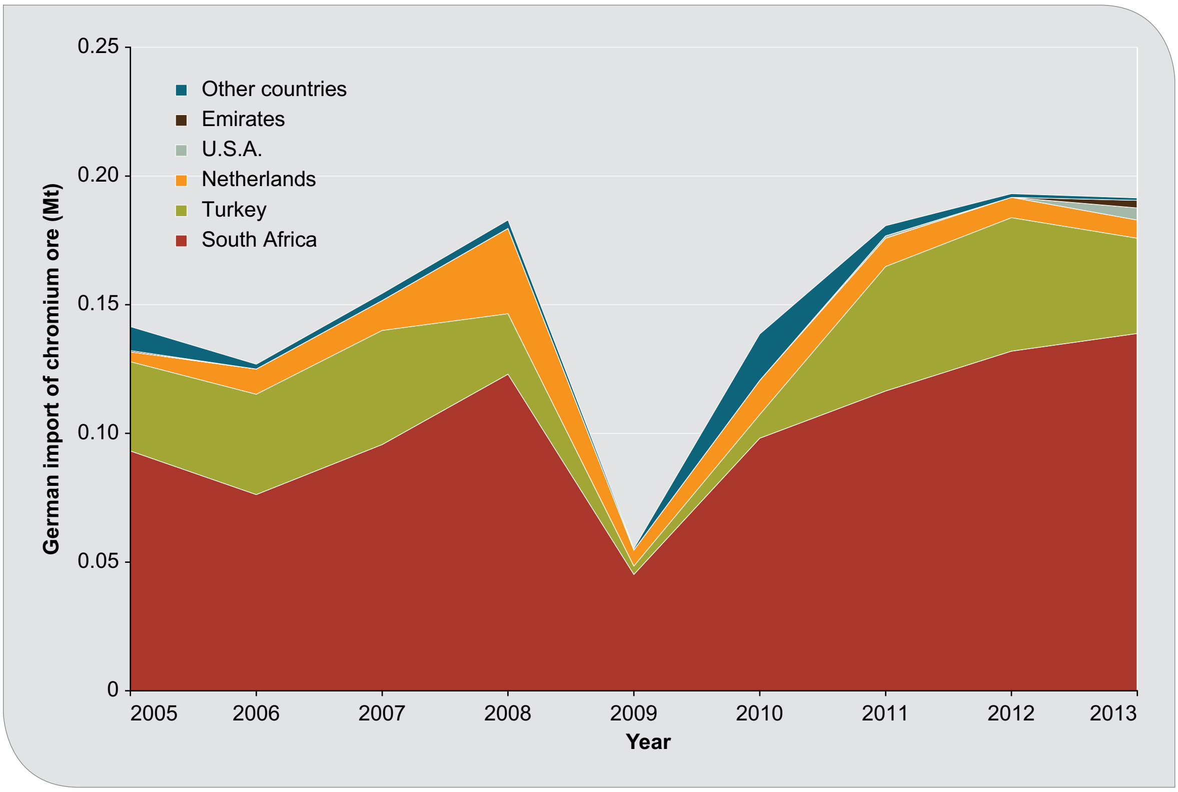

Fig. 3.7: German imports of chromium ore and concentrates from 2005 to 2013 (GTIS 2014).

pliers of high performance metals and materials. The product spectrum ranges from metallic and ceramic materials for coating technology through master alloys and functional materials for the aircraft industry to technical powders and vanadium chemicals. Chromium products include metal powder and lumps, metal ingots and granulate, as well as chromium alloys (Gesellschaft für Elektrometallurgie - GfE 2014).

Another commercial consumer of chromium is Lanxess, based in Leverkusen. Lanxess is a speciality chemical producer, which formed from the spin-off of Bayer's Chemicals and Plastics business at the beginning of 2005. The company secures its supply of chromium by operating its own mine in South Africa. Lanxess produces sodium dichromate and chromic acid at Newcastle and chromium tanning salts at Merebank, both in South Africa. In addition, the company produces chromium tanning salts at Zárate in Argentina. In Germany, chromium oxide is produced at Krefeld-Uerdingen from Newcastle sodium dichromate (LANXESS South Africa 2014).

An important German ferrochrome producer is Elektrowerk Weisweiler (EWW), which is owned by the Afarak Group. EWW produces high carbon, low carbon and ultra low carbon ferrochrome at Eschweiler. The raw material chromium ore is sourced from group-owned mines in Turkey (Afarak 2014).

Germany also exports chromium and its alloys, with France, U.S.A., UK and Austria being the leading buyers' markets of ferrochrome (Fig. 3.8). Chromium ore is mainly exported to the Russian Federation.

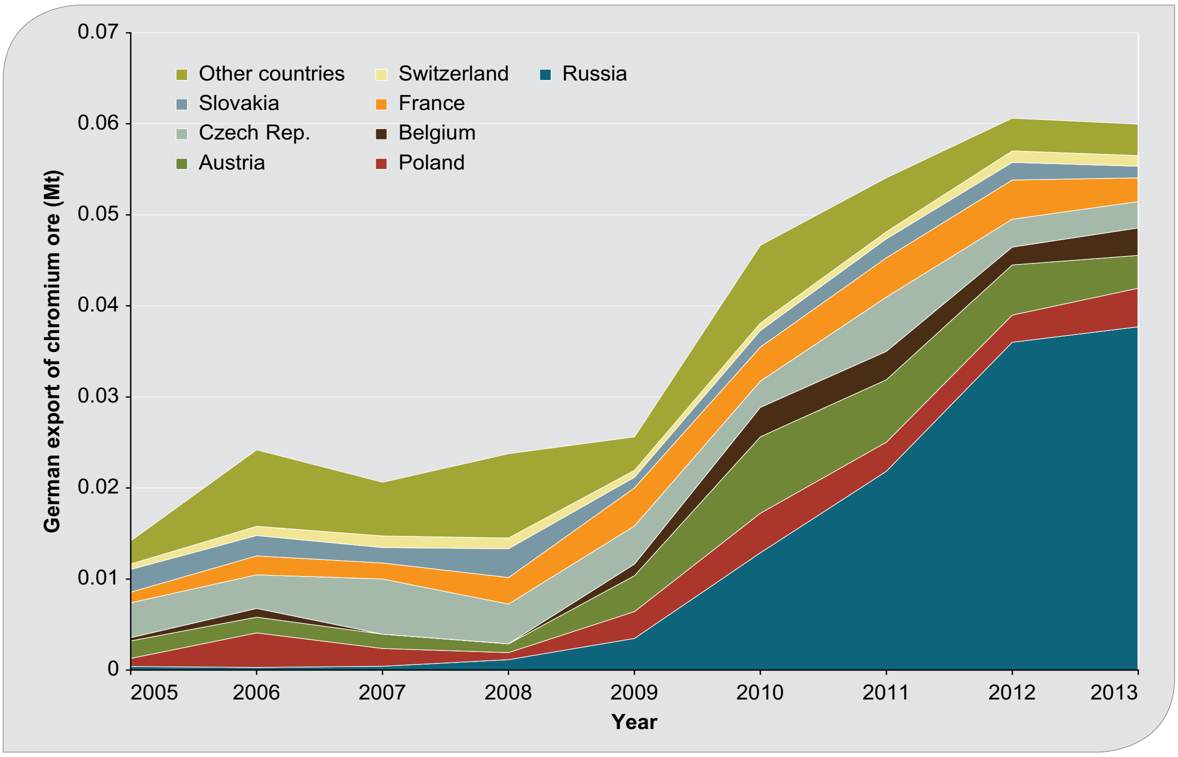

Fig. 3.8: German exports of chromium ore and concentrates from 2005 to 2013 (GTIS 2014).

3.3.3 South Africa

More than 70 % of the world chromite resources are located in South Africa and primary chromite production of 11.0 Mt in 2012 accounted for 44 % of the world total. Output, including UG2 chromite ore, is estimated to be as high as 15.5 Mt.

Exports, including UG2 material, were approximately 5.9 Mt in 2012, of which more than 70 % was shipped to China. In 2013 exports of chromite increased significantly by 45 % and totalled 8.5 Mt of which 76 % was shipped to China (Fig. 3.9).

Although South Africa is the largest producer of chromite worldwide, it has lost its position as the leading ferrochrome producer to China in 2012 (Fig. 3.4). South African ferrochrome production was 3.0 Mt in 2012, which represented 32 % of the world total. The fall in production from a peak level of 3.6 Mt in 2010 was due to the idling of capacity as part of Eskom's power buy-back programme. Selling their power allocations to Eskom's utility was more profitable than producing ferrochrome. Eskom generates approximately 95 % of the electricity used in South Africa and approximately 45 % of the electricity used in Africa. In addition, labour unrest disrupted the supply of raw materials and ferrochrome deliveries in 2012. Production of ferrochrome in 2013 increased slightly, totaling 3.2 Mt. However, rising electricity and labour costs remain the challenges in the socio-political environment.

Columbus Stainless (Pty) Ltd. is the only stainless steel producer in South Africa. Hence, nearly all ferrochrome production is exported, mainly to China, Japan, South Korea and Taiwan, as well as the U.S.A. and Germany (Fig. 3.9).

The main ferrochrome producers are Glencore (also referred to as Glencore-Merafe Chrome Venture) and Samancor Chrome (Samancor). There is also a high degree of Asian ownership/ participation including equity stakes in ASA Metals, Hernic Ferrochrome, International Ferro Metals (IFM) and Tata Steel.

Ferrochrome is exported to stainless steel producers worldwide by Glencore International through the ports of Richards Bay (670 km from Rustenburg), Durban (720 km from Rustenburg) and Maputo (Mozambique, 300 km from Lydenburg) (Roskill Information Services Ltd. 2014).

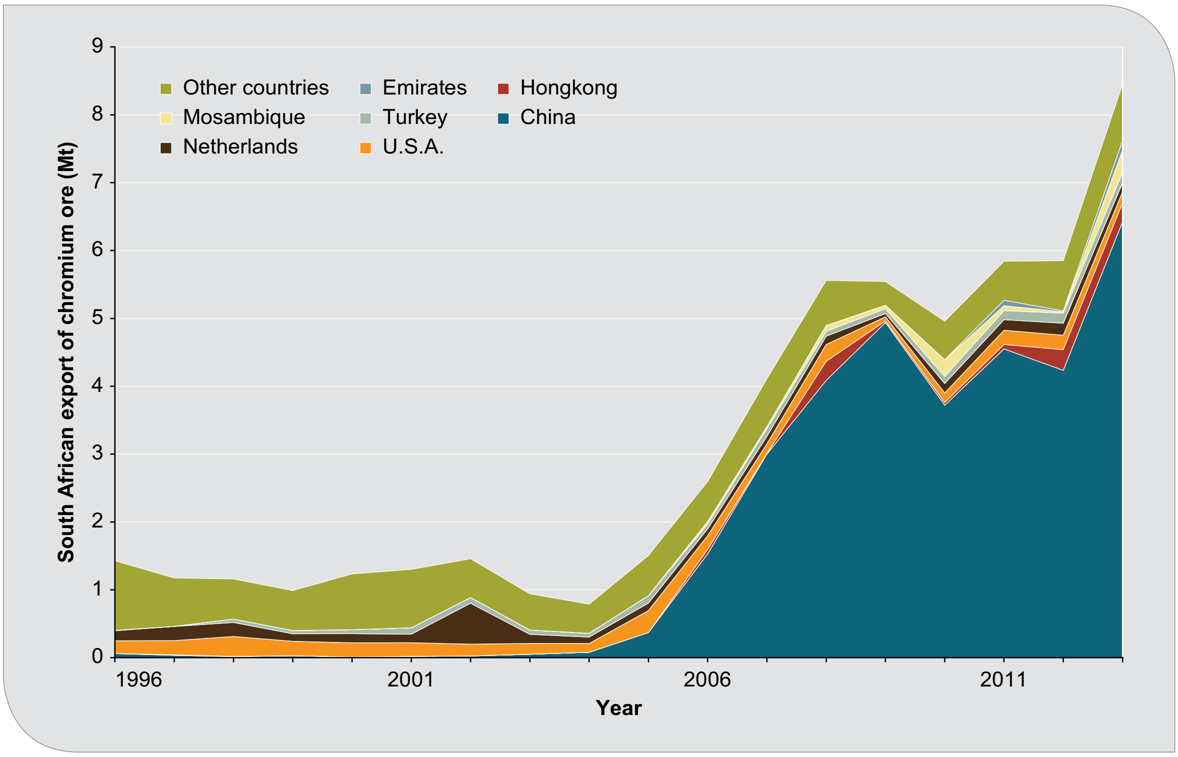

Fig. 3.9: South African exports of chromium ore and concentrates from 1996 to 2013 (GTIS 2014).

3.4 Primary Resources of Chromite in South Africa

3.4.1 Deposit Types

Chromite deposits and occurrences in South Africa are largely hosted by the Bushveld Complex (Fig. 3.10), a gigantic, layered igneous intrusion with a surface extent of more than 65 000 km^2 (Schulte et al. 2010). Chromite mineralisation within the Bushveld Complex is stratiform and characterised by cyclic and laterally contiguous seams of chromitite interlayered with mafic and ultramafic rocks.

The Bushveld Complex consists of a basal mafic to ultramafic part, known as the Rustenburg Layered Suite (RLS) and an upper part comprising granites and granophyres, namely the Roossenekal Subsuite and Lebowa Granite Suite.

The RLS is divided into Lower, Critical, Main and Upper zones (Fig. 3.14). The Lower Zone is mainly composed of bronzitites, harzburgites and dunites. The Critical Zone hosts extensive chromitite seams as well as the PGE-bearing Merensky Reef and the UG2 chromitite layer (Fig. 3.11). The Main Zone consists of norites, gabbros and anorthosites followed by the Upper Zone, which is composed of ferrogabbros and ferrodiorites (Schürmann et al. 1998).

The chromitite layers occur in the Critical Zone as three stratigraphically delineated groups, namely the Lower Group (LG), Middle Group (MG) and Upper Group (UG). The LG consists of seven chromitite layers hosted by feldspathic pyroxenite. Situated above the LG chromitite layers are the four major chromitite layers constituting the MG. These layers straddle the contact between the lower and upper Critical zones.

UG chromitite seams overlie the MG chromitites and are hosted by norite and anorthosite sequences (Schürmann, Grabe, & Steenkamp, 1998). The UG2 low-grade (43.5 % Cr_2O_3) chromitite layer (Fig. 3.11) is a major source of PGEs and is therefore mainly exploited for PGEs with chromite being recovered as a by-product.

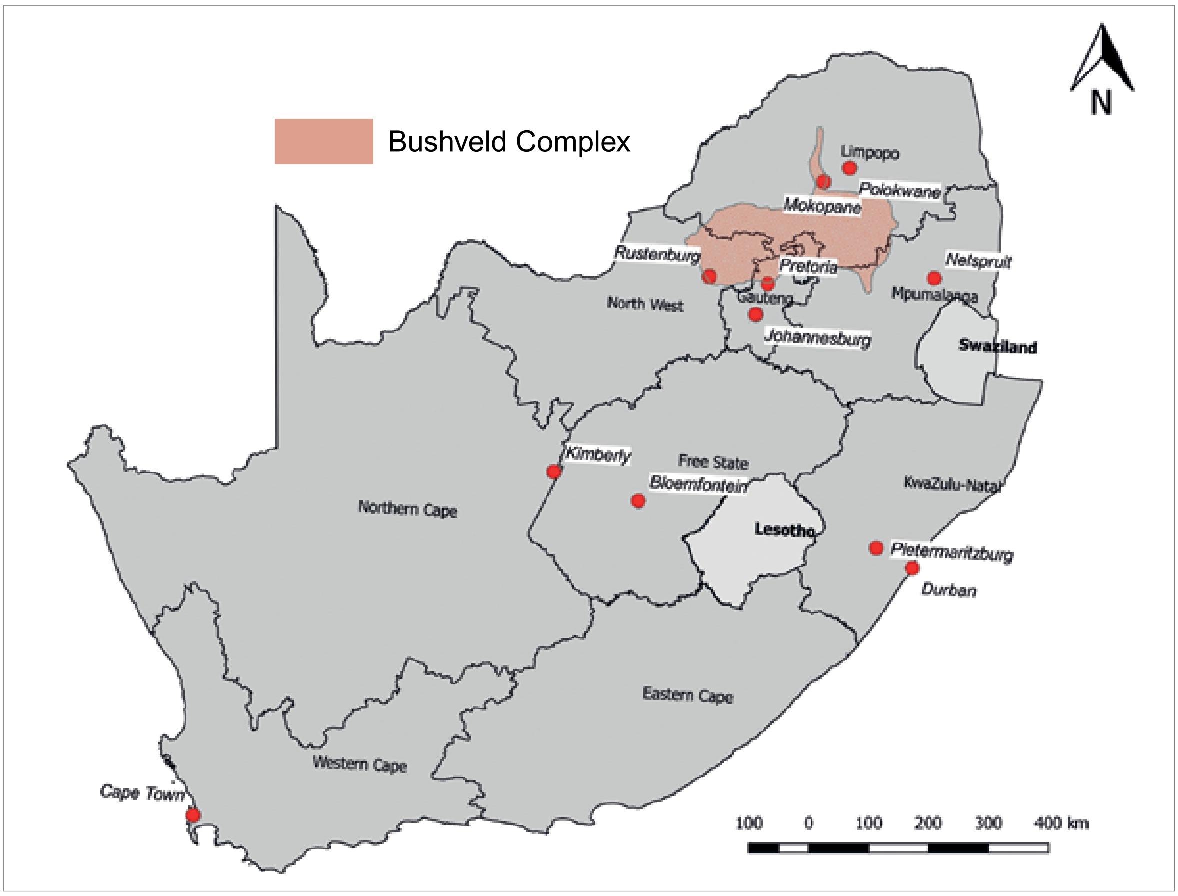

Fig. 3.10: Location of the Bushveld Complex in South Africa.

Fig. 3.11: UG2 chromitite outcrop, eastern limb of the Bushveld Complex (photo: DERA 2013).

The Merensky Reef, which stratigraphically occurs above the UG2 layer and is primarily mined for its PGE abundance, also contains chromite. However, the amount of chromium in the Merensky Reef is generally too low to be considered for extraction.

The Cr_2O_3 economic potential of the LG and MG chromitites depends mainly on their thickness, continuity and chromite content. The thickness of the chromitite seams ranges between tens of centimetres up to two metres. The grade of the LG chromitites varies from approximately 40 to 50 % Cr_2O_3. MG mineralisation is as low as 30 %. The most economically exploitable chromitite layer is LG6 (Fig. 3.12), which varies in thickness from 92 cm to 105 cm (Schürmann et al. 1998).

The majority of the South African stratiform deposits that contain the exploitable chromitites are characterised by unique chromite grades. Their Cr_2O_3 content is generally higher when compared to their equivalents in Finland and Canada (Ontario) (Fig. 3.13). According to Petrow's mapping of the deposit size (Tab. 3.5), they are classified as large to very large deposits.

There are a number of small podiform chromite occurrences in South Africa. They occur to the north of the Bushveld Complex between the towns of Polokwane and Messina. However, they are of no economic importance.

3.4.2 Chromite Mining History of the Bushveld Complex

The mining of chromite ore in the Bushveld Complex looks back on a century-old history resulting in a mining landscape characterised by the occurrence of open casts and waste and tailings dumps, amongst others. The German explorer Karl Mauch

Fig. 3.12: LG6-chromitite layer (photo: BGR 2008).

Tab. 3.5: Size classification of chromite deposits according to Petrow (Petrow et al. 2008).

Tonnes (Mt)	Deposit Size				
	Small	Medium	Large	Very large	Giant
Cr	< 0.1	0.1 – 1	1 – 10	10 – 100	> 100

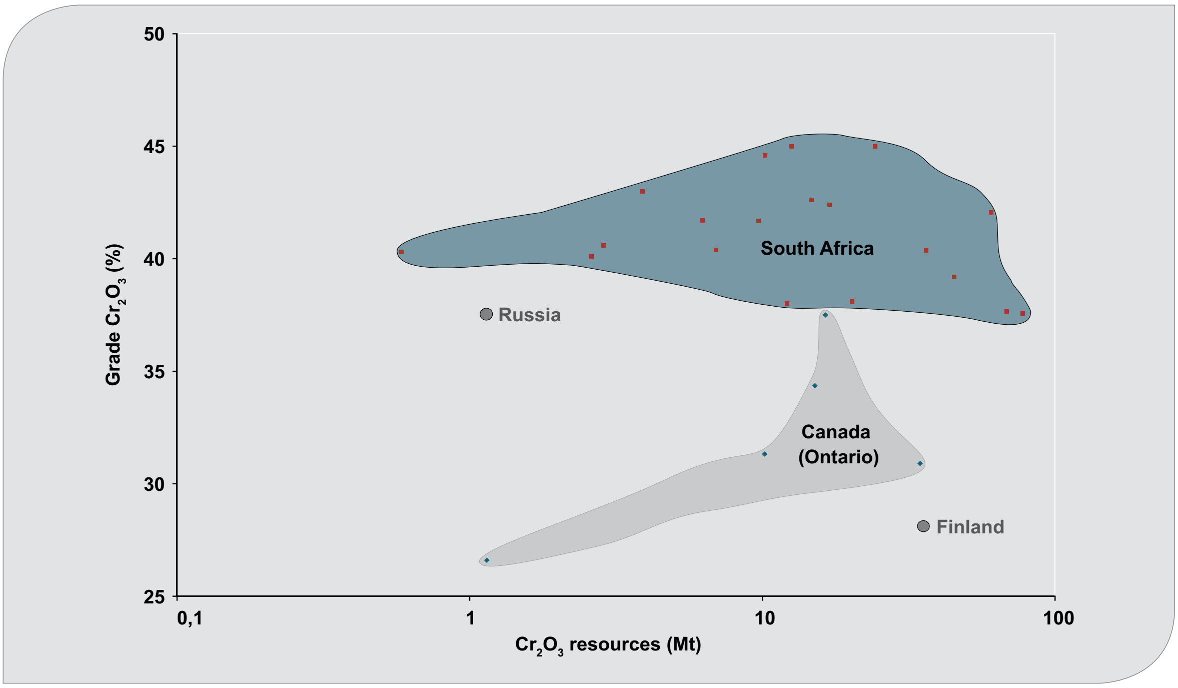

Fig. 3.13: Chromite grade versus contained metal of selected stratiform chromite deposits (Raw Materials Group 2014).

was the first person to record the occurrence of chromite in South Africa when he noticed it in the Hex River near Rustenburg in 1865 (Oancea 2008). Sustained mining of chromite in the Bushveld Complex began in 1921, and by the start of World War II, production had reached 180,000 t per year. By the 1960s, South Africa had become a major exporter of chromite ore (Wilson 2003). The mined chromite layers of the Bushveld Complex traditionally were the LG layers.

3.4.3 Operating Mines

There are currently some 30 chromite operations in the Bushveld Complex (Fig. 3.14). The following section introduces the most important mines, which were selected based on 2012 production figures, sourced from the Raw Materials Group (Tab. 3.6).

The highest production is reported from Samancor Chrome Mines. They produced 2.9 Mt Cr_2O_3 in 2012. However, this represents the cumulative production from eight individual mines. Pro-

Tab. 3.6: Most productive chromite operations in 2012 (Raw Materials Group 2014).

Mine	Owner/Operator	Resources			2012 Cr_2O_3 Production (kt)	
		Tonnes (Mt)	Grade	Contained Cr_2O_3 (Mt)		
Samancor Chrome Mines	Samancor Chrome	No data available			2,900	
Dwarsrivier	Assmang Chrome	55.03	38.11	20.97	1,004	
Thorncliffe	Glencore-Merafe Chrome Venture (Glencore)	89.79	40.36	36.24	769	2,139
Helena		115.17	39.2	45.15	686	
Kroondal		34.54	42.61	14.72	684	
Buffelsfontein	International Ferro Metals	206	37.57	77.39	550	

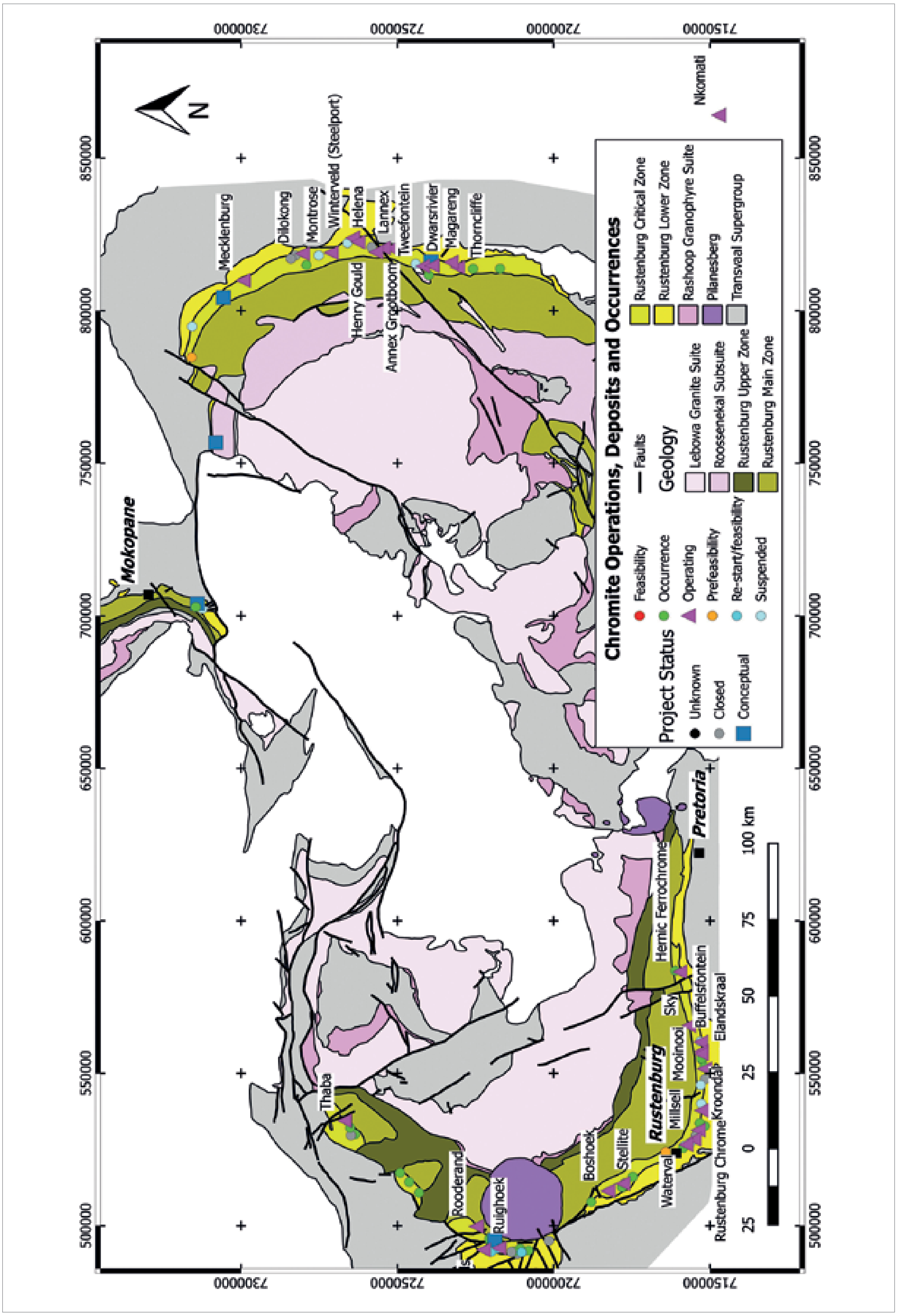

Fig. 3.14: Simplified geology of the Bushveld Complex with chromite projects (according to the Council for Geoscience 2007).

duction figures for each of these mines are not available.

The most productive single mine is Dwarsrivier with an output of approximately 1 Mt Cr_2O_3 in 2012. The mine is operated by Assmang Chrome (Raw Materials Group 2014).

Glencore has three mines in the top six production ranking, namely Thorncliffe, Helena and Kroondal. In 2012 each mine produced approximately 0.7 Mt Cr_2O_3 for a cumulative production of approximately 2.1 Mt.

Dwarsrivier, Thorncliffe, Helena and Kroondal mines are classified as very large deposits according to Petrow (Petrow, et al. 2008). However, the largest chromite resource in the Bushveld Complex is reported from Buffelsfontein Mine, which contains more than 77 Mt chromite (Tab. 3.6). Buffelsfontein Mine produced approximately 0.55 Mt Cr_2O_3 in 2012.

All six chromite mines described above are amongst the top nine chromite mines in the world in terms of the approximate value they produced in 2012. Another five South African mines are found amongst the top 30, namely Boshoek, Hernic, Rustenburg, Dilokong and Waterval chromite mines (Tab. 3.7).

Samancor Chrome Mines (Samancor Chrome)

Location & Ownership

Coordinates (approximate):

Doornbosch	24°41'13.2"S, 30°11'3.9''E
Winterveld	24°42'6.2"S, 30°12'2.2"E
Lannex	24°47'27.1"S, 30°10'12.3"E
Tweefontein	24°54'52.8"S, 30°5'59.5"E
Millsell	25°43'17.1"S, 27°16'58.5"E
Mooinooi	25°44'30.9"S, 27°33'42.2"E
Elandskraal	25°44'31.3"S, 27°34'11.4"E

Samancor Chrome's mines are located on the eastern and western limbs of the Bushveld Complex. The Eastern Chrome Mines (ECM) are located in the Steelpoort Valley, approximately 350 km from Johannesburg, along a 100 km stretch of the eastern limb of the Bushveld Complex. The Western Chrome Mines (WCM) are situated approximately 130 km northwest of Johannesburg, close to the town of Mooinooi in the North West Province.

Samancor is a private company that has recently undergone two changes of ownership. The previous shareholders BHP Billiton (60 % ownership) and Anglo American (40 % ownership) sold the company to the Kermas Group in June 2005. In November 2009 International Mineral Resour-

Tab. 3.7: Ranking of chromite mines of the world according to the approximate value produced in 2012 (Raw Materials Group 2014).

Rank	Mine	Country	Type	Owner/Operator
1	Donskoy Chrome Mines	Kazakhstan	OP,UG	ENRC plc
2	Samancor Chrome Mines	South Africa	UG	Samancor Chrome
3	Dwarsrivier Chrome Mine		UG	Assmang
4	Sukinda (Tisco) Chrome Mine	India	OP	Tata Steel
5	Eti Krom AS	Turkey		Yildirim Holding
6	Thorncliffe Chrome Mine Complex	South Africa	OP,UG	Glencore
7	Helena Chrome Mine		OP,UG	
8	Kroondal Chrome Mine		OP,UG	
9	Buffelsfontein (Lesedi and Sky) Chrome Mine		OP	International Ferro Metals
10	Kaliapani (Orissa) Chrome Mine	India	OP,UG	State of India
15	Boshoek Chrome Mine	South Africa	OP,UG	Glencore
16	Hernic Chrome Mines		UG	Mitsubishi, State of South Africa
19	Rustenburg Chrome Mine		UG	Lanxess
20	Dilokong Chrome Mine		UG	ASA Metals
27	Waterval Chrome Mine		UG	Glencore

ces (IMR) became the major shareholder with a 70 % direct shareholding in the holding company, Samancor Chrome Holdings (Pty) Limited.

Geology & Mining

ECM comprises three underground mines and two opencast mines. Samancor's eastern mines include Doornbosch, Winterveld, Lannex and Tweefontein. The last two exploit the MG1 and MG2 seams respectively. At Winterveld and Doornbosch, the LG6 seam is mined.

WCM comprises three underground mines, namely Millsell, Mooinooi and Elandskraal. LG6 is mined at Millsell. Mooinooi and Elandskraal exploit the MG1 and MG2 seams respectively.

Chromite tailings material from both WCM and ECM is treated by Sylvania Platinum (Sylvania) to extract PGE (see chapter 5.2.1.2). Chromite concentrate is produced as a by-product and supplied back to Samancor at cost price (Roskill Information Services Ltd. 2014).

Dwarsrivier Mine (Assmang Chrome)

Location & Ownership

Coordinates (approximate):
24°55'58.6"S, 30°6'59.2"E

The Dwarsrivier Mine, jointly managed by African Rainbow Minerals and AssOre through Assmang Limited, is situated on the eastern limb of the Bushveld Complex on the Dwarsrivier farm, approximately 30 km from Steelpoort and 60 km from Lydenburg, in the Limpopo Province of South Africa.

Geology & Mining

The MG1 is the source of the Dwarsrivier chromite ore. The average thickness of the seam is about 1.86 m (Assmang Chrome 2014).

The mine used to deliver its products to Assmang's Machadodorp Works Smelter to produce ferrochrome. However, in 2013 the Machadodorp smelter reverted to manganese smelting resulting in the Dwarsrivier Mine becoming a chromium ore supplier to the global market.

Chromite production from Dwarsrivier Mine is sourced from underground. The open pit reseves were exhausted in 2005. Underground mining commenced in 2005 at an annual rate of 1.2 Mt. From 2009 to 2012 production has nearly doubled (Tab. 3.8). Sales of chrome ore have been stable since 2012 and totaled 0.53 Mt in 2013 and 0.49 Mt in 2014.

Thorncliffe, Helena and Kroondal mines (Glencore)

Location & Ownership

Coordinates (approximate):

Thorncliffe	25°0'22.8"S, 30°6'47.0"E
Helena	24°43'0.7"S, 30°11'16.4"E
Kroondal	25°44'29.1"S, 27°19'29.3"E

The Glencore Merafe Chrome Venture, in which Glencore has a 79.5 % participation (Merafe

Tab. 3.8: Operational statistics for the Dwarsrivier Mine (African Rainbow Minerals 2014).

	Unit	FY2009	FY2010	FY2011	FY2012	FY12/09 %
Ore produced	000 t	684	537	866	1004	47
Ore sold*	000 t	256	272	373	521	104
Sales revenue*	R million	337	212	401	596	77
Total costs	R million	292	353	454	544	86
Operating profit	R million	45	(141)	(53)	52	16
Capex	R million	127	65	77	211	66

**excluding intra-group sales.*
FY refers to fiscal year

Resources, 2013), is the largest producer of ferrochrome worldwide (Roskill Information Services Ltd. 2014). In South Africa the venture has chromite mining operations along the western and eastern limbs of the Bushveld Complex. Its three largest mines in 2012 were Thorncliffe, Helena and Kroondal.

Geology & Mining

Kroondal Mine is located on the western limb of the Bushveld Complex together with Glencore's Waterval, Boshoek, Horizon and Wonderkop mines. The LG6 seam is mined underground at both Kroondal and Waterval mines. At Boshoek, the MG1, LG5 and LG6 chromitite layers are exploited. Horizon Mine, situated immediately west of the Pilanesberg Complex, is currently under care and maintenance.

Thorncliffe and Helena mines are situated on the eastern limb of the Bushveld Complex. These underground operations exploit the MG1 chromitite seam. Magareng Mine is the third of Glencore's chromite mines on the eastern limb, mining the MG1 seam.

3.4.4 Operations with German Participation

Thaba Mine (Cronimet Chrome Mining SA (Pty) Ltd.)

Location & Ownership

Coordinates: 24°45'22.5"S, 27°21'01.3"E

The Thaba Mine is located in the northwestern Bushveld Complex, 24 km north of Northam. The mine is owned and operated by Cronimet Chrome Mining SA (Pty) Ltd., which belongs to the Cronimet Mining Group (Cronimet). Cronimet is a worldwide specialist for stainless steel scrap, ferroalloys and primary metals, with headquarters in Karlsruhe, Germany. The company is active on four continents and has 56 subsidiaries, partnerships and representative offices (Cronimet 2014).

Geology & Mining

The Mining Right was granted in March 2010 for 30 years. Proven reserves at Thaba total 23.6 Mt at 43.6 % Cr_2O_3 for approximately 10 Mt contained Cr_2O_3. Life of mine is estimated at 26 years. The opencast 0.5 Mt per year mine was opened in 2011 and will progress to 1.1 Mt per year once the underground operations are developed.

At Thaba, LG6 as well as MG1 to MG4 chromitite seams are exploited (Fig. 3.15). The seams generally have an easterly dip between 22° and 25°.

With the mining ramped up to full capacity, today the Thaba Mine can potentially produce up to 0.5 Mt Cr_2O_3 per year and therefore become a major mine in the Bushveld Complex.

The primary mining product at Thaba is chromite ore (Fig. 3.15), which is being treated in a beneficiation plant (Fig. 3.16). The final products are metallurgical and chemical grade concentrate (Fig. 3.17) as well as foundry sand.

The company also operates a solar energy plant on-site, which was installed in 2012 (Fig. 3.18). The solar plant with a footprint of nearly 1 ha has a capacity of 1 MW. This enables the supply of approximately 50 % of the required electric power at Thaba. The additional energy demand is supplied by an on-site diesel generator.

Lanxess Chrome Mine (LANXESS Chrome Mining (Pty) Ltd.)

Location & Ownership

Lanxess Chrome Mine is situated some 14 km southeast of Rustenburg on the western limb of the Bushveld Complex. The mine is operated by LANXESS' leather business unit. LANXESS, a 2005 spin-off from Bayer, is the sole producer of chromium chemicals in South Africa. It primarily supplies companies in South Africa and Argentina that process the raw materials into chromium chemical intermediates and finally into products for, amongst other things, the processing of leather.

Fig. 3.15: LG6 chromitite seam exposed at Thaba open pit (photo: DERA 2013).

Fig. 3.16: Beneficiation plant at Thaba Mine (photo: DERA 2014).

Fig. 3.17: Chromite ore concentrate (photo: DERA 2014).

Fig. 3.18: Solar energy plant at Thaba Mine (photo: DERA 2012).

Geology & Mining

Lanxess Chrome Mine is a supplier of chromite ore. The mine exploits the LG6 seam. Fully mechanised bord-and-pillar mining methods are used. Underground reserves are approximately 18 Mt and open-cast reserves around 3.7 Mt. Run-of-mine capacity is 0.85 Mt per year. Following beneficiation, production capacity is approximately 0.5 Mt Cr_2O_3 per year (Roskill Information Services Ltd. 2014).

Processing

Products include (a) chemical concentrate, the raw material for LANXESS' chrome chemicals plants, (b) lumpy ore, (c) metallurgical concentrate and (d) foundry sand (Tab. 3.9).

LANXESS also operates two chemical plants in South Africa, one in Newcastle and the other in Merebank, near Durban. The plant in Newcastle,

Tab. 3.9: Chromite products by Lanxess, from Roskill (Roskill Information Services Ltd. 2014).

Product	Cr_2O_3 (%)	SiO_2 (%)	FeO (%)	Cr/Fe
Lumpy ore	39.5	7.14	23.0	1.52
Metallurgical concentrate	44.0	3.50	23.4	1.52
Chemical concentrate	46.0	1.20	25.8	1.57
Foundry sand	46.4	0.70	25.8	1.56

KwaZulu-Natal Province, has the capacity to produce 70,000 t of sodium dichromate equivalent per year. Capacity includes 28,000 t sodium dichromate crystals, 25,500 t sodium dichromate solution and 11,000 t chromic acid. Output was 52,000 t of sodium dichromate in 2012 (Roskill Information Services Ltd. 2014). Sodium dichromate is then shipped to the LANXESS plant in Merebank, near Durban, and used in the production of chromium tanning salts for the global leather tanning industry. Sodium dichromate from Newcastle is also used at the LANXESS plant in Krefeld-Uerdingen in Germany to manufacture chrome oxide pigments (LANXESS South Africa. 2014).

Hernic Ferrochrome (Mitsubishi Corp., Industrial Development Corp. RSA, Int. Finance Corp., Mmakau Mining, Matlapeng Res. and BBS-EE)

Location & Ownership

Coordinates of the smelters:
25°39'38"S, 27°50'21"E

Hernic Ferrochrome (Pty) Ltd. is the world's 4th largest ferrochrome producer (Hernic 2009). The mine and the plant are located on the southwestern limb, approximately 40 km west of Pretoria, near the town of Brits in the North West Province. Hernic Ferrochrome (Pty) Ltd. operates with the joint venture of Mitsubishi Corporation (50.975 %), Industrial Development Corp. RSA (21.25 %), ELG Haniel GmbH (7.775 %), International Finance Corporation (5 %), Mmakau Mining (6.5 %), Matlapeng Resources (Pty) Ltd. (6.5 %) and Kagare Resources BBS-EE (2 %).

Geology & Mining

The Middle Group (MG) chromitite is exploited in two mines, the Morula (previously known as Hernic Maroelabult Chrome Mine; Fig. 3.19 left) and the Bokone opencast and underground operations. The mean mineable thicknesses of the MG1 and MG2 layers (Fig 3.19 right) are 1.2 m with a dip angle of about 18° to the northeast. Both layers are mined in two inclined shafts. The average chemical composition of the chromitites is: 38.4 % Cr_2O_3, 1.5 % CrFe, 13 % MgO as well as 1.4 to 2.4 ppm (g/t) PGE-4E (Pt+Pd+Rh+Au) (as per personal communication with the Chief Geologist Phillip Motsoeneng).

Processing

At the ferrochrome beneficiation plant (Morula Operation), the run of mine (RoM) material is crushed and screened. The coarse fraction (120 x 20 mm) is processed through a heavy media separation. The fines (–20 mm) are milled to –1 mm and then fed to the spiral separator. The concentrate has a Cr content of 42 %. Approximately 80 % of these chromite fines have a grain size < 32 µm. They are pelletised and sintered through Outokumpu technology to produce competent

Fig. 3.19: Access to the Maroelabult (Morula) Chrome Mine (left); MG1 chromitite layer (right; photos: DERA 2013).

Fig. 3.20: The four intermittently tapped electric furnaces at Hernic Ferrochrome (photo: DERA 2013).

pellets of 13 mm in diameter. The annual production is about 600,000 t of pellets. The pellets are heated in a steel belt sintering furnace, to form strong bonds between the chromite grains to yield and agglomerate the material. The sintered pellets are then sized and fed to the smelter by belt conveyor (Hernic 2009).

Smelting

Ferrochrome is produced by using four closed electric submerged arc furnaces (2 x 37 MW, 1 x 54 MW, 1 x 78 MW; Fig. 3.20). The closed furnaces are fed with raw materials from various sources including chromite pellets, coke, char coal, quartzite and dolomite via the proportioning system for the production of ferrochrome. By heating the ore material up to 1,700°C, the valuable portion of the chromite is converted into a metallic phase (Hernic 2009).

Impurities and higher melting oxides remain in a slag phase (Hernic 2009). The finished ferrochrome product is crushed and screened to exact customer requirements. The production rate is about 400 t ferrochrome per day (Fig. 3.21).

About 15 Mt of tailings material is stored at the Morula Operation. The tails contain approximately 14 % Cr_2O_3 and 1 to 1.5 ppm PGE-4E (pers. comm. Phillip Motsoeneng).

Fig. 3.21: Ferrochrome product (photo: DERA 2013).

3.4.5 Exploration Projects

The chromite deposits and occurrences of the Bushveld Complex are hosted by the Critical Zone of the Rustenburg Layered Suite (Johnson et al. 2006). The Critical Zone within the western and eastern limbs of the complex has been extensively explored and hosts all of the current chromite operations with the exception of Samancor's Marico Chrome Mine, which occurs within an outlier of the Critical Zone to the west of the western limb.

The northern limb of the Bushveld Complex is geologically less understood and the Critical Zone is poorly developed. Due to the unfavourable geology, chromite exploration is limited on the northern limb. There are a few occurrences on the Grasvalley farm at the southern end of this limb, one of which was previously exploited by Samancor (Grasvalley Chrome Mine).

Eight exploration projects were identified in preparation of this guide (Tab. 3.10 and Fig. 3.22). Four projects are located on the eastern limb of the Bushveld Complex with Glencore's Klipfontein/Waterval project being the largest one. Three exploration projects were identified on the western limb. Glencore is advancing two projects, namely Townlands Extension 9 and Wonderkop, a suspended mining operation. Sylvania Platinum has prospecting rights for a property at Grasvalley on the northern limb of the Bushveld Complex. Detailed information for these exploration projects is not readily available in the public domain. However, published key points for each of the projects are summarised below.

Tab. 3.10: Mineral resources of chromite exploration projects, resource figures from Glencore (2014), SRK Consulting (2011), Sylvania Platinum (2014), Prime Resources Environmental Consultants (2013).

Deposit	Company	Location	Tonnage (Mt)	Cr_2O_3 (%)	Contained Cr_2O_3 (Mt)	Size*
Klipfontein/ Waterval	Glencore	Eastern Bushveld	143	42	60.00	Very large
De Grootboom			1.4	40	0.56	Small
Townlands Extension		Western Bushveld	13.94	41	5.72	Large
Wonderkop			7.05	40.6	2.86	Large
Naboom	China Minmetals	Eastern Bushveld	17	30	5.10	Large
Rooderand	International Ferrometals	Western Bushveld	Data not available			
Grasvalley	Sylvania Platinum	Northern Bushveld	Data not available	up to 46.4	Data not available	
Scheiding Chrome Mine	Samancor Chrome	Eastern Bushveld	0.22	41.6	0.09	Small

**according to Petrow et al. 2008*

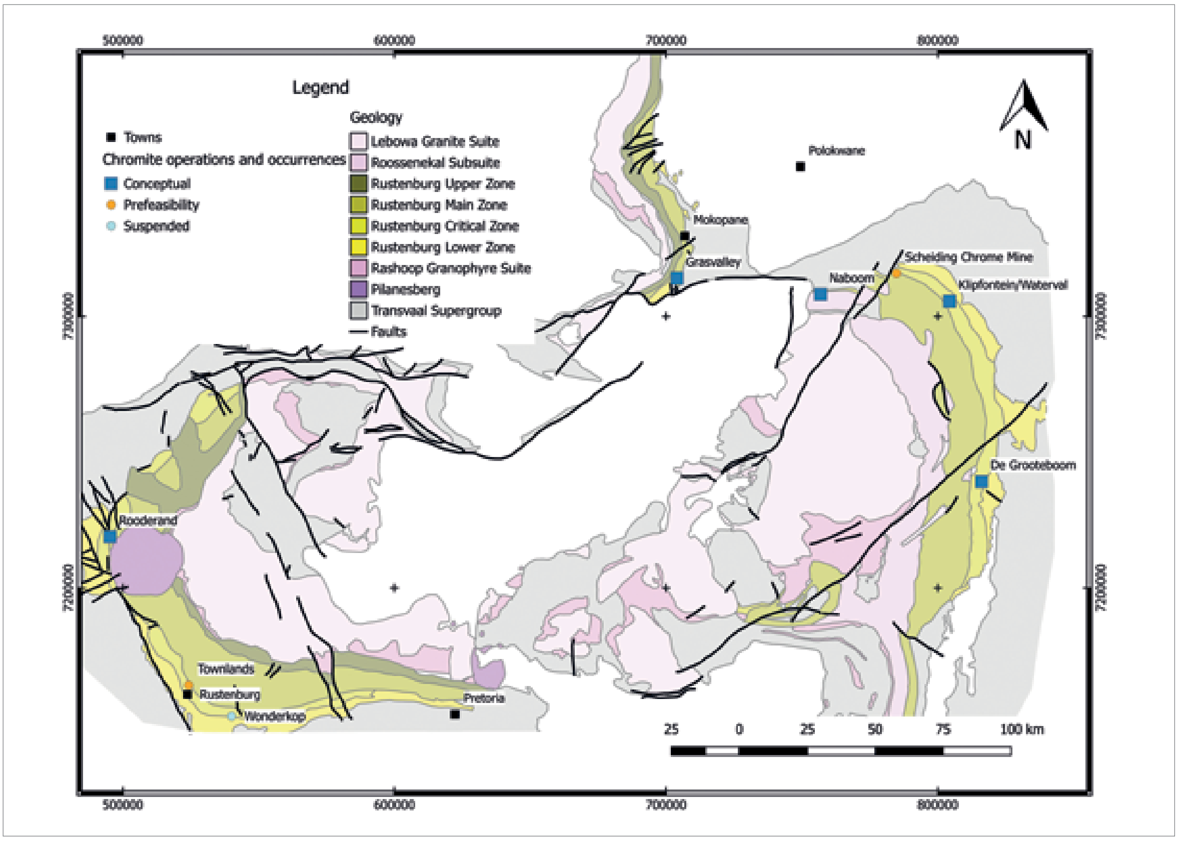

Fig. 3.22: Location of chromite exploration projects in the Bushveld Complex.

Klipfontein/Waterval (Glencore)

Coordinates (approximate):
24°19'59.4"S, 29°59'56.5"E

The Klipfontein/Waterval deposit is located on the eastern limb of the Bushveld Complex and owned by Glencore. Klipfontein/Waterval is currently the largest exploration project by value in the Bushveld Complex (SNL 2014).

Naboom Project (China Minmetals Cooperation)

Coordinates (approximate):
24°19'9.0"S, 29°31'48.3"E

The Naboom exploration project, owned and operated by China Minmetals Cooperation (Minmetals) is located approximately 55 km south of Polokwane on the eastern limb of the Bushveld Complex. It is likely to exploit the chromite contained in the LG6, MG2 and MG3 chromitite layers. Its current Inferred Mineral Resource includes more than 5 Mt contained Cr_2O_3. The ore is likely to be mined both opencast and underground (SRK Consulting 2011).

Rooderand (International Ferro Metals Limited)

Coordinates (approximate):
25°7'11.8"S, 26°58'32.3"E

In May 2014 Crometco Ltd. (Crometco) inked an agreement with International Ferro Metals Limited (IFM) to conduct exploratory drilling of the LG6 chromitite seam at Crometco's Rooderand Platinum Mine, situated on the western limb of the Bushveld Complex. Upon the successful completion of drilling, IFM will be entitled to mine up to 200,000 t of chromium ore over a twelve-month period for a per tonne fee, payable to Chrometco (SNL 2014). Beneficiation of the chromite ore will occur at IFM's smelter in Buffelsfontein.

Grasvalley Chrome Exploration (Sylvania Platinum Limited)

Coordinates (approximate):
24°16'38.3"S, 29°0'0.2"E

In December 2013 Sylvania Platinum purchased the prospecting right on portions of the farms Grasvalley and Zoetveld, which are located at the southern end of the northern limb of the Bushveld Complex. Surface exploration has to date exposed over 900 m of chromitite outcrop. Sylvania expects that the potential exists to delineate up to 4,500 m of surface outcrop. Initial assay results indicated up to 46.4 % Cr_2O_3 in situ, with a chromium/iron ratio of 2.45. Recovery tests conducted on the same samples showed that the seam can be upgraded to 55.5 % Cr_2O_3, with 89 % recovery and only one washing pass. These values indicate some of the highest chrome grades and chromium to iron ratios of any South African chrome deposits (Sylvania Platinum, 2014).

Scheiding Chrome Mine (Samancor Chrome)

Coordinates (approximate):
24°14'41.7"S, 29°48'14.0"E

Samancor has targeted a chromite resource in the Limpopo Province on the eastern limb of the Bushveld Complex for the development of an opencast mining operation with a two-year mine life (Industrial Minerals, 2013). The LG1 to LG7 chromitite sequence is well exposed in the area. From the LG5 chromitite layer upwards, the Lower Group of the Rustenburg Layered Suite consists of pyroxenite and chromitite layers.

The opencastable resource will consist of the mineable seams LG6 and LG6A. The LG6 forms the principal seam of economic interest based on its chromium content and thickness. The LG6 consists of 0.19 Mt in-situ to a mineable depth of 30 m below surface. The LG6A is located above the LG6 seam and less thick. The LG6A consists of 0.03 Mt in-situ to a mineable depth of 30 m below surface (as per Prime Resources Environmental Consultants 2013; Tab. 3.11). Samancor published the final Environmental Scoping Report in September 2013.

3.4.6 Other Occurrences

Mpumalanga Province

A chromitiferous harzburgite unit occurs within the Proterozoic Uitkomst Complex, which is considered to represent a satellite body of the Bushveld Complex. The Uitkomst Complex is located between the towns of Machadodorp and Barberton in the Mpumalanga Province. The complex is host to the Nkomati Nickel Mine (Nkomati), where chromite ore is mined as a by-product (Tab. 3.12). Previously, Nkomati mainly sold chromite ore, but in recent years it has expanded its concentrator capacity, which is reflected in the significant increase of chromite concentrate production and sale (Tab. 3.13).

The mine is managed as a 50/50 joint venture between African Rainbow Minerals and Botswana's BCL Ltd. Mining takes place both by means of an underground operation as well as by open-pit mining. Oxidised chromitite is also mined as part of the pre-strip of future open cuts (African Rainbow Minerals, 2014).

Tab. 3.11: Scheiding stratigraphy (Prime Resources Environmental Consultants 2013).

Layer	Mean thickness (m)	Average Cr_2O_3 grade (%)
LG7	0.25	No data
Pyroxenite between LG6A and LG7	25.00	-
LG6A	0.29	42.32
Pyroxenite between LG6 and LG6A	1.70	-
LG6	1.47	41.55
Pyroxenite below LG6	5.80	-

Tab. 3.12: Measured and Indicated resources at Nkomati Nickel Mine (African Rainbow Minerals 2014).

Element	Tonnes [Mt]	Grade
Nickel [%]	281.01	0.34
Chrome [%]	0.23	33.95
PGMs [ppm 4E*]	281.01	0.86

Tab. 3.13: Metal production at Nkomati Nickel Mine (African Rainbow Minerals 2014).

Metal	Unit	FY2009	FY2010	FY2011	FY2012	FY2013	FY2014
Nickel	t	4,495	9,666	10,100	14,004	23,220	22,874
Copper	t	2,268	5,210	5,210	7,371	9,877	10,116
Cobalt	t	244	578	553	744	1,101	1,133
PGMs	oz	26,727	52,574	53,610	84,044	111,185	185,194
Chrome ore sold	000 t	661	502	335	64	-	-
Chrome concentrate sold	000 t	51	314	381	441	225	342

The chromitiferous unit has an average thickness of 60 m and consists of altered harzburgite with chromite occurring as traces or as sheared chromitite lenses. Chromite mineralisation becomes more massive towards the top of the unit, where a 3 to 4 m thick (and in some boreholes up to 15 m thick) chromite seam is developed. The chromite composition varies between 8 % and 28 % Cr_2O_3, while the chromium to iron ratio ranges between 1.4 and 2.15 (Schürmann et al. 1998).

Since Nkomati installed a chrome ore concentrator, chrome ore sales have been declining. At the same time sales of chrome concentrate have been rising. The chrome concentrate is sold on the spot market. In 2014 nearly 342,000 t were sold and the company aims to achieve the sale of 370,000 t chrome concentrate in 2015 subject to market conditions.

Limpopo Province

Isolated layers and disseminations of chromite occur within amphibolites, amphibolite-feldspar gneiss and Archaean serpentinite in the Limpopo Soutpansberg District. Approximately 48 km west of Messina, chromite ore with a chromium content of 43 to 48 % Cr_2O_3 occurs as an irregular body of serpentinite extending several kilometres overall. However, a mineable deposit has yet to be located (Coertze and Coetzee 1976).

Some 60 km north of Polokwane, on the Lemoenfontein farm, a small circular (300 m in diameter) podiform chromite-bearing body is located in partially serpentinised dunite. The chromite ore is described as massive, high grade, nodular and pod-like in places. Tectonically layered and disseminated ore is also present. Although a concentrate of 64 % Cr_2O_3 was obtained from the ore, this deposit was seen as sub-economic due to the small quantity of ore available (Coertze and Coetzee 1976).

KwaZulu-Natal Province

At Tugela Rand, Sebenzani and Sithilo igneous complexes in Natal, podiform chromite mineralisation is associated with Mesoproterozoic wehrlites, dunites and serpentinites. Chromite is found as interstitial grains or as irregular bands and discontinuous pod-like deposits in the serpentinites. Although of minor economic importance, the ore contains as much as 50 % Cr_2O_3 and concentrates have reached up to 60 % Cr_2O_3 with a chromium to iron ratio of 3.5 (Coertze and Coetzee 1976).

3.4.7 Processing of Chromite Ore

Chromite ore of the Bushveld Complex is predominantly mined in underground operations. Those operations utilise scraper-mining techniques. In the eastern Bushveld Complex, breast mining is applied in the case of LG6 and up-dip mining in the case of MG1. The MG1 chromitite layer is exploited at Tweefontein in an opencast operation.

Similar underground and opencast mining techniques are applied in the western Bushveld Complex on the LG1 to LG6, LG6A, MG1 and MG2 chromitite layers (Schürmann, Grabe, & Steenkamp 1998).

Initial processing of chromite ore can be by hand or optical sorting of lumpy ores, and by heavy media or gravity separation of finer ores, to remove gangue or waste materials and produce upgraded ores or concentrates. Magnetic separation and froth flotation techniques are also applied (International Chromium Development Association 2014).

Production of Ferrochrome

The conversion of chromite to ferrochromium alloys is dominated by electric submerged arc furnace smelting with carbonaceous reductants, predominantly coke, and fluxes to form the correct slag composition. Conventionally, the electric current is three-phase alternating current (AC) and the furnaces have three equally spaced consumable graphite electrodes in a cylindrical, refractory-lined receptacle with a bottom tap-hole. Submerged arc furnaces can be open, semi-closed or closed with correspondingly better thermal efficiency and the ability to make use of the energy in the off-gases from the closed furnaces (International Chromium Development Association 2014).

The above furnaces are suitable for high-grade lumpy ore, but not for the lower grade fine-grained ore. An attempt to overcome the problem of ore fines was the introduction of DC arc, or plasma furnace technology. Some of the advantages of DC arc furnace operations include the use of fine ores without agglomeration, the use of cheaper reductants and greater choice of reductants as well as higher chromium recoveries. In addition, deliberate changes in the charge composition are reflected rapidly in the slag or metal, and closed top operation allows furnace off-gas energy to be used (International Chromium Development Association 2014).

There are currently 13 operating chromite smelters in South Africa, of which 12 are located in the Bushveld Complex (Fig. 3.23). All of the above

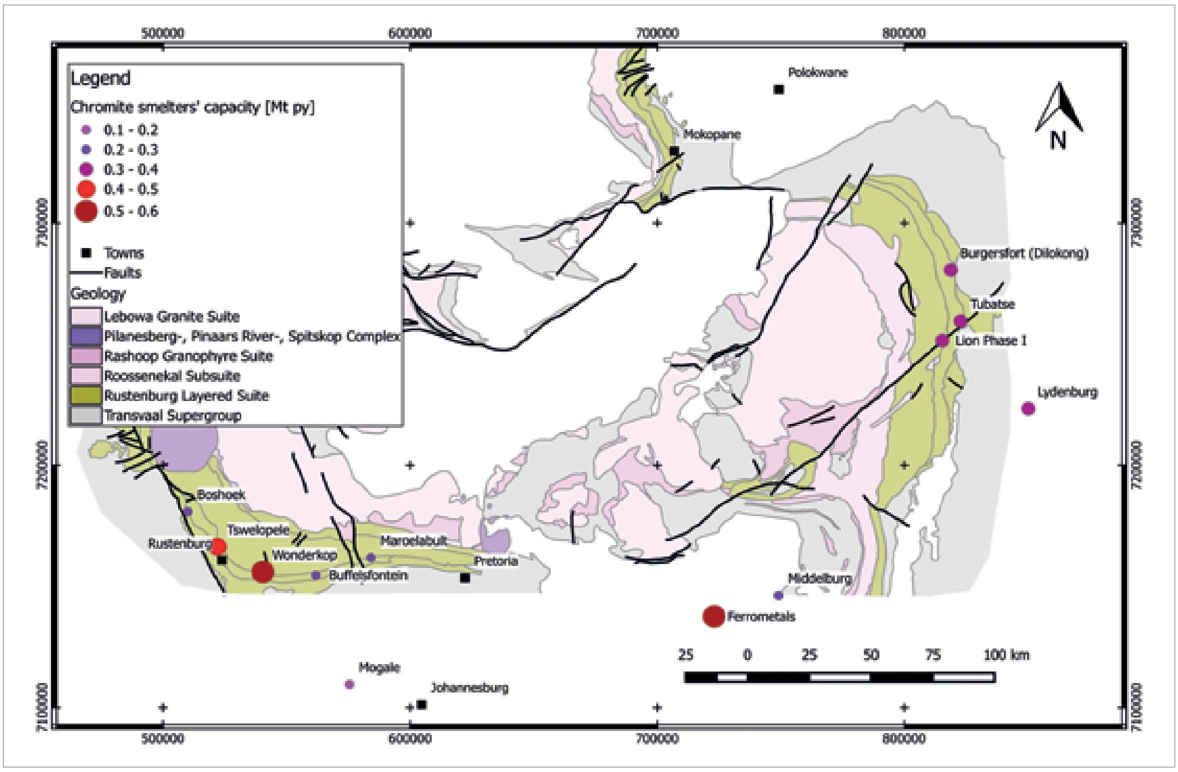

Fig. 3.23: Location and ferrochrome capacity of chromite smelters in the Bushveld Complex.

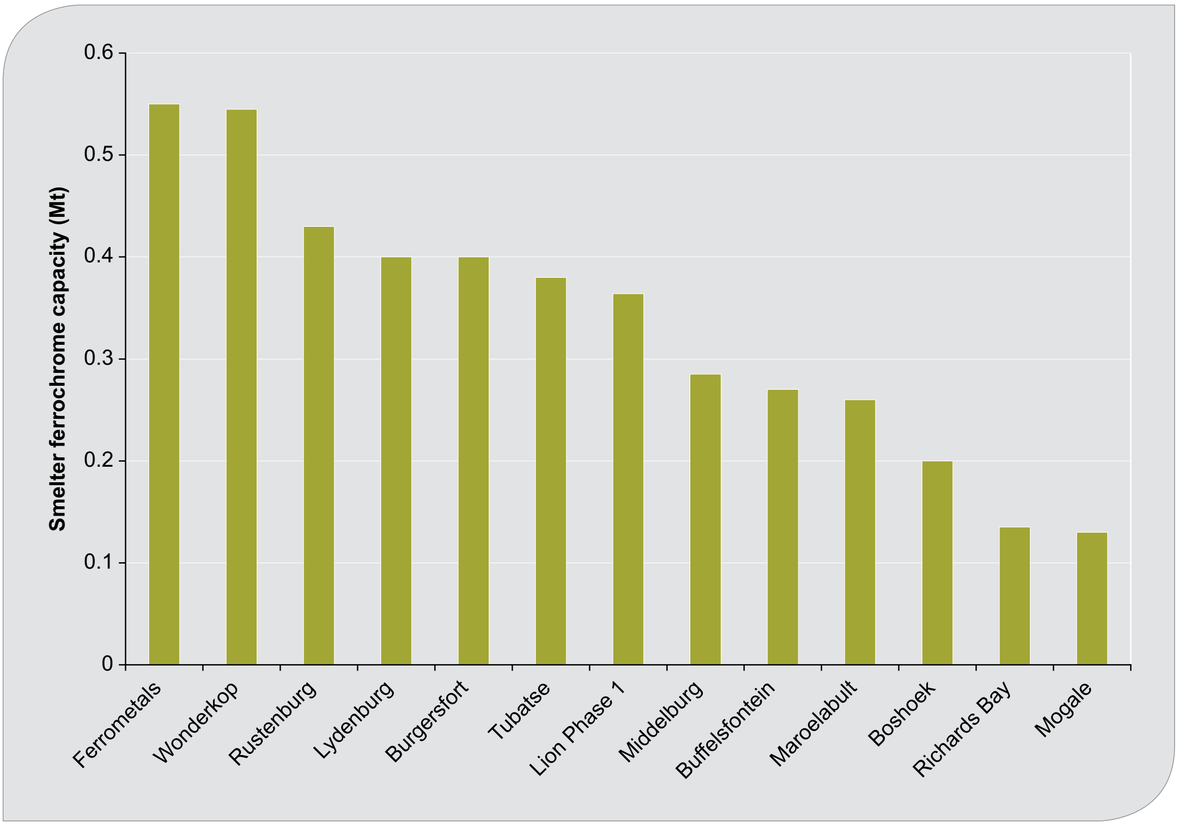

Fig. 3.24: Ferrochrome capacity (Mt) of chromite smelters in South Africa (Roskill Information Services Ltd. 2014 and Jones 2014).

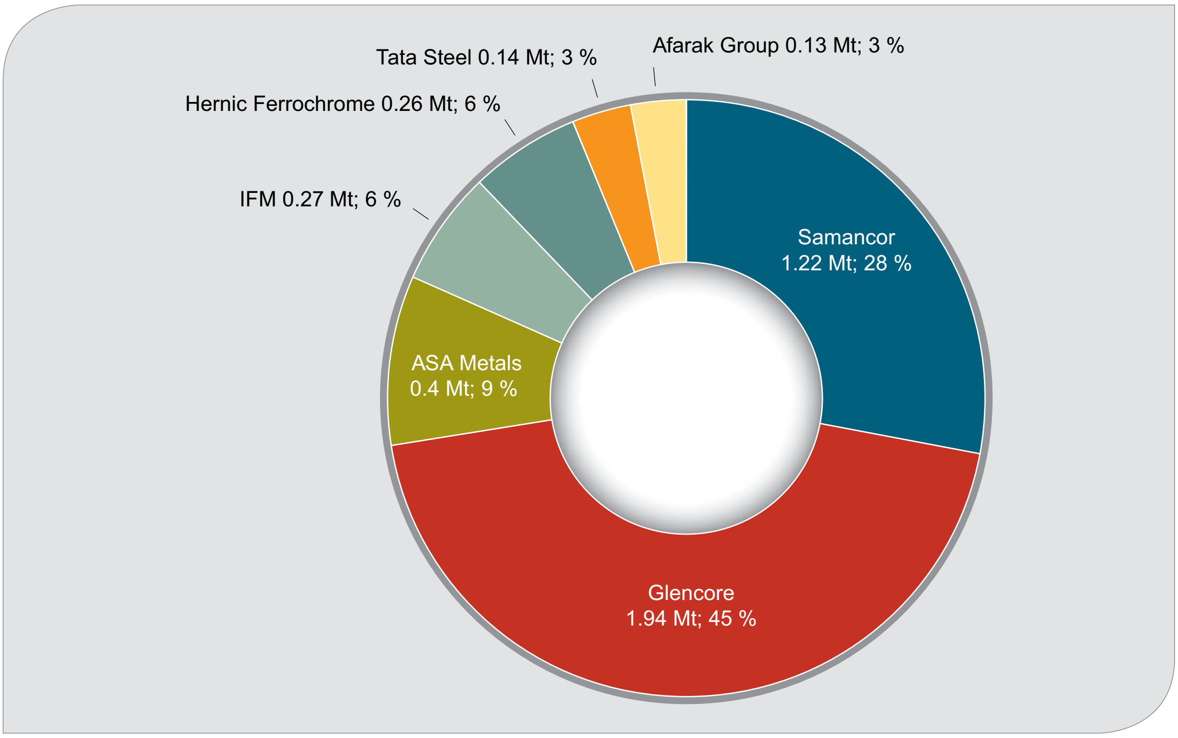

Fig. 3.25: Share of ferrochrome capacity (in Mt) by company (Roskill Information Services Ltd. 2014 and Jones 2014).

furnace types are in use. In addition, Glencore utilises the proprietary Premus technology that consumes significantly less electricity than DC and conventional AC arc furnaces (Greve 2011).

The smelters with the highest capacity are Samancor's Ferrometals smelter in the eastern Bushveld and Glencore's Wonderkop smelter in the western Bushveld, with each having a ferrochrome capacity of approximately 0.55 Mt (Fig. 3.24). Glencore is currently operating four smelters with a total capacity of nearly 2 Mt and therefore has the biggest market share of about 45 % (Fig. 3.25). The total annual ferrochrome capacity of all smelters is approximately 4.35 Mt. Their capacity utilisation in 2013 was at 73 % based on ferrochrome production figures.

A further development in treating not only ore fines but also low Cr_2O_3-grade UG2 material was the development of the pelletising technology. This technology has been implemented by all operations in the Bushveld Complex. The pelletising capacity of the individual smelters is summarised in Tab. 3.14. Total pelletising capacity is estimated to rise to nearly 8 Mt per year by 2014, reflecting the completion of Glencore's Lydenburg and Lion II units (Roskill Information Services Ltd. 2014). Pellets from ore fines are produced with the addition of coke. They are sintered (hardened) and partly pre-reduced on a steel belt sintering system. From there, the pellets are delivered to pre-heating shaft kilns that are located above submerged arc furnaces. They operate as direct feed bins, making use of the off-gas heat from the furnaces. Lump ore, coke and fluxes are also directed to the feed bins.

In general the smelting process is energy intensive, and consumes approximately 3,300 to 3,800 kWh per tonne of metal produced (Xiaowei 2013). However, Glencore's proprietary energy efficient smelter technology "Premus", which is installed at Glencore's Lydenburg and Lion smelters, consumes about a third less electricity than other smelting technologies (Greve 2011).

The Premus technology is also able to handle fine chrome ore. The raw material mix required for this process is more cost-effective and readily available, e. g. anthracite replaces expensive and scarce coke. The ore together with bentonite and a reductant such as anthracite are milled, pelletised and pre-heated before being fed into rotary kilns where partial pre-reduction of the chrome and iron oxides take place. The metalised pellets are then hot charged into closed submerged arc furnaces. The furnace off-gas is cleaned in venturi scrubbers and used throughout the plant as an energy source (Naiker 2007).

The 360,000 t per year Phase II of the Glencore's Lion ferrochrome plant (Lion II) is on track since September 2014 and is expected to reach full capacity by mid-2015, providing favourable market conditions prevail at the time (Merafe Resources

Tab. 3.14: Pelletising capacity (Roskill Information Services Ltd. 2014).

Producer	Operation	Capacity (Mt py)
ASA Metals	Burgersfort	0.60
Hernic Ferrochrome	Maroelabult	0.71
IFL	Buffelsfontein	0.40
Samancor Chrome	Emalahleni	0.62
	Middelburg	0.60
	Tubatse	0.62
Glencore-Merafe	Boshoek	0.52
	Rustenburg (Tswelopele)	0.60
	Wonderkop	1.74
	Lion I & II (planned)	0.75
	Lydenburg (planned)	0.55
Total		**7.71**

2013). Lion II, which is also based on the Premus technology, will increase Glencore's total installed capacity to over 2.3 Mt per year.

3.5 Requirements and Evaluation

South Africa is host to the largest chromite resources in the world. The currently identified chromite resources of the Bushveld Complex are estimated at more than 1 billion tonnes for more than 400 Mt contained chromite. Taking South African production figures from 2013 into account, this resource corresponds to about 40 years of primary mine production. Hence, South Africa is very likely to maintain its leading position in chromite production for years to come.

Chromite is currently mined on the western and eastern limbs of the Bushveld Complex. The northern limb is a less favourable host. The chromite deposits of the Bushveld Complex are predominantly very large deposits containing 20 Mt Cr_2O_3 on average. Contained chromite of more than 20 Mt is reported from the Buffelsfontein (77 Mt) and Waterval (60 Mt) mines, both located on the western limb, as well as from the Helena (45 Mt) and Thorncliffe (36 Mt) mines, both located on the eastern limb (SNL 2014).

The primary chromitite layers targeted for exploitation in the Bushveld Complex are the Lower Group (LG) 6, 6A and minor 5 layers as well as the Middle Group (MG) 1 and 2 layers. Chromite grades of LG6 commonly range between 46 % and 48 % with chromium to iron ratios of approximately 1.6. The MG layers are slightly lower in grade with chromite ranging between 44 % and 46 % with chromium to iron ratios between 1.35 and 1.5. These specifications allow the use of Bushveld chromite in metallurgical, chemical and refractory industries (SNL 2014).

In the short to medium term, new mine production is only expected from Glencore's prefeasibility-staged Townland Extension 9, a large deposit containing 6 Mt Cr_2O_3, located on the western limb of the Bushveld Complex. The largest undeveloped chromite deposit by far is Klipfontein/Waterval, also owned by Glencore. Klipfontein/Waterval is located on the eastern limb and currently contains approximately 60 Mt Cr_2O_3. Overall, exploration activities in the chromite sector are small in South Africa, which is likely to reflect the global market situation. Demand and supply are currently balanced and supply shortages are not expected in the next five years.

Twelve of thirteen South African chromite smelters are located in the Bushveld Complex. They have the capacity to produce approximately 4.35 Mt ferrochrome per year, which equals approximately 50 % of global demand in ferrochrome. Glencore has with nearly 2 Mt per year the biggest market share followed by Samancor with a ferrochrome capacity of 1.2 Mt per year. The capacity utilisation in 2012 was around 70 % based on ferrochrome production figures. The under-utilisation was partially attributable to the idling of capacity as part of Eskom's power buy-back programme.

China has recently been commissioning significant ferroalloy capacities, which explains its increasing demand in chrome ore. As a result, South African exports of chromium ore and concentrates, in particular to China, have risen dramatically over the last decade, from less than 2 Mt per year in 2006 to more than 8 Mt in 2013. This has pitted South African chrome ore producers including platinum miners who produce chrome as a by-product, against the country's ferrochrome producers over the export of "cheap" chrome ore. Nonetheless, the South African ferrochrome industry added new capacity last year, with local and foreign investment in ferrochrome furnaces near Rustenburg. According to Hernic Ferrochrome the capacity utilisation of the available smelters in South Africa will remain high due to a stable demand from Europe and the U.S.A. and growing markets in China (Allix 2014).

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4 Platinum Group Elements (PGE) (H. Marbler, P. Buchholz, K. Kärner)

4.1 Definition, Mineralogy and Sources

Definition

The platinum-group elements (PGEs) consist of six silver-grey-white metals namely ruthenium, rhodium, palladium, osmium, iridium and platinum.

The PGEs belong to Group VIII of the Periodic Table. They have similar geochemical behaviour and are concentrated together mineralogically. Due to their densities, a distinction is made between "light" PGEs (ruthenium, rhodium and palladium) and "heavy" PGEs (osmium, iridium and platinum; Tab. 4.1).

Economically, the most important of the PGEs are platinum, palladium and rhodium, with ruthenium, iridium and osmium being subordinate in terms of demand.

4.2 Specifications and Uses

PGEs are indispensable in many industrial applications. They are very durable and highly resistant to wear, tarnish and chemical reactions. They resist corrosion and have excellent catalytic properties. Auto catalysts are the largest demand sector for PGEs (see below).

Platinum and palladium (and to a certain extent, rhodium) are strategic metals with additional complimentary jewellery and investor demand. Producers who invest in long-term mining projects are reliant on the demand and price tensioning effect of jewellery markets during times of reduced industrial demand or medium-term price volatility. Furthermore, platinum, palladium, rhodium and to a lesser extent iridium are used in computer hard disks, mobile phones, aircraft turbines, glass, nitric acid and silicones, among other uses. They also find application in medicine for anti-cancer drugs, cardiac treatment, implants and dental applications. Platinum and ruthenium are used in fuel cell technology (International Platinum Group Metals Association 2014).

Commercial substitution of PGEs by cheaper metals has rarely been successful, although an individual PGE may readily be substituted with another. Most motor vehicle manufacturers use palladium to substitute for the more expensive platinum in gasoline-engine catalytic converters. As much as 25 % palladium can routinely be substituted for platinum in diesel catalytic converters; new technologies have increased that proportion to as much as 50 % in some applications. For other end-uses, the substitution between PGEs could lead to losses in efficiency (USGS 2014).

Nickel, copper and cobalt commonly occur together with the PGEs and are either the main or by-products in the smelters and refineries.

Tab. 4.1: Chemical and physical properties of the PGEs, from Viljoen et al. (1998).

Physical properties	Ruthenium	Rhodium	Palladium	Osmium	Iridium	Platinum
	"light" PGEs			"heavy" PGEs		
Atomic weight [amu]	101.07	102.90	106.42	190.20	192.22	195.08
Density [g/cm³]	12.45	12.41	12.02	22.61	22.65	21.45
Melting point [°C]	2,310	1,966	1,552	3,045	2,410	1,772
Boiling point [°C]	3,900	3,727	3,140	5,027	4,130	3,827
Crystal system	Hexagonal	Isometric	Isometric	Hexagonal	Isometric	Isometric
Atomic radius [Å]	1.340	1.345	1.376	1.350	1.357	1.380
Hardness [Mohs]	6.50	6.00	4.75	7.00	6.50	3.50

4.3 Supply and Demand

4.3.1 Supply

Global Situation

The world supply of PGEs, in particular platinum, is dominated by the Republic of South Africa (RSA). The South African Bushveld Igneous Complex is by far the world's premier platinum-producing region.

The PGE reserves in RSA are enormous. According to the U.S. Geological Survey (USGS 2015), 95 % of the known world reserves, i.e. 63,000 t (2,025.45 Moz) PGE, were located in the RSA in 2014. Second place is Russia with 1,100 t of PGE reserves (35.37 Moz PGE). The total world reserves are 66,000 t (2,121.9 Moz PGE).

In 2013 the RSA produced 131 t of platinum (4.21 million troy ounces – "Moz" Pt) and 75 t of palladium (2.41 Moz Pd). In 2014 the PGE production in the RSA dropped by about 20 % due to strike actions of mine workers, demanding higher wages. The strike lasted from January until June 2014 and was the longest in the South African mining history. The Russian mine production of palladium was about 80 t in 2014 (2.6 Moz Pd) and significantly higher than in the RSA (Fig. 4.1, Tab. 4.2).

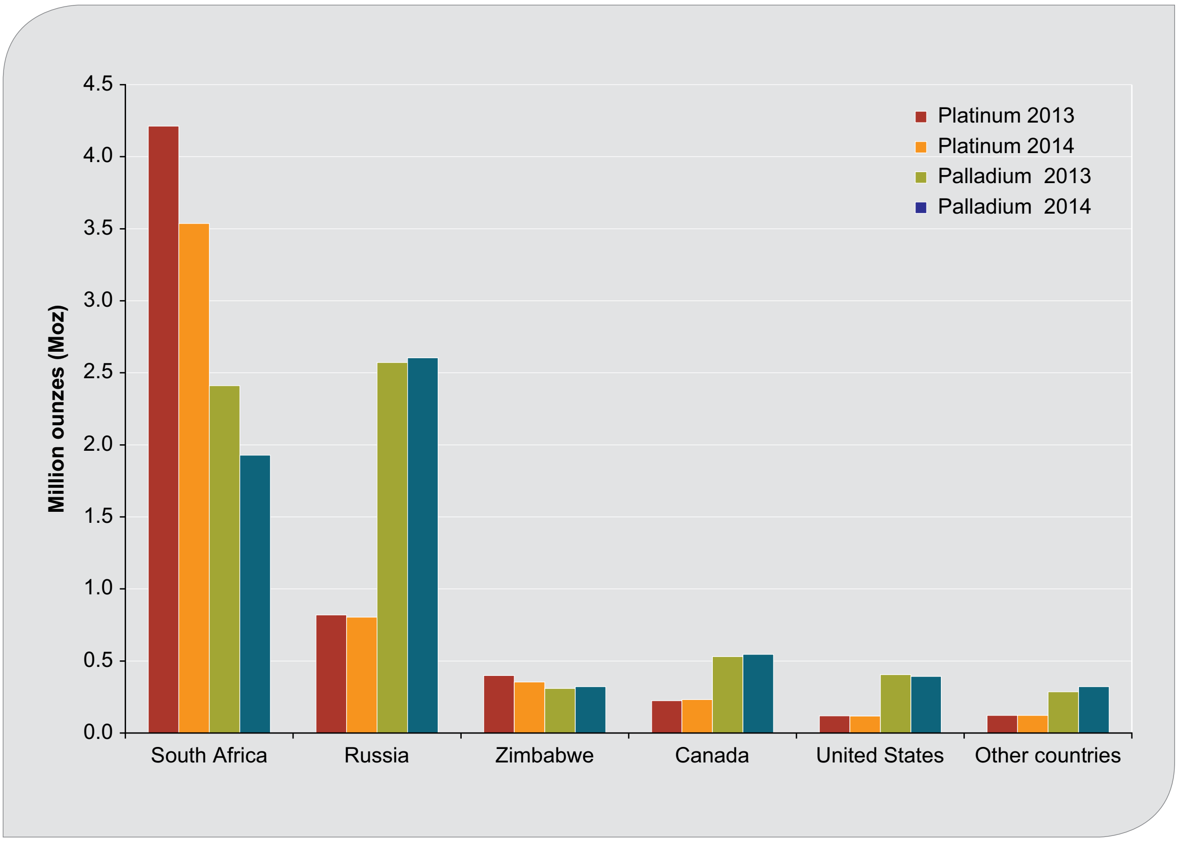

Fig. 4.1: World mine production of platinum and palladium in 2013 and 2014 by countries (USGS 2015).

Tab. 4.2: World total production of Pt and Pd (USGS 2015, BGR 2015).

Year	Pt		Pd	
	Moz	t	Moz	t
2013	5.88	183	6.53	203
2014	5.18	161	6.11	190

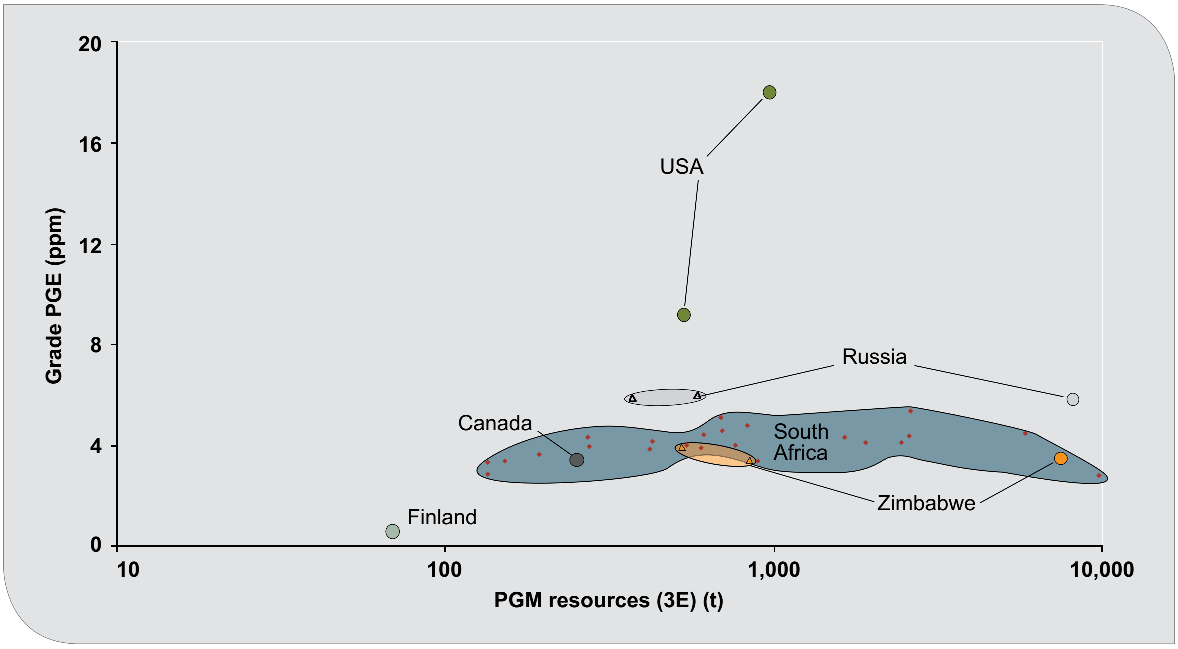

Fig. 4.2: Global grade-tonnage comparison of active PGE mines (grade vs. resources of 3E: Pt+Pd+Rh) by country: South Africa: Bushveld Complex, Zimbabwe: Great Dyke, Russia: Norilsk, U.S.A.: Stillwater Complex, Canada: Lac des Iles Complex, Finland: Penikat Intrusion. Note that the high-grade deposit is Stillwater, U.S.A., with 15.4 ppm PGE-3E (7.1 ppm Pd, 4.1 ppm Pt and 3.2 ppm Rh).

PGE resources worldwide

Deposits of PGEs are rare worldwide and economical enrichments are restricted to special geological environments. The classification of PGE deposits is based on their tectonic setting, the main types being (Maier 2005):

- PGE-enriched intervals along the base or the sidewall of intrusions, often hosted by vary-textured gabbronoritic rocks (e.g. the Platreef of the Bushveld Complex, RSA)
- PGE-mineralised intervals within ultramafic silicate cumulates in the lower portions of the intrusions
- PGE-enriched chromitites (e. g. UG2 of the Bushveld Complex, RSA)
- PGE-enriched layers associated with layered mafic-ultramafic cumulates in the central portions of intrusions (e. g. Merensky Reef of the Bushveld Complex, RSA, JM reef of the Stillwater Complex, USA)
- PGE-enriched intervals in the upper, gabbroic-dioritic, often magnetite-rich, portions of intrusions (e. g. Stella, RSA and Skaergaard, Greenland)
- PGE deposits and occurrences related to late magmatic and/or hydrothermal fluids (e. g. Lac des Iles, Canada)
- PGEs as by-products in some magmatic Ni-Cu sulfide deposits and occurrences.

Global mining of PGEs

The world's exploitable PGE resources are all associated with layered intrusions such as the Bushveld Complex in South Africa, the Norilsk Intrusion in Siberia, Russia, the Great Dyke in Zimbabwe, the Stillwater Complex in Montana, U.S.A., the Sudbury and the Lac des Iles Complexes in Canada and the Penikat Intrusion in northern Finland (stratiform deposits).

Currently 59 producing PGE mines are listed worldwide (SNL 2014, RMG 2014). Thirty three of these mines produce PGEs and the remaining 26 mines extract PGEs as by-products of nickel, copper and gold mining. The lion's share of 23 PGE mines is located in South Africa followed by Zimbabwe, Russia, North America and Canada (Tab. 4.3).

Tab. 4.3: Ranking of operating platinum mines of the world according to the approximate value they produced in 2013 (RMG – Raw Materials Group 2015).

World-rank	Mine Name	Country	Type	Controlling Company (short name)	Share (%)*
1	Impala Platinum	South Africa	UG	Impala Platinum (Implats)	0.254
2	Marikana		OP,UG	Lonmin, Incwala	0.254
3	Mogalakwena (Platreef)		OP	Anglo American Platinum (Amplats)	0.166
6	Ngezi	Zimbabwe	UG	Implats	0.101
4	Kroondal	South Africa	OP,UG	Amplats	0.086
5	Tumela		UG	Amplats	0.073
10	Two Rivers		UG	African Rainbow Minerals (ARM), Implats	0.067
8	Northam (Zondereinde)		UG	Northam	0.067
7	Union Section		UG	Amplats	0.056
9	Bafokeng-Rasimone		OP,UG	Royal Bafokeng Nation, Amplats	0.053
11	Stillwater	USA	UG	Stillwater Mining Mg Co	0.052
12	Modikwa	South Africa	UG	Amplats, ARM	0.052
14	Mimosa	Zimbabwe	UG	Aquarius, Implats	0.050
15	Khuseleka	South Africa	UG	Amplats	0.050
13	Dishaba		UG	Amplats	0.048
16	Mototolo		OP,UG	Amplats, Glencore	0.045
17	Bathopele		UG	Amplats	0.038
22	Amur Artelj Gold	Russia	Placer	Russian Platinum	0.033
18	Medvezhy Rucheu Nickel		OP	Norilsk Nickel	0.033
21	Thembelani	South Africa	UG	Amplats	0.031
19	Zapolyarny Nickel	Russia	UG	Norilsk Nickel	0.031
24	Marula	South Africa	UG	Implats	0.031
23	Siphumelele		UG	Amplats	0.029
25	Unki	Zimbabwe	UG	Anglo American	0.028
26	Lac des Iles	Canada	UG	N Am Palladium	0.025
20	Khomanani	South Africa	UG	Amplats	0.024
27	Bokoni (Lebowa)		UG	Anglo American	0.021
28	East Boulder	USA	UG	Stillwater Mg Co	0.020
30	Western Limb PGM Tailings	South Africa	Tail	Amplats	0.020
31	Elandsfontein		OP	Xstrata, Ngazana	0.016
32	Pandora		UG	Amplats, Lonmin, Bapo Ba, Northam	0.013
29	Crocodile River		OP,UG	Barplats Investments	0.006

**Share: World share of total mine production value*

EU and Germany

As the EU has no primary source of PGEs (except a small proportion from Finland) it is possible that initiatives may focus more on recycling than on the possible impact on primary supply. Therefore, the current recycling of PGEs in the EU is one of the highest rates in the world. Statistics often focus on the open recycling loop associated with PGEs in auto catalytic devices which lies between 60 and 70 % in the EU and about 90 % in the U.S.A. However, numerous closed loop recycling applications have recycling efficiencies over 90 %, such as petroleum refining and fertiliser feedstock production, for example, representing well over 50 % of annual PGE fabrication (International Platinum Group Metals Association 2014).

In Germany BASF is the leading company in catalytic converter recycling. The company determines accurate quantities of platinum, palladium and rhodium contained in refining lots by applying well-developed analytical and statistical methods (BASF 2015).

4.3.2 Demand

Platinum demand of 8.774 Moz in 2013 (Johnson Matthey 2014) comes from six distinct sectors – the automotive industry, jewellery manufacturing, the chemical, electronic and glass industry – as well as through investors (Fig. 4.3). This diverse group of buyers provides the platinum market with numerous swing factors that help to regulate supply and demand during the economic cycle, given that each group is motivated by different events. Demand from the jewellery industry tends to be flexible in terms of price, while demand from other industries generally tends to be relatively stable. Investment demand via exchange-traded funds (ETFs) remains important and holdings are at record highs, which indicate that investors are still bullish (Johnson Matthey 2014, Scotia Mocatta 2014).

The total **palladium** demand amounted to 9.913 Moz in 2013 (Johnson Matthey 2014). The highest portion of about 70 % comes from the production of autocatalysts with a forecast growth of about 4 % in 2014. The demand from other industries is analogous to the platinum usage and includes electronics, the chemical industry, glass and other emission control equipment for factories and petrol-powered machinery. In the early 2000s, with rising prices for platinum, palladium became a focal point for jewellery manufacturing. Today this sector accounts for some 4 % of total palladium demand.

The oversupply of **rhodium** over the past years resulted in lower prices for the metal. The automobile industry accounts for 80 % of rhodium's use, with chemicals using 8 %, glass 4 %, the electrical industry 0.5 % and other industries using around 7.5 % in 2013 (Johnson Matthey 2014).

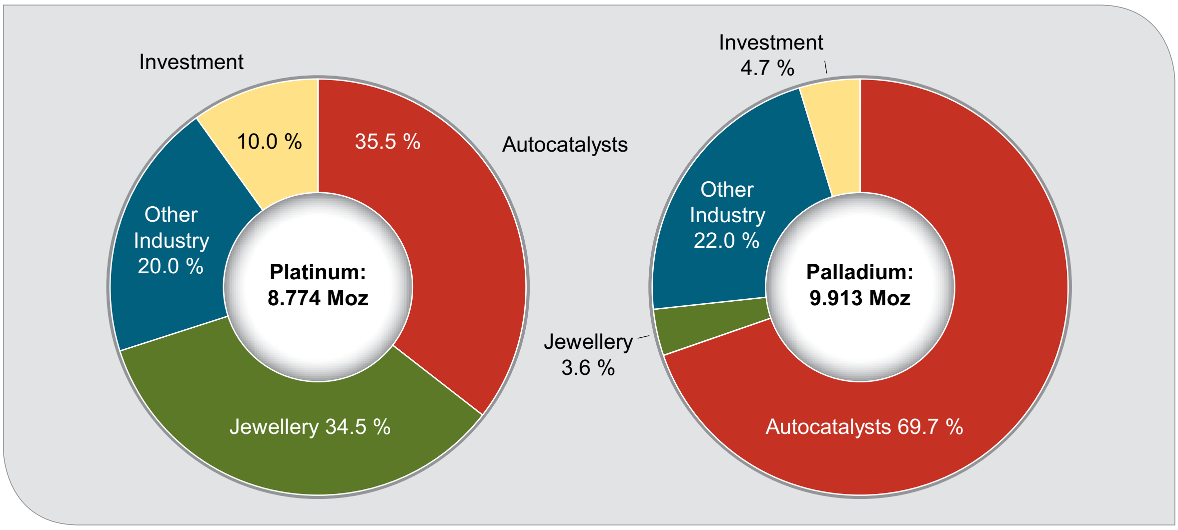

Fig. 4.3: Platinum and palladium demand in percent by sector in 2013 (Johnson Matthey 2014).

4.4 Primary PGE Deposits in South Africa

South Africa's reserves of PGEs represented 95 % (63,000) of the world total in 2014 (USGS 2015). The country's PGE output is derived almost exclusively from the Bushveld Igneous Complex, with smaller amounts coming from the Evander Gold Field, the Uitkomst Complex and the Phalaborwa Igneous Complex. In 2014 there were 23 platinum producing mines operating in the Bushveld Complex, 22 of which exploited the Merensky Reef and the UG2 Chromitite Layer, and one, the Mogalakwena Section – an opencast operation – exploiting the Platreef, on the northern limb of the complex (SNL 2015).

According to Kenan (2012), the total PGE resources available in RSA (excluding reserves, based on SAMREC Code) are about 59,085 t of contained PGEs. The total PGE reserve is about 11,508 t. Therefore, the total resources, including reserves, are about 70,592 t PGEs. The PGEs reported are mainly platinum, palladium, rhodium and minor amounts of gold ("4E").

The PGEs in the RSA occur in economic concentrations within extensive layered reefs, the Merensky Reef, the UG2 chromitite and the Platreef, associated with the mafic rocks of the Rustenburg Layered Suite of the Bushveld Complex. PGEs are mined together with their by-products gold, nickel, copper and cobalt. The PGEs are enriched in sulphide minerals (e.g. pentlandite, cooperite or braggite), occurring as platinoid minerals (e.g. sperrylite and nigglite) or as alloyed native metals.

The RSA is the world's most important PGE supplier (73 % of the global platinum, 80 % of rhodium and 37 % of palladium is produced in the RSA). At the current production rate and taking known reserves into account, exploitation of the RSA's PGE reserves is expected to continue for more than 100 years. The RSA's PGE production (3E) has been declining over a period of ten years from 2004 to 2013 from 276.4 t (8.886 Moz) to 252 t (8.102 Moz), with production peaks of around 300 t (around 9.6 Moz) between 2005 and 2007. Today PGEs contribute about 14 % to the RSA's export earnings (from goods) and about 2 % of the GDP.

In 2012 and 2014 a series of strikes created a deficit in the RSA platinum market. Through industrial action, safety stoppages and mine closures, producers in the South Africa lost about 750,000 oz of Pt in 2012 (Johnson Matthey 2014) and at least 1.5 Moz Pt in 2014 altogether.

About 95 % of the world's known reserves are hosted in the RSA and the country is responsible for 55 % of the world primary PGE production.

Russia accounts for an additional 27 %, most of this as a by-product of nickel mining (Norilsk-Talnakh). Nearly all of the remaining PGEs are produced in Zimbabwe, the United States of America, Canada and Finland (see chapter 4.3.1).

Deposits in Russia, North America and Finland have high palladium contents while deposits in the RSA and Zimbabwe are richer in platinum (International Platinum Group Metals Association 2014). The Pt/Pd ratio in the Merensky Reef often exceeds 2, the average in the UG2 layer is 1.4 and the Platreef shows an equivalent Pt/Pd ratio of 1. The "Main Sulfide Zone" in the Great Dyke, Zimbabwe, has an average Pt/Pd of 1.3. PGE deposits in Stillwater, Norilsk as well as in Finland demonstrate Pt/Pd ratios of 0.3 and Sudbury 0.5.

4.4.1 PGE Mining History in the Bushveld Complex, South Africa

In 1906, the first chromitite sample was found to contain PGEs. Later, some chromitite horizons were found to contain PGEs but there was no viable means of extracting them at that time. In 1924 a farmer named Andries Lombaard sent a sample of a concentrate he had panned on his Maandagshoek farm, north of Lydenburg in the eastern Bushveld, to the famous geologist Hans Merensky, who identified it as platinum. The farmer's initial prospecting led to the discovery of what later became known as the Merensky Reef. This reef was soon also located in the western Bushveld, near Brits, in 1925, then even closer to Rustenburg. At this latter site, the sustained mining of PGEs began in 1929 (Wilson 2003).

The Merensky Reef was the principal source of PGEs from the time that it was first worked until the end of the 20th century. However, extraction from other reefs has grown in importance, and by 2011 the Merensky Reef accounted for only 22 % of all the platinum ore processed in South Africa.

Exploitation of the Upper Group chromitites (such as UG2, for example), which stratigraphically occur below the Merensky Reef, began in the 1970s and has steadily increased. In 2011 it was the source of 63 % of PGE ore processed. The UG2 seam also contains up to 25 % Cr_2O_3. However, historically, it has been mined for PGEs only, as chromite extraction was uneconomical. In recent years both the supply of and demand for chromite from the UG2 seam has steadily increased, partly as a result of the development of the pellitising technology (Roskill Information Services Ltd. 2014), which allows the UG2 use in ferrochrome production (as referenced in Chapter 3).

The Platreef (found only at the northeastern edge on the northern limb), briefly mined in the 1920s, was not exploited on a large scale until 1993, but by 2011 accounted for 15 % of ore treated by South African platinum mines (Johnson Matthey 2014).

4.5 Mining and Processing

4.5.1 Processing

After PGE bearing ore is extracted from the mine, it undergoes the following process in sequence. The treatment of the PGE ore can be presented schematically as follows (Fig. 4.4):

Primary smelting of ore concentrates is carried out in South Africa by four companies – Anglo Platinum, Impala Platinum, Lonmin Platinum and Northam Platinum.

Conventional platinum smelting technology can only tolerate a low content of chrome (generally about 4 % Cr_2O_3 maximum). In order to limit chrome levels in a smelter feed, UG2 concentrates have to be blended with lower chromium-bearing Merensky Reef concentrates. As the Merensky Reef is gradually mined out at a number of operations, processing other ores will become more difficult. In light of this, Mintek (South Africa's national mineral research organisation) has developed a novel process for the treatment of PGE nickel-copper sulphide concentrates. The ConRoast process is

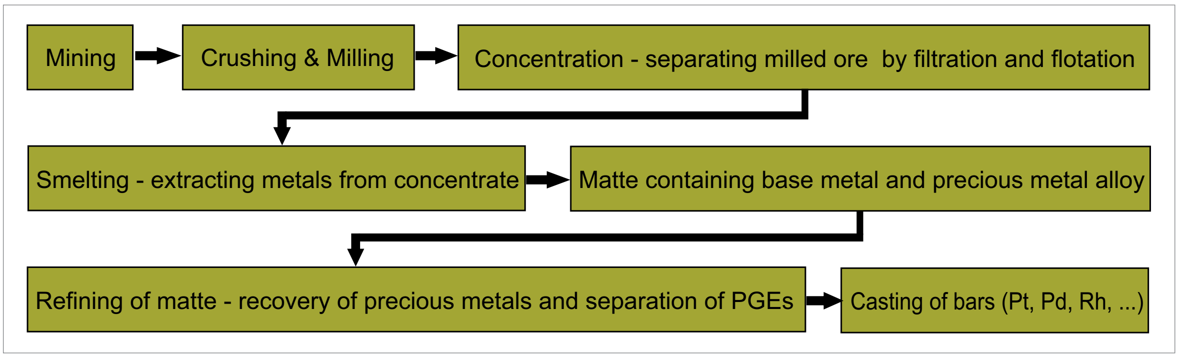

Fig. 4.4: Schematic processing of PGEs from mining to the metal bars (after DMR 2009).

Tab. 4.4: The South African platinum smelters and their production in 2013 (SNL 2015).

Name	Company	Region	Start-up	Production (Moz/a)
Waterval Smelter	Anglo Platinum	Rustenburg	1993	2.5 Pt (4.16 PGEs)
Polokwane Smelter	Anglo Platinum	Polokwane	2003	0.8 Pt
Mortimer Smelter	Anglo Platinum	Rustenburg	1973	n.a. (0.75 PGEs)
Impala Smelter	Impala Platinum	Rustenburg	1969	2.0 Pt (3.73 PGEs)
Marikana Smelter	Lonmin Platinum	Mooinooi	1971	0.9 Pt (1.76 PGEs)
Northam Smelter	Northam Platinum	Northam, Zondereinde	1992	0.2 Pt (0.39 PGEs)

based on the removal of sulfur by roasting, followed by smelting of the dead roasted concentrate in a DC arc furnace, using an iron-based alloy as a collector for nickel, copper, cobalt and PGEs (Jones 2001).

The mining exploration and development company Jubilee Platinum plc acquired Braemore Resources plc in October 2009, which holds an exclusive license to the ConRoast process for the smelting of high chrome-bearing PGE concentrates and has acquired extensive process development expertise. Today Jubilee holds the patent over the ConRoast process which allows it to unlock PGEs from low-grade ores, which have traditionally only been mined for their chrome (lower and middle group chromitite layers – LG and MG), as well as for the processing of the chromite tailings (Jubilee 2014). For further details about Jubilee activities and operations, particularly in secondary mining, see Chapter 5.2 "Chromite and PGEs in Mine Tailings". Around the Bushveld Complex, an enormous potential of PGEs occurs in oxidised ore horizons, i.e. oxidation and alteration of near-surface reefs by meteoric weathering. The processing of oxide minerals, in particular the mineral separation by common flotation techniques, is currently not economically feasible (Becker et al. 2014). These ores are therefore often left behind or, in some cases, are being stockpiled. Research projects for developing a process of economical extraction of PGEs from this oxidised ore material by (bio) leaching are currently being undertaken (please also refer to Chapter 4.6)

4.5.2 Mining – Overview of Companies and Projects

A number of companies are exploiting PGEs in 23 producing mines in RSA. The biggest players, covering about 90 % of the national PGE production, are Anglo American Platinum (Amplats), Impala Platinum (Implats) and Lonmin (Tab. 4.5).

The annual revenue of PGEs marginally increased within the 2014 fiscal year to 82 bn ZAR (South African Rand; US$ 6.68 bn) compared to 77 bn ZAR (US$ 6.27 bn) in 2012 and 2013. In terms of market capitalisation, Amplats is the top mining company in the RSA. Within the fiscal year 2014, a declining trend in the market value of the top mining companies in RSA is obvious (Fig. 4.5).

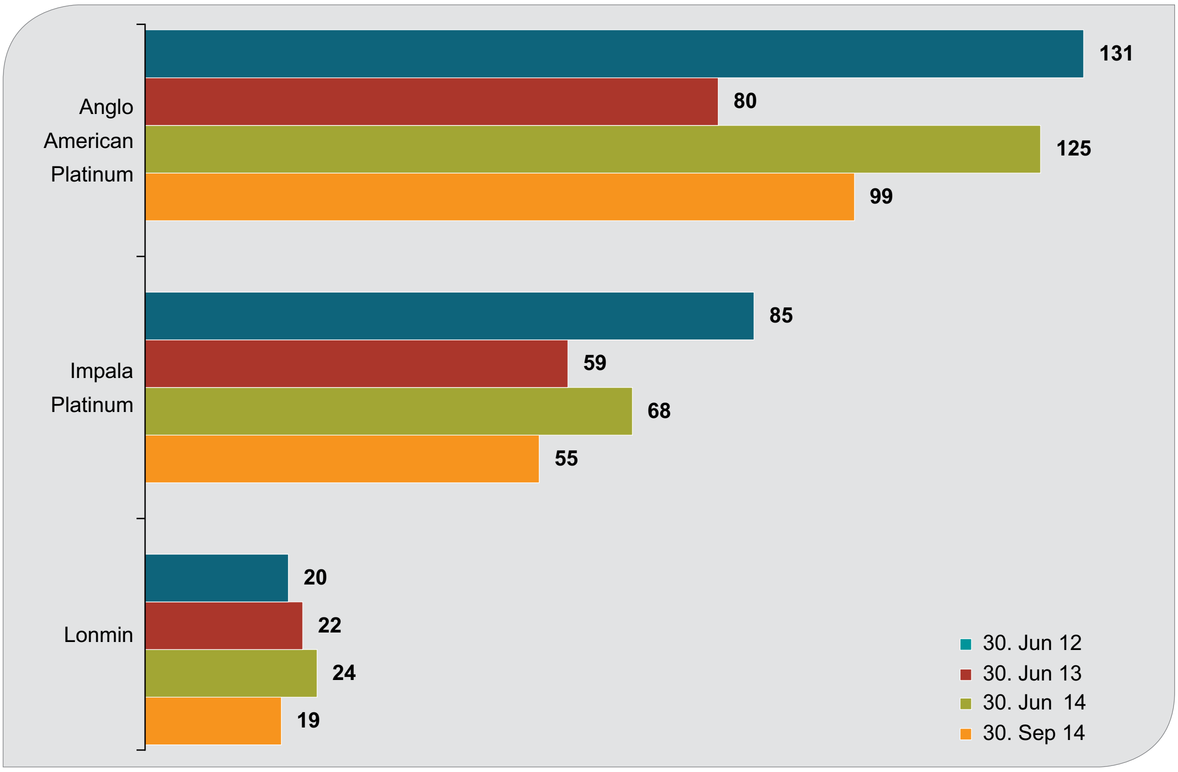

Fig. 4.5: Market value of the top three PGE miners in the RSA over the past three years in bn ZAR (1 ZAR = US$ 0.082; data source: PWC 2014).

Tab. 4.5: Mineral resources, reserves and production of the very large PGE deposits (> 1,000 t PGEs in resources) in the RSA (RMG – Raw Materials Group 2015, SNL 2015; data from 2013).

Mine	Ownership	Mine type	Resources [Mt]	Resource grade [ppm]	Reserves [Mt]	Reserve grade [ppm]	Reserves [Moz Pt]	Production/a (,000 oz Pt) 2013	PGE [t] in resource	Start-up
Mogalakwena (Platreef)	Amplats	OP	2,070.8	2.3	1,635.9	2.75	142.0	342.8	9,696	1993
Marikana	Lonmin 86% Sanduca 14%	OP, UG	578.3	4.7	368.7	3.92	28.14	706.0	6,056	1975
Amandelbult Section	Amplats	UG	579.5	6.0	151.4	4.69	22.47	363.4	3,767	2000
Bokoni (Lebowa)	Amplats 49% Atlatsa 51%	UG	736.3	5.7	75.5	4.77	11.58	170.3	3,391	1968
Rustenburg Section	Amplats	UG	448.4	4.7	92.6	3.63	10.26	500.9	2,395	2002
Impala	Implats	UG	243.6	6.0	257.1	4.58	37.77	709.2	3,027	1969
Modikwa	Amplats 50% ARM 41.5 % Local 8.5 %	UG	425.0	4.4	59.2	4.71	8.81	127.8	2,131	2002
Tumela	Amplats	UG	461.0	6.2	63.3	4.59	9.34	363.4	2,849	2000
Twickenham	Amplats	UG	545.4	5.3	28.0	5.39	4.87	10	2,258	2005
Rustenburg UG2	Amplats	UG	413.1	4.2	266.4	3.59	18.90	n.a.	1,735	2002
Bafokeng-Rasimone	Amplats 33% Bafok. 67%	OP, UG	251.7	5.5	120.2	4.10	15.90	n.a.	2,069	2000
Union Section	Amplats 85% Bakg. 15%	UG	183.7	5.2	57.9	4.18	8.12	170.8	1,360	1998

***Moz:** million troy ounces; **Resources:** total resources exclusive of reserves; **Reserves:** total reserves.*
***Amplats:** Anglo American Platinum Ltd.; **Implats:** Impala Platinum Holdings Ltd.; **Sanduca:** Sanduca Group (Pty) Ltd.; **ARM:** African Rainbow Minerals Ltd.;*
***Bafok.:** Royal Bafokeng Platinum Ltd.; **Bakg.:** Bakgatia Ba Kgafela Community; **Atlatsa:** Atlatsa Resources Corp.*

A number of exploration projects are underway around the Bushveld Complex as well as one at the Kraaipan Greenstone Belt. Four more projects are currently under construction. These are listed in Tables 4.6 and 4.7. The most promising projects are described in chapters 4.5.3, 4.5.4 and 4.5.5.

Tab. 4.6: PGE exploration projects in South Africa.

Project Name	Ownership (%)	State, Province Limb/ Location	Reserves and Resources	Value (Rand)	Expected Production	Start-up planned/ LoM
Aurora	Sylvania Plat. Ltd. (75) Impala (25)	Limpopo NL	10.77 Moz 3E	n.a.	n.a.	2016
Boikgantsho**	Amplats, (Anooraq Res.)	Limpopo NL/ Sekhukhuneland	1.9 Moz Pt	3 bn	n.a.	n.a. 32 years
Cracouw	Chile Metals Ltd.a (71) Sylvania Plat. Ltd. (29)	Limpopo EL	n.a.	n.a.	n.a.	n.a.
Der Brochen	Amplats	Limpopo EL/ 20 km ENE of Roossenekal	76.9 Moz	1.9 bn	16,000 oz (Pt+Pd)/a	n.a.
Dwaalkop	Northam Platinum Ltd. Lonmin	Limpopo EL	11.75 Moz 4E	n.a.	n.a.	n.a.
Garatau / Tubatse**	NKWE Plat. Ltd. (74) Genorah Res. (26) Zijin Min. Gr. (strat. partner)	Mpumalanga EL/ Genorah Farms	59 Moz 4E	3.6 bn	450,000 oz 4E/a	2018 28 years
Hoogland	Aquarius Plat. Ltd.	Mpumalanga EL/ 35 km W of Lydenburg	0.61 Moz 4E	n.a.	n.a.	n.a.
Kalahari PGM "Kalplats"**	ARM (51) Jubilee Platinum plc. (49) (previously Platinum Australia**)	North West/ 350 km W of Johannesburg	6.74 Moz Pt	1.15 bn	110,000 oz PGE/a	n.a. 9 years
Kennedy's Vale (Spitzkop)	Eastern Platinum Ltd. (87.5) Barplats Inv. Ltd. (Operator)	Limpopo EL/ 8 km W of Steelpoort	60.71 Moz 4E	795 mil	n.a.	n.a.
Kruid-fontein**	Sedibelo Platinum Mines Ltd. (previously Platmin)	North West WL/ 60 km N of Rustenburg	24.11 Moz 4E	n.a.	n.a.	n.a.
Lesego**	Village Main Reef Umbono	Limpopo EL	39 Moz 4E	5.1 bn	600,000 oz 4E/a	2017 23 years
Leeuwkop**	Implats Ltd. (74) Bakwena Ba Mogopa Ltd. (26)	North West WL/ 10 km W of Brits	65.68 Moz 4E	n.a.	n.a.	n.a.
Loskop	Sedibelo Platinum Mines Ltd.	Mpumalanga EL	n.a.	n.a.	n.a.	n.a.
Mphahlele	Sedibelo Platinum M. (54.3) Moepi Capital (20.7) Limpopo Dev. C. (20)	Mpumalanga EL	8 Moz Pt	n.a.	250,000 oz 4E/a	n.a.
Modikwa Mine Lease Area	Amplats (50) ARM (8.5) Local Interest (41.5)	Limpopo EL	68.6 Moz 4E	3.4 bn	n.a.	n.a.

Project Name	Ownership (%)	State, Province Limb/ Location	Reserves and Resources	Value (Rand)	Expected Production	Start-up planned/ LoM
Pilanesberg (Merensky)**	Chrometco Ltd. (100) Nkwe Plat. Ltd. (Optionor)	North West WL/ 60 km N of Rustenburg	4.45 Moz 4E	270 mil.	n.a.	n.a.
Phoenix PGM	Pan African Res.	North West WL	n.a.	n.a.	n.a.	n.a.
Rooderand	Platinum Australia* (70) ATLA Mining (30)	North West WL/ N of Pilanesberg	n.a.	n.a.	85,000 oz PGE/a	n.a.
Sheba's Ridge	Aquarius Platinum Ltd. (39) Amplats (35) Econ. Develop. Dep. (26)	Mpumalanga EL/ 55 km N of Middelburg	7.1 Moz 3E	n.a.	n.a.	n.a.
Tamboti**	Implats Ltd.	Limpopo EL	41 Moz 4E	n.a.	n.a.	n.a.
Tjate**	Jubilee Platinum (63) Matuba Holdings (37)	Limpopo EL	22.3 Moz 4E	5.37 bn	n.a.	n.a.
Vygenhoek (Everest North)	Aquarius Platinum Ltd. (50) Sylvania Platinum Ltd. (50)	Mpumalanga EL/ 40 km W of Lydenburg	0.46 Moz Pt	n.a.	n.a.	n.a.
Waterberg**	PGM Ltd. (49) JOGMEC (37) Mnombo Wethu (14)	Limpopo NL/ Blouberg Nat. Res.	8.678 Moz Pt 17.747 Moz Pd	10.14 bn	655,000 oz Pt/a	2017 20 years
Zondereinde	Northam Platinum	Limpopo WL/ Northam	7.8 Moz 4E	n.a.	n.a.	n.a.
Zondernaam	Aquarius Platinum Ltd. (74) Bakgage Mining Ltd. (26)	Limpopo EL/ 50 km E of Mokopane	15.9 Moz 4E	n.a.	n.a.	n.a.

Amplats: Anglo American Platinum Ltd.; ARM: African Rainbow Minerals; PGM: Platinum Group Metals Ltd.
**Platinum Australia was divided in Dec. 2014 amongst African Thunder Plat. Ltd., Aberdeen Int. Inc. and Pala Investments Ltd.; LoM: life of mine; Sources: DMR 2012, SNL 2014/2015.*
*** detailed description in the text*

Tab. 4.7: PGE projects under construction.

Project Name	Ownership (%)	State, Province Limb/ Location	Reserves and Resources	Value (Rand)	Expected Production	Start-up planned/ LoM
Bakubung	Wesizwe Platinum Ltd.	North West WL/ 35 km NW of Rustenburg	13.32 Moz 4E	11.67 bn 1 bn US$	n.a.	2020
Elandsfontein (W. Bushv. JV)	PGM Ltd. (82.9) Wesizwe Plat. Ltd. (17.1)	North West WL/ 30 km N of Rustenburg	11.24 Moz 4E	5.18 bn 443 mil US$	n.a.	2016
Ivanplats**	Ivanhoe Mines Ltd. (64) B-BBEE SPV (26) ITOCHU (10)	Limpopo NL/ Rietfontein	147.21 Moz 4E (68.16 Moz Pt)	20.48 bn	433,000 oz 4E (initial)	2016 31 years
Styldrift 1	Royal Bafokeng Plat. Ltd. (67) Amplats (33)	North West WL/ 25 km N of Rustenburg	20,9 Moz Pt (2009)	18.95 bn 1.62 bn US$	n.a.	2017

*Sources: DMR 2012, SNL 2014/2015. ** detailed description in the text*

4.5.3 Eastern Bushveld Complex (eastern limb)

Mining Projects

A number of active PGE mines as well as exploration projects are lined up along the Merensky Reef (MR) and Upper Group (UG2) outcrops to the west or southwest of it respectively. The dip of the MR and the UG2 in the eastern limb is relatively shallow at 7° to 15°, therefore the assessment of the ore bodies via decline shaft systems is, in general, technically feasible. The most profitable PGE mines as well as the most promising exploration projects are listed in Tables 4.6 and 4.7.

Two Rivers (African Rainbow Minerals Ltd., Impala Platinum Holdings Ltd.)

Location & Ownership

Coordinates: 24°54'57"S, 30°05'55"E

Contact person:
Dr Jabulani Khumalo (Chief Geologist):
jabulani.khumalo@arm.co.za

The Two Rivers Platinum Mine is owned by a joint venture of African Rainbow Minerals (ARM, 55 %) and Impala Platinum (Implats, 45 %). The mine is located 35 km southwest of Burgersfort and holds a contiguous old-order mining right over 2,269 ha on a portion of the farm Dwarsrivier. The conversion to a new-order mining right was executed during 2014. Agreement has been reached to incorporate portions of the adjoining Kalkfontein farm into the mining area (SNL 2015).

Geology & Mining

At Two Rivers, both the MR and the UG2 are present, but only the UG2 is currently mined (Fig. 4.6). The UG2 reef outcrops in the Klein Dwarsrivier Valley over a north-south strike of 7.5 km and dips to the west at 7° to 10°. The vertical separation between UG2 and MR is roughly 140 m.

The area hosts proven and probable reserves totaling 35.1 Mt grading 3.57 ppm 6E (6PGE – Ru + Rh + Pd + Os + Ir + Pt); measured and indicated resources totaling 149.6 Mt grading 4.19 ppm 6E; and inferred resources of 261.3 Mt and 4.29 pm 6E. By January 2007 Two Rivers had reached full production. Total capital costs were under budget at US$ 154 million (ZAR 1.103 bn). Operating costs were US$ 627.96/oz Pt, US$ 359.39/oz Pt after by-product credits (SNL 2015).

In the 2014 fiscal year (July 2013 to June 2014) Two Rivers produced 374,681 oz 6E. Further, the mine started chrome concentrate sales in October 2013, with a total of 160,951 t sold during the year. Accordingly the mine is presently the largest producer of PGEs in the eastern limb. Ending in December 2014, the mine produced 121,700 oz 6E PGE-in-concentrate from 1.32 Mt ore at a cash cost of US$ 570/oz PGE (4,347 ZAR) for

Fig. 4.6: Incline shafts of Two Rivers Mine (left) and the exposed UG2 reef underground (right) (photos: DERA 2013).

the last half of the year. Accumulated stockpiles of 243,000 t ore were being processed to reduce capital expenditures related to underground mining. Process optimisation was completed in 2009 and from that point forward the mine worked as one of the technologically best working mines in the eastern limb (SNL 2015).

Marula (Impala Platinum Holdings Ltd., Marula Community Trust, Mmakau Mining (Pty) Ltd. and Tubatse Platinum Ltd.)

Location & Ownership

Coordinates: 24°30'2.42"S, 30° 4'50.05"E

Marula is a joint venture of Impala Platinum Holdings (77.5 %), Marula Community Trust (7.5 %), Mmakau Mining (Pty) (7.5 %) and Ltd. and Tubatse Platinum Ltd. (7.5 %). The mine is situated 35 km northwest of Burgersfort in the Limpopo Province. It holds two contiguous mining rights and a prospecting right covering 5,494 ha across the farms Winnaarshoek and Clapham, as well as portions of the farms Driekop, Forest Hill and Hackney. Marula has also a royalty agreement with Modikwa Platinum Mine, which allows limited mining on an area adjacent to the Driekop Shaft.

In the year concluding in June 2014 Marula produced 78,500 oz Pt, 80,500 oz Pd, 16,700 oz Rh and 279 t Ni. Marula hosted proven and probable reserves totaling 25.1 million t grading 4.8 ppm 6E (5PGE + Au; SNL 2015).

Twickenham (Anglo American Platinum Ltd.)

Location & Ownership

Coordinates: 24°24'53.20"S, 30°1'21.26"E

Twickenham is located in the Limpopo Province, around 40 km northwest of Burgersfort close to the R37. It is a 100 % Amplats-owned project and central to unlocking the eastern limb.

Geology & Mining

Twickenham offers long-term potential for shallow mining activities on both the Merensky Reef and the UG2 horizons (Anglo American Platinum Ltd. 2013). The total reserves and resources (measured, indicated and inferred) amounted to 573.4 Mt grading 5.48 ppm 4E (5.08 ppm Pt, 0.34 ppm Pd, 0.06 ppm Rh and 0.01 ppm Au) (SNL 2014).

The feasibility study was completed in the second quarter of 2007, and in the same year Amplats produced 8,800 oz Pt, 8,800 oz Pd, 1,300 oz Rh and 300 oz Au. In 2013 Twickenham produced 10,000 oz Pt, 9,700 oz Pd, 800 oz Rh and 300 oz Au. Amplats undertook additional studies to improve Twickenham's business case. The study would evaluate earlier potential processing opportunities and conversion to ultra-low profile mining. Amplats currently develop and mechanise the Twickenham Mine, as it prepares to shed labor-intensive assets in South Africa (SNL 2015).

Bokoni (Atlatsa Resources Corp., Anglo American Platinum Ltd.)

Location & Ownership

Coordinates: 24°18'48.47"S, 29°55'27.43"E

The former called Lebowa Platinum Mine in the Limpopo Province has been active since 1968 and is one of the oldest platinum mines in the eastern limb. Today Bokoni Platinum Holdings Proprietary Limited is a 51 : 49 joint venture between Atlatsa Resources and Amplats. The mine is situated approximately 80 km southeast of the town of Polokwane in the Limpopo Province. The mining right covers a total area of 147 km^2 (SNL 2015).

Geology & Mining

Current mining infrastructure consists of a vertical shaft, three decline shafts (UM2, Middelpunt Hill and Brakfontein) and a concentrator.

Total reserves and resources at Bokoni were announced in 2013 with 812 Mt of ore, containing 5.7 ppm 4E (149 Moz 4E). The annual production in 2013 was 170,295 oz Pt by processing 1.53 Mt of ore at cash costs of US$ 1,148/oz PGE (SNL 2015).

Exploration Projects

Lesego (Village Main Reef Ltd., Umbono Capital Ltd., Industrial Development Corp.)

Location & Ownership

Coordinates: 24°23'22.83"S, 29°44'57.82"E

Contact person: Dr Richard Montjoie: montjoie@umbono.co.za

Lesego Platinum Mining is an advanced exploration project in the feasibility stage and located about 70 km south of Polokwane in the Limpopo Province. Village Main Reef effectively holds 78 % (with shares from Umbono Capital) and the Industrial Development Corporation of South Africa (IDC) holds 22 %. The exploration license area covers a total of 33 km² and extends over four farms (Dal Josephat, Koppieskraal, Spelonk and Olifantspoort; SNL 2015). Both reefs, the Merensky Reef and the UG2, occur with a distance of approximately 150 m at depth.

Geology & Mining

Total reserves and resources are 204.16 Mt of ore (MR and UG2, Figs. 4.7 and 4.8) containing 6.14 ppm 4E (39 Moz 4E). The intended annual production is announced with up to 600,000 oz 4E as well as additionally 101,277 t Cu and 204,878 t Ni (personal communication R. Montjoie, Exploration manager, Umbono).

Village holds the exploration license since 2006. A bankable feasibility study was started during 2010 and was completed by the end of 2012. A total of 58 boreholes totaling 88,655 m have been drilled (Figs. 4.8 and 4.9). The study was being funded by the Industrial Development Corporation who acquired 28 % of Lesego for US$ 18 million (142 million ZAR; SNL 2015).

In May 2014 Village Main had completed a preliminary economic assessment at Lesego focused on the mining of the upper portion of the Merensky Reef and UG2 ore bodies from a depth of 350–1,200 m, with a mill feed of 100,000 t per month. Resource from this area would yield a total plant feed of 21 Mt grading 4 ppm 4E, giving an anticipated life of mine for the upper portion of the ore body of 23 years. First production would take two to three years (2017), with full production to be achieved by year seven (2021). Following 13 years of steady state production, there would be an option of accessing further resources (~180 Mt) by deepening the existing shaft, or sinking a new one (personal communication R. Montjoie).

Total capital requirement to bring the upper portion into steady state production was estimated at US$ 215 million (2.5 bn ZAR), and US$ 439 million (5.1 bn ZAR) was estimated as total requirement over the 23 year life of the mine. The initial investment includes a twin shaft system (800 m and 1,600 m), the processing plant for milling and flotation, energy supply via a 40 km power line and water supply (personal communication with R. Montjoie).

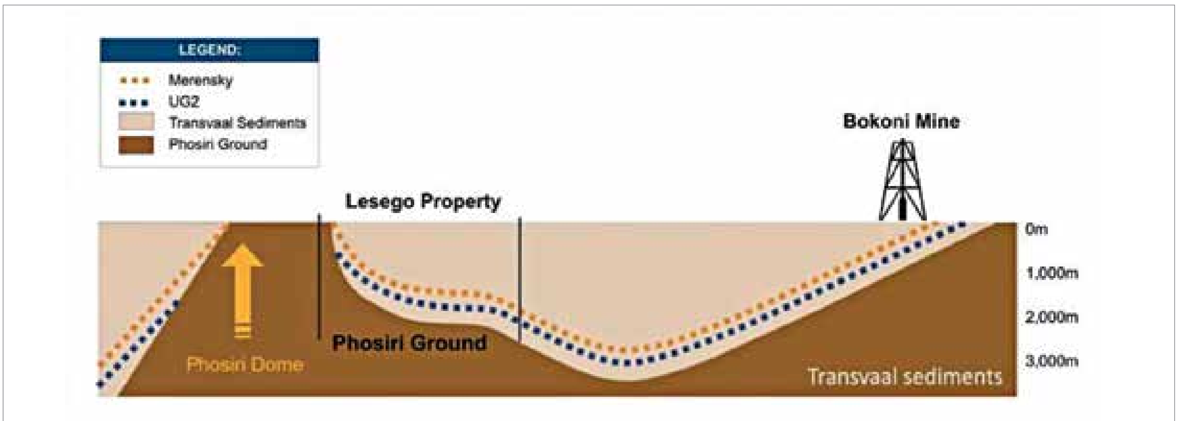

Fig. 4.7: Profile of the Merensky Reef and the UG2 formations within the Lesego area (Phosiri Ground; with courtesy of Village Main Reef).

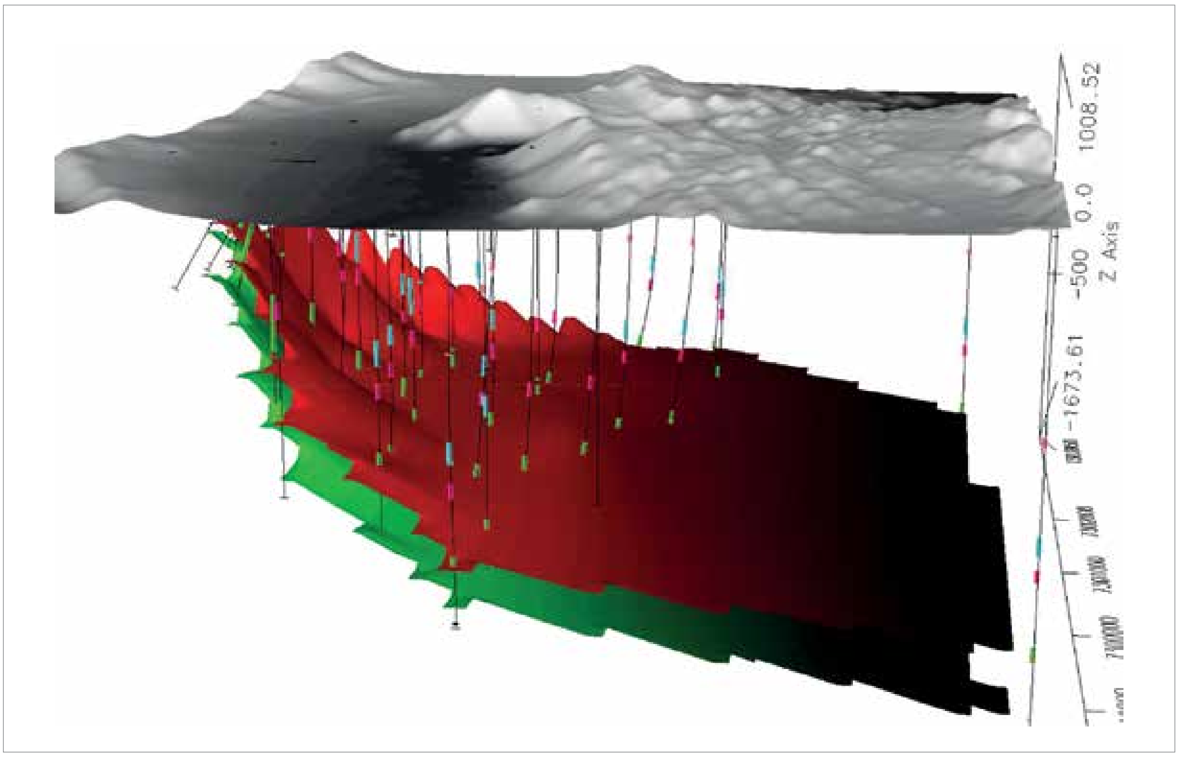

Fig. 4.8: Three-dimensional view of the ore body (Merensky Reef: red layer, UG2 chromitite: green layer) below the Lesego license area (with courtesy of Village Main Reef).

Fig. 4.9: Drill core store at Lesego with Merensky and UG2 samples (photo: DERA 2013).

Garatau Project (NKWE Platinum Ltd.)

Location & Ownership

Coordinates: 24°42'39.43"S, 30°6'4.49"E

Contact person: Mr. Abraham Li:
abraham@nkweplatinum.co.za

The Garatau project is a world-class PGE project in the Bushveld Complex of South Africa and is poised to become a PGE developer (producer). The project is a late-stage exploration project in the pre-development phase. The project is located 10 km west of Steelpoort, in the Limpopo Province. The license area covers 5,312.9 ha in surface area with a strike length of about 21 km from north to south and comprise three individual (but contiguous) farms: De Kom, Garatouw and Hoepakrantz, all underlain by the platinum-bearing Merensky Reef and the UG2 (personal communication with Dr. T.D. Manyeruke, Project leader, NKWE).

Genorah Resources Pty Ltd. is the majority shareholder in NKWE Platinum Ltd. In April 2013 Nkwe Platinum formed a strategic partnership with Zijin Mining Group ("Zijin") in respect of the development of the company's flagship Garatau project. As part of the deal Zijin invested 20 million AU$ in NKWE by a placement of three year convertible bonds convertible into 200 million NKWE shares at a conversion price of AU$ 0.10 per share. The transaction was finalised in March 2014 (SNL 2015).

Geology & Mining

The project area is underlain by the MR and UG2 platinum bearing reefs, with the former underlain by the latter. The vertical distance between the MR and UG2 reefs is about 370 m and both dip 10° to the west. The project is divided into two phases with phase 1 comprising extraction of the MR while maintaining the requirement that a monthly ROM (run of mine) tonnage to concentrator of 300,000 t be achieved and phase 2 targeting the UG2 below the refrigeration zone. To achieve from MR mining operations only, a triple decline system will be implemented underground to split the MR ore body into three similarly sized mining areas (Fig. 4.10). A mechanised bord-and-pillar mining method would be adopted (as per personal communication with T. D. Manyeruke).

The first production is scheduled for 2020 and full production for 2024. The intended annual full production will be 450,000 oz 4E with a capital cost of around US$ 510 million/oz. The life of the mine is estimated at 17 years above the refrigeration horizon at 650 m depth and an additional 11 years below (as per personal communication with T. D. Manyeruke).

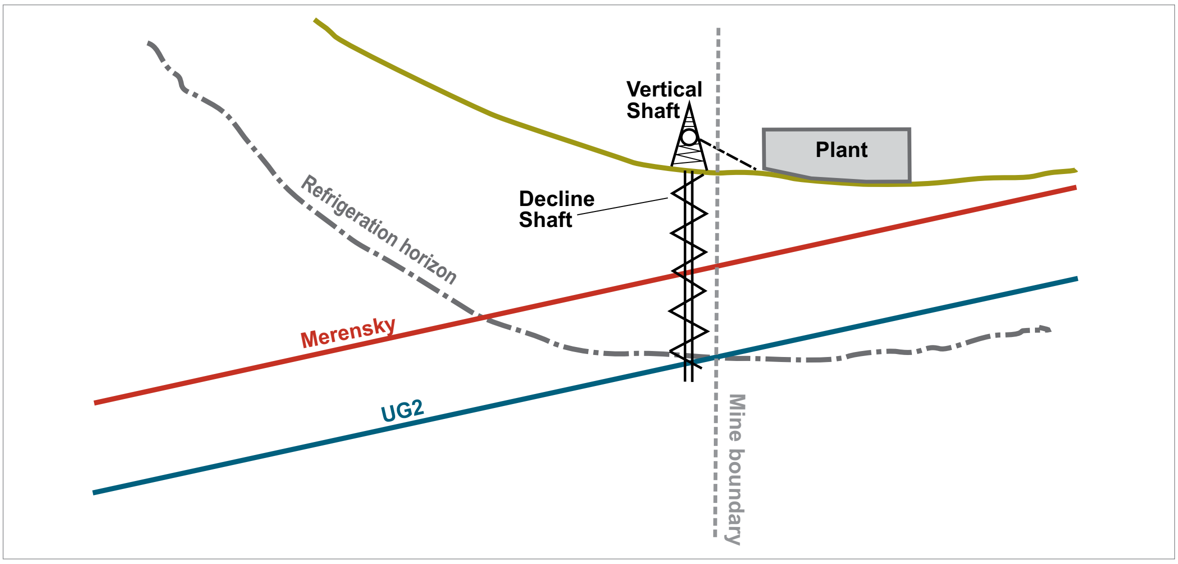

Fig. 4.10: Schematic shaft and adit system at Garatau Platinum Mine (with courtesy of NKWE Platinum 2015).

During the exploration campaign, 110 diamond drillholes were completed, including 153,360 metres drilled. The Garatau project has an independently estimated total resource of 43.689 million ounces (Moz) of 3 PGE+Au (20.51 Moz from Hoepakrantz, 21.78 Moz from Garatouw and 1.40 Moz from De Kom). The estimated initial capital costs will amount to US$ 665 million (7.6 bn ZAR), (base date August 2012, per personal communication with T. D. Manyeruke).

A bankable feasibility study was completed during the second quarter of 2012. Since that time, additional value engineering has been completed and the project is ready for the first mine to commence construction. The study focused on a 3.6 Mt/a mine producing 400,000 oz/a PGE at cash costs of around US$ 415/oz. NKWE-targeted milestones over the coming months, include securing the integrated environmental authorisation and waste management license, agreeing a suitable financing structure for mine development and beginning of ground predevelopment activities at Garatau.

Tjate (Jubilee Platinum plc, Matuba Holdings)

Location & Ownership

Coordinates: 24°30'31.37"S, 29°58'52.79"E

The joint venture project Tjate (63 % Jubilee and 27 % Matuba) is an advanced exploration project and after Jubilee it contains the world's largest defined block of undeveloped platinum ore (Jubilee 2014). Tjate is located 35 km northwest of Burgersfort and down-dip of Anglo Platinum's Twickenham and Impala Platinum's Marula mines. The license area covers 51.4 km² including the Dsjate and Fernkloof farms (Jubilee 2014).

Geology & Mining

Both reefs, the Merensky and UG2, are present and lie between 600 m and 1,000 m below the surface. Total reserves and resources are stated at 132.5 Mt of ore, containing 5.3 ppm 4E (22.3 Moz 4E) as well as 0.11 % Ni (145,800 t Ni) and 0.06 % Cu (79,500 t Cu). The capital costs are estimated at US$ 47 million (5.37 bn ZAR).

In October 2013 Jubilee and Matuba's Mining Right Application for Tjate was accepted by the Department of Mineral Resources of South Africa (DMR). The JV was in discussion regarding the timing and deadline for submission of a scoping study and an environmental management programme. In August 2014 Jubilee submitted its environmental impact assessment and environmental management programme to the DMR as a final requirement for the Tjate mining rights. In mid-February 2015, Jubilee had received formal communication from the DMR that an environmental rehabilitation guarantee at a value of 27 million ZAR has to be provided to the department, which seems to be the final step towards receiving the grant of the mining rights (Jubilee 2014).

Tamboti (Impala Platinum Holdings Ltd.)

Location & Ownership

Coordinates: 24°58'07"S, 30°02'01"E

The Tamboti exploration project is located adjacent to the west and down-dip of the Two Rivers Mine. Impala Platinum holds a prospecting right over 8,524 ha on Buffelshoek and large portions of the Tweefontein and Kalkfontein farms. In 2012 an agreement with the junior resource company Kameni over these properties was terminated.

Geology & Mining

Both the Merensky Reef and the UG2 occur at the Tamboti project with a vertical separation of around 160 m. The geological succession is broadly similar to the Two Rivers operation. The total mineral resources (inferred and indicated) are indicated at (Implats 2013): 337.4 Mt grading 2.14 ppm Pt (23.2 Moz Pt) or 3.78 ppm 4E (41 Moz 4E) or 4.35 ppm 6E (47.2 Moz). Data for the targeted annual production volume are not available.

4.5.4 Western Bushveld Complex (western limb)

Platinum mining within the western limb of the Bushveld Complex has a long tradition and therefore PGE mines are numerous. In the following the economically most important mines and exploration projects will be defined and described.

Mining Projects

Marikana (Lonmin plc, Incwala Resources Ltd.)

Location & Ownership

Coordinates: 25°41'37.43"S, 27°26'59.15"E

The Marikana Platinum Mine is a joint venture between Lonmin Plc (82 %) and Incwala Resources Ltd. (18 %). Marikana is situated some 20 km east of Rustenburg, North West Province and covers an area of 33 km^2.

Geology & Mining

Both the Merensky and the UG2 reefs are mined in underground and formerly in open pit operations. The two open pits were mined out in 2011, but one of them, the main open pit, remains open providing access to two shafts. The underground mine consists of six shafts and mining is carried out at depths of 450 m through shafts 4 and 5 (SNL 2015).

The mine garnered international attention during the mineworker's strike in August 2012, which resulted in the death of 44 people (The Marikana Commission of Inquiry 2015). Due to this incident, PGE production in Marikana decreased from about 40 to 45 % for the following three months compared to the same period in 2011 (SNL 2015).

The mine has been active since 1975 when Westplats began its production in the western limb. In 2013 the mine produced 1,142,539 oz 4E (706,012 oz Pt, 323,622 oz Pd, 95,241 oz Rh and 17,664 oz Au) by processing 11.25 Mt of ore at a cash cost of US$ 741/oz PGE. Total resources and reserves are announced at 947 Mt of ore grading 4.8 ppm 4E (144.8 Moz 4E; SNL 2015).

Impala (Impala Platinum Holdings Ltd.)

Location & Ownership

Coordinates: 25°32'45.09"S, 27°10'59.80"E

The Impala Platinum Mine is 100 % Implats owned and is situated 13 km north of Rustenburg, North West Province. Together with Royal Bafokeng Resources, adjacent to the north, Impala holds contiguous mining and prospecting rights over a total area of 335.34 km² across 20 farms. Impala is one of the oldest and most traditional platinum mines in South Africa and has been active since the late 1960s (Implats 2013).

Geology & Mining

In a 14-shaft mining complex, both reefs, the Merensky and the UG2, are mined concurrently with the conventional breast mining method. The vertical distance between the two reefs varies from about 125 m in the south to about 45 m in the north of the mining area. Mechanised (trackless) bord-and-pillar mining occurs in selected Merensky Reef areas on the 12th and the 14th shaft (Implats 2013).

Due to the five-month strike in the first half of 2014, a dramatic drop in production was recorded at Impala over the fiscal year 2014 (ended in June 2014) to 658,600 oz 3E (411,000 oz Pt, 197,400 oz Pd and 50,200 oz Rh) in comparison with 1,161,000 oz 3E (709,200 oz Pt, 350,500 oz Pd and 101,300 oz Rh) in fiscal 2013. Total mineral reserves and resources are announced with 500.7 Mt of ore grading 6.047 ppm 4E (97.32 Moz 4E). This allows a further 30-year life of mine until the year 2043 (SNL 2015).

In February 2015 Implats reported that the decrease in its Headlines Earnings Per Share (HEPS) from US$ 1.42 to US$ 0.66 was primarily due to lower production from Impala Rustenburg, impacted by the rampup of operations to reach full capacity followed by the five-month strike. Prestrike production levels were reached in November 2014. Also the operating profit of 160 million ZAR (US$ 13.6 million) dropped significantly from 1.89 bn ZAR (US$ 161 million) the year before (SNL 2015).

Impala hosts one of the largest PGE tailings dams in South Africa. The PGE potential of this 250 Mt processed ore material will be described and evaluated in chapter 5.2 and Figure 5.3.

Tumela (Anglo Platinum Ltd.)

Location & Ownership

Coordinates: 24°48'25.35"S, 27°20'4.28"E

The Tumela Mine lies within the Amandelbult Section in the northern part of the western limb between the towns of Northam and Thabazimbi. The mining right covers an area of 110 km² (Anglo American Platinum Ltd. 2013).

Geology & Mining

The mine consists of three vertical and four decline shafts. Since the year 2000 both horizons, the Merensky Reef and UG2, are mined in two production areas, the Tumela lower and the Tumela upper mine. The life of mine extends to the year 2028, although projects in study could extend that to beyond 2057 (Anglo American Platinum Ltd. 2013).

Total ore resources and reserves are announced with 730.9 Mt of ore grading 5.5 ppm 4E (125 Moz 4E). In 2013 Amandelbult produced 363,400 oz Pt, 159,400 oz Pd, 51,100 oz Rh and 6,300 oz Au at cash costs of US$ 1,064/oz PGE. The annual capital expenditure increased by 30 % to 399 million ZAR (US$ 34.9 million) in 2013 compared to 2012 with 303 million ZAR (US$ 26.5 million), due to the construction of the Tumela 5 shaft and the continuation of the Tumela 1 sub-shaft project, which entails mining the ore reserves below the Tumela 1 shaft (SNL 2015).

Zondereinde (Northam Platinum Ltd.)

Location & Ownership

Coordinates: 24°49'45.86"S, 27°20'15.77"E

This 100 % Northam Platinum owned mine, also known as Middledrift, is active since 1993 and located in the northern section of the western limb, close to the town of Northam in the Limpopo Province. The license area is spread over 6.25 km² with a strike length of 8 km (Northam Platinum Ltd. 2015).

Geology & Mining

Both the Merensky Reef and the UG2 Reef are mined. Zondereinde is one of the deepest underground platinum mines in the world. A twin shaft system is placed with depths ranging from 1,294 m to 2,112 m and extends over 12 levels. The shafts are 90 m apart and are connected at levels 4, 6, 7, 8 and 9. An intermediate pump chamber is located between the shafts at a depth of 1,019 m. Access below the 12th level is provided through a decline that is equipped with a conveyor belt system. Northam Platinum has its own smelter with an annual capacity of about 0.4 Moz PGE (Northam Platinum Ltd. 2015, see also chapter 4.5 "Mining and Processing" and Tab. 4.4).

Zondereinde holds total reserves of about 53.2 Mt of ore grading approximately 4.6 ppm 4E (7.8 Moz 4E). In fiscal 2014 the mine produced 235,693 oz PGE at cash costs of US$ 1,078/oz. Production was negatively affected following an eleven-week strike until January 2015. Due to the strike the production at Zondereinde dropped by 18.9 %. The smelter at the property was rebuilt, subsequently recommissioned and had been operating normally. Reserve development was underway after being curtailed during the strike. In January 2015 Northam decided to temporarily suspend operations at Zondereinde in the interest of securing safety during the ongoing strike (SNL 2015).

Pilanesberg (Rooderand) (Bakgatla Ba Kgafela Comm., Moepi Capital Pty Ltd. and Black Economic Empowerment Co.)

Location & Ownership

Coordinates: 25°6'17.12"S, 26°59'28.50"E

The Rooderand Mine is located 5 km northwest of Pilanesberg, about 80 km north of Rustenburg in the North West Province. It is a joint venture between Bakgatla Ba Kgafela Comm. (26 %), Moepi Capital (27.6 %), Black Economic Empowerment Co. (27.6 %) and Sedibelo Platinum Mines Ltd. (previously Platmin Ltd., 18 %) and is operated by Sedibelo Platinum Mines Ltd. (SNL 2015).

Geology & Mining

The mine operates as an open pit mine and is designed for underground mining in the future. The open pit mines the Merensky Reef and the underground option will investigate the UG2 also. Rooderand started its activity in 2009 with an estimated life of mine as open pit of approximately 9 years and a further 12 years as underground operation (SNL 2015).

The total reserves and resources are calculated at 101 Mt of ore containing 3.1 ppm 4E (9.7 Moz 4E: 5.94 Moz Pt, 2.73 Moz Pd, 0.68 Moz Rh, 0.37 Moz Au) as well as 0.087 % Ni (87,000 t Ni) and 0.024 % Cu (25,000 Cu). In 2013, Pilanesberg processed 3.96 Mt of ore and sold and dispatched 149,193 oz 4E (SNL 2015).

Pilanesberg Platinum Mine (Sedibelo Platinum Mines Ltd.; previously Platmin Ltd.)

Location and Ownership

Coordinates (Tuschenkomst pit):
25°06'27.99"S, 27°0'41.85"E

Sedibelo Platinum Mines Ltd. operates this mine a few kilometres north of Pilansberg on the western limb of the Bushveld Complex. The mine consists of an opencast West Pit (PPM Tuschenkomst pit) on the farm Tuschenkomst 135 JP, an opencast East pit (Sedibelo pit due to start during 2015) on the farm Wilgespruit 2 JQ and a PGM concentrator next to the West pit.

Geology & Mining

The mining operation recovers all six platinum group elements from the Merensky Reef. A feasibility study done by SRK Consulting and reported by Platmin in 2007 reported an indicated proven and probable PGE reserve totalling 4.4 Moz 4E with a LoM of 16 years (SNL 2015).

Exploration Projects

Pilanesberg (Merensky) (Chrometco Ltd., Nkwe Ltd.)

Location & Ownership

Coordinates: 25°6'58.56"S, 27°8'59.19"E

The Merensky Pilanesberg project, located about 5 km north of Pilanesberg, adjacent east to the Rooderand project, is a feasibility stage exploration project.

Geology & Mine Planning

In 2004 NKWE started the exploration programme at Pilanesberg and in 2006 announced indicated resources of 11.9 Mt grading 3.79 ppm 4E, plus inferred resources of 24.8 Mt grading 3.83 ppm 4E. The resources were geologically discounted at 30 % geological losses. The project's resource base was for the Merensky, UG2 and Pseudo reefs on the farm Pt 2 Rooderand. In 2014 the total reserves and resources were listed at 2.596 Moz Pt, 1.298 Moz Pd, 0.46 Moz Rh and 118,000 oz Au. By mid-August 2014 Chrometco had drilled 3,500 m and opened about 20 trenches at Pilanesberg to enable mine planning for the next phase (SNL 2015).

Kruidfontein Project (Sedibelo Platinum Mines Ltd.; previously Aquarius Platinum Ltd.)

Location and Ownership

Coordinates 25°07'48.26"S, 27°05'43.87"E

The Kruidfontein project is located 45 km north of Rustenburg, near Pilanesberg in the North West Province. The exploration project is based on a contiguous block of three farms, Kruidfontein 40 JQ, Modderkuil 39 JQ and Middelkuil 8 JQ, located to the east of the Pilanesberg Platinum Mine (Aquarius Platinum Ltd. 2014).

Geology & Mine Planning

Underlain by both the Merensky and UG2 reefs, a resource of 58.38 Mt at 8.04 ppm 4E for 15.72 Moz for the Merensky and 90.41 Mt at 5.49 ppm 4E for 16.07 Moz for the UG2 have been estimated (Aquarius Platinum Ltd. 2014). Over the period 2008 to 2010 a number of boreholes were drilled.

Leeuwkop (Impala Platinum Holdings Ltd., Bakwena Ba Mogopa Ltd.)

Location & Ownership

Coordinates: 25°38'56.82"S, 27°39'53.68"E

The Leeuwkop 402 JQ exploration project is located in the Brits area southwestern limb and is in an advanced stage. It is a 74 % Impala Platinum and 26 % Bakwena Ba Mogopa joint venture operation.

Geology & Mine Planning

Both reefs, the Merensky and the UG2, will be mined in an underground operation. Leeuwkop hosts significant reserves and resources of 333.4 Mt of ore grading 6.13 ppm 4E (65.68 Moz 4E). The complete capital cost is estimated by Implats at US$ 787.2 million.

Kalplats (African Rainbow Minerals Ltd., Platinum Australia Ltd.)

Location & Ownership

Coordinates: 26°0'52.89"S, 25°4'20.60"E

The "Kalplats" project (Kalahari PGM project) is an exploration project in the advanced feasibility stage. It is a joint venture between African Rainbow Minerals (51 %) and Platinum Australia (49 %). The project is located approximately 350 km west of Johannesburg in the Northwest Province (Mines Online 2013).

Geology & Mine Planning

Kalplats is one of the few South African platinum projects outside the Bushveld Complex and hosted within the Kraaipan Greenstone Belt. The total resources and reserves of the Kalplats project are listed at 129.65 Mt of ore grading approximately 1.7 ppm 4E (7.2 Moz 3E – Pt, Pd, Au). The project is planned to be developed as an open-pit operation, producing around 110,000 oz 3E per annum with a life of mine of nine years (Mines Online 2013).

In June 2012 Platinum Australia estimated initial capital costs at Kalplats to be US$ 136 million. During the fiscal year ending June 2014 African Rainbow announced that the approval of the retention permit for Kalplats was still pending. In mid-November 2014 Aberdeen International Inc. (TSX:AAB) reported that it has invested an initial US$ 3.8 million into African Thunder Platinum Ltd. to indirectly acquire the Smokey Hills and Kalplats platinum projects (Mines Online 2013).

4.5.5 Northern Bushveld Complex (northern limb)

The northern limb of the Bushveld Complex contains the **Platreef** horizon. In addition to the Merensky Reef and the UG2 Chromitite, the Platreef is one of the world's three largest PGE bearing layers. The Merensky Reef and the UG2 are not present in the northern limb. The Platreef is a pyroxenite-dominated formation that varies in thickness from < 50 m in the north to 400 m (locally up to 600 m) in the south. Generally the outcrop strikes NNW and dips 40° to 45° west at surface (Kinnaird et al. 2005). The Platreef differs from the Merensky Reef and the UG2 in its PGE content (~3 to 4 ppm 4E) and ratio (Pt:Pd = 1) in terms of its thickness, mineral composition and texture, as well as by the much lower occurring chromitite layers.

Today there is one operating PGE mine and about ten exploration and early stage mining projects in the Platreef area. In the following section the most promising PGE mining projects will be defined and illustrated with respect to their location and ownership, resources, reserves and production rates, as well as in terms of their latest developments.

Mining Project

Mogalakwena
(Anglo American Platinum Ltd.)

Location & Ownership

Coordinates of Mogalakwena North pit:
23°56'57"S, 28°53'07"E

The 100 % Amplats owned Mogalakwena Mine is located 30 km northwest of the town of Mokopane in the Limpopo Province. The license area extends over seven farms (Fig. 4.12) and covers a total area of 137 km². The feasibility study was completed in 1990 and the mine opened in 1993 (Anglo American Platinum Limited 2013).

Geology & Mining

Mogalakwena is the largest open-pit platinum mine in South Africa, one of Amplat's most productive PGE mines and to date the only mine processing Platreef ore. The mine is currently composed of five open pits (Mogalakwena North, Mogalakwena Central, Mogalakwena South, Zwartfontein and Sandsloot pits; Fig. 4.11). The largest open pit at the moment is Mogalakwena North (Fig. 4.12). The pits are mined with shovels and trucks. The current pit depths vary from 45 to 245 m. The ore is milled at the North Concentrator and at the older South Concentrator. The LoM extends until 2060. The current plan consists of an ore reserve of 141.6 Moz 4E (Pt+Pd Rh+Au) and mineral resources of 135 Moz 4E (Anglo American Platinum 2013). Within the next years, the construction of a "superpit" is planned, extending about 8 km from north to south, along with an increase in production.

An overall increase in production of about 12 % was recorded at Mogalakwena (Tab. 4.8) from 2012 to 2013. In February 2015 Anglo reported a record production of 370,000 oz Pt during the year 2014, an increase of about 10 % in comparison to 2013 as a result of better mine performance through higher grade, higher volume and improved output at the concentrator (SNL 2015).

Total reserves and resources comprise 3.7 bn tonnes of ore, containing 2.33 ppm Pt (277 Moz), 1.15 ppm Pd (129.3 Moz), 0.08 ppm Rh (8.3 Moz),

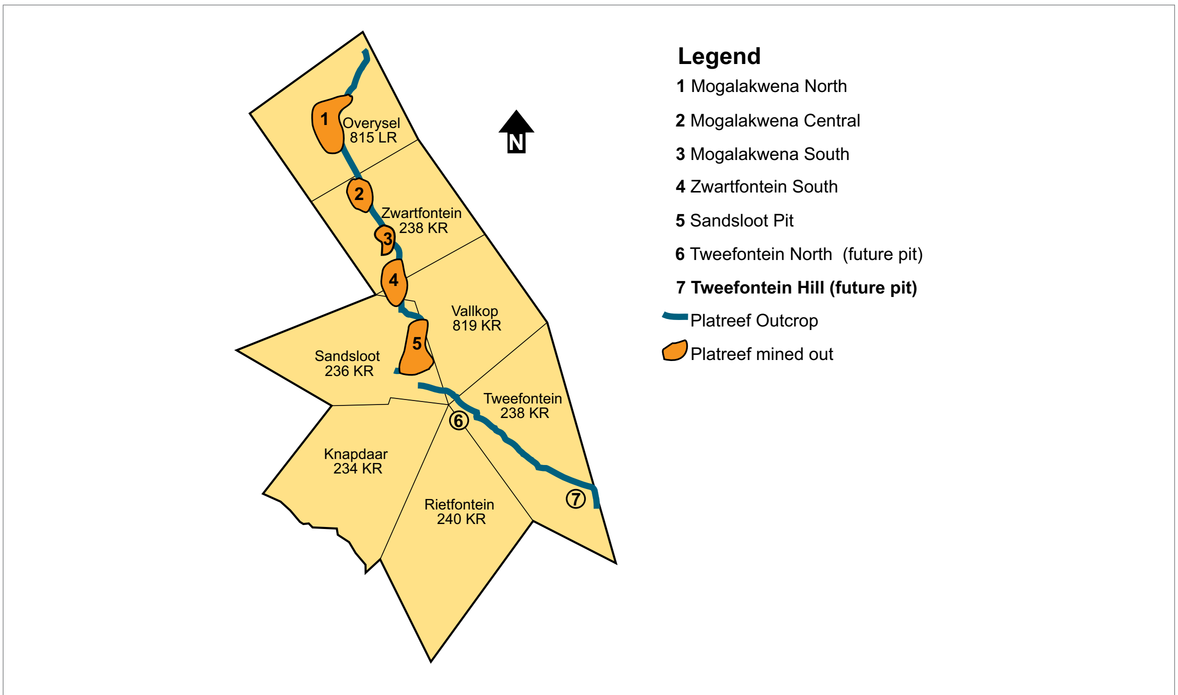

Fig. 4.11: Mining rights area of Mogalakwena Mine and farms with its five open pits, the outcrop of Platreef dipping westwards and the future pits (after: Anglo American Platinum Ltd. 2013).

Fig. 4.12: The Mogalakwena North pit, view north (photo: DERA 2013).

Tab. 4.8: Production rates in Mogalakwena (SNL 2015).

Year	Pt (oz)	Pd (oz)	Rh (oz)	Au (oz)	Cash cost (US$/oz PGE)	Ni (t)	Cu (t)
2012	304,800	327,300	19,900	44,500	814	9,000	5,800
2013	342,800	347,600	21,800	41,900	737	11,400	7,200

0.13 ppm Au (14.1 Moz) as well as 0.18 % Ni (6.3 Mt) and 0.1 % Cu (3.5 Mt) (SNL 2015).

Amplats focused on the Mogalakwena North Concentrator and expected to reach de-bottlenecked nameplate capacity by 2017. Studies were also underway to optimise the LoM schedule (SNL 2015).

An additional interesting resource in the upper part of the Platreef horizon is the occurrence of oxidised PGE ore, in particular within the Mogalakwena license area. Caused by meteorical weathering, a significant portion of the original PGE bearing sulphide minerals is altered and oxidised. Generally the first 40 metres down from the surface of the Platreef outcrop is oxidised. This ore cannot be processed economically and is therefore stockpiled. In Mogalakwena, the stockpile level of the oxidised material has averaged at least 5 Mt to date, with PGE contents of approximately 3 ppm 4E (for further information, see also Chapter 4.6).

Exploration Projects

Boikgantsho (Atlatsa Resources Corp., Anglo American Platinum Ltd.)

Location & Ownerhip

Coordinates approx.: 23°53'20"S, 28°52'40"E

The Amplats exploration project Boikgatsho is situated adjacent to and north of Mogalakwena. In 2000 Anooraq Resources Ltd. acquired this Platreef project to explore the northern portion of the Overysel farm and the adjacent Drenthe farm and started a 24,418 m drilling programme in 2004, which continued over the following two years. After an additional two years without any further activity, Atlatsa Resources Corp. acquired Boikgatsho in April 2008. In October 2013 South Africa's Department of Mineral Resources consented to the sale and transfer of mineral rights relating to Atlatsa Resource's Boikgantsho platinum project to Amplats, fulfilling an important condition and precedent for the implementation of the restructuring plan previously announced between Atlatsa and Amplats (Anglo American Platinum Ltd. 2013).

The feasibility study is still ongoing. The indicated and inferred resources totalled 281 Mt of ore grading 1.31 ppm 3E, 0.13 % Ni and 0.08 % Cu. The capital expenditures announced in 2012 amounted to US$ 900,000 (10 million ZAR) for three years (SNL 2015).

Ivanplats (Ivanhoe Mines Ltd., JOGMEC)

Location & Ownership

Coordinates: 24°05'00"S, 28°57'31"E

Contact person: Dr. Danie Grobler,
danieg@ivanplats.com

The Ivanplats mining project is located 6 km north of Mokopane and extends over three farms, Rietfontein 2, Turfspruit 241 and Macalacaskop 243. The majority owner is Ivanhoe Mines (TSX: IVN), currently holding 64 % of the shares. A Japanese consortium of ITOCHU Corporation, Japan Oil, Gas and Metals National Corporation (JOGMEC) and JGC Corporation own 10 %. In September 2014 a 26 % interest was transferred to a Broad-Based Black Economic Empowerment Special Purpose Vehicle (B-BBEE SPV) in conformance with South Africa's mining laws and in fulfilment of the requirements of the company's mining rights application. Ivanplats achieved Level 3 status in its first verification assessment on the Broad-Based Black Economic Empowerment scorecard. In March 2015 Zijin Mining Group Co. Ltd. agreed to make a C$105 million investment in Ivanhoe Mines Ltd. for an approximate 9.9 % shareholding in the company (SNL 2015).

Geology & Mining

In 2000 Ivanhoe Nickel and Platinum commenced shallow exploration at Platreef, which defined a large open-pit resource. The company subsequently began a deep drilling programme in 2007 (Figs. 4.13 and 4.15), leading to the discovery and delineation of underground resources within the Platreef – the so-called Flatreef horizon, which is also mineralised with PGE bearing sulfides (Fig. 4.14). The Flatreef represents the continuation of the Platreef at depth. In June 2014 Ivanhoe announced that South Africa's Department of Mineral Resources approved its application for a long-term mining right at Ivanplats (Ivanhoe Mines 2015a).

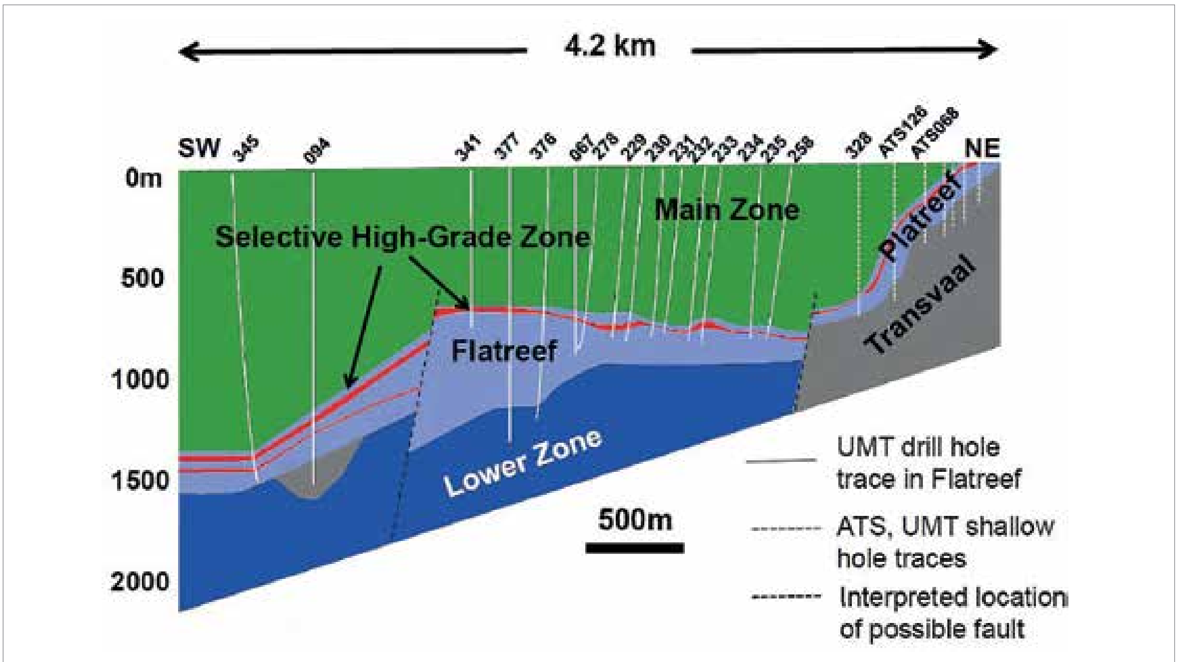

Fig. 4.13: Cross-section showing the transition of Platreef to the so-called Flatreef along the dip section of the project (Figure courtesy Ivanplats 2012).

Fig. 4.14: PGE bearing sulfide mineralisation of Platreef pyroxenite in drill core (photo: DERA 2014).

Fig. 4.15: Drilling site at Ivanplats project and evaluation of drill cores (photo: DERA 2014).

The Platreef project has resources defined for a variety of mining methods that reflects the project history. These include resources amenable to open-pit mining methods, resources amenable to underground mass mining and resources amenable to selective underground mining. The current focus of the project is to mine a selective high-grade zone and therefore the base case resource statement is considered the selective mining case.

The most current resource statement for the project was April 13, 2013. Total indicated resources at a 2 ppm 4E (Pt + Pd + Rh + Au) cut-off are 214 mt at a grade of 1.83 ppm Pt, 1.89 ppm Pd, 0.29 ppm Au, 0.12 ppm Rh, 0.34 % Ni and 0.17 % Cu. Inferred resources for the selective mineable zone at a 2 ppm 4E cut-off are 415 Mt at a grade of 1.57 ppm Pt, 1.59 ppm Pd, 0.27 ppm Au, 0.11 ppm Rh, 0.33 % Ni and 0.16 % Cu.

In addition to the selectively mineable resource, two additional exploration targets exist that could add additional resources. Target one could contain 115 to 235 million tonnes grading 3.1 to 4.5 ppm 4E (comprising 1.2 to 1.7 ppm Pt, 1.7 to 2.3 ppm Pd, 0.06 to 0.14 ppm Rh, 0.17 to 0.26 ppm Au), 0.23 % to 0.28 % Ni and 0.11 % to 0.14 % Cu over an area of 3.7 km^2. Target 2 could contain an estimated 260 to 450 Mt grading 3.4 to 4.5 ppm 4E (comprising 1.7 to 2.4 ppm Pt, 1.2 to 1.6 ppm Pd, 0.14 to 0.20 ppm Rh, 0.26 to 0.33 ppm Au), 0.30 % to 0.35 % Ni and 0.15 % to 0.18 % Cu over an area of 7.6 km^2. The tonnage and grade ranges are based on 2.0 ppm 4E intersections of mineralisation.

In January 2015 the company announced the results of a pre-feasibility study and for the first time listed reserves for the selectively mineable

Tab. 4.9: Detailed mineral resources tonnages and grades (courtesy of Ivanplats 2015).

Indicated Mineral Resources Tonnage and Grades								
Cut-off 4E (3PGE+Au)	**Mt**	**Pt (ppm)**	**Pd (ppm)**	**Au (ppm)**	**Rh (ppm)**	**4E (ppm)**	**Ni (%)**	**Cu (%)**
3 ppm	137	2.27	2.31	0.35	0.15	5.09	0.38	0.18
2 ppm	214	1.83	1.89	0.29	0.12	4.13	0.34	0.17
1 ppm	387	1.28	1.34	0.21	0.09	2.92	0.28	0.14
Contained Metal								
Cut-off 4E	**–**	**Pt (Moz)**	**Pd (Moz)**	**Au (Moz)**	**Rh (Moz)**	**4E (Moz)**	**Ni (Mt)**	**Cu (Mt)**
3 ppm	–	10.0	10.2	1.53	0.67	22.4	0.521	0.247
2 ppm	–	12.6	13.0	2.00	0.85	28.5	0.728	0.364
1 ppm	–	15.9	16.7	2.67	1.09	36.3	1.084	0.542
Inferred Mineral Resources Tonnage and Grades								
Cut-off 4E	**Mt**	**Pt (ppm)**	**Pd (ppm)**	**Au (ppm)**	**Rh (ppm)**	**4E (ppm)**	**Ni (%)**	**Cu (%)**
3 ppm	211	2.09	2.06	0.34	0.14	4.63	0.38	0.18
2 ppm	415	1.57	1.59	0.27	0.11	3.54	0.33	0.16
1 ppm	1,054	0.96	1.02	0.18	0.07	2.23	0.26	0.13
Contained Metal								
Cut-off 4E	**–**	**Pt (Moz)**	**Pd (Moz)**	**Au (Moz)**	**Rh (Moz)**	**4E (Moz)**	**Ni (Mt)**	**Cu (Mt)**
3 ppm	–	14.2	14.0	2.29	0.97	31.5	0.802	0.380
2 ppm	–	20.9	21.3	3.58	1.44	47.2	1.370	0.664
1 ppm	–	32.7	34.7	5.95	2.32	75.7	2.740	1.370

zone. The Platreef project probable reserves are 120 mt at a grade of 1.76 ppm Pt, 1.87 ppm Pd, 0.26 ppm Au, 0.13 ppm Rh, 0.32 % Ni and 0.15 % Cu containing 15.51 moz 4E, 388,170 t Ni and 185,230 t Cu. Ivanhoe reports resources inclusive of reserves, so the stated reserve should be considered a subset of the resource and not an additive to the resource.

In October 2014 Ivanplats closed its initial public offer raising US$ 307 million. Ivanplats subsequently tabled a prefeasibility study proposing the development of an underground mine in three phases. The first phase involves the development of a large, mechanised, underground mine with an initial 4 Mt/a concentrator and associated infrastructure to establish an operating platform to support future expansions. The second phase will double production to 8 Mt/a. The third phase involves the expansion of the mine to a steady state of 12 Mt/a, making it among the largest PGE mines in the world (Ivanhoe Mines 2015a, SNL 2015).

Ivanplats is currently constructing an exploration shaft with a planned average depth of 800 m below surface and a diameter of 7.5 m, which will be used for initial access, bulk-sample collection and early underground development. Later this shaft will be used as a ventilation shaft. The completion of shaft No. 1 is targeted for 2017. In total four vertical shafts are planned. The mining zones occur at depths between 700 and 1,200 m. The estimated complete capital cost of the project is AU$ 1.72 bn (US$ 1.5 bn). The planned initial annual production is announced with 433,000 oz 4E plus 9,000 t Ni and 5,500 t Cu (Ivanhoe Mines 2015a). The probable total mineral reserve of 15.5 Moz 4E will allow a LoM of 31 years.

Latest reports from the drilling campaign in the Flatreef horizon (Fig. 4.15) included 13.04 m at 5.83 ppm 4E, 0.33 % Ni and 0.16 % Cu, including 3.56 m at 11.03 ppm 4E, 0.49 % Ni and 0.21 % Cu; 13.69 m at 3.48 ppm 4E, 0.22 % Ni and 0.12 % Cu; and 8.06 m at 3.85 ppm 4E, 0.55 % Ni and 0.29 % Cu. The results confirmed an expansion of the Flatreef deposit (Ivanhoe Mines 2015a). Detailed mineral resources (indicated and inferred) are listed in Table 4.9.

The recent investment from the Zijing Mining Group will provide support for three of Ivanhoe Mines' development stage projects, beside the Platreef in RSA also the Kamoa copper-cobalt project and the Kipushi zinc-copper-cobalt project, both in the Democratic Republic of the Congo (SNL 2015).

Ivanhoe Mines Executive Chairman Robert Friedland and Managing Director Patricia Makhesha announced that the company employs more than 700 permanent and contract workers after receiving approval from the South African Government.

At the annual mining conference "Mining Indaba" in Cape Town in February 2015, Mr Friedland commented that "Ivanhoe Mines previously has committed itself to developing its Platreef project in full compliance with local South African laws and we want to meet the expectations of local communities and government as we proceed to build a world-class new platinum mine. The result of Ivanplats' first verification assessment is proof that, indeed, Ivanplats is living up to those expectations" (Ivanhoe Mines 2015b).

The Ivanplats project, as well as the Waterberg project (see below), offers new exploration potentials within the deeper stratigraphic layers of the Bushveld Igneous Complex, as the Flatreef and the Platreef. This will be an important aspect of future supply of PGEs.

Waterberg (Platinum Group Metals Ltd.)

Location & Ownership

Coordinates: Drilling zone "Super F":
23°22'25"S, 28°53'43"E

The Waterberg project is owned by the TSX and NYSE.M listed Platinum Group Metals Ltd. (PTM-TSX; PLG-NYSE MKT) in joint venture with the Japan Oil, Gas and Metals National Corporation (JOGMEC). Platinum Group acquired the prospecting rights for Waterberg in 2009. In the same year Platinum Group entered into an agreement with JOGMEC. The project is situated in the northern extension of the northern limb, about 120 km north of Mokopane in the Limpopo Province.

Geology & Mining

Under shallow sediment cover of Waterberg sandstones, several thick layered intrusions (troctolite, harzburgite and feldspatic harzburgite) containing PGE and gold bearing sulphide mineralisation was discovered. The sequence has a NE strike and dips 28 to 35° to the NW. It was divided into four zones, the T1, T2, FH and FP layers, varying in thickness and PGE contents.

The geophysical survey was completed in 2012. First results from the drilling campaign reveal in 663 m depth a 16 m section grading 2.07 ppm Pt, 4.04 ppm Pd and 0.3 ppm Au. In 2012 Platinum Group Metals announced inferred resources for Waterberg of 68 million t grading 0.939 ppm Pt, 1.706 ppm Pd, 0.367 ppm Au, 0.091 % Cu and 0.106 % Ni (Platinum Group PR 10/21/14, 2014).

In September 2012 Platinum Group reported that drilling at Waterberg expanded the newly discovered area outside the defined resource area. Results of this extension area included 2 m grading 1.06 ppm Pt, 2.09 ppm Pd and 0.18 ppm Au, and 2 m grading 0.77 ppm Pt, 1.42 ppm Pd and 0.42 ppm Au (SNL 2015).

In October 2014 Platinum Group announced the completion of about 71,000 m of vertical core drilling using 24 machines at the Waterberg Joint Venture and Waterberg Extension projects (collectively the Waterberg projects, Fig. 4.16) since June 2014. The drilling programme expanded and detailed the Waterberg T-, F- and Super F zones as part of an ongoing pre-feasibility study. Better intersections included 80 m at 4.80 ppm 3E (1.41 ppm Pt, 3.18 ppm Pd, 0.21 ppm Au, 0.1 % Cu and 0.23 % Ni); and 46.79 m at 3.76 ppm 3E (1.06 ppm Pt, 2.51 ppm Pd, 0.19 ppm Au, 0.1 % Cu and 0.19 % Ni). Additional assays were pending. Further drilling along strike is planned. A Preliminary Economic Assessment (PEA) on the original Waterberg joint venture was completed in June 2014 and a pre-feasibility study on the New Waterberg joint venture is currently underway (Platinum Group PR 10/21/14, 2014; Platinum Group Metals 2015).

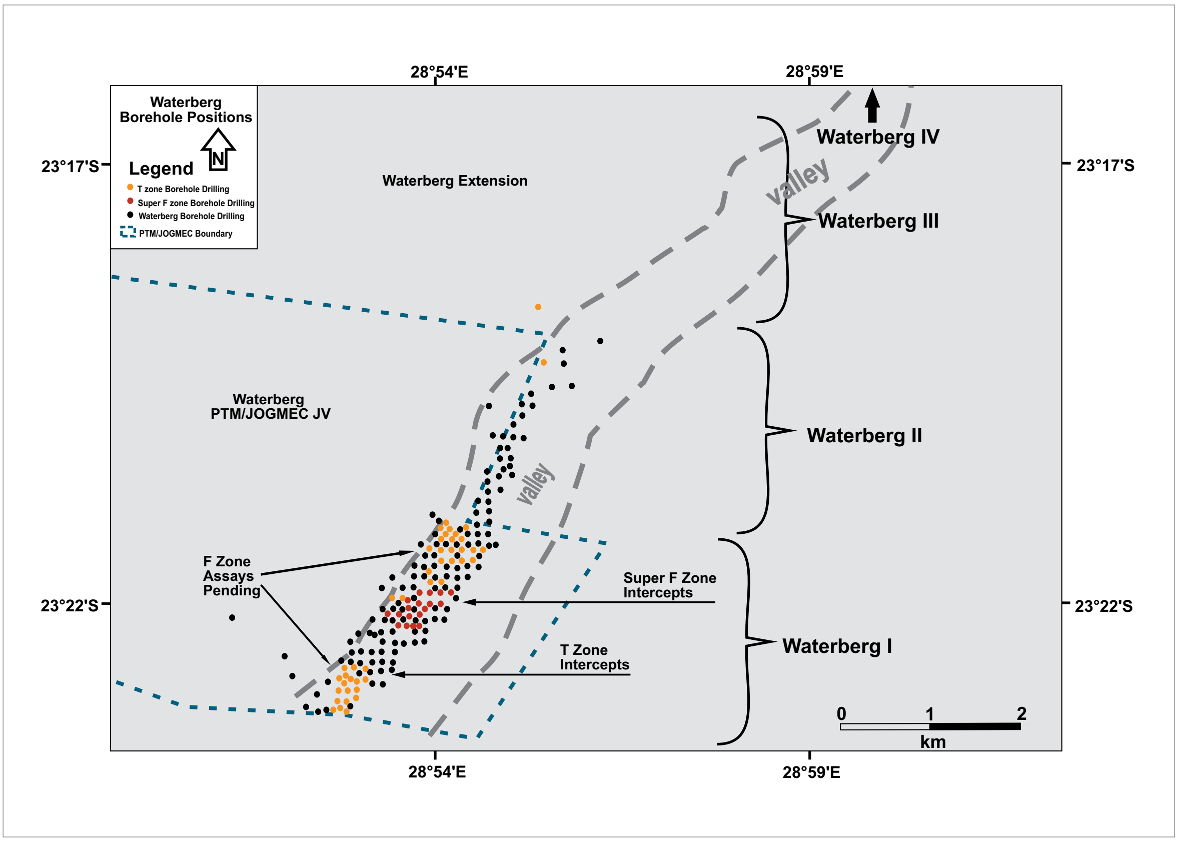

Fig. 4.16: Schematic draft of the Waterberg PTM/JOGMEC boundary and the extension area as well as the drilling zones T, F and Super F (after: Platinum Group Metals 2015).

Platinum Group estimates the annual production at Waterberg of 655,000 oz 3E (Pt, Pd and Au). In February 2014 Platinum Group announced results from a preliminary economic assessment on the Waterberg project. Operating costs, including copper and nickel credits, were projected at US$ 655/oz 3E and total capital costs of US$ 885.3 million (10.14 bn ZAR). The projected start of production will be in 2018, with a mine life of more than 20 years (SNL 2015).

In June 2014 Platinum Group revised the total resources and reserves at Waterberg and announced 288.88 Mt of ore containing 0.94 ppm Pt (8.88 Moz Pt), 1.92 ppm Pd (17.77 Moz Pd), 0.26 ppm Au (2.36 Moz Au) as well as 0.097 % Cu (278,156 t Cu) and 0.172 % Ni (492,061 t Ni) (SNL 2015).

4.6 Requirements and Evaluation

An evaluation of all primary PGE deposits and mines was carried out by taking into account the PGE resources (content in the ore) and the grade of the ore of all active mines in the Republic of South Africa. Both layers, the Merensky Reef and the UG2 Reef, were added together and in the case of Mogalakwena, the Platreef was also taken into consideration. Using these data, a grade tonnage diagram was calculated (Fig. 4.17).

In the South African deposits the grade moves generally in the range between 3 and 5 ppm PGE but in terms of resources there are significant differences between the individual mines. The largest resources are demonstrated by Mogalakwena in the northern limb (Platreef) and Marikana in the southwestern limb (Fig. 4.17). It must be noted that Marikana consists of several shafts. After the classification of PETROW (2008), the PGE deposits of the RSA can generally be categorised as large to very large deposits (Tab. 4.10).

A global comparison in the form of a grade-tonnage diagram of all known mines worldwide is also presented in chapter 5.2. The most promising mining projects with large resources and high-grade contents of PGE are listed in Table 4.11, taking their characteristics in infrastructure, production rates and cash costs into consideration.

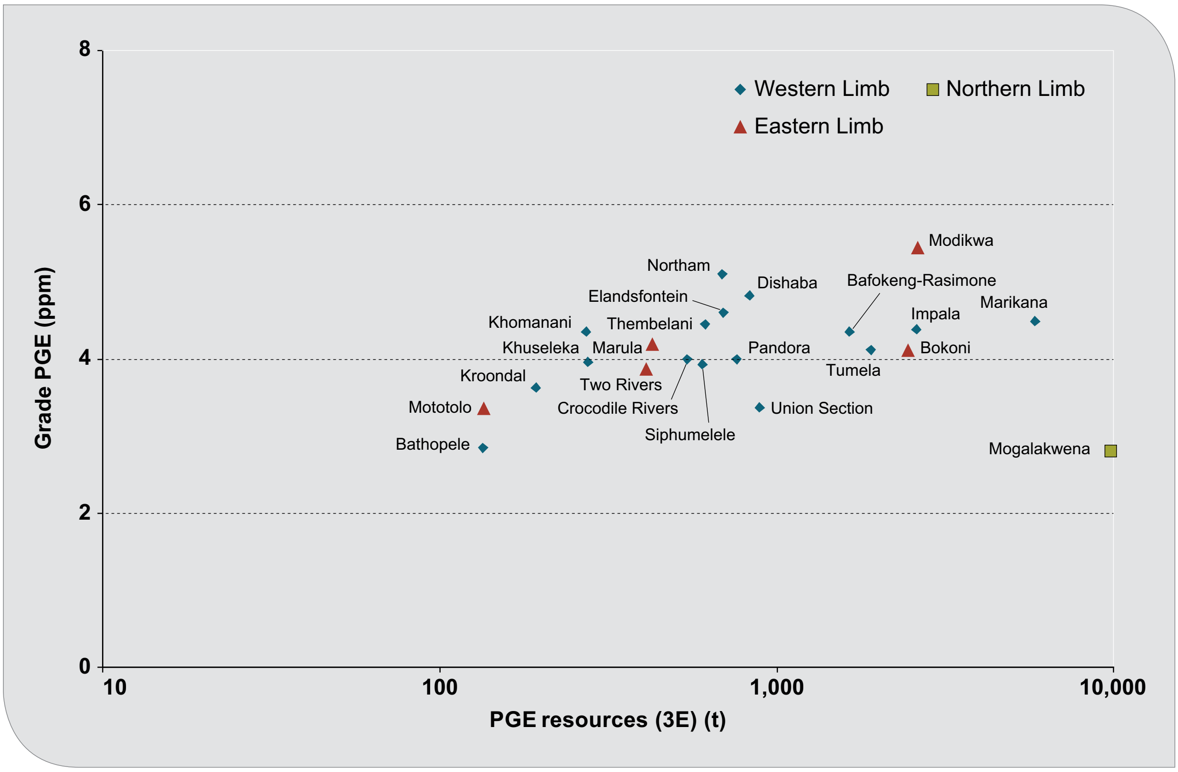

Fig. 4.17: PGE grade (3E: Pt+Pd+Rh) versus contained 3E of all active PGE mines in the RSA (data source: RMG 2015).

Tab. 4.10: Size classification of PGE deposits after PETROW (2008).

Tonnes [t]	Deposit Size			
PGM	Small	Medium	Large	Very large
	< 10	10 – 100	100 – 1,000	> 1,000

Tab. 4.11: The six most promising PGE mines with resources > 1,000 t PGE-3E and PGE-3E contents > 4 ppm in their production, cash costs and infrastructure.

Mine	Modikwa	Bokoni	Impala	Marikana	Bafokeng-Rasimone	Tumela
Reserves (Moz 3E)	8.8	11.6	37.8	26.5	15.9	22.5
Resources (Moz 3E)	59.8	137.1	59.5	59.1	49.8	100
Production ('000 oz 3E)	127.8	194 (Pt)	658.6 (1,161 in 2013)	678.5 (1,142.5 in 2013)	n.a.	573.9 (in 2013)
Cash cost (US$/oz 3E)	1,060	1,328	1,434	1,402	816	1,029
Paid metal ('000 oz 3E)	104.1	91.2	575	730.5	176.4	370
Infrastructure						
City nearby/ province	**Steelpoort/ Limpopo**	**Steelpoort/ Limpopo**	**Rustenbug/ North West**	**Rustenburg/ North West**	**Rustenburg/ North West**	**Rustenburg/ North West**
Road	R 37, 5 km	R 37, 0 km	R 565, 0.5 km	N 4, 6 km	R 565, 0.5 km	R 24, 2 km
Railway (Station)	Ladana, 115 km	Ladana, 75 km	Phokeng, 2 km	Marikana, 5 km	Boshoek, 3 km	Marikana, 32 km
Airport 1	JNB, 345 km	JNB, 303 km	JNB, 187 km	JNB,143 km	JNB, 201 km	JNB, 123 km
Airport 2	Polokwane, 122 km	Polokwane, 81.5 km	Rustenburg Airfield, 19 km	Rustenburg Airfield, 46 km	n.a.	Rustenburg Airfield, 30 km
Water	Moopetsi River, 2 km	Olifantsrivier, 2 km	Rockwall Dam, 20 km	Sterkstroom, 2 km	Rockwall Dam, 20 km	Amandelbult Mine Town, 1 km
Energy	Electric energy is available for all mines					

Source: SNL 2015

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4.8 PGE Resource Potential of Oxidised Ores

Near the surface, oxidised ore bearing platinum group elements (PGEs) have a large potential for open pit mining. They typically occur in a 30 to 40 m deep weathered zone of PGE ore bodies. To date all attempts to extract the PGEs from oxidised ores proved uneconomical due to low PGE recoveries: << 50 % (Prendergast 1990) and < 40 % (Becker et al. 2014). At present most of the oxidised ores of the Merensky Reef and Platreef of the Bushveld Complex are either left in situ, stockpiled or discarded. Occasionally, oxidised ores have been added to the conventional flotation process resulting in low PGE recoveries, such as at the Smokey Hills Mine (UG2 Reef) in the eastern Bushveld Complex, for example (Mines online 2014).

The problem with processing of oxidised ores is attributed to their complex mineralogical nature and polymodal distribution of the PGEs in the ores, prohibiting a commercial upgrading of the ores by conventional metallurgical methods. Additionally, the distribution of platinum group minerals (PGMs) in primary ores of the Bushveld Complex varies on a regional scale, especially with respect to the amount of Pt-Pd sulfides, (bismutho) tellurides and Pt-Fe-alloys (Kinloch 1982), which also may have implications to the processing behaviour of the overlying oxidised ores.

Ongoing or future research may lead to a commercial breakthrough, however, and not only in South Africa, if a cost-effective bulk or heap leaching technology can be developed.

The PGE bearing oxidised ore resource potential of the Main Sulfide Zone at the Great Dyke in Zimbabwe is cautiously estimated between 160 Mt and 250 Mt of ore (Oberthür et al. 2013) as compared to 389 Mt according to Prendergast (1988). In these oxidised ores, the PGE grades from 3 to 4 ppm for an in-situ metal content of 15 Moz to 32 Moz PGEs. A similar or even larger potential exists in the Bushveld Complex, the subject of this evaluation.

Fig. 4.18: Outcrop of an oxidised UG2 chromitite layer near the ancient Smokey Hills Platinum Mine on the eastern limb (photo: DERA 2013).

4.8.1 Geochemistry and Mineralogy of Oxidised PGE Ores

The near-surface ores of the Merensky Reef, the UG2 (Fig. 4.18) and the Platreef (Fig. 4.19), generally show low temperature alteration by surface weathering. The PGEs are hosted predominantly by secondary oxides, hydroxides or PGE alloys comprising a complex mineralogy (Oberthür et al. 2013, Becker et al. 2014). These three reefs have the largest resource potential of oxidised PGE ores in South Africa. The PGE distribution within the oxidised ores of the near-surface chromitite reefs from the Lower and Middle Group (LG and MG) has not been investigated in the present study, although they may have an additional resource potential of oxidised PGE ores. Amongst others, this is one focus of the German-South African joint research project AMREP ("Applied Mineralogy for Resource Efficiency of Platinum Metals"), a three-year project that commenced in December 2014 for the chromitite ores of the western Bushveld Complex.

Oxidised PGE ores are generally characterised by a loss of palladium relative to platinum due to the larger solubility and mobility of palladium, e.g. observed in oxidised ores of the Main Sulfide Zone (MSZ) of the Great Dyke in Zimbabwe (Locmelis et al. 2010, Oberthür et al. 2013).

In general the PGEs in oxidised MSZ ores occur in different modes (Oberthür et al. 2013 and references therein):

(1) As relict primary platinum group minerals ("PGMs", mainly sperrylite, cooperite and braggite)
(2) In solid solution in relict sulfides, dominantly Pd in pentlandite
(3) As secondary PGM neoformations (e.g. Pt-Fe alloy and zvyagintsevite)
(4) As PGE oxides/hydroxides that either replace primary PGMs or neoformations
(5) Hosted in secondary oxides/hydroxides and silicates such as iron oxides/hydroxides, manganese oxides/hydroxides and phyllosilicates.

A similar mineralogy is proposed for the oxidised PGE ores of the Bushveld Complex (see also Korges 2014).

Fig. 4.19: The comparison of a fresh (pristine, left) to an oxidised (right) PGM bearing ore from the Platreef (drill core samples from the Mogalakwena Mine, Anglo Platinum Ltd.).

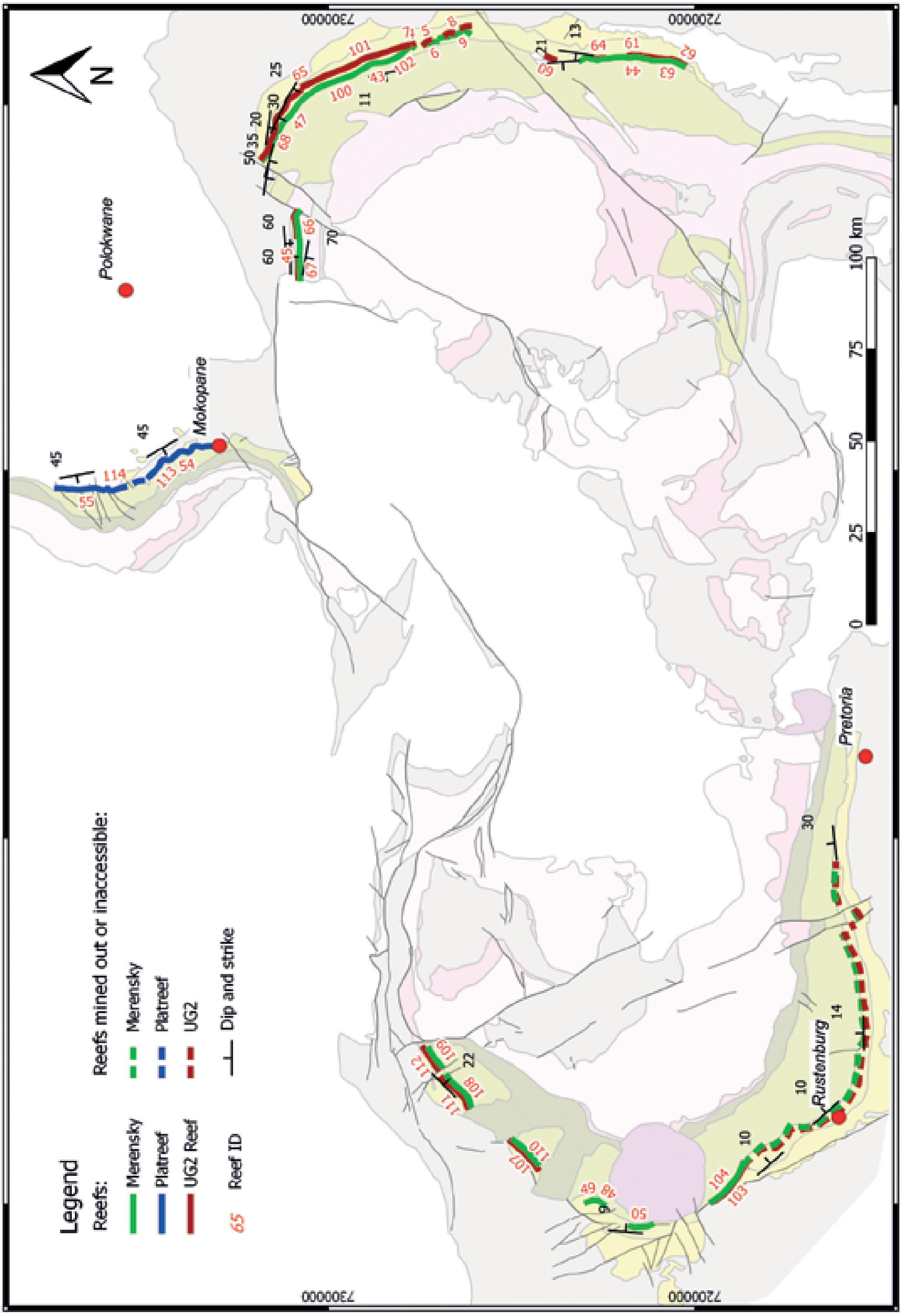

Fig. 4.20: Map of the Bushveld Complex showing the outcrops of the Merensky Reef, UG2 and Platreef with strike directions and dip angles, as well as the mined out areas (including inaccessible areas) of the near surface reefs and reef IDs used for calculating the resource potential (see Tab. 4.12). For the legend of the geological units, please refer to Fig. 3.14.

Tab. 4.12: Relevant parameters for calculating the PGE resource potential of oxidised ores of the Merensky, UG2 and Platreef, Bushveld Complex.

Reef	Limb	ID	Thick-ness (m)	Oxidation depth (m)	PGE grade (ppm 4E)	Dip angle (°)	Outcrop length (m)	Density (t/m³)	Downdip length (m)	Volume (m³)	Tonnage	PGE (t)	PGE (oz)
Merensky	Eastern	4	0.8	30	5.5	15	1,470	2.6	115.4	135,861	353,239	1.9	62,270
Merensky	Eastern	5	0.8	30	5.5	15	3,050	2.6	115.4	281,258	731,270	4.0	128,910
Merensky	Eastern	8	0.8	30	5.5	15	8,310	2.6	115.4	766,570	1,993,082	11.0	351,345
Merensky	Eastern	43	0.8	30	5.5	15	6,250	2.6	115.4	577,179	1,500,665	8.3	264,540
Merensky	Eastern	44	0.8	30	5.5	15	28,560	2.6	115.4	2,636,078	6,853,802	37.7	1,208,202
Merensky	Eastern	45	0.8	30	5.5	60	18,460	2.6	34.5	509,250	1,324,049	7.3	233,406
Merensky	Eastern	47	0.8	30	5.5	25	27,260	2.6	71.4	1,557,615	4,049,800	22.3	713,907
Merensky (interpr.)	Eastern	100	0.8	30	5.5	20	12,110	2.6	88.2	854,838	2,222,578	12.2	391,801
Merensky (interpr.)	Eastern	102	0.8	30	5.5	15	6,970	2.6	115.4	643,329	1,672,656	9.2	294,859
Merensky	Western	48	0.8	30	5.5	10	1,490	2.6	176.5	209,701	545,222	3.0	96,113
Merensky	Western	49	0.8	30	5.5	10	2,400	2.6	176.5	338,320	879,631	4.8	155,063
Merensky	Western	50	0.8	30	5.5	10	5,740	2.6	176.5	810,089	2,106,231	11.6	371,291
Merensky (interpr.)	Western	103	0.8	30	5.5	10	13,530	2.6	176.5	1,910,009	4,966,023	27.3	875,421
Merensky (interpr.)	Western	107	0.8	30	5.5	22	9,110	2.6	81.1	591,197	1,537,113	8.5	270,965
Merensky (interpr.)	Western	108	0.8	30	5.5	22	10,260	2.6	81.1	665,666	1,730,731	9.5	305,097
Merensky (interpr.)	Western	109	0.8	30	5.5	22	5,660	2.6	81.1	367,077	954,400	5.2	168,244
UG2	Eastern	60	0.8	30	4	15	2,140	3.2	115.4	197,252	631,207	2.5	80,924
UG2	Eastern	61	0.8	30	4	15	3,560	3.2	115.4	329,003	1,052,810	4.2	134,976
UG2	Eastern	62	0.8	30	4	15	910	3.2	115.4	83,752	268,005	1.1	34,360
UG2	Eastern	63	0.8	30	4	15	9,340	3.2	115.4	862,234	2,759,149	11.0	353,737
UG2	Eastern	64	0.8	30	4	15	2,300	3.2	115.4	212,241	679,172	2.7	87,073
UG2	Eastern	65	0.8	30	4	25	1,450	3.2	71.4	82,977	265,527	1.1	34,042
UG2	Eastern	66	0.8	30	4	60	6,690	3.2	34.5	184,419	590,142	2.4	75,659
UG2	Eastern	67	0.8	30	4	60	5,340	3.2	34.5	147,346	471,507	1.9	60,450
UG2	Eastern	68	0.8	30	4	25	22,730	3.2	71.4	1,298,570	4,155,425	16.6	532,747
UG2 (interpr.)	Eastern	101	0.8	30	4	20	28,900	3.2	88.2	2,040,148	6,528,472	26.1	836,984
UG2 (interpr.)	Western	104	0.8	30	4	10	13,330	3.2	176.5	1,882,062	6,022,597	24.1	772,128
UG2 (interpr.)	Western	110	0.8	30	4	22	10,370	3.2	81.1	672,316	2,151,411	8.6	275,822
UG2 (interpr.)	Western	111	0.8	30	4	22	10,540	3.2	81.1	683,368	2,186,778	8.7	280,356
UG2 (interpr.)	Western	112	0.8	30	4	22	6,770	3.2	81.1	439,402	1,406,086	5.6	180,267
Platreef	Northern	54	50	40	1.5	45	15,950	2.4	56.3	44,929,577	107,830,986	161.7	5,184,182
Platreef	Northern	55	50	40	1.5	45	13,940	2.4	56.3	39,273,239	94,255,775	141.4	4,531,528
Platreef	Northern	113	50	40	3	45	6,110	2.4	56.3	17,211,268	41,307,042	123.9	3,971,831
Platreef	Northern	114	50	40	3	45	4,520	2.4	56.3	12,732,394	30,557,746	91.7	2,938,245
Total										**ca. 136,115,605**	**ca. 336,540,300**	**ca. 819**	**ca. 26,256,740**

Outcrop lengths were rounded up to whole 10 m. ID numbers of the outcrop sections are given in the map, Fig. 4.20.

Merensky Reef:

Geochemical and mineralogical profiles across drill cores of the oxidised Merensky Reef were studied from the Richmond and the Twickenham project areas of Anglo American Platinum Corporation Ltd. (Korges 2014). The research showed that the platinum share of the total PGE content was between 65 % and 85 % compared to 59 % in pristine ore. Palladium has been removed and depleted by a factor of three (i. e. from ca 3 ppm in pristine ore to 1 ppm in weathered ore). Most of the other elements such as copper, nickel and cobalt showed neither depletion nor enrichment with the exception of sulphur, which was depleted.

Korges (2014) demonstrated that PGEs in the weathered Merensky Reef are mainly present as relict phases (e.g. cooperite-braggite and laurite), authigenic PGMs (Pt-Fe alloys and Pt-oxides) or are hosted by iron hydroxides and secondary hydrosilicates (e. g. chlorite and serpentine). The distribution of PGEs in the above minerals is highly variable. The siting of larger proportions of PGEs in iron hydroxides and hydrosilicates is regarded as a main reason of the low recovery rates, in which palladium is the predominant PGE. In addition, relict cooperite-braggite and laurite minerals often have smaller grain sizes than in the pristine ore (Korges 2014).

UG2 Reef:

Hey (1998 and 1999) studied the geochemistry and mineralogy of the weathered UG2 Reef from the Union Section of Anglo American Platinum Corporation Ltd. using drill core intersecting the reef between 5 m to 30 m depth (Hey 1998). Platinum has not been significantly redistributed during weathering and Pt-contents range from 3.6 to 3.9 ppm along the weathering profile (avg. 3.7 ppm).

In contrast, palladium was significantly depleted in the upper part (1.1 ppm) of the weathered zone and mostly enriched in the lower part around 25 m depth (2.7 ppm; avg. 1.9 ppm). As a result, the Pt/Pd ratio decreased from 3.2/1 in the weathered ore to 1.3/1 in the pristine ore.

The total Pt+Pd grade averaged at 5.63 ppm across the weathering profile varying between 4.8 ppm in the upper (weathered) part and 6.4 ppm in the lower part.

The bulk of the PGEs occurs interstitially in silicates or attached to base metal sulfide grains, and to a lesser extent as PGE oxides (Hey 1998, Hey 1999; Fig. 4.18).

Platreef:

Profiles across the oxidised Platreef are studied on drill core from three boreholes at the Mogalakwena Mine near Mokopane in the northern Bushveld Complex (Junge et al. 2015; Fig. 4.19). At Mogalakwena Mine, surface weathering extends to 40 m depth. The Pt/Pd ratio decreases from 1.15 to 0.75 from oxidised to pristine ore due to the greater mobility of Pd. However, the total PGE content is uniform throughout the weathering profile. Only relict PGMs and sulphides have been detected in the oxidised ore so far, and on-going work points to a major association of PGEs with secondary Fe-hydroxides (Junge et al. 2015).

Evaluation methodology

The oxidised PGE resource potential of the Merensky Reef, UG2 Reef and Platreef in the Bushveld Complex was determined using the strike length of the outcrop or inferred outcrop of the reef, its thickness and dip angle as well as the depth of weathering/oxidation. The following assumptions were made (Tab. 4.11):

- Strike length of outcropping reefs as well as dip directions and angles of reefs are taken from published maps at various scales: 1:330,000 (CGS 2007), 1:800,000 (Zientek et al. 2014). Some strike lengths were interpreted based on inferred near surface outcrop.
- The mineable thickness of the Merensky and UG2 reefs is 0.8 m each (Cawthorn 2010).
- A weathering/oxidation depth of 30 m for the Merensky and UG2 reefs (25–30 m, Hey 1999) and 40 m for the Platreef (Junge et al. 2015; Anglo American, personal communication 2014).
- The density of oxidised ores is ca 2.4 t/m^3 for the Platreef, 2.6 t/m^3 for the Merensky Reef

and 3.2 t/m³ for the UG2 Reef, considering an estimated weight loss of ca 20 % in comparison to pristine ore.

– The average PGE (4E; Pt + Pd + Rh + Au) grade is 5.5 ppm for the Merensky Reef (Pd loss of ca 70 % considered), 4 ppm for the UG2 Reef and 1.5 to 3 ppm for the Platreef (Korges 2014, Cawthorn et al. 2002, Cawthorn 2010). For the Platreef, grades of 3 ppm are applied to the license areas north of Mokopane (ca 10.6 km strike length of available oxidised ore, Anglo American license areas). Reefs previously mined out or inaccessible were not included.

For example, the Merensky Reef with a thickness of 0.8 m, an outcrop length of 1 km and a dip angle of 15° would reach a volume of 92,308 m³. With an assumed density of 2.6 t/m³ this results in 222,857 t of oxidised ore. Accordingly a PGE grade of 5.5 ppm 4E would give a total amount of about 1.3 t PGE 4E (42 857 oz 4E).

4.8.2 Results

The calculated total tonnage of the available oxidised ores across the Bushveld Complex amounts to ca 337 Mt of ore. All reefs combined, the Platreef, the Merensky Reef and the UG2-Reef, give a total PGE resource of about 819 t 4E (26.3 Moz 4E; Fig. 4.21).

Because of its average thickness of approximately 50 m, the bulk of the PGE resource, about 63 %, is contained in the Platreef horizon of the northern limb (Tab. 4.13 and Fig. 4.21). At Anglo American´s

Tab. 4.13: Input parameters (explanation see text).

Layer	Thickness (m)	Density (t/m³)	Depth of weathering from surface (m)	Grade PGE (ppm)
Platreef	50	2.4	40	1.5 – 3.0
Merensky	0.8	2.6	30	5.5
UG2	0.8	3.2	30	4.0

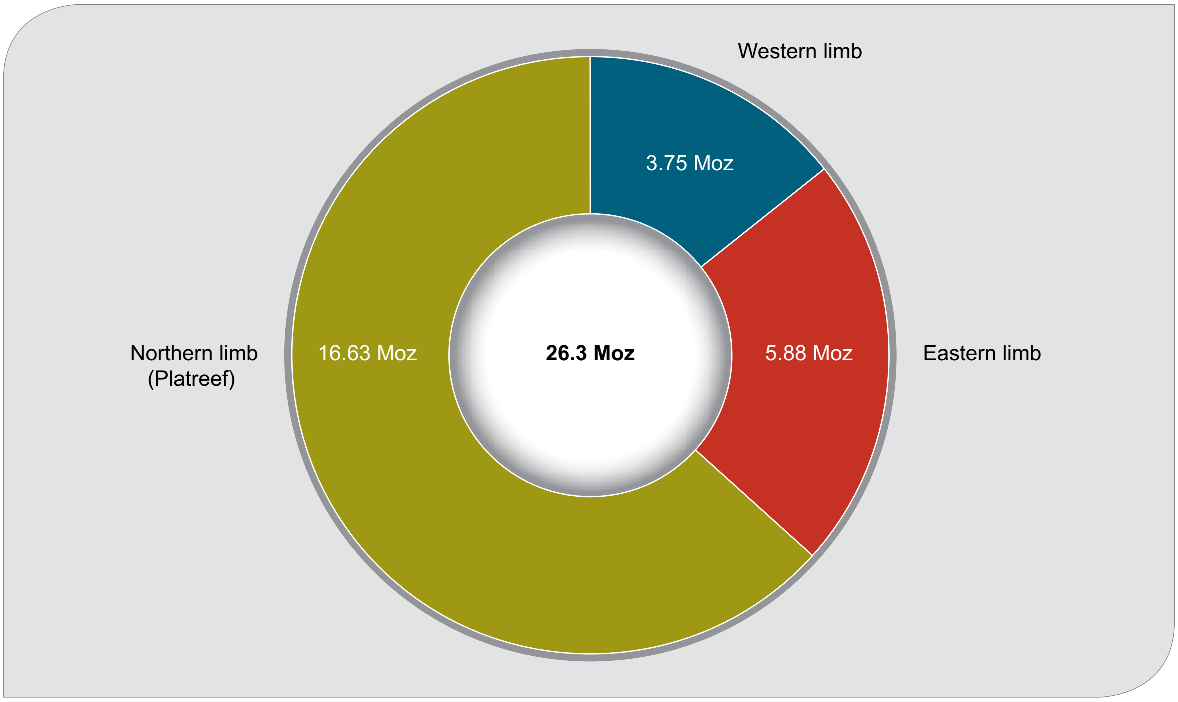

Fig. 4.21: PGE resources in million ounces (Moz) 4E in oxidised Merensky, UG2 and Platreef around the Bushveld Complex.

Mogalakwena Mine near Mokopane, several million tonnes of oxidised ore from the Platreef are already stockpiled (see chapter 4.5.5). Further oxidised ore resources may be stockpiled over time as several exploration projects along the Platreef are currently underway.

In the Western limb, most of the near surface reefs have been mined or are inaccessible due to other land uses. These areas were not evaluated. However, to the west and northwest of the Pilanesberg, the Merensky Reef is still in place at the surface and accessible and hence has been included in the calculation. The oxidised ore resource potential of the western Bushveld Complex includes approximately 117 t 4E (3.75 Moz 4E).

4.8.3 Extraction Methods

An initial effort to extract PGEs from oxidised ores of the Merensky Reef is known from the 1930s (Schneiderhöhn et al. 1939). Tailings material of processed oxidised ores were treated with hydrochloric acid, aqua regia, sulfuric acid and chlorine water combined with roasting and addition of catalysers, as well as amalgamation. The best results were achieved with hydrochloric acid under various conditions, providing a recovery rate of 60 % to 93 %. However, major problems occurred through subsequent precipitation of the dissolved PGEs within the tailings material, prohibiting transportation for further processing.

Later, Prendergast (1990) and Evans (2002) pointed to pyro- and hydrometallurgical methods for treating oxidised ores. The methods were not considered feasible due to either the requirement of large-scale technical equipment or the use of expensive reagents. To date conventional metallurgical methods have not proved successful (Becker and Wotruba 2008).

In 2009 Platinum Australia reported results from the treatment of oxidised ore at its Smokey Hills Mine in the Bushveld Complex. The conventional flotation process resulted in significantly lower recoveries than those achieved with primary (pristine) ore. Recoveries ranged between 40 % and 65 % and averaged just over 50 % (Platinum Australia 2009). To date conventional flotation tests have had limited success.

More recently several projects have been carried out aiming at improving processes for the recovery of PGEs from oxidised ores. Becker et al. (2014) conducted flotation tests using controlled potential sulfidisation (CPS) with sodium hydrogen sulfide (NaHS) of oxidised PGE ores of stockpile material of the Pilanesberg Platinum Mines (mixed Merensky and UG2 reefs), which resulted in a recovery up to 52 % for Pt and 17 % for Pd. The PGE mineralogy of the feed sample (a mixture of both mostly oxidised reefs) used by Becker et al. (2014) was dominated by fine-grained PGE alloys (21 % PtFe, 10 % PtRuFeNi) and PGE sulfides (19 % laurite, 7 % braggite), PGE arsenides (8 % sperrylite, 7 % arsenopalladinite) and PGE tellurides (7 % kotulskite). A total of 59 % PGMs were liberated by flotation. The majority of the unliberated PGMs were locked in gangue (16 %), attached to gangue (13 %) or associated with the iron oxides (11 %).

Work by the BGR in Germany revealed that PGEs from oxidised ores from the Main Sulphide Zone (MSZ) of the Zimbabwean Great Dyke are concentrated in the smaller grain size fractions by a factor of approximately two as compared to the coarser fractions. The highest concentrations of PGEs were found in the magnetic fraction but the separated volumes were low (Locmelis et al. 2010). Applying electric pulse disintegration and hydroseparation, platinum and palladium fractionates become successively enriched in the fine grain size fractions (Locmelis et al. 2010). However, all the test work performed did not arrive at conclusive indications for economic recovery.

Bioleaching experiments with acidophilic bacteria on two milled samples of oxidised PGE ores from the MSZ, carried out by the BGR Geomicrobiology Unit, demonstrate a very poor and commercially unviable recovery of platinum, palladium and gold. The experimental conditions, in terms of micro-organisms used and chemical composition of the solutions, were largely comparable to industrial heap leaching operations, e.g. for the recovery of copper. Kaksonen et al. (2014) and Schippers (personal communication, 2014) consider the use of complex forming micro-organisms for the successful application of bioleaching and the recovery of precious metals.

Another approach has been undertaken by the Jacobs University in Bremen on behalf of the BGR/DERA using single and multi-step hydrometallurgical processes involving acids and various organic complexing agents, applied to oxidised ores from the MSZ of the Great Dyke (Bau et al. 2012, Mohwinkel et al. 2013). Test work on the laboratory scale has already achieved platinum recoveries of up to 50 % with siderophores for hydrochloric pre-treated samples. Further research by Kraemer et al. (2015) on oxidised ores of the MSZ demonstrates that a combination of conventional inorganic acid leaching (with mild hydrochloric acid) and the organic complexing agent DFOB (Desferrioxamine B) leads to a platinum recovery between 30 % and 80 % (Kraemer et al. 2015). However, due to the expensive chemicals (DFOB agent), this technology has not yet been used economically on an industrial scale. Test work is still ongoing and has now been concentrated on the Platreef ores of the Bushveld Complex.

4.8.4 References

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5 Secondary Chromite and PGE Potentials in Mine Tailings (K. Kärner, H. Marbler)

Tailings, which are also referred to as slimes or tails, are the materials left behind following the process of separating the valuable fraction of the ore from the uneconomic fraction (gangue). As the valuable fraction is generally not completely recovered during the processing of the ore, tailings commonly still contain valuable minerals. Valuable elements within the tailings could prove very interesting future resources. Nevertheless some of the chromite tailings are currently processed for PGEs and chromite.

As extraction techniques improve over time, it is not unusal for tailings to be reprocessed using improved methods to recover the remaining valuable minerals, providing favourable market conditions prevail at the time.

There are two types of tailings dumps containing chromite in the Bushveld Complex. The first type includes tails derived from the processing of LG and MG chromitites at chromium mines. These tailings may still contain up to 20 % Cr_2O_3 (chromite). The second type includes tails derived from the processing of UG2 and Merensky Reef material at platinum mines. Chromite grades of these tailings are estimated to be as low as 5 % for Merensky Reef material and 10 % for tails from the processing of the UG2 layer.

Due to the paragenetic association of chromite and PGEs, these two tailings types not only contain chromite, but also PGEs.

5.1 Mineral Resource Potential

5.1.1 Methodology

The mineral resource potential of both chromite and PGE tailings dumps across the Bushveld Complex was assessed by DERA in preparation of this guide utilising freely available satellite imagery and company data.

Google Earth Software was used to localise and vectorise the tailings dumps. The area of PGE tailings is on average 20 times bigger than the area of the chromite tailings, which made the identification of the former easier. By contrast the localisation of the chromite tailings dumps, in particular historical (and vegetated) ones, was difficult.

The tailings outline polygons generated in Google Earth were subsequently exported to the free GIS software QGIS 2.2.0-Valmiera and a tailings register was produced. The area for each tailings dump was calculated using GIS tools (array calculator). Assumptions were made in terms of grade distribution and density (Table 5.1) based on published figures and information gathered during site visits. The height of the tailings dumps was estimated by counting the number of benches of each tailings dump discernible on the Google Earth satellite images. Each bench was estimated to be 5 m in height, understanding that variations occur throughout the mine encampments and tailings types.

Validity checks in terms of tonnage, grade (PGE) and metal content (PGE ounces) have been conducted comparing DERA's assessment results to published company data. PGE resource figures were available for a number of tailings from both chromite and PGE mines. Chromite figures were

Tab. 5.1: Input parameters for the calculation and evaluation of the mineral resource potential.

Tailings Type		Density (t/m³)	Cr_2O_3 (%)	PGE (ppm)	
				Lowest	Highest
Chrome Mine		2.7	20	1.5	3
PGE Mine	UG2	2.5	10	0.5	0.8
	Merensky	2.3	5	0.5	0.8

not included in the validation due to a lack of published data for chromite grades in the tails.

The validation indicated that the assessment by DERA provides tonnages within an acceptable margin of error of ±30 %, except for one outlier. A range of PGE grades was tested in the assessment (Tab. 5.1) and the validation demonstrated that the best match between company and assessment data is achieved by using PGE grades of 0.65 ppm for PGE mine dumps and 2.25 ppm for chrome mine dumps. Using these figures, the majority of the tailings dumps reports the metal content within a margin of error of ±30 %.

5.1.2 Results

Tailings from PGE Mining

Twenty eight mine sites with PGE tailings dumps have been identified. The total mineral resource potential contained in these dumps is estimated at more than 2 billion tonnes at 0.65 ppm PGEs containing 39 Moz PGE and 172 Mt Cr_2O_3 (Tab. 5.2 and Fig. 5.1).

Eighty percent of this potential, which is equivalent to approximately 32 Moz PGEs and 140 Mt chromite, is located on the western limb of the Bushveld Complex (Fig. 4.20).

Tab. 5.2: Mineral resource potential of PGE tailings dumps in the Bushveld Complex.

Average grade		Tonnes (Mt)	PGE (Moz)	Cr_2O_3 (Mt)
PGE (ppm)	Cr_2O_3 (%)			
0.65	5 – 10	2,089	39	172

Tab. 5.3: Mineral resource potential of chromite tailings in the Bushveld Complex.

Average grade		Tonnes (Mt)	PGE (Moz)	Cr_2O_3 (Mt)
PGE ppm)	Cr_2O_3 (%)			
2.25	20	43.5	2.8	8.7

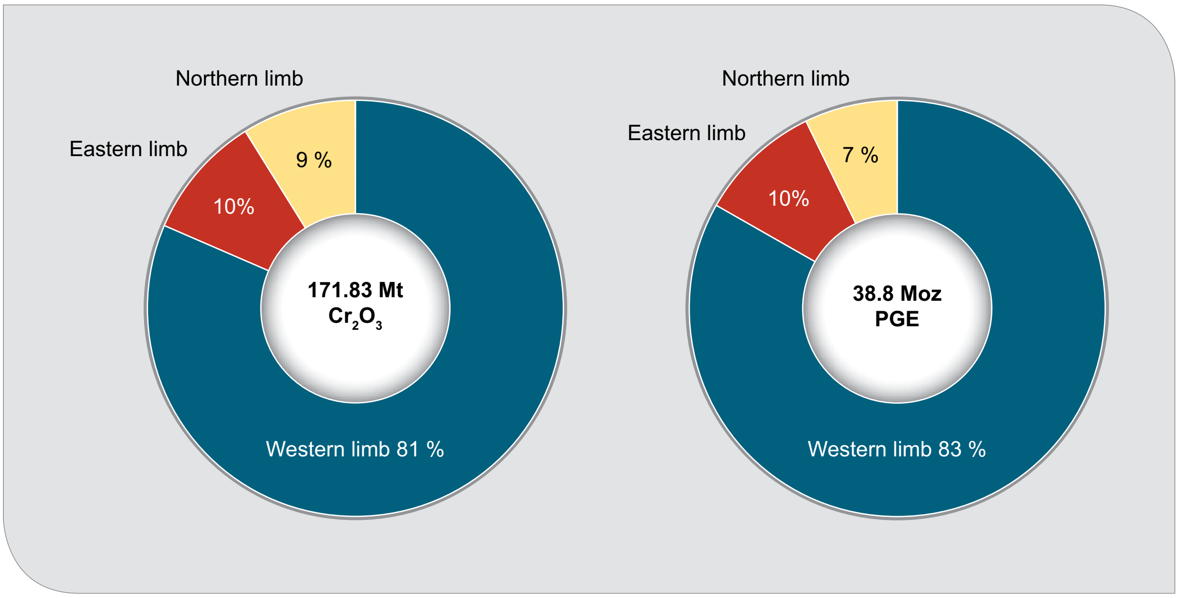

Fig. 5.1: PGE and chromite potential in tailings from platinum mining.

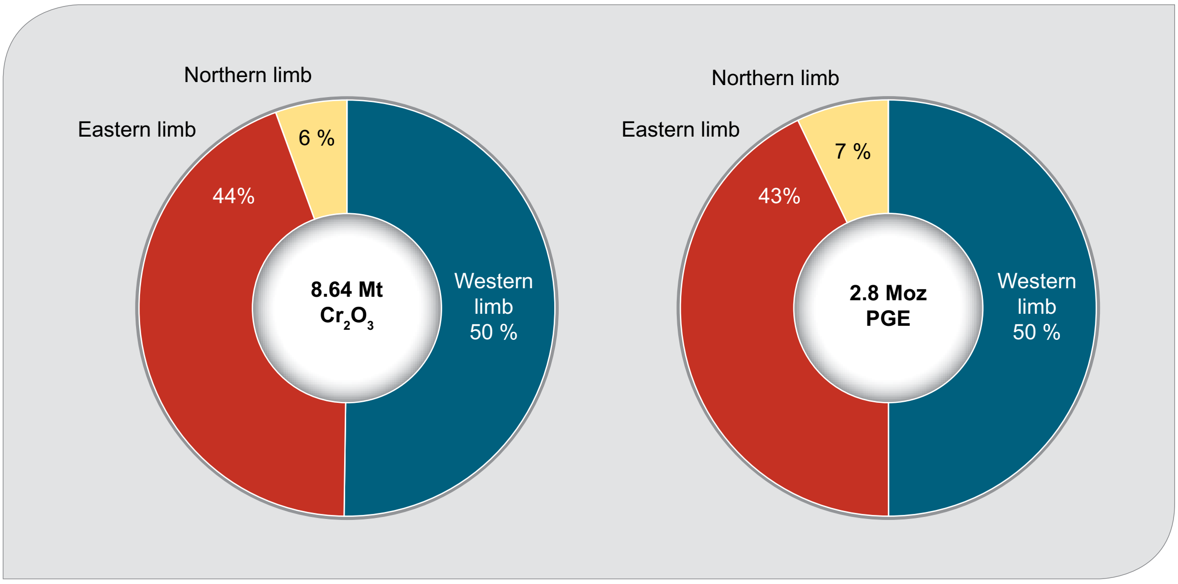

Fig. 5.2: PGE and chromite potential in tailings from chromite mining.

The three largest individual PGE tailings dumps occur at Thembelani, Impala and Tumela mines, all located on the western limb of the Bushveld Complex. With the exception of Impala (Fig. 5.3), which is owned by Impala Platinum, the mines are owned and operated by Anglo Platinum (Anglo).

Tailings from Chromite Mining

Twenty two mine sites with chromite tailings dumps have been identified. The total mineral resource potential contained in these dumps is estimated at approximately 43 Mt at 20 % Cr_2O_3 and 2.25 ppm PGE containing 8.6 Mt Cr_2O_3 and 2.8 Moz PGE (Tab. 5.3).

Fifty percent of this resource potential, which is equivalent to 1.4 Moz PGEs and 4.3 Mt chromite, is contained in tailings of mines located on the western limb (Fig. 5.2).

According to these investigations, the three largest individual tailings dumps occur at the Buffelsfontein, Tweefontein and Mooinooi mines, which are operated by International Ferro Metals and Samancor Chrome.

5.2 Economical Aspects

The mineral resource potential identified in the tailings dumps should not be mistaken for a mineral resource. The estimated potential is based on a number of generalised assumptions in terms of grade and tonnage. The economic viability of retreating individual tailings dumps was not investigated.

5.2.1 Tailings Treatment Operations

5.2.1.1 Platinum Mines

At present Anglo has taken the leading role in re-treating tailings material and recovering both PGEs and chromite. Anglo is re-treating tailings at its Rustenburg platinum mines (RPM) Thembelani, Siphumelele, Khomanani and Bathopele.

Moreover, Northam Platinum is re-treating its tailings material at Zondereinde Mine (Northam Platinum Ltd. 2014).

At Two Rivers Mine, a PGE tailings scavenger plant was installed in 2012 designed to improve the overall PGE recovery for Two Rivers (DMR 2012).

Eastern Platinum Limited commissioned a tailings retreatment plant and constructed a chrome re-

Fig. 5.3: Tailings dump at Impala Platinum Mine (about 220 Mt material containing 0.7 ppm PGE-4E; photo: BGR 2008).

covery plant at its Crocodile River Mine in 2007 and 2008 respectively. The mine is currently under care and maintenance (SNL 2015).

Furthermore, International Ferro Metals (IFM) and Lonmin intend to recover chromite from old PGE tailings dumps and current mine risings. These producers supply ferrochrome producers and chrome ore processors with UG2 chromite produced as PGE by-products.

In 2012 IFM constructed a chrome re-treatment plant in order to process tailings from the UG2 concentrator at Anglo's Waterval operations in Rustenburg. According to the supply agreement IFM has the right to receive the first 15,000 t of metallurgical concentrate production per month from the plant, which has a design capacity of about 50,000 t per month. The plant was shut down from mid-September to late December 2012 due to strike action at Anglo. Under the supply agreement Anglo is required to make up any losses in tonnage incurred at a rate of an additional 5,000 t per month from subsequent production. By 30 June 2013 the backlog in production had been fully accounted for (International Ferro Metals 2013).

Lonmin signed a contract with Glencore-Merafe in March 2010 for the construction of a Chrome Recovery Plant (CRP) to treat tailings from the UG2 concentrator at Lonmin's Marikana operations. Glencore-Merafe constructed and now operates the CRP and also purchases the chromite concentrates produced. In 2011 two additional CRP modules were built at the Rowland shaft and a third module at the Karee 4 plant. The CRPs treat some 1.5 Mt chromite concentrate contained in tailings feed per year (Roskill Information Services Ltd. 2014).

However, despite efforts made by a number of platinum producers the chromite and PGE resource potential of many of the existing PGE tailings dumps across the Bushveld Complex remains untapped.

5.2.1.2 Chrome Mines

Von Gruenewaldt and Hatton (1987) investigated PGE concentrations in chromite tailings in the late 1980s and concluded that their extraction appears to be a highly profitable exercise. They sampled a number of chromite tailings dumps across the Bushveld Complex and reported PGE concentrations of up to 10 ppm. It was estimated that the chromite tailings dumps contain close to 400,000 oz of PGEs, to which about 38,000 oz are added annually. Based on their findings there could be approximately 2.3 Moz PGEs trapped in the chromite tailings existing today, taking the increased chromite production rate into account. For comparison DERA's recent assessment detailed in section 5.1.2 of this report suggests a PGE potential of 2.8 Moz PGE.

Nearly two decades have passed between von Gruenewaldt and Hatton's work in 1987 and the installation of the first commercial chromite tailings re-treatment plant (CTRP).

The CTRP on the western limb of the Bushveld Complex was the first of its kind and is jointly owned by Sylvania Platinum (25 %), Ivanoe Platinum (25 %) and Aquarius Platinum (50 %). The plant, which is currently under care and maintenance, was constructed in 2004 on the concept of extracting low-cost, low-risk PGEs from the tailings of chromite mines. The CTRP, which has only been recovering PGEs, served as the model for each of the Sylvania Platinum's Dump Operations (SDO) built subsequently (see below). Since 2006 SDO have been re-treating the tailings from Samancor's chrome mines recovering both chromite and PGEs. Their six production facilities in the Bushveld Complex include a chrome tailings re-treatment plant recovering chrome concentrate and a PGE flotation plant recovering PGE concentrate (Sylvania Platinum 2013).

In addition, AssOre is reprocessing tailings to produce a chromite concentrate at its closed Zeerust Chrome Mine, 70 km north of Zeerust in the North West Province (Assore 2013).

More recently, Jubilee Platinum has entered the chromite tailings treatment business after signing an agreement with ASA Metals on the treatment of tailings from Dilokong Chrome Mine (see below).

Sylvania Dump Operations (Sylvania Platinum Ltd.)

Sylvania Platinum, listed on London's Alternative Investment Market (AIM: SLP), runs six wholly-owned dump operations in South Africa: Steelpoort, Lannex, Doornbosch and Tweefontein in the eastern limb of the Bushveld Igneous Complex as well as Millsell and Mooinooi in the western limb (Fig. 5.4). The development of the Chromite Tailings Re-treatment Plant (CTRP; see above) was the cornerstone for Sylvania's success in the past decade. A further CTRP on the western limb was constructed in 2004, under the ownership of the RK1 consortium, of which Sylvania would acquire a 25 % interest on the revolutionary concept of extracting low-cost, low-risk PGEs from the tailings of the chromite mines in the area (Sylvania Platinum 2013).

The Sylvania chrome tailings re-treatment plants (Fig. 5.4) recover chrome and PGEs from surrounding chrome mines across the western and eastern limbs. The feed material to the chrome mines is comprised of chrome ore reserves in the Lower Group and Middle Group chromitite seams (LG6 and MG1). LG6 has a Cr_2O_3 content of 43 to 47 % and a Cr:Fe ratio of 1.6:1, while MG1 averages 42 % Cr_2O_3 and has a Cr:Fe ratio of 1.5:1. The feed to the plants is comprised of the tailings dump stockpiles with an additional portion of fresh ore, which combines to a metallurgical feed of between 1.5 and 3 ppm PGEs and approximately 28 % Cr_2O_3. In the first step chromite concentrate is produced by gravitational separation in spiral separators (Figs 5.5, 5.6 and 5.7). The PGEs are recovered from the material by the implementation of three to four flotation steps to receive a PGE concentrate containing 200 to 300 ppm 4E.

At the Mooinooi operation in the western limb, North West Province, a second plant treats run of mine material from the MG2 chrome seam of which lumpy chrome and concentrate is recovered followed by a PGE flotation plant for PGE recovery.

The processed tailings material is generally fine grained and contains up to 25 % Cr_2O_3 and a significant amount of Fe, Mg and Al (Tab. 5.4).

Measurements at Sylvania and at the BGR show an average of 2 ppm PGE feed per plant from the dump tailings. Also, the produced con-

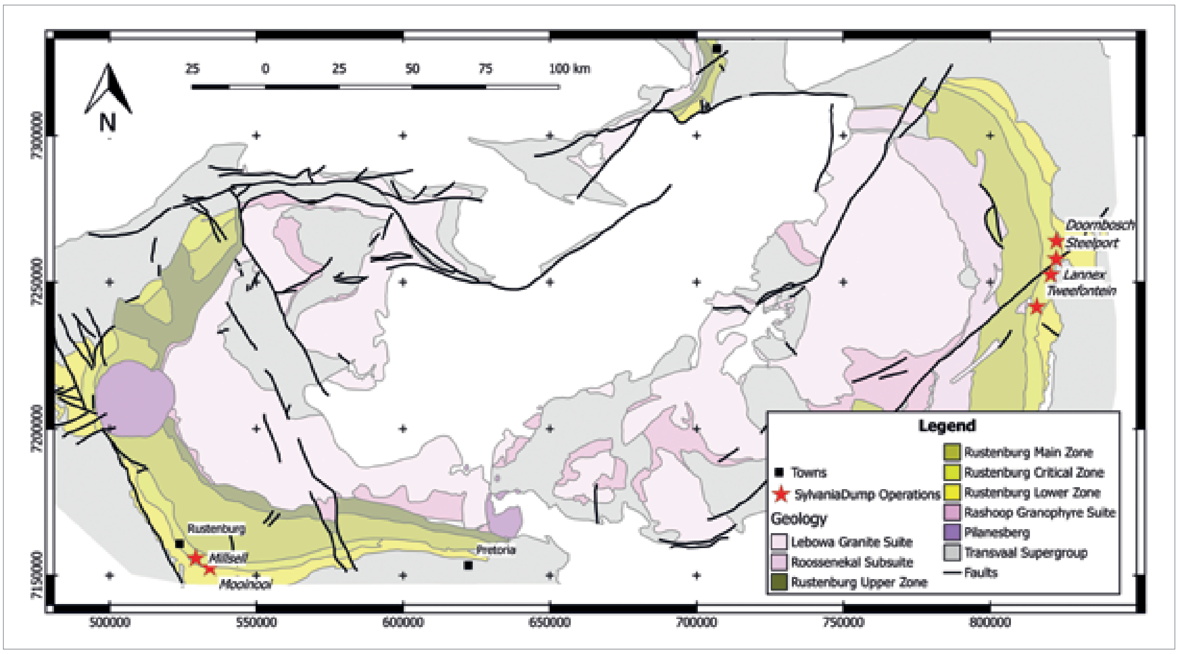

Fig. 5.4: Location of Sylvania's dump operations in the Bushveld Complex.

centrates of all six plants were analysed at the BGR (Tab. 5.5).

Tailings and run of mine (RoM) materials to the Sylvania plants derived from following sites (Fig. 5.4):

- **Mooinooi Plant:** Mooinooi RoM (MG2), Buffelsfontein RoM (MG1); tailings: Mooinooi, Buffelsfontein, Hernic Void, Elandsdrift.
- **Millsell:** tailings: Waterkloof, Old Millsell.

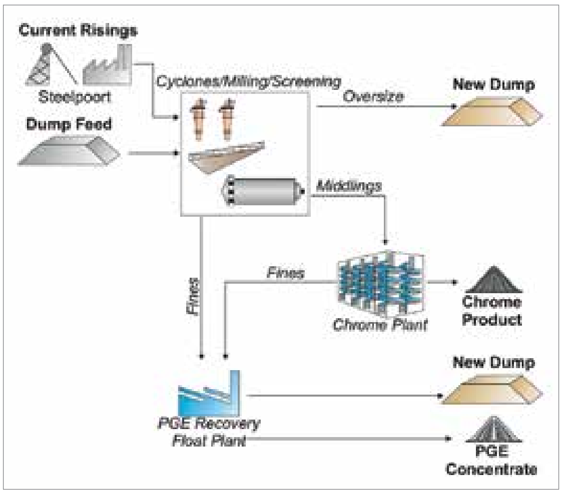

Fig. 5.5: Basic process flow of the Sylvania dump operations (source: Sylvania Platinum 2013.).

- **Steelpoort:** tailings: Mooihoek, Onverwacht, Doornbosch, Steelpoort (LG6 and LG3).
- **Doornbosch:** tailings: Groothoek, Montrose.
- **Lannex:** Broken Hill RoM, Spitzkop RoM; tailings: Lannex.
- **Tweefontein:** tailings: Tweefontein.

The transport of the materials to the plants is handled mostly by truck but is also delivered through a slurry pipeline (Sylvania Platinum 2013).

During the fiscal year 2014 (July 2013 to June 2014), Sylvania produced 53,808 oz 4E in comparison with 44,095 oz 4E in fiscal 2013, by the processing of 2.5 Mt of material. The mill-head grade is 3.7 ppm 4E and the recovery average 42 % (39.9 to 44 % within the past five years). However, Sylvania operates its plants with relatively low cash costs of approximately US$ 665/oz Pt, which constitutes a drop-down of 6 % from 2013 at US$ 708/oz. The total reserves and resources of its tailings operations is announced with 7.36 Mt f ore material containing 2.2 ppm 4E (518,700 oz) (SNL 2015, Sylvania Platinum 2013).

Sylvania is also involved in the development of shallow mining operations, especially in the northern limb, as well as in developing processing methods for low-cost PGE extraction (Sylvania 2014).

Fig. 5.6: The spiral separation facility (left) at Mooinooi plant (right), in the western Bushveld, for recovering chromite from tailings material (photos: DERA 2014).

The **Volspruit** project on the northern limb, 20 km south of Mokopane, Limpopo Province, covers two adjacent ore bodies that will be mined for PGEs and base metals, such as copper and nickel, via two open-cast pits. According to planning, at full production, Volspruit should feed three 100,000 tpm capacity plants. Its reserves are 1.1 Moz PGE, 39.8 Mt Ni and 11.6 Mt Cu.

Everest North is an exploration project on the eastern limb, Mpumalanga Province. An agreement is in place between Sylvania and Aquarius Platinum South Africa (AQPSA), intended as a joint venture, whereby Sylvania would mine PGEs and AQPSA would process them, with the produced ounces and profits being split accordingly.

The **Northern Limb Projects** are located at the extreme northern part of the northern limb, and comprise "hot spots" at the Cracouw 391 LR, Aurora 397 and Harriets Wish 393 LR farms. These have been identified as prospective platinum and palladium targets (2E), together with copper and nickel deposits. Each hot spot could potentially lead to a

Fig. 5.7: Flotation equipment for producing PGE concentrates at Mooinooi plant (left). PGE bearing sulfide minerals are concentrated within the foam (right) (photos: DERA 2014).

Tab. 5.4: Main metal contents in tailings as well as in concentrates of the Sylvania dump operations.

Oxide/Element (wt%)	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	Cr_2O_3	Ni
Millsell (t)	29.29	0.548	13.80	15.42	14.27	3.58	0.72	0.396	18.53	0.07
Millsell (c)	52.47	0.285	3.36	6.92	25.78	1.41	0.14	0.081	2.09	0.18
Mooinooi (t)	22.81	0.577	13.21	19.16	13.34	2.82	0.35	0.194	24.44	0.07
Mooinooi (c)	52.94	0.283	3.32	6.70	26.03	1.42	0.16	0.085	1.87	0.17
Mooinooi-1 (t)	26.52	0.49	12.80	18.32	14.73	2.88	0.41	0.19	22.35	0.71

t: tailings; c: concentrate; method: XRF, analysed by BGR.

Tab. 5.5: PGE and Au data from tailings and concentrates of the Sylvania dump operations.

Element	Os	Ir	Ru	Rh	Pt	Pd	Au	4E[2]	Pt/Pd
Dimension[1]	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppm	ratio
Tailings:									
Millsell	97	214	1,480	430	1,310	675	13.4	**2.43**	1.94
Mooinooi	71	148	681	261	1,130	492	< 0.5	**1.88**	2.30
Mooinooi-1	49	78	488	144	552	318	4.8	**1.00**	1.74
Doornbosh*	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	**2.09**	n.a.
Steelpoort*	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	**2.20**	n.a.
Lannex*	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	**1.64**	n.a.
Tweefontein*	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	**1.66**	n.a.
Concentrates:									
Millsell	2,170	4,520	19,700	7,890	57,200	20,000	145	**85.24**	2.86
Mooinooi	1,950	4,010	17,100	7,320	48,200	17,500	145	**73.17**	2.75
Doornbosh	12,600	32,300	129,000	98,300	144,000	130,000	376	**372.68**	1.11
Steelpoort	10,900	33,500	109,000	63,400	150,000	107,000	380	**320.78**	1.40
Lannex	6,910	12,500	65,000	20,500	83,500	65,400	323	**169.72**	1.28
Tweefontein	5,040	10,400	48,200	18,000	78,900	53,200	261	**150.36**	1.48

data from BGR (Method: NI-FINA, ACTLABS, Canada)
** data from Sylvania; [1]ppb: mg/t; ppm: g/t,[2]4E: Pt+Pd+Rh+Au*

new mine, with innovative, multiple, small processing plants planned that could be moved between operations. In March 2015 Sylvania secured the mining rights from the Department of Mineral Resources (DMR) to mine PGEs in these projects (SNL 2015).

Western Limb Tailings Retreatment (Anglo American Platinum Ltd.)

Coordinates: 25°41'14"S, 27°23'51"E

In 2004, following two years of development, Anglo Platinum started a tailings retreatment project with a tailings plant near the Brakspruit shaft at its Rustenburg complex in the North West Province. The processed material derived from a number of tailings dumps in the Klipfontein and Waterval areas.

Fig. 5.8: Mooinooi tailings dam, 25 km east of Rustenburg, with an average height of 6 m (photo: DERA 2014).

In 2013 the plant produced 59,700 oz Pt, 21,300 oz Pd, 3,500 oz Rh and 5,300 oz Au at cash costs of US$ 630/oz, a production increase of 29 % (4E production) compared to 2012. The resources amount to 58 Mt of tailings material with an average content of 1 ppm Pt (1.87 Moz Pt) and 0.31 ppm Pd (0.58 Moz Pd).

Two Rivers Tailings Retreatment Plant (Two Rivers Platinum Pty)

Coordinates: 24°54'57"S, 30°05'55"E

The PGE tailings scavenging plant is situated at the Two Rivers mine site in the eastern limb, Mpumalanga Province, and is 100 % owned by Two Rivers Platinum, in which African Rainbow Minerals Ltd. (ARM) has a 55 % economic interest. The plant was completed in 2013 but to date no production data is available. The expected annual production is 7,500 oz PGE (3E) (SNL 2015).

Dilokong Tailings Project (Jubilee Platinum plc)

Coordinates: 24°33'06"S, 30°08'42"E

The AIM-listed Jubilee Platinum was awarded the rights to recover PGEs from chromite tailings from current and future operations at Dilokong chrome mines in the eastern limb of the Bushveld Complex. Jubilee announced that the tailings dumps contain between 3.5 and 4 ppm PGEs (4E) and 90,000 to 100,000 oz 4E, respectively (SNL 2015).

In October 2013 Jubilee completed funding arrangements required to begin the processing of the tailings, which was scheduled to commence within three months based on the expected timelines for recommissioning the processing plant. The funding arrangement included a debt offering of US$ 10 million, of which Jubilee would initially only access US$ 750,000, the amount required for the start-up. In June 2014 Jubilee entered into a Tailings Access Agreement with ASA Metals Proprietary and its subsidiary Dilokong Chrome Mines Proprietary for the recovery of PGEs and chrome from the surface tailings dump. The access agreement paved the way for establishing an independent processing facility for the processing of platinum containing chrome ores (Jubilee 2014, SNL 2015).

As described in chapter 4.5 "Mining and Processing", the ConRoast technology is central to Jubilee Platinum's strategy of becoming a fully integrated, low-cost PGE producer. The company added the ConRoast technology to its 63 % owned flagship Tjate asset in 2009 through the acquisition of Braemore Resources plc, then in 2010 bought the Middelburg ferroalloy smelting facility, where the existing AC furnaces can be tweaked to process the ConRoast recipe, but this will eventually be upgraded for ConRoast treated platinum production by adding a DC furnace. Since this time, it has been accumulating near-surface, high chrome deposits, largely tailings, in order to start a low-cost platinum producing business (Jubilee 2014).

PGE processing project at Hernic Ferrochrome (Jubilee Platinum plc)

Coordinates: 25°39'39.07"S, 27°50'17.85"E

Jubilee Platinum entered into an agreement with Hernic Ferrochrome Ltd. (subsidiary of Mitsubishi Corp. – see also chapter 3.4.4) near Brits in the southwestern limb in January 2015 to recover chrome and PGEs from Hernic tailings. The contract allows the processing of about 1.7 Mt of chrome tailings material, with the potential to exceed 3 Mt through additional drilling programmes. The construction and operation of a processing plant at Hernic Proprietary is planned (Jubilee 2015).

Phoenix Platinum (Pan African Resources plc)

Coordinates: 25°43'30.29"S, 27°36'46.68"E

The Phoenix Platinum project is located on the western limb of the Bushveld Complex near Mooinooi, some 40 km east of Rustenburg. The 100 % Pan African Resources owned tailings retreatment plant for the recovery of PGEs. The tailings material is sourced from several mines, including Elandskraal and Kroondaal as well as Lesedi (Pan African Resources 2014a, 2014b).

In fiscal year 2013, Phoenix produced 6,480 oz PGEs (6E: Pt + Pd + Rh + Ru + Ir + Os) at cash costs of US$ 854/oz (ZAR 7 550/oz). In the following fiscal year 2014 sales from Phoenix totaled 7,204 oz 6E. Phoenix tailings resources and reserves total 5.9 Mt grading 3.22 ppm 6E (0.6 Moz). Plant recovery rates increased to 29 % during the year 2014 (2013: 21 %). This was achieved through adjusting the reagent suite in the extraction process to deal with variable feed sources. According to this recovery rate, the resources would supply a life of mine of 28 years (Pan African Resources 2014a).

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