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## DERA Rohstoffinformationen



### Investor's and Procurement Guide South Africa Part 1: Heavy Minerals, Rare Earth Elements, Antimony

## Impressum

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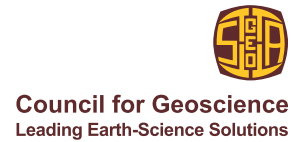
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# **Investor's and Procurement Guide South Africa**

## **Part 1: Heavy Minerals, Rare Earth Elements, Antimony**

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



## Foreword

This is the first part of the "Investor's and Procurement Guide South Africa", a handbook for investing and doing business in South Africa's mineral industry. It is anticipated that this publication will aid potential investors into considering South Africa as an investment 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, suppliers and mine equipment exporters through the process of doing business in Africa's biggest and dynamic economy.

As well as detailing the mineral raw materials heavy minerals, rare-earth metals and antimony, the handbook provides a general introduction to South Africa and its infrastructure, the economical, political and judicial frame of the South African mining industry and an overview of the economic geology.

South Africa has a long and complex geological history which dates 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, has 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 in the foreseeable future.

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

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



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## 1 Introduction

### 1.1 Aim of the study and background

#### *South Africa has much to offer for investors*

South Africa is a well-established, functioning parliamentary democracy with separation of powers and an independent judiciary. Since the defeat of apartheid, South Africa has been released from its former isolation and is now one of the leading role players on the continent. Regarding its gross domestic product (GDP), as well as its trade volume and structure, South Africa is by far the strongest and most diverse economy in Sub-Saharan Africa. The country has extensive resources in its minerals, but also in the industry, infrastructure, military, science and technology.

Regarding its mineral production, its resource policy and its changing political situation, South Africa is worth getting very special attention. The country is under the world's top producers and suppliers of steel-refining metals, precious metals and industrial minerals. These commodities play a significant role, also, and in particular, in the German Industry.

South Africa has consistently been recognised by credible international surveys as having an environment conducive to business opportunities. After the 2013 economy ranking (THE WORLD BANK GROUP 2013) South Africa lies on rank 41 out of 189 countries surveyed (No. 1: Singapore; Germany: No. 21), up from rank 50 in 2012. It is the third-highest ranked country in Africa (after Mauritius and Rwanda) as well as within the BRICS (Brazil, Russia, India, China and South Africa) group of nations.

The South African government seeks to create a positive business environment conducive to both foreign and domestic investments. Political stability, fiscal discipline and an effective monetary policy since 1994 have brought about the country's longest stretch of continuous economic growth in its history, while substantially lowering taxes, inflation, interest rates and government debt. In this regard, the handbook complements also a recent

study by DERA, the German Chamber of Commerce and Industry of Southern Africa (AHK) and the Germany Trade and Invest GmbH (GTAI) on cooperation possibilities for German companies in the South African mining sector (ALETTER, MARBLER & STUMPF 2013).

### 1.2 Country profile

#### *Geography*

South Africa occupies the southern tip of Africa, its long coastline stretching more than 2,500 km from the desert border with Namibia on the Atlantic coast, southwards around the tip of Africa, then north to the border with subtropical Mozambique on the Indian Ocean. The low-lying coastal zone is narrow for much of this distance, soon giving way to a mountainous escarpment that separates it from the high inland plateau. In some places, notably the province of KwaZulu-Natal in the east, a greater distance separates the coast from the escarpment. Further information available on SOUTHAFRICA.INFO (2013).

#### *Climate and Vegetation*

The western Part of South Africa, in particular the Karoo Basin has an extreme climate with very hot summers and cold winters. At the eastern coastline on the Indian Ocean the climate is strongly influenced by the warm Mozambique Current, with mangroves growing along this coast. The southern coast, which is known as the Garden Route, is green with moderate temperatures. The Cape of Good Hope has a Mediterranean climate, with cool, wet winters and warm, dry summers (becoming hotter in the interior valleys). Snow commonly falls in on the higher grounds of the Cape Fold Mountains, snow is also common in winter. The Cape is characteristic for its southeastern or northwestern winds, blowing all year round and for its sunny and dry summer. The eastern section of the Karoo and the flat landscape of the Free State are semi-arid, with occasional rains. North of the Vaal River, the Highveld is better watered, with an annual rainfall of 760 mm and a high altitude up to 1,750 m which mitigates the extremes of heat. Winters are cold and dry. Further north and to the east, to the Lowvelds and

to the northeastern Bushveld temperatures are tropical. Further information available on WIKIPEDIA (2013a, [http://en.wikipedia.org/wiki/Geography\\_of\\_South\\_Africa](http://en.wikipedia.org/wiki/Geography_of_South_Africa)).

### Vegetation Zones

#### Kalahari Savannah

The largest zone is the Kalahari Savannah, which consists of grasslands and small groups of trees. The Kalahari Savannah covers most of Botswana, Namibia and part of South Africa.

#### Karoo Schrubland

The second-largest zone is the Karoo Schrubland area, which covers most of South Africa. The Karoo Schrubland is rugged in some parts, with canyons, valleys and a few perennial rivers. Many species, including Mixed Woodland, are restricted to this zone, including Kaokoland, Damaraland, Richtersveld and Namaqualand.

The largest game parks in this region are found in the Mixed Woodland vegetation area, which consists of grass, tree and mountainous vegetation areas. This is a type of savannah that is identified by relatively short trees, including Acacia and broad-leaved species.

#### Bushveld

Generally occurring at altitudes below 1,500 m, Bushveld includes much of the lowveld of Mpumalanga. It offers a wide range of species, but few are restricted to this biome.

The fynbos vegetation zone in the Cape is one of the six Floral Kingdoms of the earth. This type of vegetation is unique to South Africa and is the smallest vegetation biome in the world. It covers a very small area in the southwestern Cape and it is home to more than 7,000 plant species.

#### Forests

Dominated by large evergreen trees, forests contain few mammals but many birds. The coastal and lowland forests occur along the eastern seaboard, while montane forest occurs in specific pockets at about 1,200 m. See also SIYABONA AFRICA TRAVEL

(PTY) LTD (2013, [http://www.southafrica.org.za/south-africa-info-vegetation-zones\\_p2.html](http://www.southafrica.org.za/south-africa-info-vegetation-zones_p2.html)).

### Environment

South Africa has a wide range of climatic conditions and many variations in topography, such as a narrow coastal plain, a steep escarpment and a large plateau.

The country is rich in diverse species. Though it has a land surface area of 1.2 million km<sup>2</sup> – representing just 2 % of the Earth's total land surface – South Africa contains almost 10 % of the world's total known bird, fish and plant species, and over 6 % of the world's mammal and reptile species.

The vision of the Department of Environmental Affairs is to create a prosperous and equitable society living in harmony with the environment.

Government leads protection of the environment by example. At regional level, the provincial conservation agencies are major role players, and independent statutory organisations such as South African National Parks (SANParks) and the South African National Biodiversity Institute (Sanbi) are valuable partners in the country's total conservation effort.

South Africa has taken several concrete steps to implement the United Nations' (UN) Agenda 21 on Sustainable Development. These include reforming environmental policies, ratifying international agreements and participating in many global and regional sustainable-development initiatives.

### World heritage sites

South Africa has eight world heritage sites proclaimed by Unesco, namely:

- Robben Island
- iSimangaliso Wetland Park
- the hominid sites at Swartkrans, Sterkfontein and Kromdraai (known as the Cradle of Humankind)
- Ukhahlamba-Drakensberg Park (a mixed natural and cultural site)
- Mapungubwe Heritage Site
- Cape Floral Kingdom
- Vredefort Dome



- Richtersveld Cultural and Botanical Landscape.

### Habitat and wildlife management areas

These areas include conservancies; provincial, regional or private reserves created for the conservation of species, habitats or biotic communities; marshes; lakes, and nesting and feeding areas.

### Sustainable-use areas

These areas emphasise the sustainable use of products in protected areas such as the Kosi Bay Lake System in KwaZulu-Natal.

### Wetlands

Wetlands include a wide range of inland and coastal habitats – from mountain bogs, ferns and midland marshes to swamp forests and estuaries, linked by the green corridors of streambank wetlands.

Until 2011 about 115,000 wetlands, covering over four million ha and comprising close to 4 % of the country's total surface area, had been mapped in South Africa.

The Working for Wetlands Programme focuses on wetland restoration, while maximising employment creation, support for small, medium and micro-enterprises and skills transfer.

Many wetland plants have medicinal value. In South Africa, traditional medicine is the preferred primary healthcare choice for about 70 % of the people. Wetlands provide some of the 19,500 tons of medicinal plant material, which is used by some 28 million South Africans every year.

Sanbi manages the Working for Wetlands Programme, with its offices based at the Pretoria National Botanical Garden.

### Marine-protected areas (MPAs)

MPAs conserve natural environments and assist in the management of fisheries by protecting and rebuilding economically important stocks. These are also used to develop and regulate coastal eco-tourism opportunities.

Government shares joint responsibility for South Africa's MPAs with SANParks and Ezemvelo KwaZulu-Natal Wildlife.

South Africa's MPAs include:

- **KwaZulu-Natal:** Aliwal Shoal MPA, Trafalgar MPA, iSimangaliso MPA;
- **Western Cape:** Betty's Bay MPA, De Hoop MPA, Goukamma MPA, False Bay MPA, Robberg MPA, Stilbaai MPA, Tsitsikamma MPA, Table Mountain MPA, Langebaan Lagoon, Sixteen Mile Beach, Malgas Island, Marcus Island, Jutten Island MPA;
- **Eastern Cape:** Bird Island MPA, Dwesa-Cwebe MPA, Hluleka MPA, Sardinia Bay MPA, Pondoland MPA.

In September 2011 the Amathole MPA was announced. It is an important addition to South Africa's network of coastal MPAs. It comprises three separate marine areas, namely the Gxulu, Gonubie and Kei areas. It will provide formal and long-term protection to the inshore marine habitat and biodiversity of the Eastern Cape.

### Overview of the Political and Mining History

At several archaeological sites, there is evidence of sophisticated political and material cultures.

The first European settlement in southern Africa was established by the Dutch East India Company in Table Bay (Cape Town) in 1652. Shortly after the establishment of the colony, slaves were imported from East Africa, Madagascar and the East Indies.

In 1806, Britain reoccupied the Cape. From the mid-1800s, the Voortrekkers coalesced in two land-locked, white-ruled republics, the South African Republic (Transvaal) and the Orange Free State.

The discovery of diamonds north of the Cape in the 1860s brought tens of thousands of people to the area around Kimberley.

The discovery of the Witwatersrand goldfields in 1886 was a turning point in the history of South Africa. The demand for franchise rights for English-speaking immigrants working on the new goldfields was the pretext Britain used to go to

war with the Transvaal and Orange Free State in 1899 with the war ending in 1902.

In 1910, the Union of South Africa was created out of the Cape, Natal, Transvaal and Free State. In 1948, the pro-Afrikaner National Party (NP) came to power with the ideology of apartheid. In 1961, the NP Government under Prime Minister HF Verwoerd declared South Africa a republic. The Government embarked on a series of limited reforms in the early 1980s. In February 1990, President FW de Klerk announced the unbanning of the liberation movements and the release of political prisoners, notably Nelson Mandela. After a difficult negotiation process, South Africa held its first democratic election in April 1994 under an interim Constitution. Further information available on GOVERNMENT COMMUNICATIONS AND INFORMATION SYSTEM (GCIS) (2013a, [http://www.gcis.gov.za/sites/www.gcis.gov.za/files/docs/resourcecentre/pocketguide/003\\_history.pdf](http://www.gcis.gov.za/sites/www.gcis.gov.za/files/docs/resourcecentre/pocketguide/003_history.pdf)).

### Major Towns

#### South Africa has three capitals:

Cape Town, in the Western Cape, is the legislative capital and this is where the country's Parliament is found. Bloemfontein, in the Free State, is the judicial capital, and home to the Supreme Court of Appeal. Pretoria, in Gauteng, is the administrative capital, and the ultimate capital of the country. It is home to the Union Buildings and a large proportion of the public service.

The largest and most important city is Johannesburg, the economic heartland of the country. Other important centres include Durban and Pietermaritzburg in KwaZulu-Natal, and Port Elizabeth in the Eastern Cape. Further information available on SOUTHAFRICA.INFO (2013, <http://www.southafrica.info/about/geography/geography.htm#ixzz2RZL-nvoqU>).

### Industries of South Africa

The economy of South Africa accounts for 24 % of Africa's Gross Domestic Product in terms of PPP and is therefore the largest economy on the continent. South Africa is ranked as an upper-middle income economy by the World Bank. South

Africa is represented beside Botswana, Gabon and Mauritius, in this category. About a quarter of the population is unemployed, but unofficial estimates put the real unemployment rate as high as 40 %. A quarter of South Africans live on less than US\$ 1.25 a day.

South Africa has a comparative advantage in the production of mining, agriculture and manufacturing products relating to these sectors. South Africa has shifted from a primary and secondary economy in the mid-twentieth century to an economy driven primarily by the tertiary sector in the present day which accounts for an estimated 65 % of GDP or US\$ 230 billion in nominal GDP terms. The country's economy is reasonably diversified with the key economic sectors including mining, agriculture and fishery, vehicle manufacturing and assembly, food processing, clothing and textiles, telecommunication, energy, financial and business services, real estate, tourism, transportation, and wholesale and retail trade. Further information available on WIKIPEDIA (2013b, [http://en.wikipedia.org/wiki/Economy\\_of\\_South\\_Africa](http://en.wikipedia.org/wiki/Economy_of_South_Africa)).

### Agricultural Products

#### Field crops and horticulture

- Maize is the largest locally produced field crop, and the most important source of carbohydrates in the Southern African Development Community (SADC) for animal and human consumption. South Africa is the main maize producer in the SADC region, with an average production of about 9.7 million tons (mt) a year over the past 10 years. It is estimated that more than 8,000 commercial maize producers are responsible for the major part of the South African crop, while the rest is produced by thousands of small-scale producers. Maize is produced mainly in North West, the Free State and Mpumalanga. A total of 13.4 Mt of maize were produced in 2009/10 on 3.3 million hectares of land (non-commercial agriculture included).
- Wheat is produced mainly in the winter-rainfall areas of the Western Cape and the eastern parts of the Free State. In 2010, 1.52 Mt were produced on 558,000 ha of land.

- South Africa is the world's 12th-largest producer of sunflower seed, which is produced in the Free State, North West, on the Mpumalanga Highveld and in Limpopo. An area of 397,700 ha was planted in 2009/10, producing 509,000 t.
- South Africa is the leading exporter of protea cut flowers, which account for more than half of its proteas sold on the world market.

The most important horticultural products in South Africa are maize, wheat, sugar cane, grain sorghum, soya beans, sunflower seeds, deciduous and citrus fruit, subtropical fruit, vegetables and potatoes.

The livestock sector contributes up to 49 % of agricultural output. South Africa generally produces 85 % of its meat requirements, while the remaining 15 % is imported from Namibia, Botswana, Swaziland, Australia, New Zealand and Europe. The livestock industry is the largest national agricultural sector.

The South African dairy industry is important to the job market, with over 4,000 milk producers employing 60,000 farm workers and providing 40,000 people with indirect jobs within a value chain such as milk processing.

Further information available on GOVERNMENT AND INFORMATION SYSTEM (GCIS) (2013b, [http://www.gcis.gov.za/sites/www.gcis.gov.za/files/docs/resourcecentre/pocketguide/013\\_agriculture.pdf](http://www.gcis.gov.za/sites/www.gcis.gov.za/files/docs/resourcecentre/pocketguide/013_agriculture.pdf))

## People

South Africa's biggest asset is its people; a rainbow nation with rich and diverse cultures. South Africa is often called the cradle of humankind, for this is where archaeologists discovered 2.5 million year old fossils of our earliest ancestors, as well as 100,000 year old remains of modern man. According to Statistics South Africa's (Stats SA) *Mid-Year Population Estimates, 2011*, released in July 2011, there were 50.59 million people living in South Africa, of whom 79.5 % were African, 9 % coloured, 2.5 % Indian and 9 % white. Approximately 52 % of the population was female.

Nearly one third (31.3 %) of the population was aged younger than 15 years and approximately 7.7 % (3.9 million) was 60 years or older. Of those younger than 15 years, approximately 23 % (3.66 million) lived in KwaZulu-Natal and 19.4 % (3.07 million) lived in Gauteng.

The South African population consists of the Nguni (comprising the Zulu, Xhosa, Ndebele and Swazi people); Sotho-Tswana, who include the Southern, Northern and Western Sotho (Tswana people); Tsonga; Venda; Afrikaners; English; coloured people; Indian people, and those who have immigrated to South Africa from the rest of Africa, Europe and Asia and who maintain a strong cultural identity. Members of the Khoi and the San also live in South Africa.

## Official Languages

The diversity of the unique cultures of South Africa means that there are 11 official languages.

These languages include English, Afrikaans, isiXhosa, isiZulu, isiNdebele, Sesotho sa Leboa, Sesotho, Setswana, siSwati, Tshivenda and Xitsonga. The Constitution also requires the Pan South African Language Board to promote the use of the Khoi, Nama and San languages, and sign language.

**Tab. 1.2.1: Mother tongues in South Africa**

Mother tongues	
isiZulu	22.7 %
IsiXhosa	16 %
Afrikaans	13.5 %
Sesotho sa Leboa	9.1 %
English	9.6 %
Setswana	8 %
Sesotho	7.6 %
Xitsonga	4.5 %
siSwati	2.5 %
Tshivenda	2.4 %
isiNdebele	2.1 %
Other	2 %

Source: *IL NUOVO LIBRO* (2013).

Although English is the mother tongue of only 9.6 % of the population, it is the language most

widely understood, and the second language of the majority of South Africans.

However, Government is committed to promoting all the official languages.

### **National and Cultural Monuments**

These are natural or cultural features, or both, and may include botanical gardens, zoological gardens, natural heritage sites and sites of conservation significance.

### **Religion**

According to the 'Constitution', everyone has the right to freedom of conscience, religion, thought, belief and opinion.

Almost 80 % of South Africa's population follows the Christian faith. Other major religious groups are the Hindus, Muslims, Jews and Buddhists. A minority of South Africa's population does not belong to any of the major religions, but regard themselves as traditionalists of no specific religious affiliation.

Further information available on SOUTH AFRICAN GOVERNMENT INFORMATION (2013, <http://www.info.gov.za/aboutsa/people.htm>).

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## 2 Infrastructure

### Transport

Transport and its related services is a catalyst for economic growth, and direct and indirect job creation in South Africa. The provision of affordable, safe and reliable transportation of goods and people is critical to the development of the country.

Government boosted transport infrastructure spending to R 66 billion in the 2011/12 financial year and is expected to raise it to R 80 billion by 2013/14. The improvements are spread across the country, with urban and rural parts expected to benefit from the creation of jobs and tourism opportunities.

Over the next three years, an additional R 2.5 billion will be allocated to municipalities for public-transport systems and infrastructure.

South Africa has the longest road network of any country in Africa.

**The South African Roads Agency Ltd (Sanral)** oversees the national road system and is responsible for the design, construction, management and maintenance of South Africa's national road network of some 16 170 km (about 3,000 km are tolled and 13,000 non-tolled). The remainder of South Africa's 600,000 km road system is managed and maintained by provincial and local governments.

The toll-road network comprises about 19 % (3,120 km) of the national road grid. About 1,288 km of the tolled sections of the national road have been concessioned to private companies to develop, operate and maintain.

**Transnet Freight Rail**, the largest operating division of Transnet, has as its primary purpose the transportation of rail freight. Core freight activities account for about 95 % of its revenue.

**Transnet Ltd**, operating and controlling South Africa's major transport infrastructure, is also responsible for ensuring that the country's transport industries operate according to world-class



Fig. 2.1: Railway network of South Africa



standards. Forming an integral part of the southern African economy, Transnet:

- moves 17 % of the nation's freight annually
- exports 100 % of the country's coal
- exports 100 % of the iron ore
- has annual revenues of over R 14 billion
- will, over the next five years, invest R 35 billion in capital.

The company maintains an extensive rail network across South Africa that connects with other rail networks in the sub-Saharan region, with its rail infrastructure representing about 80 % of Africa's total railway infrastructure.

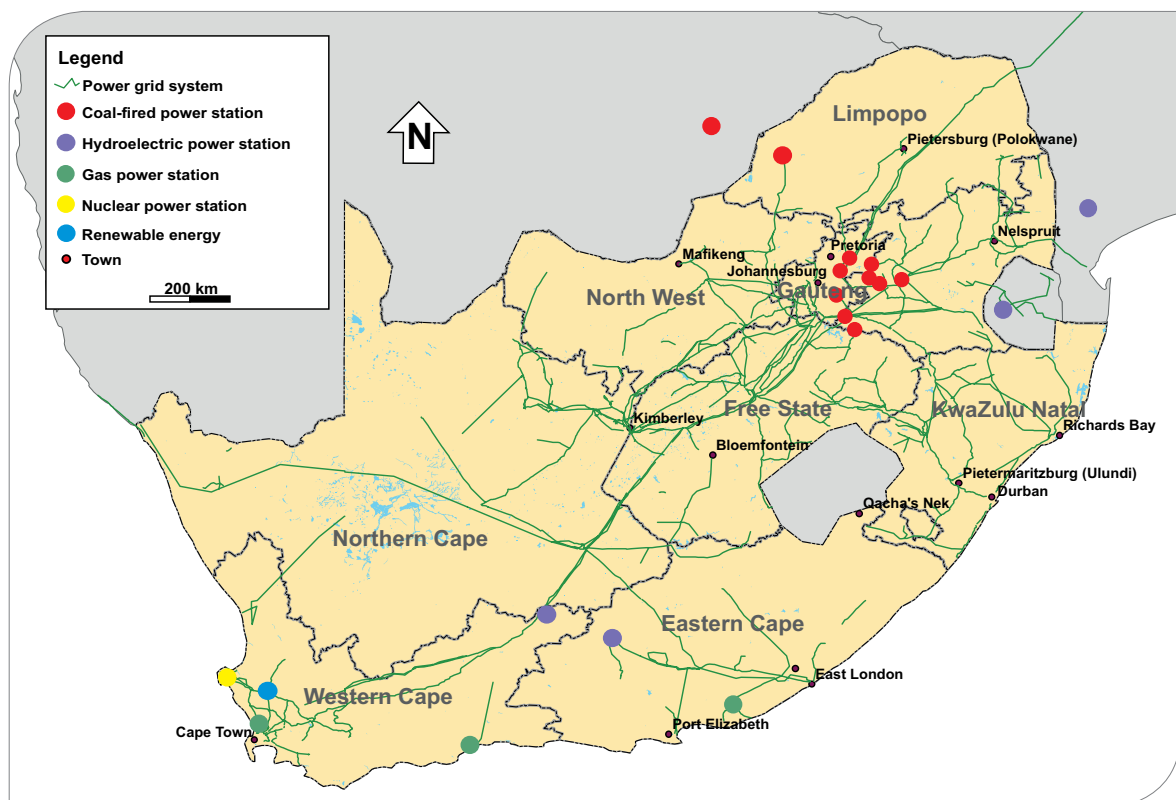
**Transnet's National Ports Authority and Port Terminal** operates the nation's ports and harbours. About 95 % of the nation's exports and imports, by value, are handled by South Africa's six main harbours – Durban, Cape Town, Port Elizabeth, Richards Bay, Saldanha and East London. Traffic has increased two-fold over the past decade, despite inefficiencies and delays across the ageing transport system.

## Water

Water distribution requires extensive infrastructure for recycling or transferring water from storage dams to other regions. The rising population and economic growth will require substantial investment, primarily in water storage capacity, to be able to meet anticipated demands. Nearly R 10 billion has been budgeted for accelerated construction of the De Hoop Dam in the Cape and implementing phase two of the Lesotho Highlands Water Project. The Department of Water and Environmental Affairs has allocated more than R 1 billion to its Dam Safety and Rehabilitation Programme. The price of water is in the global comparison in South Africa currently in the mid-range and lies at US\$ 1 per cubic meter (Germany: US\$ 2.5 per m<sup>3</sup>).

## Electricity

Eskom generates 95 % of the electricity used in South Africa and approximately 45 % of the electricity used in Africa. Eskom generates, transmits and distributes electricity to industrial, mining,



**Fig. 2.2: Power grid system and existing power stations in South Africa.**  
(Further information available on **ESKOM HOLDINGS LTD**, 2009).

commercial, agricultural and residential customers and redistributors. Eskom is currently elaborating on a capacity expansion programme, which will increase generation capacity by 17,000 MW and transmission lines by 4,700 km. The programme will cost about R 340 billion by completion in 2018. Two new coal-fired power plants are scheduled to come on line in the next two years and a wind plant and solar plant are planned to meet the rising electricity demand in South Africa.

The Department of Energy has released an Integrated Resource Plan (IRP) which proposes that by 2030, South Africa's energy needs will be met by a mixture of resources, with dependence on coal much reduced. Currently, coal is the source of 93 % of the power generation. The IRP sets goals of 46 % of power generation from coal; 26 % from renewable energy, 13 % from nuclear power and the remainder from gas turbines and pump storage. With the coal reserves of 200 years readily available and given the high cost of renewable energy, these plans may prove to be overly ambitious.

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## 3 Economical, Political and Judicial frame of the South African Mining Industry

### 3.1 Key government legislation and policies regarding mineral industry

The following are a selection of enabling policies and regulatory frameworks in South Africa for effective mineral exploration, mining, beneficiation and related downstream industries. These enabling policies and regulatory frameworks include:

- Mineral and Petroleum Resources Development Act of 2002 (Act No. 28 of 2002)
- The Mining Charter
- Precious Metals Act
- The Beneficiation Strategy.

#### *Mineral and Petroleum Resources Development Act of 2002 (Act No. 28 of 2002)*

The **Mineral and Petroleum Resources Development Act** (MPRDA) of 2002 (Act No. 28 of 2002) replaced Minerals Act 50 of 1991. The core objectives of the MPRDA Act include promoting the economic growth and mineral resources in South Africa. The MPRDA provisions support exploration and mining investment in order to increase mining output, beneficiation, economic growth and employment opportunities.

According to the MPRDA, the terms that are used to describe the right to prospect or mine are reconnaissance permission, prospecting right, mining permit and mining right. Reconnaissance permission involves non-invasive prospecting such as airborne geophysical surveys. Reconnaissance permission is valid for two years and is not renewable. Furthermore, it does not entitle the holder to conduct any prospecting or mining operations for any mineral in the land in question or any exclusive right to apply for or be granted a prospecting right or mining right. Owing to this restriction, most applicants (if not all) apply for a prospecting right which gives the full rights to prospect for a period of three years and may be renewed for a further three years. The MPRDA promotes

minerals development by applying the 'use it and keep it' principle. This principle means that if one holds a prospecting right but cannot prospect by virtue of such holding then there is no value in holding such rights, and the right will be lost. In addition, a prospecting right that is 'in use' may be renewed once for a period of not exceeding three years. The application for renewal of a prospecting right will not be accepted without a proper exploration work programme being conducted.

According to section 27 of the MPRDA, a mining permit is only issued if the mining area in question does not exceed 1.5 ha in extent. In addition, a mining permit may only be issued if the mineral in question can be mined optimally within the period of two years. If the area to be mined exceed 1.5 ha, then a mining right should be applied for. Section 23 (1) of the MPRDA Act states that the Minister must grant a mining right if, among others, the mineral can be mined optimally, the applicant has access to financial resources and a technical ability to conduct the proposed mining operation, the mining will not result in unacceptable damage to the environment, and the applicant has provided financially for the prescribed social and labour plans. The duration of the mining right is 30 years, however, the mining right may be renewed for further periods, each of which may not exceed 30 years at a time.

It has to be noted that prospecting or mining rights cannot be transferred without a written consent of the Minister of Mineral Resources, except in the case of change of controlling interest in listed companies.

An applicant of prospecting or mining rights must make prescribed financial provision for the rehabilitation; these financial provisions must be assessed annually by the holder of the prospecting or mining rights based on the environmental liabilities and increase the financial provisions accordingly. The holder of a prospecting right, mining right or mining permit remains responsible for any environmental liability until the Minister of Mineral Resources has issued a closure certificate to the holder concerned. The holder of prospecting or mining rights must apply for a closure certificate upon the lapsing or cancellation of the right in question, the cessation of the operation, and completion of the prescribed closing plan to which the right relates, amongst

others (CHAMBER OF MINES OF SOUTH AFRICA 2008, McCOURT, J. L. 2012).

The MPRDA provides for supporting mineral beneficiation in section 26 of the Act. If the Minister of Mineral Resources, in consultation with the Minister of Trade and Industry, finds that a particular mineral can be beneficiated economically within South Africa, then the Minister may promote such beneficiation subject to the terms and conditions as the Minister may determine.

### **Amendments of the MPRDA Act**

A process of reviewing the MPRDA Act is underway following Cabinet approval which meant the proposals for the amendments of the MPRDA Bill were gazetted towards the end of 2012. The Amendment Bill was submitted to Parliament for advanced consultation as well as public engagement.

The focus on the amendments is, inter alia, to remove ambiguities in the Act that create room for multiple interpretations; align provisions of the Act with relevant legislation in other parts of the Government, such as the environment; strengthen administrative processes; introduce provision to promote beneficiation of minerals, and provisions for enhanced sanctions for non-compliance.

### **The Mining Charter (Broad-Based Socio-Economic Empowerment Charter for the Mining Industry)**

The basis for empowerment in the Minerals Sector is found in Chapter 2 (Fundamental Principles) of the MPRDA (Act No. 28 of 2002), which highlights one of the objectives of the MPRDA as being to "substantially and meaningfully expand opportunities for historically disadvantaged persons, including women, to enter the mineral and petroleum industries and to benefit from the exploitation of the nation's mineral and petroleum resources" (Section 2 d). Section 100 (2 a, b) of the MPRDA gives effect to this objective, empowering the Minister to develop a broad-based socio-economic empowerment charter that would set the framework, targets and timetable for effecting the entry of **Historically Disadvantaged South Africans**



**(HDSA)** into the mining industry, and would allow South Africans to benefit from the exploitation of mining and mineral resources.

The Broad-Based Socio-Economic Empowerment Charter for the South African Mining and Minerals Industry, amended in 2010, has given mining companies provision to offset the value of the level of beneficiation achieved against a portion of its HDSA ownership requirements of up to 11 % as compared to the current required level of 26 %. Furthermore, mining companies are required to procure a minimum of 40 % of their capital goods, 70 % of their services and 50 % consumables from Black Economic Empowerment entities (REPUBLIC OF SOUTH AFRICA 2004).

### **Precious Metals Act of 2005 (Act No. 37 of 2005)**

The objectives of the Act are to ensure that precious metal resources of the Republic of South Africa are exploited and developed in the best interest of the people of South Africa; to promote equitable access to, and local beneficiation of, the Republic's precious metals; to promote the sound development of precious metal enterprises in South Africa, and to advance the objectives of broad-based socio-economic empowerment as prescribed.

Provisions of the Precious Metals Act give priority to applicants who will promote equitable access to and the orderly local beneficiation of precious metals. Section 12 of the Precious Metals Act prohibits export of unwrought gold and platinum, except with the written approval of the Minister. The Minister will grant the approval subject to the promotion of equitable access to local beneficiation.

### **The Beneficiation Strategy**

As South Africa develops a more coordinated approach to industrialisation, the role of the country's mineral commodities as inputs into the economy will be even more significant in both short-term and long-term planning.

The Beneficiation Strategy aims at "providing a strategic focus for South Africa's minerals industry

in terms of developing mineral value chains and facilitating the expansion of beneficiation initiatives in the country, up to the last stages of the value chain" (DMR 2009, p. 6). It makes provision for a framework "within which South Africa can implement and orderly development the country's mineral value chains in order to leverage benefit from inherent comparative and competitive advantages" (DMR 2009, p. 5).

The beneficiation strategy seeks to facilitate economic diversification, accelerate the move towards a knowledge-based economy, and achieve an incremental GDP growth in mineral-value addition per capita (DMR 2009). The strategy focuses on the beneficiation of ten mineral commodities, with the selection of five value chains that would flow from these commodities (DMR 2009). The five value chains include (DEPARTMENT OF MINERALS AND ENERGY 2009):

- energy, using the commodities of coal and uranium
- steel and stainless steel, using iron-ore, chromium, manganese, vanadium and nickel
- pigment production, using titanium
- auto-catalyst and diesel particulate manufacture, using platinum-group metals
- diamond processing and jewelry, using gold, platinum and diamonds.

## **3.2 Taxation policy**

South Africa's tax regime is set by National Treasury, and managed by the South African Revenue Service (SARS) which was established by legislation (The SARS Act) to collect revenue and ensure compliance with tax laws. SARS administers the following Acts which impact on the mining industry:

- Income Tax Act No. 58 of 1962
- Value Added Tax Act No. 89 of 1991
- Customs and Excise Act No. 91 of 1964
- Skills Development Levies Act No. 9 of 1999
- Diamond Export Levy Act No. 15 of 2007
- Diamond Export Levy (Administration) Act No. 14 of 2007
- Mineral and Petroleum Resources Royalty Act No. 28 of 2008
- Mineral and Petroleum Resources Royalty (Administration) Act No. 29 of 2008.

### **Income Tax Act No. 58 of 1962**

Income tax (or corporate tax) is one of the most important levies on the minerals sector. According to Section 5 of the Income Tax Act, subject to the provisions of the Fourth Schedule (PAYE 'Pay-as-you-earn' and Provisional tax), there shall be paid annually for the benefit of the National Revenue Fund, an income tax in respect of taxable income received by or accrued to or in favour of any person (other than a company) during the year of assessment ended the last day of February each year; and any company during every financial year of such company.

The Eighth Schedule to the Income Tax Act deals with the determination of taxable capital gains and assessed capital losses to be included in gross income. The majority of mining capital assets qualify for a special capital redemption/allowance deduction and are therefore not subject to the Eighth Schedule. The specific assets which are excluded from the special capital redemption/allowance deduction include mineral rights and land.

Individuals currently pay tax on a sliding scale which increases as taxable income increases and companies pay tax on the basis of a fixed percentage of taxable income. The formula applicable for companies is given as  $y = a - (ab/x)$ , where;

'y' is the tax rate to be determined, 'a' is the marginal tax rate, 'b' is the portion of tax-free revenue, and 'x' is the ratio of taxable income to total income. By 2005 the marginal tax rate was 35 %.

### **Value Added Tax Act (VAT Act)**

The VAT Act provides for taxation in respect of the supply of goods and services and the importation of goods and requires the following fundamental compliance requirements: Registration as a vendor if annual turnover exceeds R 300,000 (compulsory) or, if annual turnover exceeds R 200,000 (voluntary);

File VAT returns by the 25<sup>th</sup> of the appropriate month (monthly, 2 monthly, 4 monthly, 6 monthly or once a year).

### **Customs and Excise Act**

The Customs Act provides for the levying of customs and excise duties and a surcharge; for a fuel levy, the prohibition and control of the importation, export or manufacture of certain goods, and for matters incidental thereto.

### **Skills Development Levies Act**

The Skills Development Levies Act provides for the imposition of a skills development levy which is one per cent of the leviable amount (remuneration paid to employees).

### **Mineral and Petroleum Resources Royalty Act**

Royalties are amongst the most popular additional mining levies globally. They are used as an element in the fiscal control in most mining jurisdictions. In South Africa, the intention of the Mineral and Petroleum Resources Royalty Act is to impose a royalty on the extraction and transfer of South Africa's mineral resources.

### **Diamond Export Levy Act**

The Act is intended to promote downstream local beneficiation of rough diamonds which are currently exported for beneficiation. The Act allows an exemption from the proposed export levy if an appropriate percentage of rough diamond is sold to local beneficiaries.

## **3.3 Black Economic Empowerment Act**

Government's objective is to achieve a more equitable distribution of national wealth and employment opportunities without impeding economic growth.

**The Broad-Based Black Economic Empowerment (B-BBEE) Codes of Good Practice** which came into effect in 2007 constitute the guidelines for promoting and measuring black empowerment.

- Small enterprises with a turnover of R5 million or less are exempted from participation and are considered fully compliant.
- Medium-size enterprises with a turnover of between R 5 and R 35 million may choose four out of the seven elements for calculating their empowerment scores.
- Foreign multinationals may ignore the ownership element if head office policy prohibits surrendering equity, and can make up the deficit through other BEE initiatives.
- Weightings of the seven elements of the “scorecard” give enterprises more flexibility while still keeping the emphasis on enterprise development and employment equity.
- Indirect ownership such as pension fund shareholding is now recognised, with a cap of 40 %.
- If a BEE company sells its investment in an enterprise, the enterprise does not have to re-qualify in terms of ownership.

Negotiated Industry and Sector Charters set goals for black participation and target dates. All charters have to conform to the codes.

The codes are legally binding only on government agencies; compliance by private companies is voluntary. However, non-compliance could seriously impede doing business with other companies seeking to obtain BEE points and practically eliminate the ability to compete for government licence concessions and tenders. Verification agencies that are authorised to verify black empowerment compliance must be accredited by the South African National Accreditation System Agency (SANASA).

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## 4 Overview of the economic geology

The geological evolution of South Africa is long and complex and covers some 3,700 million years (Ma) of Earth history. The foundation upon which the geological formations of South Africa have subsequently developed is the Kaapvaal Craton, which occupies the northeastern part of the country (Fig. 4.1). This ancient crustal block is made up largely of Archaean tonalitic and trondhjemitic gneisses and granitoids, along with lesser volumes of metamorphosed volcanosedimentary rocks known as greenstone belts. The greenstone occurrences are economically important, hosting many gold, antimony, copper, zinc, iron, talc, mercury, magnesite, barite and gemstone deposits (WILSON & ANHAEUSSER 1998).

### *Archean Cratons and Supergroups*

The Barberton Supergroup is the most significant gold-producing greenstone belt in South Africa, whilst the Murchison Belt, made up of rocks of the Gravelotte Group, continues to be an important source of antimony, gold, zinc and copper. The Kaapvaal Craton most probably formed by the accretion of many smaller terranes or crustal blocks, and was welded together and strengthened by underplating and igneous intrusions. A period of extensional tectonics followed, resulting in the formation of large sedimentary basins, such as the Witwatersrand and Pongola basins, and the outpouring of the Dominion and Nsuzi Group lavas, respectively. Hydrothermal remobilisation and concentration of the mineralisation occurred, probably as a result of thermal metamorphism caused by the intrusion of the Bushveld Complex to the north.

Collision between the Zimbabwe and Kaapvaal Cratons resulted in crustal thickening, which gave rise to the high-grade metamorphism associated with the Limpopo Belt. The oblique nature of this collision is thought to have initiated or re-activated major transcurrent fault systems, resulting in important structures, such as the Thabazimbi–Murchison lineament, which prepared the craton for later Proterozoic basin development. Extensive karsting of the Campbell Group dolomites in the Griqualand West area resulted in the formation and accumulation of substantial manganese deposits which, along with the vast deposits in the Kalahari Manga-

nese Field to the north, around Hotazel, constitute what may be the largest land-based repositories of manganese on earth, with more than 80 % of the known reserve base. Fluorspar deposits are also developed within the dolomite formations; overlying these are substantial deposits of banded iron formation which are exploited for iron ore in several places, the most important being Sishen and Thabazimbi. The iron formation also hosts amphibole asbestos, which was extensively mined in the past (WILSON & ANHAEUSSER 1998).

### *The Bushveld Igneous Complex*

The Bushveld Complex is the world's largest known layered intrusion and has an estimated areal extent of 66,000 km<sup>2</sup>. It contains an ultrabasic to basic unit, up to 9 km thick, known as the Rustenburg Layered Suite, which crops out as eastern, western and northern lobes, associated with acid (largely granitic) rocks termed the Lebowa Granite and Rashedoop Granophyre Suites. Though several intrusive centres have been recognised for Bushveld Complex rocks, there are many broad similarities in the basic–ultrabasic succession which has traditionally been divided into a Lower, Critical, Main and Upper Zone. The economically viable chromite reserves of the Bushveld Complex, most of which are hosted in the Critical Zone, are estimated at 68 % of the world's total, whilst the Complex also contains 56 % of all known platinum-group metals. The Merensky Reef, which has developed near the top of the Critical Zone, can be traced along strike for 240 km and is estimated to contain 60,000 t of platinum-group metals to a depth of 1 200 m below surface. The pyroxenitic Plat Reef horizon, north of Mokopane (Potgietersrus), contains a wide zone of platinum mineralisation, along with higher grades of nickel and copper than occur in the rest of the complex. Vanadium-bearing minerals occur in concentrations of between 0.3 and 2 % in up to 21 layers of titaniferous magnetite in the Upper Zone of the Complex, which contains almost 45 % of the world's vanadium (WILSON & ANHAEUSSER 1998).

### *Other economically important intrusions and geological events*

A very much smaller, though economically important, intrusive of similar age to the Bushveld Complex is the alkaline (carbonatite) complex at

Phalaborwa, in the east of the Limpopo Province. It is unique in that it is the only carbonatite in the world currently being mined for its copper content. By the time that the Palabora open-pit closed in 2002, an estimated 3.4 Mt of copper metal had been extracted along with more than 200 Mt of titaniferous magnetite and significant amounts of nickel, lead, selenium, tellurium, baddeleyite, gold, silver, rare-earth elements, uranium and platinum-group metals.

After basin development in the northern Kaapvaal Craton with the formation of the Waterberg basin and the subsequent infilling with lavas of predominantly clastic red bed sediments, the craton stabilised at about 1 800 Ma. The only other economically significant geological events that affected the Kaapvaal Craton during Proterozoic times were the intrusion of the Pilanesberg Alkaline Complex and the Premier diamond pipe at 1 300 Ma. The Premier pipe yielded the world's largest gem diamonds, and large gems continue to be recovered from time to time. The focus of tectonic activity and mineralisation within South Africa then moved to the Namaqua–Natal Metamorphic Belt, to the south and west of the craton. The Namaqua–Natal Metamorphic Province forms an arcuate belt, up to 400 km wide, which is draped onto and around the western and southern margins of the Kaapvaal Craton.

During the late Precambrian period the Pan-African orogeny was associated with the formation of a 3 000 km long chain of geosynclines around the southern and western Cape, and up into Namibia. Into these geosynclinal basins the Gariiep Supergroup and the Malmesbury, Kango, Kaaimans, Gamtoos, Nama and Vanrhynsdorp Groups were deposited; however, no economically significant mineralisation, except for limestone, has yet been discovered in the thick, largely sedimentary deposits (WILSON & ANHAEUSSER 1998).

### **Gondwana events and depositions**

Permo-Carboniferous glaciation followed when South Africa was migrating over the South Pole, leading to the deposition of glacial sediments of the Dwyka Group. Following this, parts of the vast Karoo basin, which covers about two-thirds of South Africa, were filled with basinal muds, deltaic sands and less extensive coal-forming peats. The latter occur in the northeastern part of the

basin, and resulted in the formation of the extensive Ecca Group coal measures, which provide the main source of energy for South Africa and support a massive export industry. Some heavy mineral placers are also developed in the Karoo sediments. Extensive basic and acid lavas of the Lebombo and Drakensberg Groups cap the Karoo Supergroup and their extrusion preceded the fragmentation of Gondwanaland. South Africa began breaking away from Australia in the northeast around 200 Ma, and this breakup proceeded southwards and then westwards until the proto-Atlantic was formed about 120 Ma. This was accompanied and followed by widespread anorogenic alkaline magmatism of the kimberlitic, carbonatitic and ring-complex types. The kimberlites in particular are economically significant as some of them host important diamond deposits (WILSON & ANHAEUSSER 1998).

### **Cenozoic age**

Since the breakup of Gondwanaland, Cretaceous and Cenozoic basins and structural traps have developed around the coastal areas in which deposits of oil and natural gas have accumulated, and some success has been achieved in the delineation and exploitation of these resources. A thick blanket of terrestrial and fresh-water sediments of Cenozoic age, loosely known as the Kalahari Group sands, was deposited in the Northern Cape. Substantial quantities of minerals and metals occur in coastal dune sands, though their concentrations are only economically viable in a few places. Major mining operations at Richards Bay, on the KwaZulu-Natal coast, and at the Namakwa Sands project, on the Western Cape coast, extract large tonnages of titanium minerals, zircon and monazite. Diamonds have been concentrated in alluvial deposits in the Northern Cape and North West Provinces, and have been exploited for over a century. South Africa's long and varied geological history is certainly reflected in its extraordinary array of mineral deposits and occurrences (WILSON & ANHAEUSSER 1998).





## 5 Mineral raw materials

For this report, certain mineral commodities were studied regarding their potential in South Africa. Six different mineral commodities were selected, according to their significance and criticality for the German industry. New and promising mining and exploration projects as well as established and profitable mines of these commodities were visited and investigated in several field works. In this first part of the Investor's and Procurement's Guide occurrences of **heavy minerals**, **rare-earth elements** and **antimony** are specified and evaluated. After the common specifications and description of uses of these raw materials, the deposits and occurrences in South Africa are characterized by general information of the owners, the regional geology, the infrastructure and climate, also data for reserves, resources and production as well as an evaluation of the deposit are provided in this chapter. All known producers and suppliers are listed, further procurement information is available at DERA.

In the upcoming second part of the Investor's and Procurement's Guide, the raw materials chromite, fluor spar and platinum group elements will be specified.

### 5.1 Heavy Minerals

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Reviewed by *Dr. Gregory A. Botha*  
and *Dr. Douglas I. Cole*

#### 5.1.1 Definition, mineralogy and sources

##### *Definitions and characteristics*

Heavy minerals (HM) constitute all minerals with a density exceeding that of quartz, with economic deposits called placers. Heavy minerals enriched in placers which can be exploited commercially include ilmenite and its weathering products up to leucoxene, rutile and anatase, zircon, monazite and xenotime, staurolite, aluminum silica minerals (i.e. kyanite, andalusite and sillimanite), minerals of the garnet group, magnetite, chromite, cassiterite, tantalite-columbite, wolframite and

scheelite as well as precious metals, i.e. gold and platinum, gemstones, i.e. diamonds, rubies and sapphires. Although there are important placers of diamonds in South Africa, this report will only focus on placer deposits of ilmenite/leucoxene, rutile, zircon and garnet. Monazite and rare xenotime from placers do not constitute valuable minerals in South African mining operations at present. Monazite is usually highly radioactive and categorised as a contaminant. However, owing to an increasing demand for rare-earth elements and concomitant escalating prices, the use of monazite is nevertheless considered. The heavy mineral industry of South Africa is characterised by two major products: feedstocks (for the  $\text{TiO}_2$  pigment, titanium metal and welding electrode industries) and zircon. Low-grade titanium ores can be processed to form titanium slag. As a by-product of the titanium slag industry, pig iron is extracted in large quantities.

Of the numerous heavy minerals, only a few have economic significance owing to their properties and prevalence. These are called *valuable heavy minerals*, abbreviated as *VHM*. English references also use the terms *heavy mineral concentrate*, abbreviated as *HMC* and *total heavy minerals*, abbreviated as *THM*, to denote the total volume of heavy minerals within a deposit. The abbreviation *HMS* is used for heavy mineral sands deposits.

##### *Mineralogy*

Ilmenite ( $\text{FeTiO}_3$ )/leucoxene (a natural alteration product of ilmenite with a  $\text{TiO}_2$  content ranging from approximately 70 % to more than 90 %) and rutile ( $\text{TiO}_2$ ) represent the minerals with the greatest commercial importance as sources of titanium. Ilmenite may contain a theoretical maximum of 53 %  $\text{TiO}_2$ . Owing to leaching of iron, the  $\text{TiO}_2$  concentration of ilmenite in older beach sands in tropical climate may increase up to 70 %. South African beach sands contain ilmenites with some 48 %  $\text{TiO}_2$  (WIPPLINGER 1998). Rutile consists of virtually pure  $\text{TiO}_2$ , but may contain up to 10 % impurities in form of iron and vanadium oxides.

At present, bulk zircon production is obtained from zircon sand (containing zirconium as silicate). Currently mainly beach-sand deposits are of commercial importance, where zircon ( $\text{ZrSiO}_4$ ) is recovered in HM mining operations which also

produce ilmenite and rutile. Zircon theoretically consists of 67.2 %  $ZrO_2$  and 32.8 %  $SiO_2$ . In zircon the naturally occurring radioactive elements uranium and thorium are very often present.

### Sources of heavy minerals

In a normal weathering and erosional environment ilmenite, rutile and zircon are stable. They survive transport by water in fluvial and littoral environments and can be concentrated both by water activity and by aeolian processes to form placers. Heavy mineral placers are formed by the early settling of the heavy minerals from a transport medium when the flow energy abates. Placer deposits in fossil coastal dunes contain the bulk of the world's titanium and zircon resources. The most important heavy mineral placers in South Africa are:

**Coastal dunes (aeolian placers)** are formed by the blow-out of beach placers. Owing to the preferred incorporation of light minerals, dunes should generally be less rich in heavy minerals than the adjacent beach sands - however, there are exceptions because sorting also takes place in the dunes: in the windward area by the wind and on the leeward side through simple gravitational processes. Coastal dunes worldwide constitute very large, but frequently also relatively low-grade, deposits. An important example of this is the Richards Bay deposit in KwaZulu-Natal (ELSNER 2010).

Globally, very large deposits of ilmenite, rutile and zircon form so-called **beach placers (littoral placers)**. These are formed through complicated physical processes which result in a prominent concentration of heavy minerals in the foredune areas. After the deposit of a skin of sediment by a breaking wave, all the minerals initially exist in an unsorted assemblage. Owing to the flowback, the wave no longer has enough energy to remobilise the heavy minerals. These are therefore left as *lag deposits* after the removal of the lighter minerals. These lag deposits are often easily recognisable by the colour gradations of the minerals on the beach where they have been deposited and sorted according to their density. Beach placers formed in this way may contain very high concentrations of heavy minerals, on average 10 – 50 % and up to 100 %. They

mainly form concentrations of heavy minerals of economic interest (e.g. rutile, monazite, zircon, ilmenite, garnet) rather than lighter heavy minerals (e.g. epidote, hornblende). For such placers to be preserved in the long term, there must also be a fall in the sea level (through regression, uplift of the land etc.). The geomorphological characteristics of such beach placers are their narrow width (on average 100 m, up to 1,000 m), extensive length (on average 1 – 2 km, up to >15 km) and low thickness (on average 3 m, up to 11 m) (ELSNER 2010).

Most heavy mineral mines operate in placer deposits, with the majority located close to current or ancient shorelines, but there are also hard-rock ilmenite mines (e.g. in Canada, China and Norway). The mining of mineral sand deposits is conducted either "wet," by dredging, or "dry," using earth-moving equipment to excavate and transport the sands. Dredging is generally the favoured method of mining mineral sands, provided that the ground conditions are suitable and that water is readily available. In situations involving hard ground, discontinuous ore bodies, small tonnage or very high grades, dry mining techniques are generally preferred.

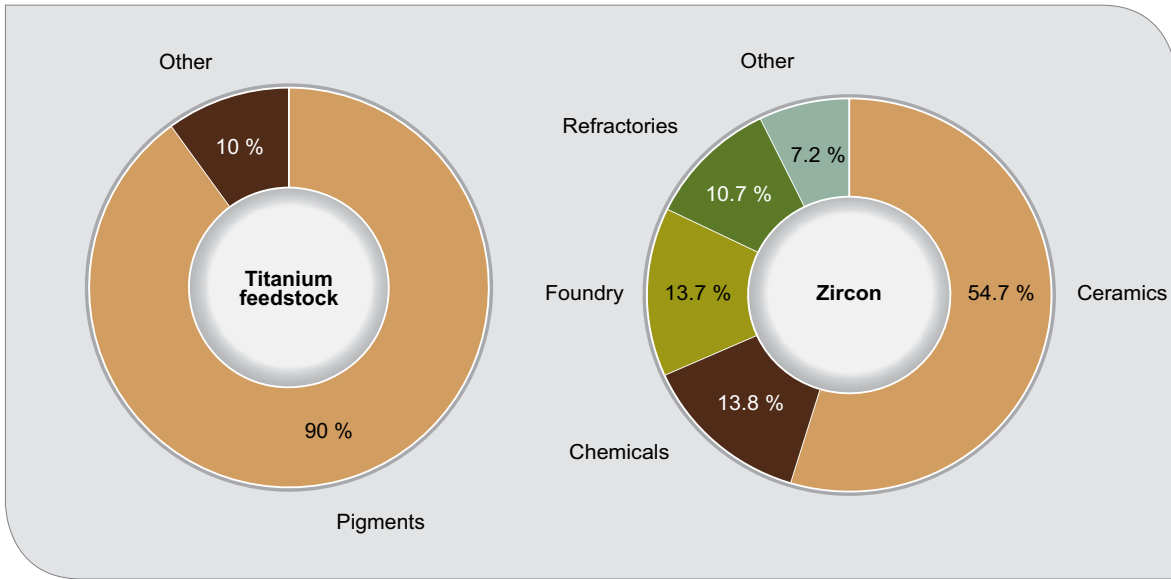
### 5.1.2 Specifications and use

Titanium minerals (ilmenite, rutile and leucoxene), titanium slag (chloride slag and sulfate slag), upgraded slag and synthetic rutile are all used primarily as feedstock (**titanium feedstock**) for the production of  $TiO_2$  pigment. There are two industrial processes for the manufacture of titanium dioxide, namely the sulphate process and the chloride process.

The main application (~90 %) of ilmenite, rutile and leucoxene (titanium feedstock) is in the  $TiO_2$ -pigment industry, with only a minor amount used to produce titanium metal. Other uses are in the production of titanium-based chemicals and of welding electrodes.

In 2011, about 54 % of the worldwide share of zircon was used in finely ground form in the ceramics industry. Zircon is also used in foundries (approx. 14 %), refractories (approx. 11 – 14 %), and chemicals (13.8 %) (ELSNER 2013).



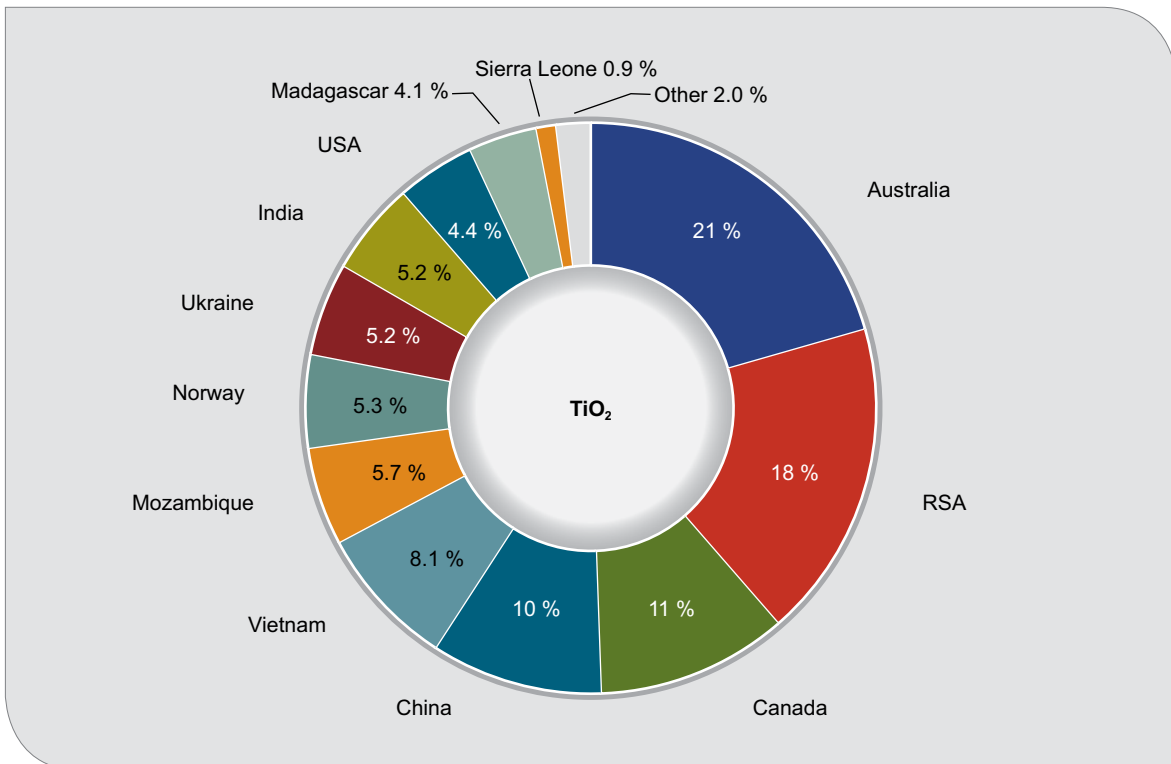


**Fig. 5.1.1: Worldwide consumption of titanium feedstock (estimated) and zircon by end-use in 2011 (after ROSKILL 2011).**

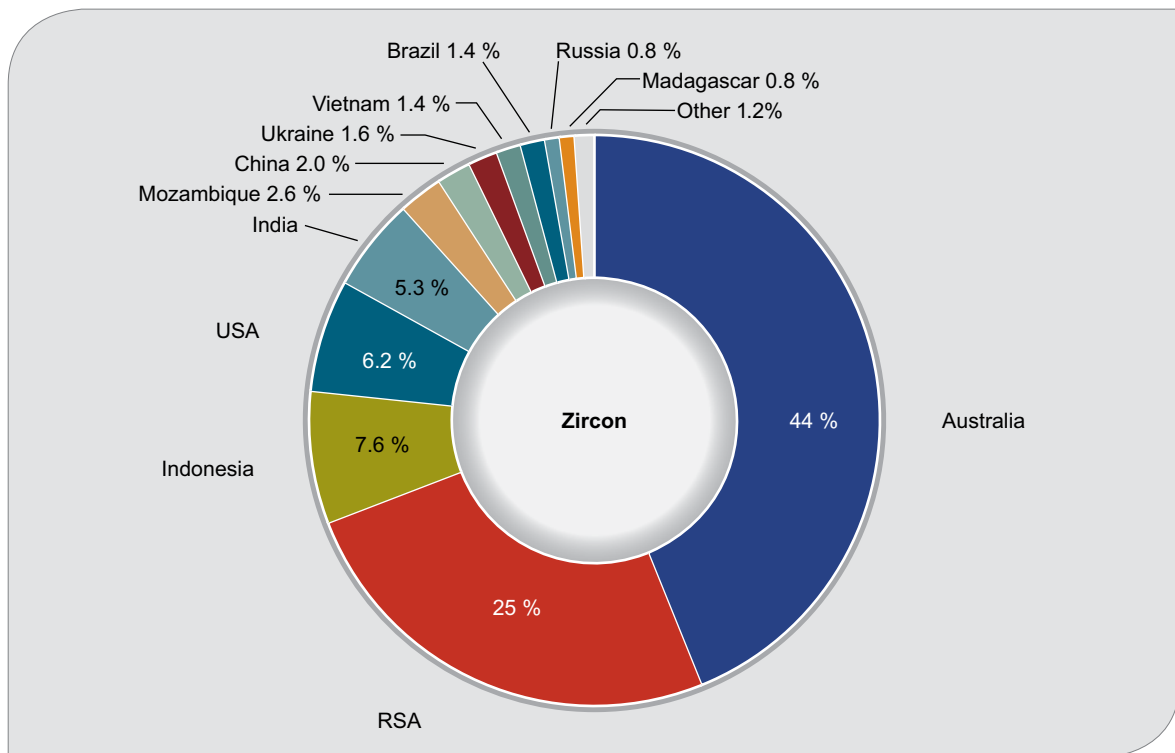
### 5.1.3 Supply and demand

The major ilmenite and rutile mining countries are the Republic of South Africa, Australia, Canada,

China, Vietnam and Mozambique. The major zircon mining countries are Australia, the Republic of South Africa, Indonesia, the USA, India, Mozambique, China and the Ukraine.



**Fig. 5.1.2: World mine production of titanium mineral concentrates (in TiO<sub>2</sub>) by country in 2011 (after BEDINGER 2013).**



**Fig. 5.1.3: World mine production of zircon by country in 2011 (ELSNER 2013).**

In 2011 around 6.80 million tonnes of titanium dioxide ( $\text{TiO}_2$ ) were produced (BEDINGER 2013). Within the  $\text{TiO}_2$  feedstock market there are two major product streams: chloride and sulphate. Of the total supply, chloride feedstock accounted for approx. 55.4 % while the other 44.6 % were constituted by sulphate feedstock. The largest end use of titanium feedstock is the pigment industry which accounts for almost 90 % of total demand. The average annual growth of this segment has been broadly in line with GDP, which was around 4 % p.a. over the last ten years, although much smaller other end uses including metal have experienced stronger growth at around 12 % p.a. (LUKA RESOURCES 2013).

In 2011 world zircon production reached a peak of 1.69 million tonnes. Zircon demand was about 1.385 – 1.396 million tonnes (ELSNER 2013). Although many consumers obviously stockpiled zircon for fear of even higher prices, supply was much higher than demand. This surplus of zircon on the world market in 2011 may have been about +300,000 tonnes (ELSNER 2013).

Currently, the heavy mineral mining industry of South Africa is favourably placed within the

world market, producing 427,000 tonnes zircon, which is just over 25 % of the world's total yield (1.69 million t) (ELSNER 2013) and about 1.23 million tonnes  $\text{TiO}_2$ , or 18 % of the world's ilmenite and rutile output (6.80 million tonnes  $\text{TiO}_2$ ) in 2011 (BEDINGER 2013). However, South Africa's heavy mineral industry is export oriented as a result of the limited demand in the local market.

#### 5.1.4 Resources in South Africa

South Africa's heavy mineral sands resources are mainly extensive beach placer and coastal dune deposits and are generally found at several localities along the Atlantic coast (Northern Cape, Western Cape) and along the Indian Ocean coast (KwaZulu-Natal, Eastern Cape). The localities of South African heavy mineral deposits are shown in figure 5.1.4. Titanium is contained in the minerals ilmenite/leucoxene and rutile. South African beach sands contain ilmenites with some 48 %  $\text{TiO}_2$  (WIPPLINGER 1998). Zircon is recovered as a by-product in all HM mining operations.

In South Africa, three heavy mineral mines are currently in operation: Namakwa Sands in the

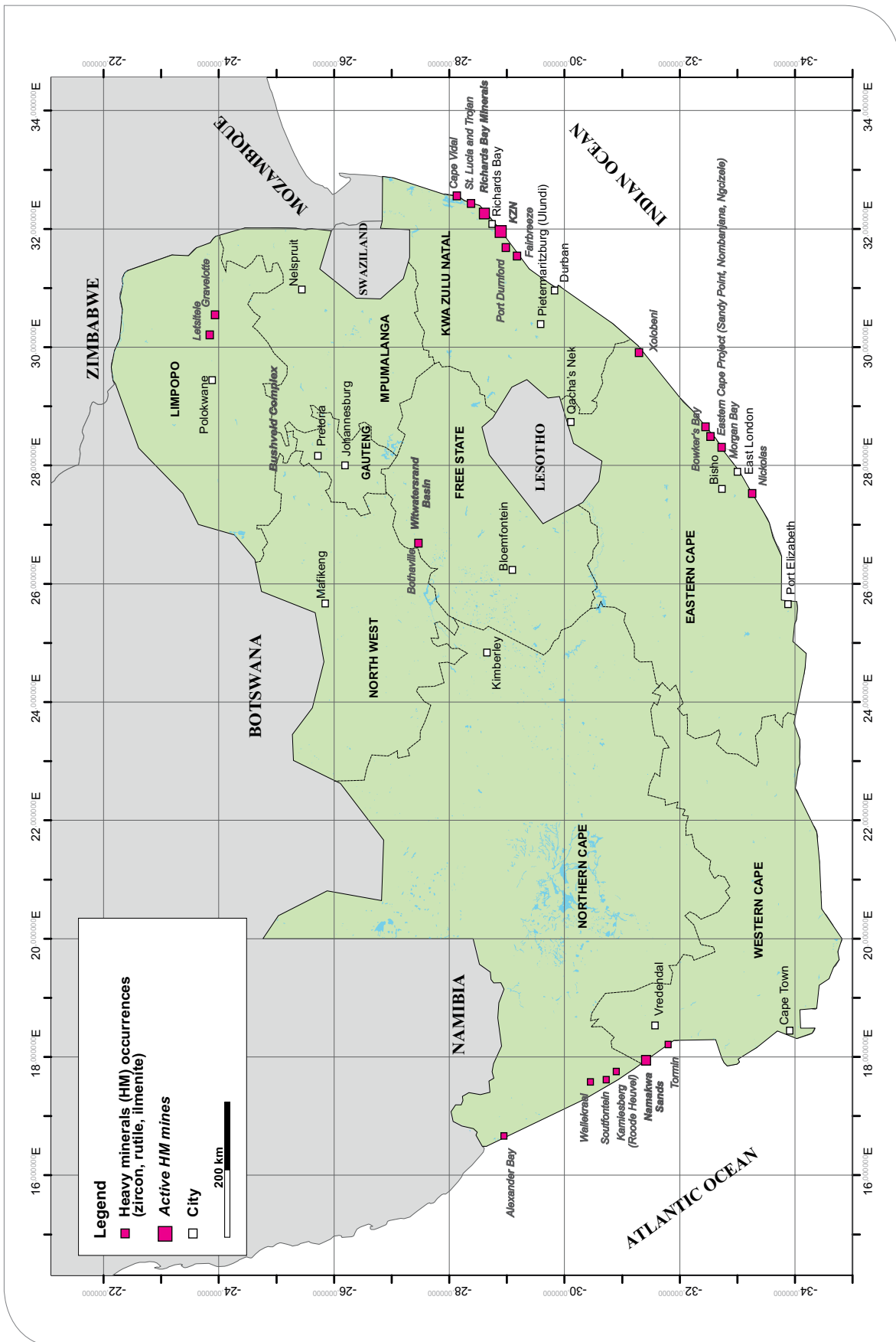


Fig. 5.1.4: Distribution of heavy mineral sand occurrences and deposits in South Africa.

Western Cape, KZN Sands (Hillendale Mine) and Richards Bay Minerals (RBM) in KwaZulu-Natal. Namakwa Sands started in 1994 and KZN Sands has been in operation since 2001. Both are owned by Tronox Ltd, based in Stamford, CT, USA. Richards Bay Minerals, which was established in 1976, is majority-owned by Rio Tinto Iron & Titanium Inc. (74 %). These operations produce titanium feedstock, including ilmenite, chloride and sulphate slag, rutile as well as the co-products zircon and pig iron and in Namakwa Sands also garnet.

In addition to the producing mines, several HMS projects are being developed at various stage (see the following chapters and the requirements and evaluation chapter).

#### 5.1.4.1 Wallekraal, Soutfontein, Alexander Bay, diamond mining dumps (Northern Cape)

The West Coast heavy mineral beach sands were initially investigated in the mid-1950s and again in the late 1960s, when an airborne radiometric survey was carried out by the Geological Survey of South Africa (the present-day Council for Geoscience). The coast line between Alexander Bay and Lambert's Bay was covered by this survey (WIPPLINGER 1998). Several heavy mineral deposits were discovered between the Groen River and Alexander Bay. These are, for example, Alexander Bay in the Northern Cape Province, the Wallekraal prospect, Soutfontein and Roode Heuvel (WIPPLINGER 1998). In all these areas there are diamond mining concessions, so access is restricted.

The **Wallekraal prospect** extends 20 km southwest of Wallekraal. The sand of this occurrence has a weaker radiometric signal than others of the area. According to WIPPLINGER (1998), no further exploration work has been done since the survey carried out by the Geological Survey of South Africa.

The **Soutfontein** occurrence is located 14 km south of the estuary mouth of the Bitter River. The terrain is flat without dunes and covers an area of 12 x 3 km. The sand has a radiometric signature and limited auger drilling produced about 12.3 %

heavy minerals in unconsolidated sand with a relative concentration of 8.8 % ilmenite, 0.1 % rutile and 1.8 % zircon. Monazite and hematite were also reported. It is estimated that the occurrence would contain 7.9 million t, should the value of about 12.3 % heavy minerals in unconsolidated sand be accepted as representative (HERZBERG 1970a, 1970b).

At **Alexander Bay**, black sand is found in association with diamondiferous gravels north and south of the estuary mouth of the Orange River. A sample of black sand from the modern beach at the Cape Voltas (11 km south of Alexander Bay) contained 26 % magnetite, 10 % ilmenite, 4 % hematite, 0.25 % monazite and some zircon. The viability of the occurrences is doubtful owing to the poor quality of the ilmenite, the limited size, the configuration and the remoteness of the occurrence (HAMMERBECK 1976).

The Alexander Bay Development Corporation investigated the possibility of exploiting heavy minerals from the marine diamond placers at Alexander Bay. The survey examined unmined marine terraces (Rietfontein-Grobler, Rietfontein-Higher, Gifko-Grobler and Langpan-Grobler), tailings dumps (Noordsif, Muisvlak Old, Muisvlak, Gifkop Old, Gifkop, Rietfontein Old, Rietfontein, Kaap Voltas Old and Kaap Voltas) and the Alexander Bay beaches with the intention of quantifying the resource, evaluating the material and evaluating the feasibility of exploitation.

It was estimated that the occurrence contained some 324,000 t ilmenite, 7,000 t rutile, 13,000 t zircon and 5,000 t monazite (KRUGER & DUARTE, 1992). KRUGER & DUARTE (1992) stated that the resource contained in the different deposits about 200,000 to 250,000 metric t of combined mineral concentrate on the terraces (monazite ~3,500, zircon ~7,500, ilmenite ~215,000 and rutile ~3,500 t), while the silt dams contained between 75,000 and 90,000 t of minerals (monazite ~1,300, zircon ~4,000, ilmenite ~75,000 and rutile ~3,000 t) and the beach approximately 40,000 t (monazite ~500, zircon ~1,500, ilmenite ~37,500 and rutile ~500 t). The terraces showed the most potential with the Rietfontein-Grobler terrace containing approximately 110,000 to 130,000 t of combined mineral concentrate. However, the feasibility of the occurrences is doubtful owing to their limited size, scattered nature and the fact that a large amount

of the ilmenite is too iron-rich. The feasibility of exploiting these heavy minerals in conjunction with the diamond mining should be assessed (WIPPLINGER 1998).

**Diamond mining dumps:** In the mine dumps of the onshore diamond mining operations between Koingnaas, Kleinzee and Alexander Bay, a coastal section of 250 km contains a large and underestimated heavy mineral resource. Diamonds are recovered from gravels above the strandline. These gravels are often overlain by heavy mineral, zircon-rich unconsolidated marine and dune sands that have to be moved to access the gravels. So far only limited attempts have been made to estimate the THM grade of the sands and the viability of recovering the economic minerals (PHILANDER 1999 in ROZENDAAL & PHILANDER 2008).

#### 5.1.4.2 Kamiesberg (Roode Heuvel, Leeuvlei) (Northern Cape)

##### Location and owner

Coordinates: 30°40'S / 17°37'E

The Kamiesberg Mineral Sands Project is located on the West Coast of the Northern Cape Province approximately 70 km north of Namakwa Sands, directly north of the Groen River, some 10 km from the estuary mouth of the river, about 30 – 40 km to the west of Garies.

Australian based Zircon Resources Ltd is developing the Kamiesberg Mineral Sands Project. Zircon Resources, a private, South African-focused mineral sands exploration and development company is a subsidiary of Minerals Corp. Ltd and was founded in 2005.

**Description of the prospecting areas:** The Kamiesberg Mineral Sands Project consists of two prospecting rights: the Roode Heuvel (6,000 ha) in the south and Leeuvlei (6,004 ha) in the north. 74 % of the prospecting right (heavy minerals) of Leeuvlei is held by Belcosat (Pty) Ltd, while 74 % of the prospecting right (heavy minerals) of Roode Heuvel is held by Zirco Roode Heuvel Pty (Ltd). Both subsidiaries are BEE compliant. The heavy minerals prospecting right for Leeuvlei was ex-

cuted in May 2011 and is valid for four years. The prospecting right for Roode Heuvel, granted in November 2007 is valid for five years and is renewable for three additional years. Namakwa Sands (Tronox) owns prospecting rights to the west of the project (De Klipheuvel and Roode Heuvel 502/4 and 502/7). These prospecting areas are named Groen River.

##### Geology

The heavy mineral assemblage is found in Quaternary unconsolidated sand (feldspathic aeolian sand, red aeolian sand unit) overlying Kamieskroon leucocratic gneisses.

##### Mining and processing

**Potential products** of Kamiesberg, identified by a scoping study 2012, are ilmenite (399,000 tpa), rutile and zircon (together 50,000 tpa) as well as monazite (4,000 tpa). The high manganese ilmenite (at 47.9 % TiO<sub>2</sub>) is suitable for blended feed into titanium slag production or sulphate process. Local offtake opportunities for REE-rich monazite are seen in potential local REE projects.

**Exploration/project history, resources:** The property is the southern portion of a radiometric anomaly measured in the 1960s. Anglo American Corporation located major resources during 1985 – 1990. In 2011, a JORC-compliant mineral resource estimate of 99.7 Mt at 5 % THM was established for the upper 3 m of approximately 2,000 ha of the estimated 10,000 ha. TZMI completed a positive scoping study in 2012. The scoping study is based on a 20 year life of mine and an ore feed of 210 Mt, producing 520 ktpa of concentrate. An updated JORC-compliant mineral resource estimate was announced to be completed in December 2012. Zirco Resources has an exploration target of more than 1,000 Mt heavy mineral sands for the entire project area, mineralised from surface to ±25 m below surface. A prefeasibility study is in progress, scheduled for completion by mid-2013, with a planned start up of the mine in 2016.

Namakwa Sands Groen River Property has been evaluated by Exxaro/Namakwa Sands to contain resources of 419.5 Mt ore sand at 4.07 % THM.

**Infrastructure:** Access to the national power grid is envisaged at Zandkopsdrift (a rare-earth project from Frontier Rare-Earths) in 2015, 35 km away from Kamiesberg. This assumes that Zandkopsdrift will be implemented. Groundwater, sea water and sea water desalination are specified as potential water sources. It is likely that the freshwater

supply will require a pipeline. The project area is accessible via a secondary road from Garies, about 50 km away. The nearest railway connection is at Bitterfontein, some 85 km away. Springbok in the north and Vredendal in the south are the nearest major towns. Skilled workers for the mine who are ready to move to the region are needed.

**Tab. 5.1.1: Resources and mineral assemblage of Kamiesberg.**

	Tonnes (Mt)	HM (%)	Ilmenite (%)	Zircon (%)	Rutile (%)	Leucoxene (%)	Monazite (%)
<b>Total</b>	99.7	5.00	3.99	0.39	0.13	0	0.06
		HM (%)	Ilmenite (% in HM)	Zircon (% in HM)	Rutile (% in HM)	Leucoxene (% in HM)	Monazite (% in HM)
		5.0	79.8	7.8	2.6	0	1.2

Source: ZIRCO RESOURCES LTD (2012).

**Tab. 5.1.2: Resources and mineral assemblage of Namakwas Groen River.**

	Tonnes (Mt)	THM (%)	Ilmenite (%)	Zircon (%)	Rutile (%)	Leucoxene (%)
<b>Groen Rivier</b>	419.53	4.07	3.46	0.46	0.14	0.32
		THM (%)	Ilmenite (% in HM)	Zircon (% in HM)	Rutile (% in HM)	Leucoxene (% in HM)
		4.07	85.0	11.3	3.4	7.9

Source: GOLDER ASSOCIATES (2010).

**Tab. 5.1.3: Summary of data for the Kamiesberg Mineral Sands Project (ZIRCO RESOURCES LTD 2012).**

<b>Total HM resource</b>	99.7 Mt @ 5 % THM
<b>Contained HM</b>	5 Mt
<b>Planned annual production</b>	399,000 t ilmenite; 50,000 t rutile + zircon; 4,000 t monazite
<b>Annual mine production capacity (ore tpa)</b>	520,000 t HM concentrate
<b>Estimated mine life</b>	20
<b>Mining method</b>	Open cast
<b>Mineral separation plant</b>	No data
<b>Recovery rate</b>	No data
<b>Risks (for mining, processing and mine waste storage)</b>	Infrastructure, low zircon content, processing
<b>Stage</b>	Scoping study, prefeasibility study in progress
<b>Planned start of mining</b>	2016
<b>Cash cost (US\$/t)</b>	No data
<b>Capex (million US\$)</b>	183



**Fig. 5.1.5: Location of the Kamiesberg Project (modified after ZIRCO RESOURCES LTD 2012).**

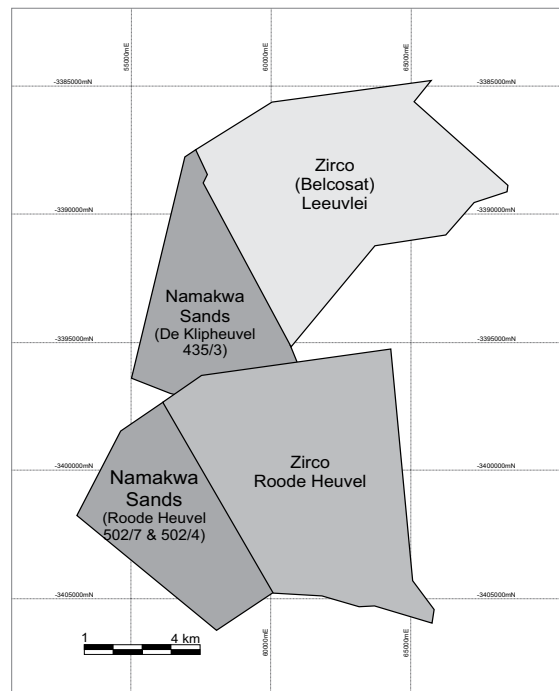
### 5.1.4.3 Namakwa Sands (Brand-se-Baai) (Western Cape)

#### Location and owner

Coordinates: 31°16'S / 17°54'E

The Namakwa (Namaqualand) Sands open-pit mines and concentration plants are located at Brand-se-Baai, 385 km north of Cape Town, about 50 km north of the estuary mouth of the Olifants River, with the nearest towns being Koekenaap, Lutzville and Vredendal.

The Namakwa Sands operation is one of the largest mineral sand operations in the world. The business encompasses exploration, mining, mineral concentration, separation and smelting operations. The Mineral Separation Plant (MSP) is located 52 km from the mine on the way to Vredendal, 7 km northwest of Koekenaap (near Lutzville). The smelter is situated near Saldanha Bay, 150 km from Cape Town.



**Fig. 5.1.6: Prospecting areas of the Kamiesberg Project and Namakwa Sands Groen River (modified after ZIRCO RESOURCES LTD 2012).**

Namakwa Sands is owned by Tronox Ltd, based in Stamford, CT, USA. Tronox owns 74 % in KZN Sands and Namakwa Sands. The operation was formerly owned by Exxaro Resources Ltd, but in June 2012 the mineral sands business of Exxaro Resources was taken over by Tronox Ltd. Exxaro's mineral sands operations consist of a 26 % direct equity interest in KZN Sands and the Western Cape operations of Namakwa Sands as well as a 44.65 % equity interest in Tronox Limited, which is listed on the New York Stock Exchange.

The heavy mineral operations of Tronox in South Africa comprise Namakwa Sands and KwaZulu-Natal (KZN) Sands.

**Description of the deposit:** The Namakwa Sands orebody, including proximate satellite extensions, covers more than 26,000 ha (PHILANDER & ROZENDAAL 2012). This area stretches approximately 5 km along the coast, encompassing an area commencing at a line running roughly parallel to and some 300 m inland from the high water mark of the West Coast and reaching almost 14 km inland.





**Fig. 5.1.7: Namakwa Sands operation showing primary density separation and secondary magnetic separation in the foreground and an extensive working pit in the background (Photo courtesy of Dr. D.I. Cole, Western Cape Unit, Council for Geoscience).**

### Geology

Heavy minerals are widely distributed along the entire West Coast and are mainly concentrated in a late Cenozoic sequence of unconsolidated near-shore marine, terrestrial and aeolian sands. The sediments were deposited on a gently sloping arid coastal plain during the mid-Miocene (~17 Ma) to late Pleistocene (0.1 Ma).

The economic mineralisation is hosted in three distinct geological units. The two localised heavy mineral-enriched marine strandline deposits (STR) are the oldest units, located at 20 and 35 m above mean sea level, respectively, are tens of metres thick and overlie a non-mineralised megadune. Heavy minerals are anomalously concentrated along the log-spiral morphology of the residual STR beaches. The Orange Feldspathic Sand unit (OFS) comprises 45-m-thick orange-yellow reworked terrestrial sand containing the bulk of the mineralisation. The Red Aeolian Sand unit (RAS), a 1–3-m-thick surface aeolinite, caps the deposit. By contrast to the STR, heavy mineral distributions of the overlying aeolian OFS and RAS are visibly aligned along a SW–NE strike, bearing testimony to the dominant prevailing wind directions at the time of their deposition. Generally, the mineralisation extends from the surface down to the footwall and no overburden stripping is required.

The bulk of the mineralisation is hosted by this strandline-aeolian sequence, partly negatively affected by several layers of superimposed Ca-Mg – Al-Fe – Si duricrust lithologies which semilithified the sands to various degrees. Lithified zones may be up to tens of metres thick (PHILANDER & ROZENDAAL 2012, ROZENDAAL & PHILANDER 2000, 2008, ROZENDAAL et al. 2009).

### Mining and processing

**Mining method:** Mining is undertaken at two mine sites and pre-concentration is undertaken at two primary plants and one secondary concentration plant at Brand-se-Baai. Namakwa Sands extracts heavy mineral sands using dry mining techniques (truck-and-shovel method). Shallow sand mining takes place in the East Mine (4–8 million tpa ore) and deeper, more compacted sand is exploited in the West Mine (12–14 million tpa ore).

Produced concentrate at Brand-se-Baai is transported over 52 km by truck to the mineral separation plant (MSP) at Koekenaap. At the MSP, electrostatic, dry magnetic and gravity methods separate the ilmenite, garnet, rutile and zircon. Zircon is acid leached to remove iron coatings. The three products are dispatched by rail via the Sishen-Saldanha line to the smelter near





**Fig. 5.1.8: Mining of unconsolidated Namakwa ore sands using front-end loaders (load-and-carry operation). The hardened layers are mined using hydraulic excavators in a backhoe configuration or by trackdozer. The mined material is transported by trucks to the mineral sizers where primary reduction takes place (Photo DERA).**

Saldanha Bay. There, Namakwa Sands operates two furnaces where the ilmenite is smelted to produce titanium slag and pig iron. Products for the overseas market are shipped predominantly via the Saldanha harbour.

**Products, capacity:** The saleable product portfolio includes titanium feedstock, including ilmenite, chloride slag, slag fines and rutile concentrate as well as zircon and pig iron as by-products. Current capacity is 125,000 tpa zircon, 210,000 tpa

titanium slag (chloride and sulphate), 110,000 tpa pig iron and 25,000 tpa rutile/leucoxene. In addition, garnet is separated during the ilmenite beneficiation process. The coarser garnet fraction is further refined by a local customer to produce sandblasting material. At Namakwa Sands, a premium-grade zircon, a zircon product called "Zirkwa" and zircon rejects containing about 20 % zircon are produced. The latter product was previously sold to China, but Tronox plans to beneficiate it itself in the near future.

**Tab. 5.1.4: Production by Namakwa Sands.**

	2006 (t)	2007 (t)	2008 (t)	2009 (t)	2010 (t)	2011 (t)	2012 (t)
<b>Ilmenite</b>	272,000	300,000	315,000	244,000	251,000	377,000	183,000
<b>Zircon</b>	128,000	115,000	130,000	116,000	128,000	135,000	54,000
<b>Rutile</b>	28,000	24,000	27,000	26,000	28,000	31,000	18,000
<b>Pig iron</b>	83,000	91,000	103,000	73,000	82,000	109,000	58,000
<b>Scrap iron</b>	8,000	11,000	6,000	–	–	1,000	–
<b>Chloride slag</b>	112,000	126,000	135,000	97,000	119,000	152,000	68,000
<b>Sulphate slag</b>	23,000	27,000	24,000	20,000	23,000	27,000	13,000

Source: EXXARO RESOURCES LTD, Annual Reports.

Most of the impure zircon and leucoxene, along with monazite, pyroxene and garnet, are rejected to stockpiles for possible future reclaim. In the Namakwa Sands deposit, considerable resources of REEs, U and Th are hosted in the monazite, impure zircon, leucoxene and garnet. For more information about REE Potential in Namakwa, refer to the chapter on Rare-Earths.

**Exploration/Mining history:** The discovery of diamonds drew significant interest to the South African West Coast. Investigations of the West Coast beach sands were done in the mid-1950s. In the late 1960s, the Geological Survey of South Africa (now the Council for Geoscience) carried out an airborne magnetic/radiometric survey. In the mid-1980s, Anglo American Corp. initiated

**Tab. 5.1.5: Heavy mineral sands reserves, estimated at 31 December 2012.**

	Tonnes (Mt)	HM (%)	Ilmenite (% in HM)	Rutile (% in HM)	Zircon (% in HM)	Leucoxene (% in HM)
Proved	271.9	9.7	33.8	2.4	9.5	5.2
Probable	160.3	7.1	34.7	2.7	8.1	6.0
<b>Total</b>	<b>432.2</b>	<b>8.8</b>	<b>35.1</b>	<b>2.5</b>	<b>9.1</b>	<b>5.4</b>

Source: EXXARO RESOURCES LTD (2012).

**Tab. 5.1.6: Heavy mineral sands resources<sup>1)</sup> estimated at 31 December 2012.**

	Tonnes (Mt)	Ilmenite (%)	Zircon (%)
Measured	509.6	3.11	0.79
Indicated	257.4	2.55	0.62
Inferred	142.3	2.38	0.61
<b>Total</b>	<b>909.3</b>	<b>2.84</b>	<b>0.72</b>

<sup>1)</sup> Incl. reserves. Source: EXXARO RESOURCES LTD (2012).

**Tab. 5.1.7: Summary of data for the Namakwa Sands Mine (from EXXARO RESOURCES LTD 2012).**

<b>Total HM resource end 2012 (cut-off grade 0.2 % zircon)</b>	Reserves: 432.2 Mt @ 8.8 % HM Resources <sup>1)</sup> : 909.3 Mt @ 2.84 % ilmenite, 0.72 % zircon
<b>Contained HM</b>	Ilmenite: 253.7 Mt Zircon: 6.5 Mt
<b>Production 2012</b>	255,000 t HM (ilmenite, zircon, rutile) + 58,000 t pig iron
<b>Annual mine production capacity (ore tpa)</b>	21 Mt ore
<b>Life-of-mine plan (by year)</b>	20 years (2030)
<b>Mining method</b>	Dry mining, open-cast mining
<b>Mineral separation plant/smelter</b>	MSP and smelter operated by Tronox
<b>Recovery rate</b>	90 % HMC grade <sup>2)</sup>
<b>Risks (for mining, processing and mine waste storage)</b>	–
<b>Start of mining</b>	1994
<b>Cash cost</b>	No data
<b>Capex</b>	No data

<sup>1)</sup> incl. reserves. <sup>2)</sup> Percentage of total heavy minerals in the heavy mineral concentrate.

exploration for economic concentrations of zircon, ilmenite and rutile along the coast. The Namakwa Sands deposit was identified as an electromagnetic and radiometric anomaly from the airborne radiometric survey. In 1987, scout drilling penetrated heavy mineral-bearing Tertiary sands to depths of 35 m and extending several km inland from the coast. Anglo American started mining at Brand-se-Baai in September 1994. Exxaro acquired effective ownership of Namakwa Sands on 1 October 2008. Since 2009, Namakwa Sands has used an annual drilling programme to enable better long-term planning. In July 2011, Exxaro submitted an application to extend its mining activities beyond the border line. Exxaro received approval from the DMR in March 2012, subject to a number of conditions. A resource definition drilling programme, as part of the Namakwa Sands Mine expansion, is planned.

**Resources:** Total resources at the end of 2012 stood at 909.3 million t ore sand, grading 2.84 % ilmenite and 0.72 % zircon. Rutile is estimated at 0.2 %, leucoxene at 0.5 % and monazite at 0.02 %. This figure includes total reserves of 432.2 million t ore sand grading 8.8 % HM constituting 34.1 % ilmenite, 2.5 % rutile, 5.4 % leucoxene and 9.1 % zircon, i.e. ilmenite reserves are 13 million t, rutile 0.9 million t, leucoxene 2.0 million t and zircon reserves are 3.5 million t. Namakwa Sands is estimated to have production reserves to sustain a life of mine of 35 years (ANGLO AMERICAN 2007).

In the north, the Groen River occurrence (see Kamiesberg Project) is still being evaluated.

**Infrastructure:** The mining area can be accessed by public or tar roads, for which Namakwa Sands has the right of way. These roads had to be constructed. Fresh water had to be delivered from Koekenaap to the mine via a pipeline. The SishenSaldanha railway connects the mineral separation plant near Lutzville and the smelter. Shipping takes place from the Saldanha Bay deep water harbour.

The region is dominated by agriculture. Vredendal is the nearest major town.

#### 5.1.4.4 Tormin (Geelwal Karoo) (Western Cape)

##### Location and owner

Coordinates: 31°35'S / 18°07'E

The Tormin Mineral Sands Project is a zircon and rutile deposit located on the coast of the Western Cape, approximately 400 km north of Cape Town, north of the Oliphants River outfall and south of the Namakwa Sands heavy mineral mine.

The Tormin heavy mineral mining rights are held by Mineral Sands Resources (Pty) Ltd (MSR), a 50 %-owned South African subsidiary of Mineral Commodities Ltd (MRC), the other 50 % are owned by Black Economic Empowerment (BEE) partner Blue Bantry Investments (Pty) Ltd (Blue Bantry). Mineral Commodities Ltd (MRC) is an Australian Stock Exchange (ASX) quoted Company which has two mineral-sands projects under development in South Africa, namely Xolobeni and Tormin. Trans Hex Operations (Pty) Ltd (THG), a South African diamond producer, holds the rights to diamond production from the area.



**Fig. 5.1.9:** Geelwal Karoo heavy mineral beach placer, 24 km west of Lutzville. The heavy mineral sands occur on both the foreshore and backshore with the reddish colour being attributable to an abundance of garnet (Photo courtesy of Dr. D.I. Cole, Western Cape Unit, Council for Geoscience).

**Description of the deposit:** The heavy mineral placer deposits have accumulated along the ~12-km-long, 100-m-wide beach, to a maximum depth of 12 m.

### Geology

Tormin has beach deposits of zircon, rutile and ilmenite with garnet, pyroxene and leucoxene contained within the assemblage. The predominant heavy mineral is garnet. The heavy mineral placer is situated in an active beach environment. Large quantities of heavy minerals are concentrated in the Neogene marine terraces along the West Coast. The coastal environment is still being supplemented through erosion by a 25-m-thick heavy mineral-enriched sand deposit, which rests on a paleobeach terrace situated locally up to 35 m above the current sea level (MACDONALD & ROZENDAAL 1995). MRC (2013) confirms the established geology of the region, a heavy mineral-rich offshore zone, as the source of the beach deposits. The beach is continuously replenished through the tidal transportation of sands from deeper waters. MRC assumed that the geomorphology of the J-shaped coastline works as a natural concentrator of offshore-sourced heavy minerals on the beach. Owing to the combination of near-shore currents and the morphology of the coastline, heavy minerals are more concentrated by the action of the water in the curve of the J at the south end of the beach than in the north (MIRABAUD SECURITIES LLP 2013).

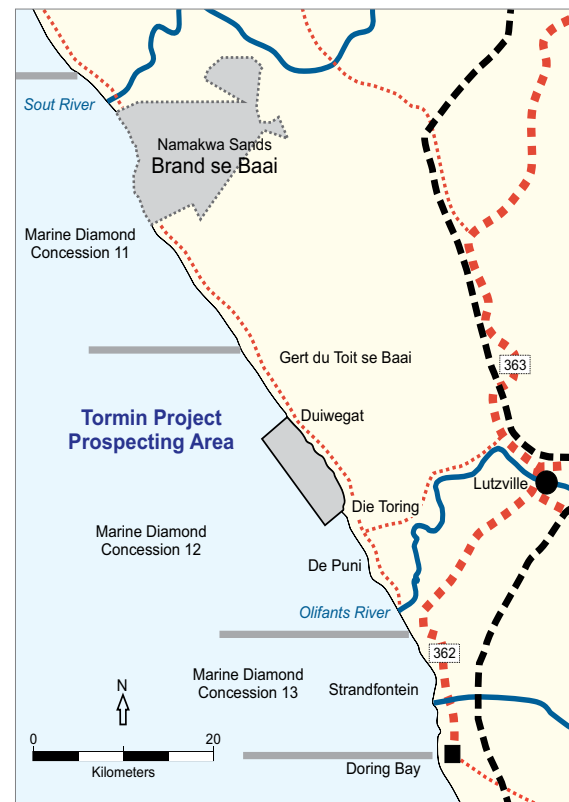
### Mining and processing

**Potential mining method, capacity and products:** It is envisaged that the primary concentrate of 500,000 tpa recovering >95 % of zircon and rutile will be produced by mobile primary beach concentrators (PBC, primary spiral-plant concentrators). Pre-concentration will be followed by secondary concentration through a wet high-intensity magnetic separation circuit (WHIMS, located in a central position off the beach) and screens which will separate magnetic ilmenite from zircon and rutile before bagging and shipment to destination markets. Assuming an initial four to five year expected life of mine, MRC announced the operational processing of approximately 47,800 t

of enriched non-magnetic concentrate, containing 38,700 t zircon and 5,500 t rutile annually, plus garnet as a by-product (134,000 tpa grading 71 %). These production levels refer to the initial two years of the four to five year life of mine when higher grades are scheduled to be mined and processed. Production levels will drop in the latter years as feed grades decline.

In addition, the company could produce approximately 100,000 – 125,000 t of low-grade (47.5 % – 48.7 %  $\text{TiO}_2$ ) ilmenite once MRC installs its own dry concentration facilities (which is planned to be incorporated into Blastrite's nearby dry mineral separation plant).

**Exploration history and resources:** Several feasibility studies on the Tormin Project have been completed. The diamond producer Trans-Hex Group (THG) completed several phases of drilling and bulk sampling between 1989 and 1991. Based on that work and the feasibility study, Tormin resources were defined in 1992 for the



**Fig. 5.1.10: Location of the Tormin prospecting permit application (after MINERAL COMMODITIES LTD 2005).**

entire beach as 4.9 million t grading 42.3 % HM (9.2 % ilmenite, 0.6 % rutile, 2.6 % zircon, 22.3 % garnet). Adapted from the historical drilling results from THG and its own bulk sampling of the southern beaches, MRC compiled a JORC-compliant indicated resource estimate of 2.71 million t grading 49.4 % heavy minerals, yielding about

92,400 t zircon, 18,700 t rutile and 286,500 t ilmenite in 2006. This statement is valid for the southern portion of the beach only and so far indicates only a short-lived operation. Additional work is planned to improve and upgrade the 4.9 million t resources from 1992 to JORC standards. The exploration target resource for Tormin on which MRC plans

**Tab. 5.1.8: Tormin JORC indicated resources (2006).**

	Tonnes (Mt)	HM (%)	Ilmenite (%)	Rutile (%)	Zircon (%)	Garnet (%)
<b>Indicated resources</b>	2.7	49.4	10.6	0.7	3.4	25.3

Source: MINERAL COMMODITIES LTD (2012).

**Tab. 5.1.9: Trans Hex historical resource (1992).**

	Tonnes (Mt)	HM (%)	Ilmenite (%)	Rutile (%)	Zircon (%)	Garnet (%)
<b>Inferred resources</b>	4.9	42.3	9.2	0.6	2.6	22.3

Source: MINERAL COMMODITIES LTD (2012).

**Tab. 5.1.10: MRC exploration targets (2012).**

	Tonnes (Mt)	HM (%)	Ilmenite (%)	Rutile (%)	Zircon (%)	Garnet (%)
<b>Target</b>	5.0	41.3	8.5	0.5	2.6	16.4

Source: MINERAL COMMODITIES LTD (2012).

**Tab. 5.1.11: Summary of data for the Tormin Sands Project (from MIRABAUD SECURITIES LLP 2013; MINERAL COMMODITIES Ltd 2006, 2012, 2013).**

<b>Total HM resource</b>	Indicated resources: 2.7 Mt @ 49.4 % HM
<b>Contained HM</b>	Zircon: 92,400 t Rutile: 18,700 t
<b>Planned annual production</b>	40,000 t zircon-rutile concentrate
<b>Annual mine production capacity (ore tpa)</b>	500,000 ore
<b>Estimated mine life</b>	4 – 5 years
<b>Mining method</b>	Dry mining, open-cast mining
<b>Mineral separation plant</b>	MSP by Blastrite in Lutzville
<b>Recovery rate</b>	95 %
<b>Risks (for mining, processing and mine waste storage)</b>	Shorter-lived operation; low reserve estimates
<b>Start of mining</b>	End 2013
<b>Cash cost (US\$/t)</b>	12.92 of ore mined / 18.22 cif China
<b>Capex (million US\$)</b>	16 (incl. 10 % contingency, excl. working capital); additional ~4 if ilmenite is recovered



the lifetime of the mine is therefore 5 million t grading 41.3 % HM (13.6 % ilmenite, 0.7 % rutile, 3.4 % zircon, 18.3 % garnet).

It is believed that there is potential for mined-out voids to be replenished by wave action over time with heavy mineral-bearing sediments currently lying offshore. MSR plans to test this theory further, and was awarded the offshore prospecting rights to the area extending 1 km out to sea from the low-water mark along the entire 12 km length of the Tormin beach tenement in 2012. The company is optimistic that replenishment from, or exploitation of, this area or the direct exploitation of potentially heavy mineral-bearing submarine sands could extend the life of mine by at least five additional years. This theory has yet to be tested and quantified.

**Costs:** MRC estimates direct cash production costs at US\$ 12 – 13/t of ore mined (at an FX assumption of US\$ 1 = R 8.20) and all-in total cash costs (inclusive of assumed cif costs to China) at just over US\$ 18/t. MRC estimates that recovering a finished ilmenite product could be achieved for an increase of just ~US\$ 5/t of ore mined to total cash costs. MRC estimates the upfront Capex at US\$ 16m (inclusive of 10 % contingency, but excluding working capital), with an additional US\$ 4m required if the objective to recover an ilmenite product is pursued (MIRABAUD SECURITIES LLP 2013).

**Status:** The Tormin beach deposit is permitted and ready for development as a zircon-rutile concentrate-producing operation. Mine construction has commenced in April 2013 and first production is expected by the end of the third quarter of 2013, with peak production levels in 2014 and 2015.

**Infrastructure:** The site is accessible from Lutzville by gravel road. National roads link the project to the Cape Town and Saldanha Bay deep water harbours. MRC has concluded an MOU with Blastrite in order to provide mining, processing, procurement, warehousing, logistics, human resource management, financial administration, IT and regulatory compliance for Tormin. Blastrite's MSP is located in Lutzville.

#### 5.1.4.5 Bowker's Bay, Morgan Bay, Nickolas (Eastern Cape)

The **Bowker's Bay** (also known as Cebe) occurrence, investigated by the Transkei Mining Corporation, is centred on the Cebe Cottages and extends from the mouth of the Cebe River for about 5 km in a southwesterly direction. A resource of 7.5 Mt of sand containing 5.78 % ilmenite, 0.26 % rutile and 0.49 % zircon has been outlined (E. L. BATEMAN ENGINEERING LTD 1988).

The **Morgan Bay** (also known as Cape Morgan) deposit is situated on the coast, 6 km southwest of the Kei River Mouth. Here, 64 Mt of unconsolidated aeolian sand rests on a dolerite sill and sediments of the Beaufort Group. The sand is considered to be a wind-reworked beach deposit consisting of quartz grains, ilmenite (2.8 %), rutile (0.14 %) and zircon. The clay content of the sand is low and little colloidal suspended material is present, which should ensure successful processing (E. L. BATEMAN ENGINEERING LTD 1988).

At Morgan Bay, the older dunes appear to have been entirely removed by erosion and only younger, reworked beach sand remains, characterised by an absence of constituents that would go into colloidal suspension if tailings from the deposit were disposed of into the sea.

During the past 20 years or so, several entrepreneurs have, from time to time, been interested in the deposit; one has claimed a reserve of 70 million t of sand containing 7.9 % heavy minerals within a suitable lease area and others contended that values are generally too low and inconsistent to allow for exploitation. The compositions of the ilmenite and rutile are similar to those from Sandy Point (HAMMERBECK 1976). The Morgan deposit was exploited to some extent in the 1960s (COAL, GOLD AND BASE MINERALS 1967). Production was by means of the "dry" plant of the now-defunct Umgababa operations.

At **Nickolas**, situated on the coast about 40 km southwest of East London, a subeconomic resource of 64 Mt aeolian sand with high clay content has been demonstrated. Little is known about the surrounding geology, but the dune sand consists of quartz and the heavy minerals ilmenite (3.26 %), rutile (0.15 %) and zircon (E. L. BATEMAN ENGINEERING LTD 1988).

### 5.1.4.6 Xolobeni (Eastern Cape)

#### Location and owner

Coordinates: 31°10'S / 30°06'E

The Xolobeni Mineral Sands Project is situated on the coast of the Eastern Cape, approximately 300 km north of East London and 200 km south of Durban, south of Port Edward.

The Xolobeni rights are held by a South African subsidiary of the Australian-based Mineral Commodities Ltd (MRC), Transworld Energy and Minerals Resources (SA) (Proprietary) Ltd (TEM). Xolobeni Empowerment Company (Pty) Ltd (XolCo), the empowerment partner, holds a 26 % stake in the company.

Mineral Commodities Ltd (MRC) has two mineral sands projects under development in South Africa, Xolobeni and Tormin.

**Description of the occurrence:** The Xolobeni tenement covers an area of 2,867 hectares over a strike length of 22 km and a width of 1.5 km. The deposit is divided into five distinct blocks by rivers, the Mpahlane, Mnyameni, Kwanyana, Sikombe

and Mtentu blocks. MRC was granted prospecting rights on four of the five property blocks that make up the Xolobeni Project. A conditional mining licence on the Kwayana block (which accounts for 40 % of the total project resources) was revoked in May 2011 for environmental reasons.

#### Geology

The heavy mineral-bearing sand occurs in a coast-parallel band of dunes resting on quartzite of the Msikaba Formation and Natal Metamorphic Province granites (WIPPLINGER 1998). The area consists of three main dune systems which range from 25 m to 95 m above sea level. The mineralised sands are found within recent sands and remainder red beds of the Plio-Pleistocene Berea Formation. The area is not covered by overburden and the predominant valuable heavy mineral is ilmenite.

#### Mining and processing

**Exploration history, resources:** The deposit has been explored by Rhombus Exploration and Richards Bay Minerals, who decided not to follow up the project, mainly on the basis of the low ilmenite concentrations (WIPPLINGER 1998).

Tab. 5.1.12: Xolobeni JORC resources.

	Tonnes (Mt)	HM (%)	Ilmenite (% in HM)	Ilmenite (%)	Ilmenite (t)
Measured	224	5.7	54.5	3.1	
Indicated	104	4.1	53.7	2.2	
Inferred	18	2.3	69.6	1.6	
<b>Total</b>	<b>346</b>	<b>5.0</b>	<b>54.0</b>	<b>2.7</b>	<b>9,300,000</b>

Source: MINERAL COMMODITIES LTD (2012).

Tab. 5.1.13: Xolobeni block resource data.

Area	Resource Status	Tonnes (Mt)	HM (%)	Ilmenite (%)
Mtentu	Not drilled			
Sikombe	Measured	85	5.5	3.1
Kwanyana	Measured	139	5.8	3.1
Mnyameni	Indicated	104	4.1	2.2
Mpahlane	Inferred	18	2.3	1.6
<b>Total</b>		<b>346</b>	<b>5.0</b>	<b>2.7</b>

Source: MINERAL COMMODITIES LTD (2005).



**Tab. 5.1.14: Summary of data for the Xolobeni Mineral Sands Project**  
(from *MIRABAUD SECURITIES LLP 2013, MINERAL COMMODITIES LTD 2006, 2012, 2013*).

<b>Total HM resource</b>	Resources: 346 Mt @ 5.0 % HM
<b>Contained HM</b>	17.3 Mt HM Ilmenite: 9,300,000 t
<b>Planned annual production</b>	No data
<b>Annual mine production capacity (ore tpa)</b>	No data
<b>Estimated mine life</b>	25 years
<b>Mining method</b>	Open-cast mining
<b>Mineral separation plant/smelter</b>	Construction is proposed
<b>Recovery rate</b>	No data
<b>Risks (for mining, processing and mine waste storage)</b>	Environmental concerns, poor infrastructure
<b>Stage</b>	Prefeasibility study
<b>Start of mining</b>	No data
<b>Cash cost (US\$/t)</b>	No data
<b>Capex (million US\$)</b>	No data

Mineral Commodities Ltd (MRC) took control of Xolobeni in 2001. In February 2002, the company was granted a prospecting permit. After an extensive drilling programme in 2002, MRC completed a prefeasibility study and in 2003 announced a major resource upgrade at Xolobeni according to the JORC code. There has been a significant increase the discovery of resources in the central Kwanyana and Mnyameni blocks. The majority of resources has been enhanced from inferred to measured and/or indicated status. Xolobeni has an estimated resource of 346 million t ore sand grading 5.0 % HM, containing some 17 million t HM and 9.3 million t ilmenite. Rutile, zircon and leucoxene add significant value to the deposit. The expected life of mine is 25 years.

MRC renewed its prospecting rights in October 2005. The prospecting rights, excluding the Kwanyana block, were extended in November 2011. However, the conditional mining rights were revoked in 2011 for environmental reasons.

Xolobeni is a world-class HM project in terms of scale. MRC, who, since 2001, had hoped to develop it, has faced significant environmental opposition. Considerable uncertainty remains as to if and when prospecting rights will be secured for the Kwanyana block, and/or whether a mining right will be awarded for the wider project thereafter.

#### 5.1.4.7 Eastern Cape Project: Sandy Point, Nombanjana, Ngcizele (Eastern Cape)

##### Location and owner

Coordinates: 32°35'S / 28°31'E

The Eastern Cape Project (also known as Centane Project) is situated about 80 km northeast of East London, on the coast some 15 km north-east of the Kei River Mouth, in the vicinity of Centane (Mnquma).

Tronox Ltd (formerly Exxaro Resources), a company based in Stamford, CT, USA, has held the prospecting rights on the deposits known as Sandy Point, Nombanjana (renamed from Wavecrest) and Ngcizele (renamed from Kobonqaba). Exxaro holds 44.65 % equity interest in Tronox Limited (Tronox).

**Description of the deposit:** The three discrete Eastern Cape Project heavy mineral deposits arise along the southern part of the former Transkei coast and are situated, from north to south, at Sandy Point, Nombanjana and Ngcizele. The prospecting permit, which was for the first time granted in 1998, covers an area of about 1,972 hectares and is subdivided by two perennial rivers.

The intention is that the Eastern Cape Project deposits are a potential long-term supplier of ilmenite feed for the smelter operation of Tronox (KZN Sands) at Empangeni in KwaZulu-Natal, where titanium slag is produced.

### Geology

There are four principal heavy mineral deposits: Sandy Point Recent, Sandy Point Old, Nombanjana and Ngcizele. The Sandy Point Old, Nombanjana and Ngcizele deposits consist of undulating fixed inland dune cordons straightened parallel to the coast and are generally 4 to 5 km wide and up to 80 m thick. These heavy mineral-bearing aeolian dunes were deposited during a marine regression in the late Tertiary to early Quarternary. Intense weathering resulted in the deep red colour of the Berea-type red sands and in higher silt content. The Sandy Point Recent deposit consists of younger dunes and partly reworked beach sands, separating the older fixed dunes from the sea.

### Mining and processing

**Exploration history:** A number of companies, including Anglo American Prospecting Services in 1987 and Rhombus Exploration in 1988, have evaluated heavy mineral deposits along the coast in the vicinity of Centane since early 1970. They have conducted detailed exploration work as part of their prefeasibility studies on Centane. In 1994, Iscor Heavy Minerals (IHM), now Tronox, acquired the right to the deposits from Shell South Africa and Rhombus, when Iscor Limited purchased Natal Mineral Sands. In 1998, the Department of Minerals and Energy (DME) granted a prospecting permit on the three discrete deposits known as Sandy Point, Wavecrest

(renamed Nombanjana) and Kobonqaba (renamed Ngcizele).

In October 2002, the DME requested all activities in the Eastern Cape to stop. The new Mineral and Petroleum Resources Development Act (Act 28 of 2002) was promulgated in 2003 and all existing prospecting permits had to be converted into new-order prospecting rights.

In October 2006, the older-order prospecting permit, covering 1,972 hectares, was converted into a new-order prospecting right in compliance with the Mineral and Petroleum Resources Development Act (MPRDA). An embargo on prospecting activities in the Eastern Cape remained in force until the DMR issued a clarification in February 2008 to proceed with prospecting activities.

In 2008, Exxaro drilled 66 boreholes on the Ngcizele deposit. However, drilling on the Nombanjana deposit has not been finalised because local communities interrupted and stopped the drilling because they had decided that they did not want mining in the area.

In October 2011, the new-order prospecting right over the Eastern Cape Project property lapsed. A renewal for the prospecting right has been submitted, but the outcome is still pending.

**Resources:** Estimated resources (31 December 2012) amount to 255.9 million t ore sand with 11.5 million t ilmenite content (grading at 4.5 % ilmenite). A study by SRK CONSULTING LTD in 2006 lists estimated mineral resources for Sandy Point, Kobonqaba (renamed Ngcizele) and Wavecrest (renamed Nombanjana) of 232.94 million t ore sand (16 million t THM), containing 4.5 % ilmenite, 0.2 % rutile and 0.4 % zircon.

**Tab. 5.1.15: Mineral sands resources, estimated at 31 December 2012.**

Eastern Cape Project (Nombanjana, Ngcizele, Sandy Point (old and recent))	Tonnes (Mt)	Ilmenite (%)
Measured	226.2	4.62
Indicated	9.9	3.30
Inferred	19.8	3.92
<b>Total</b>	<b>255.9</b>	<b>4.51</b>

Source EXXARO RESOURCES LTD (2012).

**Tab. 5.1.16: Mineral sands resources, estimated at 1 January 2006.**

Indicated Mineral Resources	Tonnes (Mt)	THM (%)	Ilmenite (%)	Zircon (%)	Rutile (%)
Kobonqaba (Ngcizele)	85.38	5.8	4.2	0.4	0.2
Sandy Point Old <sup>(1)</sup>	34.21	9.5	5.5	0.5	0.3
Sandy Point Recent	34.63	9.5	5.6	0.5	0.3
Wavecrest (Nombanjana)	78.72	5.8	3.9	0.4	0.2
<b>Total</b>	<b>232.94</b>	<b>6.9</b>	<b>4.5</b>	<b>0.4</b>	<b>0.2</b>

<sup>1)</sup> The new-order prospecting right application was submitted on 30/08/2005 to renew the old-order prospecting permit No. 3/2000 PP (expiry date 17/09/2005). Source: SRK CONSULTING LTD (2006).

**Tab. 5.1.17: Summary of data for the Eastern Cape Project (Centane Prospecting Project) (from EXXARO RESOURCES LTD 2012).**

Total HM resource	255.9 Mt @ 4.51 % Ilmenite
Contained HM	Ilmenite: 11.5 Mt
Planned annual production	No data
Annual mine production capacity (ore tpa)	No data
Estimated mine life	No data
Mining method	No data
Mineral separation plant	No data
Recovery rate	No data
Risks (for mining, processing and mine waste storage)	Environmental restrictions, infrastructure
Stage	Application for renewal of the prospecting right has been lodged
Start of mining	No data
Cash cost (US\$/t)	No data
Capex (million US\$)	No data

**Infrastructure:** The area is remote and lacks infrastructure. There is currently no infrastructure in place to supply power or water to the Eastern Cape Project deposits. In addition, the area is situated far from railway and port connections.

#### 5.1.4.8 Cape Vidal, St Lucia and Tojan (KwaZulu-Natal)

##### Location

The area of the St Lucia and Tojan deposits is centred about 20 km northeast of St Lucia in the northern KwaZulu-Natal Province. The deposits extend over a 22-km-long and 2-km-wide shore-parallel sand dune belt.

The Cape Vidal occurrence is located nearly 37 km northeast of St Lucia in the northern KwaZulu-Natal province. It consists of a strip of shore-parallel coastal Quaternary sand dunes some 9 km long and about 2 km wide.

##### Geology

The heavy mineral deposits are confined to the Maputaland Group (Fig. 5.1.11) which extends, with some variation, northwards from the Durban area to the Mozambique coastal plain. Similar deposits can be traced to the Eastern Cape border, beyond which they become discontinuous (ROBERTS et al. 2006).

The dunes rest on lagoonal sediments, older dune sand and limestones, sandstones and

conglomerates of the Maputaland Group (MAUD & BOTHA 2000, ROBERTS et al. 2006, BOTHA & PORAT 2008, BOTHA & PORAT 2009). The dunes consist of unconsolidated red and white Quaternary aeolian sand. Details on the lithostratigraphy of the deposits, based on prospecting drilling, along with cross-sections, are contained

within the geological specialist report by DAVIES et al. (1992) which was part of the Environmental Impact Assessment. The heavy minerals composition of the ore sand is estimated to be 3.2 % ilmenite, 0.2 to 0.4 % rutile and 0.3 to 0.7 % zircon and leucoxene (WIPPLINGER et al. 1999, HAMMERBECK 1976).

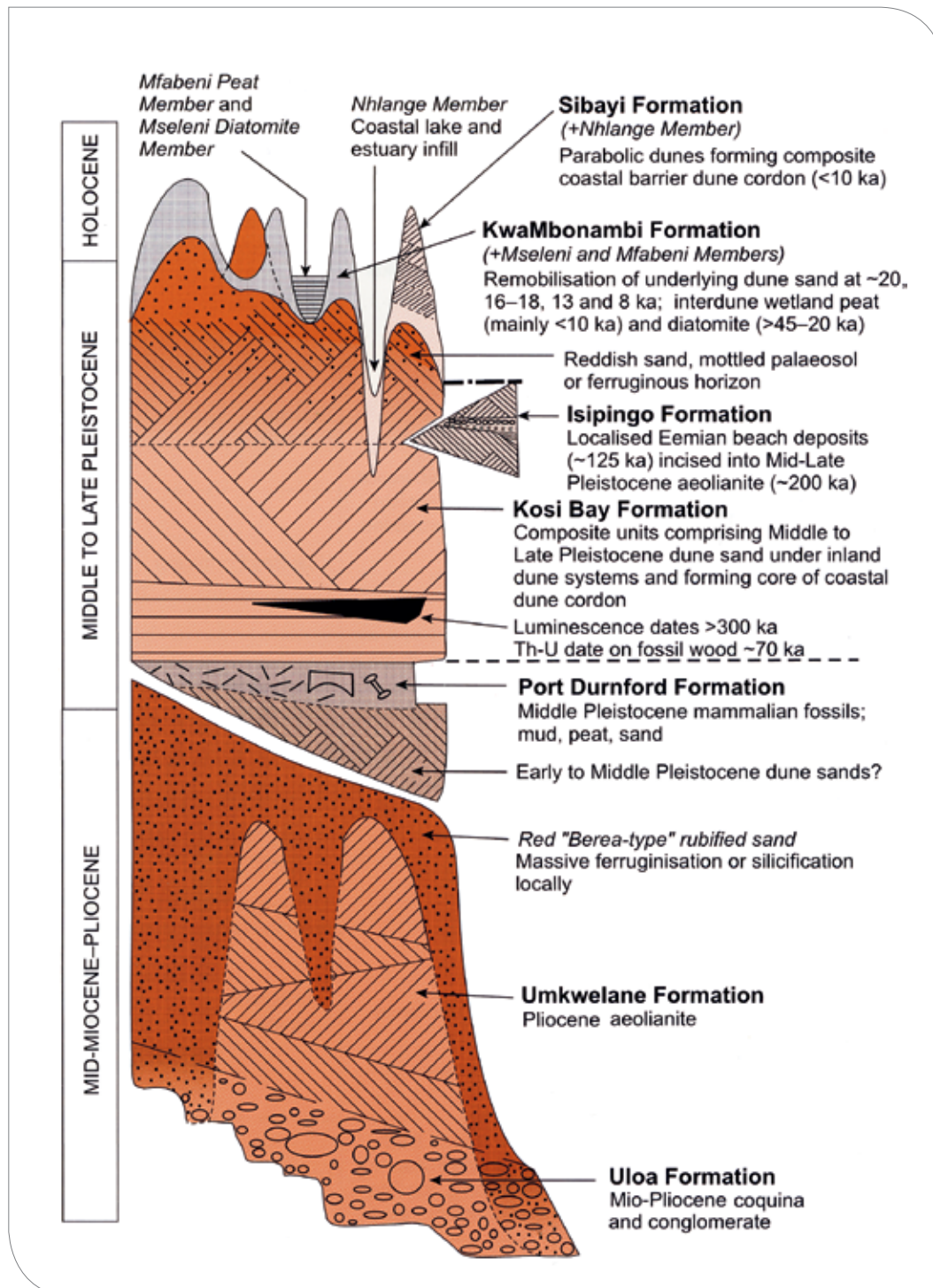


Fig. 5.1.11: Idealised composite section of the Maputaland Group (after ROBERTS et al. 2006).

### Mining and processing

Richards Bay Minerals surveyed the St Lucia and Tojan deposits and, according to WIPPLINGER (1998), 351 million t of ore-grade sand was outlined. It was proposed that the deposit would replace the Tisand deposit of Richards Bay Minerals when the latter had been mined out. An environmental impact study from 1993 proved positive in terms of exploitation and related issues. However, in 1996, the government of South Africa denied RBM permission to extend its mineral sand mining leases in the St Lucia estuary. One of the reasons was the unsurmountable conflict of interests between the mining industry and the Natal Parks Board who wanted the sand belt to be incorporated into a proposed park (WIPPLINGER 1998), which now forms part of the iSimangaliso Wetland Park, a UNESCO World Heritage Site.

Gold Fields (Pty) investigated the **Cape Vidal** occurrence in the 1970s. About 104 million t of ore-grade sand was outlined by means of auger drilling (WIPPLINGER 1998). However, owing to environmental considerations, no mining lease was issued.

The St Lucia, Tojan and the Cape Vidal deposits, even further to the north, will not be mined owing to environmental restrictions.

#### 5.1.4.9 Richards Bay Minerals (Zulti North, Tisand, Zulti South) (KwaZulu-Natal)

##### Location and owner

Mining area coordinates: 28°37'S / 32°17'E

The Richards Bay Minerals lease area is situated along the coast, north of Richards Bay and south of St Lucia, within the local Mbonambi and uMhlatuze Municipalities.

Richards Bay Minerals (RBM) operates a heavy mineral sand mine, a mineral separation plant (MSP) and a smelter complex which is situated between Lake Mzingazi and Lake Nhlabane within the uThungulu District Municipality.

In line with South Africa's Broad-Based Black Economic Empowerment (BBBEE) legislation and, after the sell-out of the former joint venture partner BHP Billiton in February 2012, Richards Bay Minerals (RBM) is now owned by Rio Tinto Iron & Titanium Inc. (74 %), a BBBEE Consortium Blue Horizon (24 %) and by an employees' trust (2 %). Richards Bay Minerals (RBM) is the trading name for two registered companies, Richards Bay Mining (Pty) Ltd (formerly Tisand (Pty) Ltd) and Richards Bay Titanium (Pty) Ltd. Richards Bay Mining undertakes the dune mining and mineral separation operations, while the smelting and beneficiation processes are carried out by Richards Bay Titanium.

**Description of the deposit:** The RBM heavy mineral-rich sands coastal dune deposits (Tisand, Zulti North) extend parallel to the beach. Mining was started within the Tisand lease just north of Richards Bay. Currently, the Zulti North mining lease (north of Lake Nhlabane) is being mined. The deposit covers a coast-parallel dune belt some 20 km long and about 2 km wide. The height of the dune is about 60 – 110 m, with increasing altitude northwards. The Zulti North Extension, the St Lucia, Tojan and the Cape Vidal deposits even further to the north will not be mined owing to environmental restrictions. Most of the area south of Zulti North, the Tisand lease, has already been mined and rehabilitated by RBM. Zulti South, south of Richards Bay, is still under exploration.

##### Geology

Quaternary heavy mineral-bearing aeolian dunes of the upper portions of the Maputaland Group (Sibayi and Kwambonambi Formations) resting on a Pleistocene beach are mined. Clay-enriched, weathered Kosi Bay Formation dune sands and the Port Durnford Formation estuarine deposits form the underlying beds. KZN Sands, located south of the Mhlatuze River, mined the clay-enriched, rubified weathering profile which formed within the older Umkwelane Formation dune ridge. FOCKEMA (1986) was involved with the establishment of Richards Bay Minerals from the initial investigations in 1967 until production commenced in 1975. Based on the results obtained from 1,400 boreholes, a summary of the heavy mineral distribution, mineralogy, cross-sections and ore reserves of the orebody in the dune area are described.



According to WIPPLINGER (1998) the dune sand contains about 10 % heavy minerals, on average consisting of 6.08 % ilmenite, 0.28 % rutile and 0.83 % zircon. The heavy mineral assemblage also comprises monazite and magnetite. The grade of the ilmenite is too low (49.7 % TiO<sub>2</sub> on average) to be marketable in its existing form and thus has to be upgraded by a smelting process to produce an 85 % TiO<sub>2</sub> slag.

### Mining and processing

**Mining method:** Mining is conducted by dredging. RBM uses six floating dredges at four mine sites (B, C, D and E) at various places within the dunes. In areas inaccessible to the dredges, or in dunes which are higher than 60 m, dry mining is performed. Mining proceeds from south to north. The HM concentrates are trucked to a central processing plant.

**Products:** Products are several grades of ilmenite, titanium slag, rutile (3 grades), zircon (4 grades) and high-quality pig iron. Monazite-rich talings are stockpiled, with RBM investigating its potential as a source of rare-earths.

Up to 160,000 tpa of zircon can be acid leached to produce a premium-grade zircon. Thus, the zircon grades currently produced are a premium calcined grade (ZPG), an uncalcined grade (ZUG), a standard grade (ZSG) and an intermediate (refractory) grade (ZIG). Production of foundry-grade zircon (ZFG) was stopped in 2012 (ELSNER 2013).

**Exploration/mining history, resources, capacity:** Richards Bay Minerals (RBM) is a HM mining and processing operation, which was formed by Union Corporation (later Gencor and now BHP Billiton) and Quebec Iron and Titanium Corporation in 1976. Since 1977, RBM has been mining the elevated dunal sand deposits north of Richards Bay. In 1977, extraction of heavy minerals was initiated with the Tisand deposit. Later the mining rights to additional ore reserves situated north (Zulti North) and south (Zulti South) of the original deposit were acquired with mining of the Zulti North deposit starting in 1987. Mining in this lease should last until 2033. The current capacity of the dry mill is estimated at up to 2 million tpa ilmenite, 300,000 tpa zircon and 100,000 tpa rutile. Since 1992, when a fourth furnace and mining plant were installed, the titania slag capacity of RBM has been about one million tpa and the pig iron production

Tab. 5.1.18: Production by RBM (in tonnes).

	2010	2011	2012
<b>Titania slag</b>	926,467	1,037,098	880,844
<b>Zircon</b>	221,987	264,076	263,673
<b>Rutile</b>	75,733	100,406	97,489
<b>Pig iron</b>	484,551	521,527	451,316

Source: RICHARDS BAY MINERALS (2012).

Tab. 5.1.19: Mineral sands reserves, estimated at end 2012.

RBM	2011 Titanium dioxide feedstock (Mt)	2012 Titanium dioxide feedstock (Mt)
<b>Proved</b>	7.9	6
<b>Probable</b>	16	15
<b>Total</b>	<b>24</b>	<b>21</b>

Source: RIO TINTO (2012) Annual Report.

Tab. 5.1.20: TiO<sub>2</sub> resources, estimated at end 2012.

RBM	Titanium dioxide feedstock (Mt)
<b>Measured</b>	–
<b>Indicated</b>	1.2
<b>Inferred</b>	1.2
<b>Total</b>	<b>2.3</b>

Without reserves.

Source: RIO TINTO (2012) Annual Report.

**Tab. 5.1.21: Summary of data for Richards Bay Minerals (from Rio Tinto 2012, RICHARDS BAY MINERALS 2012).**

<b>Total TiO<sub>2</sub> resources end 2012</b>	Reserves: 21 Mt titanium dioxide feedstock Resources: 2.3 Mt titanium dioxide feedstock
<b>Production 2012</b>	880,844 t titania slag, 263,673 t zircon, 97,489 t rutile, 451,316 t pig Iron
<b>Annual mine production capacity</b>	Titania slag to 1 Mt Zircon 250,000 t Rutile 100,000 t
<b>Life of mine plan (by year)</b>	Zulti North: 2034; Zulti South: 2043
<b>Mining method</b>	Hydraulic mining by dredges, open-cast mining
<b>Mineral separation plant/smelter</b>	MSP and smelter operated by Rio Tinto Iron & Titanium Inc.
<b>Recovery rate</b>	100 %
<b>Risks (for mining, processing and mine waste storage)</b>	–
<b>Start of mining</b>	1977
<b>Cash cost</b>	No data
<b>Capex</b>	No data

555,000 tpa. Including rutile and zircon, RBM has the annual capacity to produce nearly two million t combined output.

In March 2011, RBM commissioned a tailings treatment plant (TTP), with production beginning in April 2011. The operation had stockpiled 16 million t tailings from its mineral separation plant during the previous 30 years. In 2011, this TTP treated 415,034 t old tailings and 730,654 t new tailings from the MSP (RICHARDS BAY MINERALS 2011). On average, RBM can treat 2.2 million t tailings per year, yielding 60,000 tpa zircon, among others.

In March 2011, RBM announced its intention also to mine its Zulti South mining lease area south of Richards Bay, extending mining operations to around 2043. RBM expects that the pre-feasibility study and environmental approval will be completed by June 2017. Mining in the Zulti South area could start as early as 2017. Estimated resources for the latter lease are given as 22.3 million t net VHM.

**Infrastructure:** The Richards Bay area has developed industrial infrastructure in the form of roads, railways, electricity, water and waste disposal facilities. The multi-purpose, bulk-handling plant at Richards Bay harbour is one of the largest plants

of its kind in the world and RBM is one of its major customers.



**Fig. 5.1.12: Mining lease areas of RBM (after RICHARDS BAY MINERALS 2013).**



#### 5.1.4.10 KZN Sands (Hillendale) (KwaZulu-Natal)

##### Location and owner

Mining area coordinates: 28°50'S / 31°55'E

KZN Sands operates a heavy mineral sands mine at Hillendale, 20 km southwest of Richards Bay and a mineral separation plant (MSP) and a smelter at the central processing complex at Empangeni, located 20 km west of Richards Bay.

KZN Sands was once owned by South African steel giant ISCOR Ltd and Ticom Ltd of Australia (Ticom SA). After 2005, KZN Sands was owned by Exxaro Resources Ltd but, in June 2012, the mineral sand business of Exxaro Resources was taken over by Tronox Ltd. Tronox owns 74 % in KZN Sands. Exxaro's mineral sands operations consist of a 26 % direct equity interest in KZN Sands as well as a 44.65 % equity interest in Tronox Limited, which is listed on the New York Stock Exchange.

**Description of the deposit:** The Hillendale Mine area covers about 1,206 ha, which includes four properties: Hillendale, Reserve 10, Braeburn and Braeburn Extension. The mining operations consist of a mining area, a primary wet plant, a residue dam and a return water dam.

The Hillendale deposit is formed by an about 3.8 km long, 600 m wide dune ridge which runs parallel to the Mhlathuze River, about 8 km from the present coastline. The average height of the dune is 50 m, with the maximum height reaching 75 m above the river's flood plain.

##### Geology

The Hillendale HM deposit consists of the red-brown, Berea-type red sand weathering profile developed within rubified Plio-Pleistocene dunes which are older than the coastal dunes of Richards Bay and contain a higher clay content. The sediments are generally well sorted and fine to medium grained. Compared to modern dune sands, the Berea-type red sand weather-



**Fig. 5.1.13:** Hydraulic mining of HM-rich sands at KZN Sands in KwaZulu-Natal, Republic of South Africa (Photo DERA).

ing profile has a remarkably high content of fine-grained material that indicates decalcification and extensive weathering of feldspathic sand grains to kaolin. The aluminium-bearing phases are dominant in the fine-grained material.

Within the Hillendale deposit, the silt content varies from 15 % to 45 %. The average sand thickness ranges between 18 m and 21 m; the THM content is between 1 % and 25 % with valuable heavy minerals (VHM) constituting 10 % to 70 % of the THM set (SRK CONSULTING 2006).

### Mining and processing

**Mining method:** KZN Sands uses a unique hydraulic mining method. The *in-situ* sand is loosened and caved in by high-pressure water-jets, aimed at the mining face. The water operates as a carrier medium for the sand, owing to the high slimes content contained in the orebody. The slurry flows to a collection sump, oversize is removed and the residual material is pumped to the primary concentration plant where the heavy mineral concentrate is produced by a wet gravity separation process. The concentrate is transported by 35 t road trucks to the central processing complex ("CPC") at Empangeni for further processing (TRONOX LTD 2012). As Hillendale has already been mined out, current work focusses on the rehabilitation of the site.

**Capacity:** The design capacity of the Hillendale Mine is about 12 million tpa ore and that of the primary wet plant about 931,000 tpa heavy mineral concentrate. The design capacity of the mineral separation plant is about 596,000 tpa ilmenite,

60,000 tpa zircon and 30,000 tpa rutile. The design capacity of the smelter is about 220,000 tpa titanium slag (186,000 t chloride process slag and 30,000 t sulphate process slag) and 124,000 tpa pig iron (TRONOX LTD 2012).

**Products:** KZN Sands produces ilmenite, titanium slag, slag fines, zircon (a standard grade (30 – 40 vol. %) and a ceramic grade (60 – 70 vol. %)), rutile (2 grades: pigment rutile and standard), leucocoxene and low manganese pig iron. Zircon and rutile products are exported via Richards Bay harbour. The crude ilmenite product from the MSP is used as feedstock for the smelters at the central processing complex, where TiO<sub>2</sub> slag and low manganese pig iron are produced.

**Exploration history, resources:** The Hillendale deposit was initially sampled during the late 1980s. The KZN (KwaZulu-Natal) Sands Project started mining in July 1994 when several HM projects in South Africa, including Hillendale and Fairbreeze, were sold by Shell South Africa and Rhombus Exploration Ltd (Rhoex Ltd) to ISCOR Ltd. Tigor SA commenced hydraulic mining of the silt-rich ore sands at Hillendale in 2001. The operation is expected to end owing to depletion in the Braeburn Extension deposit at the end of 2013. It is planned that the Fairbreeze deposit, 25 km to the southwest will substitute the Hillendale Mine and that it will supply heavy mineral concentrate for the central processing complex (MSP and smelter) at Empangeni. As production at Fairbreeze cannot start before mid-2015, there will be a gap in HM production by KZN Sands of about 1.5 years. KZN Sands is considering scavenging or mining the Kidney Dam deposit (4–5 million t of sand @ 1 % HM) to extend the life of the Hillendale Mine.

Tab. 5.1.22: Production by KZN.

	2006 (t)	2007 (t)	2008 (t)	2009 (t)	2010 (t)	2011 (t)	2012 (t)
<b>Ilmenite</b>	319,000	367,000	229,000	368,000	236,000	168,000	147,000
<b>Zircon</b>	50,000	34,000	34,000	36,000	33,000	28,000	9,000
<b>Rutile</b>	25,000	17,000	19,000	20,000	17,000	17,000	7,000
<b>Pig iron</b>	75,000	90,000	50,000	108,000	71,000	51,000	46,000
<b>Scrap iron</b>	10,000	20,000	16,000	15,000	12,000	7,000	5,000
<b>Chloride slag</b>	134,000	150,000	95,000	104,000	113,000	129,000	66,000
<b>Sulphate slag</b>	36,000	26,000	18,000	24,000	29,000	22,000	42,000

Source: EXXARO RESOURCES LTD Annual Reports.

**Tab. 5.1.23: Mineral sands reserves, estimated at 31 December 2012.**

Hillendale Mine + Braeburn + Braeburn Ext.	Tonnes (Mt)	THM (%)	Ilmenite (% in THM)	Rutile (% in THM)	Zircon (% in THM)	Leucoxene (% in THM)
Proved	2.9	5.3	61.3	4.0	7.6	2.0
Probable	0	–	–	–	–	–
<b>Total</b>	<b>2.9</b>	<b>5.3</b>	<b>61.3</b>	<b>4.0</b>	<b>7.6</b>	<b>2.0</b>

Source: EXXARO RESOURCES LTD (2012).

**Tab. 5.1.24: Mineral sands resources (incl. reserves), estimated at 31 December.**

Hillendale Mine + Braeburn + Braeburn Ext.	Tonnes (Mt)	Ilmenite (%)
Measured	14.6	2.9
Indicated	0	–
Inferred	0	–
<b>Total</b>	<b>14.6</b>	<b>2.9</b>

Source: EXXARO RESOURCES LTD (2012).

Tronox is running its mineral processing plant at Empangeni at less than 40 % capacity during 2013, with no production planned for 2014 and the first half of 2015 as production winds down at the Hillendale site outside Richards Bay. Tronox aims to

keep the two furnaces operational during the production gap by using local ilmenite stockpiles and additional feedstock from Namakwa Sands on the West Coast. This move was an interim measure to meet supply commitments and to avoid the huge costs associated with shutting down furnaces.

KZN affirms that it has sufficient inventory to continue running its KZN processing/smelter operations at capacity during the gap between the end of mining at Hillendale and Fairbreeze coming online in mid-2015.

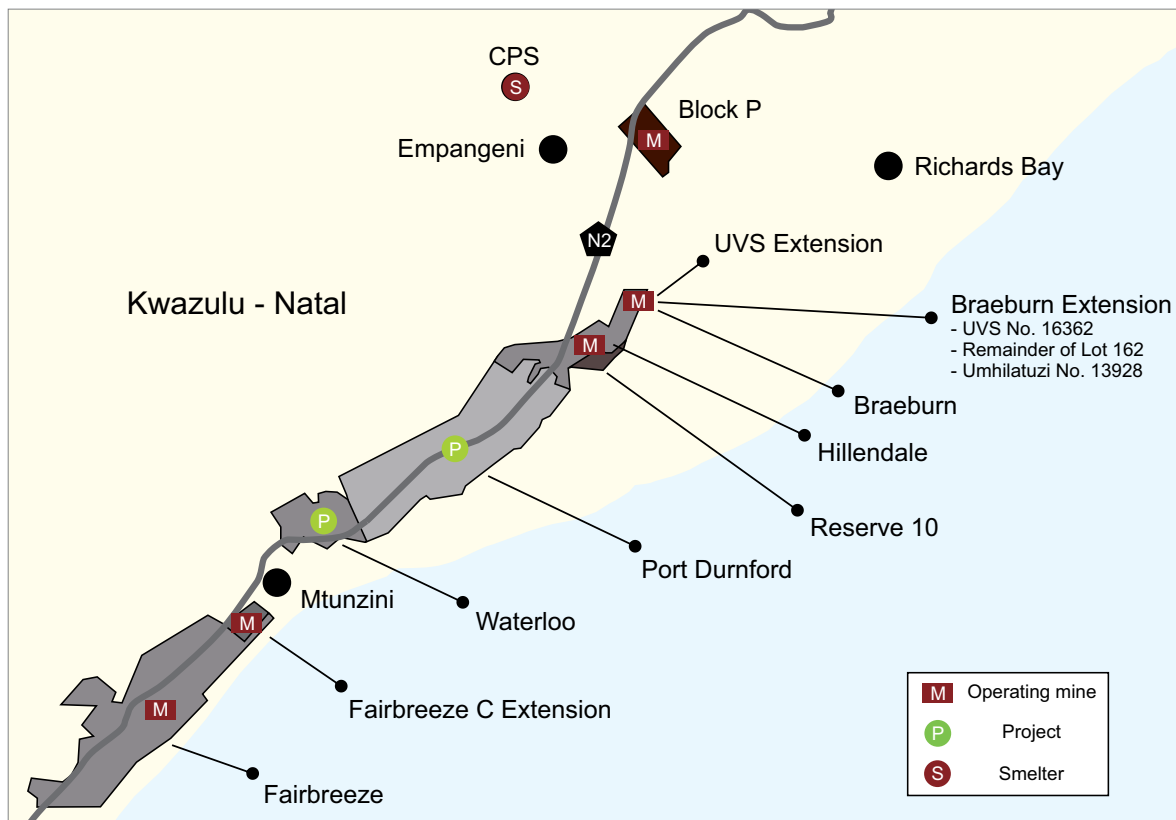
**Infrastructure:** The Hillendale mining operations have an independent electrical distribution system. Raw water is supplied to the Hillendale mining operations from a dam on the Mhlathuze River. Roughly 50 % of the water used at the primary wet plant is recycled.

**Tab. 5.1.25: Summary of data for the Hillendale mining operations (from EXXARO RESOURCES LTD 2012)**

<b>Total HM resource end 2012 (cut-off grade 1.5 % Ilmenite)</b>	Reserves: 2.9 Mt @ 5.3 % HM
	Resources <sup>1)</sup> : 14.6 Mt @ 2.90 % Ilmenite
<b>Contained HM end-2012</b>	Ilmenite: 423,400 t
<b>Production 2012</b>	163,000 t HM (ilmenite, zircon, rutile) + 46,000 t pig iron
<b>Annual mine production capacity</b>	12 Mt ore
<b>Life of mine plan (by year)</b>	End 2013
<b>Mining method</b>	Hydraulic mining, open-cast mining
<b>Mineral separation plant/smelter</b>	MSP and smelter operated by Tronox
<b>Recovery rate</b>	87 – 92 % HMC grade <sup>2)</sup>
<b>Risks (for mining, processing and mine waste storage)</b>	Mined out
<b>Start of mining</b>	2001
<b>Cash cost</b>	No data
<b>Capex</b>	No data

<sup>1)</sup> incl. reserves.

<sup>2)</sup> Percentage of total heavy minerals in the heavy mineral concentrate (HMC).



**Fig. 5.1.14: Mineral sand mines and projects in KwaZulu-Natal**  
(after EXXARO RESOURCES LTD 2011).

#### 5.1.4.11 Fairbreeze (KwaZulu-Natal)

##### Location and owner

Coordinates: 29°00'S / 31°43'E

KZN Sands is developing the Fairbreeze Project, which is located about 45 km southwest of Richards Bay in northern KwaZulu-Natal. The area lies just south of Mtunzini and extends 12 km along a coastal stretch, which ends near the Fairbreeze off-ramp on the N2.

KZN Sands is owned by Tronox Ltd, based in Stamford, CT, USA. Tronox took over the KZN Sands Fairbreeze Project with the mineral sand business from Exxaro Resources, in June 2012. Tronox owns 74 % in KZN Sands. Exxaro's mineral sands operations consist of a 26 % direct equity interest in KZN Sands and the Western Cape operations of Namakwa Sands as well as a 44.65 % equity interest in Tronox Limited, which is listed on the New York Stock Exchange.

Most of the land on which Tronox has mining rights for the Fairbreeze Project is owned by Mondi Ltd, which is currently subject to land claims by the Obanjeni Community. Tronox has not been denied access to the property, but further ownership disputes may arise.

**Description of the deposit:** The Fairbreeze Project covers an area of about 4,140 ha and is about 12 km long and 2 km wide. The area is characterised by a ridge of ancient dunes located 2 to 2.5 km inland from the present coastline. Rivers and streams have trenched the dune ridge. In the Fairbreeze area, ancient dunes reach a maximum height of 109 m above mean sea level. The more recent dunes, parallel and closer to the present coastline, reach 28 m above mean sea level.

The deposit is divided into five separate blocks: A, B, C, C Extension and D, which are all aligned parallel to the coast. The Block C and Block C extension orebodies have the highest total heavy mineral grades and are therefore intended to be mined first. The 487 ha Block P area is located

9 km northeast of Empangeni and also forms part of the Fairbreeze mining right but Tronox does not currently have any plans to mine Block P.

### Geology

The deposits at Fairbreeze area are hosted within the Berea-type red sand weathering profile developed in probable Pliocene Umkwelane Formation dune sands. The deposits represent a coastal barrier dune ridge associated with raised paleostrandlines and beaches. The A and B deposits are considered to represent two sections of a set of strandline deposits separated by a bedrock outcrop. Strandlines represent tabular zones of concentrated heavy mineral accumulations that are preserved by gradual marine regression leaving the strandline above the level of marine erosion. The C deposit has been interpreted to be a beach deposit formed on the low-energy side of an ancient headland that projected into the sea. The D deposit has been interpreted to represent a set of strandlines deposited to the east of Fairbreeze A, B and C deposits, during progressive sea-level regression. The Fairbreeze Project deposits contain about 30 % silt (SRK CONSULTING 2006).

### Mining and processing

**Mining method:** Tronox intends to move the mining infrastructure and concentration plant from Hillendale to Fairbreeze. The hydraulic mining method from Hillendale is also planned to be used in a similar way at Fairbreeze (see KZN Hillendale). The produced heavy mineral concentrate has to be transported 47 km from Fairbreeze to the central processing complex at Empangeni.

**Products and capacity:** The Fairbreeze Mine will replace the feedstock from the Hillendale Mine. The mine is expected to produce an average of 500,000 tpa ilmenite, 60,000 tpa zircon and 25,000 tpa rutile.

**Exploration/project history:** An initial feasibility study was completed in 1999, with updates in 2005 and 2010. The Fairbreeze area was identified as a replacement for the Hillendale Mine. Original plans to open the Fairbreeze deposit soon after the decommissioning of the Hillendale Mine were postponed in December 2009, but reactivated in March 2011.

**Tab. 5.1.26: Mineral sands reserves, estimated at 31 December 2012.**

Fairbreeze A + B + C + C Ext + D	Tonnes (Mt)	THM (%)	Ilmenite (% in THM)	Rutile (% in THM)	Zircon (% in HM)	Leucoxene (% in THM)
Proved	114.3	7.74	62.73	3.46	8.52	1.71
Probable	25.4	5.02	56.19	3.29	7.81	1.50
<b>Total</b>	<b>139.6</b>	<b>7.24</b>	<b>61.9</b>	<b>3.44</b>	<b>8.43</b>	<b>1.69</b>

Source: EXXARO RESOURCES LTD (2012).

**Tab. 5.1.27: Mineral sands resources (incl. reserves), estimated at 31 December 2012.**

Fairbreeze A + B + C + C Ext + D	Tonnes (Mt)	Ilmenite (%)
Measured	156.1	4.29
Indicated	55.7	2.56
Inferred	09.0	1.92
<b>Total</b>	<b>220.9</b>	<b>3.76</b>

Source: EXXARO RESOURCES LTD (2012).

**Tab. 5.1.28: Mineral sands resources, estimated at 31 December 2012.**

Block P	Tonnes (Mt)	Ilmenite (%)
Measured	0	–
Indicated	40.6	3.05
Inferred	0	–
<b>Total</b>	<b>40.6</b>	<b>3.05</b>

Source: EXXARO RESOURCES LTD (2012).



**Tab. 5.1.29: Summary of data for the Fairbreeze Project**  
(from EXXARO RESOURCES LTD 2012, TRONOX LTD 2012).

<b>Total HM resource end-2012 (cut-off grade 2 % Ilmenite)</b>	Reserves: 139.6 Mt @ 7.24 % HM Resources <sup>1)</sup> : 220.9 Mt @ 3.76 % Ilmenite
<b>Contained HM</b>	Ilmenite: 8,305,840 t
<b>Planned annual mine production capacity</b>	12 Mt ore
<b>Estimated mine life</b>	15 years
<b>Mining method</b>	Hydraulic mining, open-cast mining
<b>Mineral separation plant</b>	MSP and smelter operated by Tronox
<b>Recovery rate</b>	–
<b>Risks (for mining, processing and mine waste storage)</b>	Delays in obtaining regulatory approvals, land claims
<b>Stage</b>	–
<b>Start of mining</b>	Mid-2015
<b>Cash cost (US\$/t)</b>	–
<b>Capex</b>	R3 billion

<sup>1)</sup> incl. reserves.

Depending on the timing of regulatory approval and subsequent construction, the Fairbreeze Mine could commence operations in mid 2015.

**Resources:** Total resources for the Fairbreeze deposit (A, B, C, C Extension and D Blocks) stand at 220.9 million t ore sand grading 3.76 % ilmenite (8.3 million t), including proven and probable reserves of 139.7 million t ore sand grading 7.24 % THM on average. Thus, at Fairbreeze THM, reserves are 10.1 million t, ilmenite reserves are 6.2 million t, rutile reserves are 347,000 t, zircon reserves are 850,000 t and leucosene reserves are 170,000 t. The expected mine lifetime is about 15 years.

The Block P deposit has resources of 40.6 million t THM grading 3.1 % ilmenite (1.2 million t). The THM grade is around 5 %.

**Infrastructure:** The intention is to reuse most of the existing electrical and instrumentation equipment from the Hillendale primary wet plant at the Fairbreeze Mine. The only viable water supply option for the Fairbreeze Project is the Mhlathuze River, which is currently used to supply water for the Hillendale mining operations. Therefore it is planned to construct a raw water supply pipeline from Hillendale to Fairbreeze.

#### 5.1.4.12 Port Durnford (KwaZulu-Natal)

##### Location and owner

Coordinates: 28°53'S / 31°51'E

The Port Durnford deposit is situated 25 to 35 km west-southwest of Richards Bay, directly south of the Hillendale Mine.

A joint venture between Tronox Ltd (KZN Sands) (51 %) and Imbiza Consortium, a BEE group (49 %), hold the prospecting rights to the Port Durnford area.

**Description of the deposit:** The Port Durnford Project area spans 3 946 ha and extends over approximately 13 km between the Hillendale Mine in the north and the town of Mtunzini in the south. The area is transected by the N2 and bordered by the eSikhawini township and the coastal railway line to Durban to the east and the R102 road to the west.

##### Geology

The deposit forms part of a dune belt which consist of Sibayi Formation coastal barrier dunes overlying

ing Kosi Bay Formation dunes and the Port Durnford Formation estuarine deposits close to sea level. The orebody is high in silt content, which is the result of weathering with time.

### **Mining and processing**

**Mining method:** Owing to the high silt content hydraulic mining is expected to be the most effective. It is planned that the primary wet plant to be used at the Fairbreeze Mine will be relocated to Port Durnford once the mining operations at Port Durnford have started.

**Products, capacity:** Port Durnford will be a source of ilmenite feed for the smelter operations at Hillendale's central processing complex in Empangeni. The production rate at Port Durnford could be 22 million t run of mine per year which is higher than at Fairbreeze as a result of dropping ilmenite grades. The life of mine is planned to be approximately 15 years.

**Exploration history:** In 1979 and 1980, Richards Bay Minerals (RBM) carried out limited exploration activities on Port Durnford. These activities were revised between 1988 and 1989, indicating the presence of a low-grade heavy mineral deposit in the Port Durnford area with high silt content. It was noted, however, that the deposit was uneconomic to exploit at that time. In

1984, additional exploration of the area was conducted by Industrial Development Corporation of South Africa Ltd, a state-owned organisation. In 2003, Exxaro conducted aerial radiometric and magnetic geophysical surveys and began an initial exploratory drilling programme in February 2006 and an infill drilling programme between November 2007 and July 2008. A prefeasibility study for the Port Durnford Project was completed in 2009.

A renewal for the Port Durnford prospecting right was submitted in June 2010. The outcome is still pending. Land claims have been made for the land, subject to a Port Durnford prospecting rights application by the Mkhwanazi Tribe.

### **Resources:**

**Tab. 5.1.30: Mineral sands resources, estimated at 31 December 2012.**

Port Durnford Project 51 % Tronox (prospecting)	Tonnes (Mt)	Ilmenite (%)
Measured	142.5	3.04
Indicated	340.1	2.75
Inferred	466.0	2.52
<b>Total</b>	<b>948.6</b>	<b>2.68</b>

Source: EXXARO RESOURCES LTD (2012).

**Tab. 5.1.31: Summary of data for Port Durnford (from EXXARO RESOURCES LTD 2011, TRONOX LTD 2012).**

<b>Total HM resource</b>	948.6 Mt @ 2.7 % Ilmenite
<b>Contained HM</b>	Ilmenite: 25.6 Mt
<b>Planned annual production</b>	No data
<b>Annual mine production capacity (ore tpa)</b>	22 million t ore (ROM)
<b>Estimated mine life</b>	15 years
<b>Mining method</b>	Hydraulic mining
<b>Mineral separation plant</b>	Tronox Ltd in Empangeni
<b>Recovery rate</b>	No data
<b>Risks (for mining, processing and mine waste storage)</b>	Land claims by the Mkhwanazi Tribe
<b>Stage</b>	Application for renewal of the prospecting right
<b>Start of mining</b>	When Fairbreeze is mined out (~2030)
<b>Cash cost (US\$/t)</b>	No data
<b>Capex (million US\$)</b>	303



**Infrastructure:** Power is expected to be supplied to the Port Durnford mining operations by the Eskom transmission line that currently feeds the Hillendale and Fairbreeze mining areas and it is planned that the existing Fairbreeze electrical equipment at Port Durnford will be reused. Water is expected to be supplied to Port Durnford from the same pipeline to be used for Fairbreeze, which will pass approximately 1.5 km from the Port Durnford site. The raw water is expected to be sourced at the present Hillendale pump station, but will be upgraded to provide for additional demand.

#### 5.1.4.13 Bothaville (Free State)

##### Location and owner

Approximate coordinates: 27°12'S / 26°30'E

The Bothaville heavy mineral occurrences are located near Bothaville in the Free State, some 200 km southeast of Johannesburg.

The mineral sand exploration company Southern Mining Corporation Ltd (SMC) owns the mining rights to the Bothaville heavy mineral occurrence. SMC was listed on the Johannesburg Stock Exchange in October 1997. Shareholders are Southern Mining Corporation BV – Netherlands (65 %) and Industrial Development Corporation of South Africa Ltd – Sandown, South Africa (9.5 %).

**Description of the occurrence:** Large north-west-striking occurrences of consolidated heavy mineral placer deposits are located in the area between Bothaville and Wolma-

ransstad. The occurrences in the Bothaville area are exposed over an area measuring approximately 30 km in a northeasterly direction and 15 km in a northwesterly direction (BEHR 1986). An array of occurrences is situated in a zone some 12 km wide with a maximum strike length of 16 km, located on fairly flat terrain. The single largest deposit is 4 km long and up to 900 m wide. The greatest thickness of heavy minerals described so far is 6.5 m and the average thickness is 2.75 m (HAMMERBECK 1976, WIPPLINGER 1998).

##### Geology

The Bothaville and Wolmaransstad heavy mineral concentrations occur in Permian-aged sandstones of the arenaceous coal-bearing Vryheid Formation of the northern facies of the Ecca Group of the Karoo Sequence (BEHR 1986). Deposition of the essentially arenaceous fluviodeltaic and littoral sediments of the northern Ecca facies took place during several transgressive-regressive cycles. Periods of coastal reworking of delta-front sands is suggested as a model for the heavy mineral deposits during temporary periods of marine regression.

The heavy minerals are concentrated in consistently planar laminated, fine-grained, well-sorted sandstones (BEHR 1986).

A heavy mineral content of more than 50 % is common in enriched beds. Ilmenite averages 60 %, zircon 7 % and garnets, monazite, rutile are a few per cent each of the heavy mineral suite. Some chromite is present (the ore contains about 0.2 – 0.3 % Cr<sub>2</sub>O<sub>3</sub>). Ilmenite, which commonly contains haematite intergrowths, is rimmed by leucoxene consisting of microcrystal-

**Tab. 5.1.32: Mineral sands resources, after BEHR (1965).**

	Ore (Mt)	Ilmenite (% in THM)	Zircon (% in THM)	Anatas, rutile (% in THM)	Leucoxene (% in THM)
Possible	32.20	22.36	2.33	0.46	1.55
Probable	58.65	22.16	2.39	0.51	2.05
<b>Total</b>	<b>90</b>				

Probable ore implies a minimum of 40 % heavy minerals over 1 m thickness.

Possible ore implies a minimum of 25 % heavy minerals over 0.6 m thickness.

Sources: BEHR (1965), WIPPLINGER (1998).

line anatase. Quartz, feldspar and mica are light minerals. Iron and sulphides, siderites, chlorite and anatase are present in place of sulphides and siderites.

### Mining and processing

**Potential treatment problems:** The Bothaville deposits are difficult to beneficiate owing to the presence of excessive amounts of goethite, silica and chromite which contaminate any concentrate that could be generated. The goethite, produced by the altered ilmenite, coats and permeates all the grains and availa-

ble pore spaces, necessitating an acid treatment to produce a high-grade titania concentrate. The relatively advanced stage of alteration to leucoxene and goethite has rendered the minerals friable, resulting in high sliming losses. The excessive attrition of the heavy minerals in the milling circuit leads to sliming and poor mineral separation. That portion of the ilmenite which is relatively unaltered is very difficult to separate from the small, but objectionable amount of chromite present in the deposits. However, during processing, this incidence could possibly be reduced by electromagnetic treatment (BEHR 1986, WIPPLINGER 1998).

**Exploration history:** In 1955/56, the Geological Survey identified high concentrations of heavy minerals in the Bothaville area and conducted ground radiometric surveys. The largest known reserves were found in the Bothaville occurrences. Also in 1956, the Bothaville occurrences east of the Vaal River were prospected by General Mining and Finance Corporation Ltd. In 1967 – 1969 the promising Bothaville occurrences were reinvestigated by

**Tab. 5.1.33: Mineral sands resources, after BEHR (1986).**

	THM (Mt)	Ilmenite (Mt)
Possible	9.14	6.50
Probable	16.85	11.80
<b>Total</b>	<b>25.99</b>	<b>18.30</b>

**Tab. 5.1.34: Estimated mineral sands resources.**

	Ore (Mt)	VHM (Mt)	Recoverable VHM (Mt)	Ilmenite (% in VHM)	Zircon (% in VHM)	Titaniferous minerals (% in VHM)	Monazite (% in VHM)
<b>Total</b>	<b>185</b>	<b>40</b>	<b>30</b>	<b>68</b>	<b>9</b>	<b>23</b>	<b>&lt;1</b>

Sources: PRINSLOO (2008), DME (2007), MBENDI (n.d.).

**Tab. 5.1.35: Summary of data for the Bothaville occurrences.**

<b>Total HM resource</b>	Resources: 185 Mt @ 30 % HM
<b>Contained HM</b>	40 Mt VHM, recoverable 30 Mt VHM
<b>Planned annual production</b>	No data
<b>Annual mine production capacity (ore tpa)</b>	No data
<b>Estimated mine life (by year)</b>	No data
<b>Mining method</b>	No data
<b>Mineral separation plant</b>	No data
<b>Recovery rate</b>	75 %
<b>Risks (for mining, processing and mine waste storage)</b>	Beneficiation problems
<b>Stage</b>	Planned
<b>Start of mining</b>	No data
<b>Cash cost (US\$/t)</b>	No data
<b>Capex (million US\$)</b>	No data

Gold Fields of South Africa and in 1969/70, the feasibility of producing synthetic rutile from titanium was investigated by Anglo American Corporation of South Africa Ltd (BEHR 1986). In 1974, the Geological Survey conducted an airborne survey. The prospecting activity and assessments indicated that the Bothaville occurrences do not constitute an economically viable heavy mineral resource (BEHR 1986). In 1998, studies showed the mineralogy of Bothaville to be complex and that additional processing advances would be required for optimal exploitation. Even the zircon potential of the Bothaville deposits is not sufficiently high to warrant exploitation.

**Resources:** The resources of the SMC large titanium deposits near Bothaville are stated with total inferred resource in excess of 185 million t ore grading 30 % THM. The *in situ* valuable heavy mineral content is estimated an approximately 40 million t at a 75 % recovery 30 million t of valuable heavy minerals. The composition of these heavy minerals is estimated to be ilmenite (68 %), zircon (9 %), other titaniferous minerals (23 %) and monazite (<1 %) (PRINSLOO 2008, DME 2007).

**Infrastructure:** The more important occurrences are well served by road, rail and power links (BEHR 1986).

#### 5.1.4.14 Gravelotte (Limpopo)

##### *Location and owner*

The Gravelotte heavy mineral deposit is located approximately 8 km north of the town of Gravelotte, Limpopo Province.

Exxaro Resources Ltd, a South Africa-based mining group, listed on the JSE Limited, holds the mineral title of the heavy mineral deposits of the Gravelotte sands and pebbles and of the Gravelotte rock.

**Description of the occurrence:** The sand resource is present within an area which is approximately 24 km long and 2.5 km wide. The total area spans 6,888.83 ha (SRK CONSULTING 2006).

The Gravelotte orebody comprises sand, pebbles and hard-rock ilmenite. The ilmenite-rich sand, derived from weathering, is accumulated above a basal pebble layer that has accumulated above the recent unconformity, developed above the Rooiwater Igneous Complex lithologies. The sand layer is, on average, 0.9 m thick and the pebble layer 0.3 m thick. Some hard-rock mineralisation has also been included within the mineral resource.

##### *Geology*

The principal resource consists of eluvial sand deposits containing ilmenite linerated from the weathering of Archaean magnetite-rich rocks of the Rooiwater Complex, developed along the northern flank of the east-trending Murchison Greenstone Belt. As a result of the metamorphism of the Rooiwater Igneous Complex, the ilmenite has recrystallised as discrete crystals of ilmenite. Owing to the weathering of this material, most of the magnetite has disintegrated and the magnetite and ilmenite have largely disaggregated, resulting in an ilmenite-enriched eluvial residue which makes it possible to segregate the ilmenite from the magnetite (SRK CONSULTING 2006, WIPPLINGER 1998).

Preliminary investigations indicate the presence of large tonnages of vanadiumbearing titaniferous magnetite in two parallel orerich layers in the Rooiwater Complex, underlying the eluvial deposits (REYNOLDS 1986). These layers are each approximately 8 m thick. The ore of the lower layer contains moderate concentrations of TiO<sub>2</sub> (14.5 – 15.1 %) and V<sub>2</sub>O<sub>5</sub> (1.3 – 1.4 %), as well as minor concentrations of Cr<sub>2</sub>O<sub>3</sub> (0.45 – 1.39 %). The upper layer contains as much as 24.5 % TiO<sub>2</sub>, less vanadium (0.8 % V<sub>2</sub>O<sub>5</sub>) and insignificant amounts of chromium (WIPPLINGER 1998).

##### *Mining and processing*

**Exploration history:** In the 1990s, Iscor Mining Ltd investigated two extensive eluvial deposits at Gravelotte.

**Resources:** Mineral resource estimates have been developed for the sand unit, as well as the pebble layer and the underlying hard-rock bodies and can be classified in the measured, indicated and inferred categories.

The Gravelotte orebody is deemed a pre-development project.

The local infrastructure is quite good.

**Tab. 5.1.36: Mineral sands and pebbles resources, estimated at 31 December 2011.**

Gravelotte sands and pebbles	Tonnes (Mt)	Ilmenite (%)
Measured	–	–
Indicated	74.9	9.90
Inferred	–	–
<b>Total</b>	<b>74.9</b>	<b>9.90</b>

Source: EXXARO RESOURCES LTD (2012).

**Tab. 5.1.37: Mineral-rock resources, estimated at 31 December 2011**

Gravelotte rock	Tonnes (Mt)	Ilmenite (%)
Measured	0	–
Indicated	9.7	23.10
Inferred	113.9	18.20
<b>Total</b>	<b>123.6</b>	<b>18.60</b>

Source: EXXARO RESOURCES LTD (2012).

### 5.1.4.15 Letsitele (sand project, rock project) (Limpopo)

#### Location and owner

The Letsitele sand and rock prospecting project is located 4 km south of the town of Letsitele, Limpopo Province, South Africa (at 23°55'S, 30°23'E). The mineral title is held 100% by Exxaro Resources Ltd.

#### Geology

The ore deposit occurs as a V-Ti-magnetite rock mineralisation rich in ilmenite. Exxaro stated that the potential of the Letsitele Project is reasonably well known.

The local infrastructure is fairly good.

## 5.1.5 Requirements and Evaluation

### 5.1.5.1 Ilmenite

#### Size of deposits

The reference values specified in Tab. 5.1.38 can be applied to the size assessment of deposits that are predominantly mined for ilmenite/leucoxene.

The ilmenite/leucoxene concentration and their composition are not the only important aspects when assessing a placer deposit. Other accompanying valuable heavy minerals, mainly zircon and rutile, formerly also monazite/xenotime, provide significantly more added value per tonne and thereby make the mining of some deposits economically viable.

The most recent experience in the Murray Basin in Victoria, Australia, has also shown that despite all the processing technologies available today, the absolute majority of heavy minerals must be present in the particle size range >63 µm (ELSNER 2012).

Ilmenites concentrated in placers with TiO<sub>2</sub> content below the stoichiometric concentration of 52.66% are - unless they are to be processed into titanium slag or synthetic rutile - normally not worth mining. This explains the lack of interest of the industry in several deposits that have been known for a long time (ELSNER 2012). In South Africa, where those grades are not to be reached, the ilmenite concentrations have to be processed into titanium slag.

#### Requirements for ilmenite for the manufacture of TiO<sub>2</sub> pigments

There are two industrial processes for the manufacture of TiO<sub>2</sub> pigments:

- The older sulfate process requires as initial raw materials either ilmenite with a TiO<sub>2</sub> content of 45 – 65% or a titanium slag with 70 – 80% TiO<sub>2</sub>.
- The more recent chloride process requires intensely weathered ilmenite, leucoxene, natural rutile, synthetic rutile or a titanium slag with >85% TiO<sub>2</sub> as the basic raw materials.

**Tab. 5.1.38: Reference values for the assessment of ilmenite-leucoxene deposits.**

	All deposits <sup>1)</sup> TiO <sub>2</sub> -content	Placers <sup>2)</sup> mineral content
<b>Not mineable</b>		2 million tonnes
<b>Small</b>	0.5 – 1 million tonnes	2 – 5 million tonnes
<b>Medium</b>	1 – 10 million tonnes	5 – 10 million tonnes
<b>Large</b>	10 – >50 million tonnes	10 – 30 million tonnes
<b>Very large</b>		>30 million tonnes

<sup>1)</sup> LORENZ (1991), <sup>2)</sup> ELSNER (2012)

Low-grade titanium ores can be processed to form titanium slag or synthetic rutile using various processes to increase their primary TiO<sub>2</sub> content in a secondary manner.

According to HARBEN (2002), the ilmenite concentrates for TiO<sub>2</sub> pigment manufacture based on the **sulfate process** should have:

- TiO<sub>2</sub> contents between approx. 50–60 % (<50 % often contain too many foreign substances; >60 % often do not completely break down by sulfuric acid),
- a high FeO/Fe<sub>2</sub>O<sub>3</sub> ratio (must react with sulfuric acid),
- a low Fe content (low quantities of Fe sulfate as by-product),
- low Cr, V and Nb contents (act as color pigments and form toxic waste materials),
- low Ca and P contents (impede optimum crystallization),
- low U, Th and Ra contents (continually decreasing lower limits for radioactivity in educts, products and waste materials).

The physical properties of ilmenite have no significance as long as it can be precipitated cleanly from the mineral spectrum of the placer using conventional methods.

Ilmenite/leucoxene concentrates for TiO<sub>2</sub> pigment manufacture using the chloride process should have the following properties according to HARBEN (2002):

- TiO<sub>2</sub> contents >60 % (<60 % contain too many foreign substances that occur in the form of waste materials),
- low alkaline values: <0.2 % CaO, <1 % MgO (form liquid chlorides at 1000 °C and impede

the distillation of the titanium tetrachlorides as a result),

- a low Fe content (leads to formation of iron chloride, that melts at 700 °C and blocks the lines),
- <0.5 % Cr<sub>2</sub>O<sub>3</sub> and V<sub>2</sub>O<sub>5</sub> (color change of the white pigment, toxic waste materials, form liquid chlorides that clog the reactor bed),
- low Sn and As contents (accumulate with the titanium tetrachloride),
- <2 % SiO<sub>2</sub> (coats grains and impedes the reaction),
- low U, Th and Ra contents of <500 ppm in total (always lower limits for radioactivity in educts, products and waste materials).

To be suitable as a raw material for the chloride process, ilmenite must have a particle size of 5 – 100 µm and a sufficiently high apparent density after processing. A narrow particle size spectrum is advantageous because this avoids blow over effects during chlorination in the reactor as well as dust losses.

### 5.1.5.2 Zircon

#### Size of deposits

When assessing zircon deposits, the amount of titanium minerals (ilmenite, leucoxene, rutile) contained is of greater importance than their zircon content. This means that zircon is close to always a secondary, only rarely a primary valuable heavy mineral when it is being extracted from placers.

The reference values specified in Tab. 5.1.39 can be applied to the size of deposits where zircon is also mined.

**Tab. 5.1.39: Reference values for the assessment of zircon deposits.**

	All deposits <sup>1)</sup> ZrO <sub>2</sub> -content	Placers <sup>2)</sup> mineral content
<b>Small</b>	<50,000 – 100,000 tonnes	100,000 – 250,000 tonnes
<b>Medium</b>	100,000 – 1 million tonnes	250,000 – 500,000 tonnes
<b>Large</b>	1 –>10 million tonnes	500,000 – 1 million tonnes
<b>Very large</b>		>1 million tonnes

<sup>1)</sup> LORENZ (1991), <sup>2)</sup> ELSNER (2012).

### Requirements for Zircon

GARNAR (1986) lists the specifications for zircon concentrates for different applications as follows:

- A zircon concentrate that is to be used as foundry sand must contain <3 % by mass kyanite and <0.1 % by mass staurolite. The corundum content (Al<sub>2</sub>O<sub>3</sub>) must also be low.
- For the purposes of the refractory and ceramics industry, the limits are <2 % by mass kyanite and <0.1 % by mass staurolite.
- For zircon that is used for casting aircraft parts, the following limits apply to trace elements: <25 ppm Pb, <75 ppm Zn, <1 ppm Bi, <25 ppm Sn and <160 ppm Ce. Here, Sn is often contained in the spinel gahnite, which can be separated electromagnetically however.
- Zircon for steel casting must be well rounded and calcinated and have a mean grain diameter of 110 – 150 µm. The concentrate must contain <0.1 % by mass accompanying minerals with low melting points.
- If zircon is to be ground wet or dry into zircon flour and then used as an opacifier, only zircon concentrates of premium or intermediate grade can be used as feedstock due to the specifications for the Fe content (<0.04 % Fe).

Depending on the application and processing quality, zircon concentrates are put onto the market by the producers or commodities traders with the affix *premium (prime)*, *intermediate*, *standard* or *ceramic*.

As a bearer of U and Th, zircon is slightly radioactive and therefore carcinogenic. In general, a global limit of 500 ppm U + Th or U + (0.4 x Th)

< 100 ppm applies. Different countries, however, have adopted differing limits.

Compliance with the above limits of U and Th in zircon concentrates has been one of the most important assessment criteria for its suitability for some years. The lower the level of U and Th, the higher the marketing potential. Moreover, according to current legislation, zircons with U and Th levels exceeding the legal limits do not constitute valuable heavy minerals, but radioactive waste material! Radioactive zircons (which are often weakly magnetic) must therefore be separated out during processing. This, however, leads to high production losses and to the storage of radioactive materials from zircon, xenotime and monazite, which is undesirable in ecological terms.

### 5.1.5.3 Evaluation

In general, a good grade deposit would contain more than 5 % valuable heavy metals. The grade or quality of the ilmenite therein should be high enough so that it can be used by the chloride or sulphate slag route. The general break-even grade for ilmenite is considered to be 47 % to 48 % TiO<sub>2</sub>. The existence of any radioactive minerals, even potentially valuable ones like monazite, poses a major problem. If a new mine will extract and separate ilmenite, rutile and zircon for direct sale, then capital costs are minimal. However, if a slagging plant is being developed, then much greater investments will be required. The deposit must then be large enough to support a much longer mine life, probably approaching thirty years (TYLER & MINNITT 2004).



**Tab. 5.1.40: Resources and grades for the South African heavy mineral projects (assessment after ELSNER 2012).**

Deposit / Occurrence	Ilmenite content (t)	Grade (% Ilm)	Assessment	Zircon content (t)	Grade (% Zr)	Ore sand (Mt)	Assessment
Namakwa Sands	253,694,700	2.8	very large	6,546,960	0.72	909.3	very large
RBM	23,300,000 TiO <sub>2</sub> -feedstock	–	large	–	–	–	–
Zulti South	° 20,000,000	–	large	° 2,000,000	° 0.5	–	very large
Fairbreeze	8,305,840	3.76	medium	–	–	220.9	–
KZN Hillendale	423,400	2.9	mined out	–	–	14.6	–
KZN Hillendale: Block P	1,258,600	3.1	not mineable	207,060	0.51	40.6	small
Port Durnford	25,600,000	2.7	large	–	–	948.6	–
Eastern Cape Project	11,500,000	4.5	large	1,024,000	0.4	255.9	very large
Bothaville	° 20,400,000	° 20	large	° 2,700,000	° 2.7	–	very large
Xolobeni	9,300,000	2.7	medium	–	–	346	–
Kamiesberg	3,978,000	3.99	small	388,800	0.39	99.7	medium
Tormin	286,490	10.6	not mineable	92,400	3.4	2.7	small
Gravelotte rock	22,989,600	18.6	large	–	–	123.6	–
Gravelotte sands & pebbles	7,415,100	9.9	medium	–	–	74.9	–
Letsitele rock	° 13,880,000	° 25.9	large	–	–	° 53.6	–
Letsitele sand	° 1,300,000	° 10.5	not mineable	–	–	° 12.5	–
Wallekral	–	–	–	–	–	–	–
Soutfontein	° 695,200	° 8.8	not mineable	° 142,200	° 1.8	° 7.9	–
Alexander Bay	° 324,000	–	not mineable	° 13,000	–	–	–
St Lucia and Tojan	° 11,232,000	° 3.2	large	–	–	° 351	–
Cape Vidal	° 3,328,000	° 3.2	small	–	–	° 104	–
Bowker's Bay	° 433,500	° 5.8	not mineable	–	–	° 7.5	–
Morgan Bay	° 1,798,400	° 2.8	not mineable	–	–	° 64	–
Nickolas	° 2,086,400	° 3.3	small	–	–	° 64	–

Ilm: ilmenite; Zr: zircon

°: estimated, not JORC compliant

–: is not known

According to the classification after LORENZ (1991) and ELSNER (2012) (Tab. 5.1.38, Tab. 5.1.39), the heavy mineral projects and deposits Richards Bay Minerals Zulti North and Zulti South and Namakwa Sands, Port Durnford, Eastern Cape Project, Bothaville, St Lucia together with Tojan and Cape Vidal as well as Gravelotte rock and Letsitele rock can be classified as large for ilmenite (>10 million tonnes ilmenite). With regard to zircon, Namakwa Sands, Richards Bay Minerals, Eastern Cape Project and Bothaville are also very large in size. Fairbreeze, Xolobeni, Gravelotte sands & pebbles are medium in size for ilmenite. Kamiesberg has to be classified as small for ilmenite but medium for zircon. Letsitele sand, without Letsitele rock, is not mineable. With current resource estimates, Tormin and KZN's Hillendale Block P are not economic for ilmenite but for a small-sized zircon deposit. Wallekraal, Soutfontein and Alexander Bay in Northern Cape as well as Bowker's Bay, Morgan Bay and Nickolas in Eastern Cape are small or not mineable (Tab. 5.1.40).

The most interesting areas for placer mining are several localities along the Atlantic coast Namaqualand and West Coast (Northern Cape, Western Cape) and along the Indian Ocean coast, near Richards Bay (KwaZulu-Natal) and north East London (Eastern Cape).

The deposits/occurrences owned by Richards Bay Minerals (RBM) and Tronox are significant HMS deposits on a world scale. Additionally RBM and Tronox are experienced in the HM mining business and titanium dioxide slag production.

The most interesting large to very large deposits for HM placer mining (both zircon and ilmenite) are RBMs **Zulti North** and **Zulti South** (KwaZulu-Natal), Tronox' **Namakwa Sands** (Western Cape) and the **Eastern Cape Project** (Eastern Cape). However, the Eastern Cape Project lies in a remote area without any notable infrastructure. Further limitations include environmental restrictions. Another large ilmenite occurrence of Tronox is **Port Durnford** (KwaZulu-Natal) which is a low-grade ilmenite deposit with high silt content. Mining in Port Durnford is planned to start sometime in 2030 once Fairbreeze is mined out. Land claims have been made for the land, subject to a Port Durnford prospecting rights application.

Tronox' medium sized ilmenite deposit **Fairbreeze** (KwaZulu-Natal) seems the most likely new ilmenite project to succeed in South Africa. It is a medium, reasonable grade deposit which has to replace the mined out Hillendale mine of Tronox as ilmenite source for the near by smelter in Empangeni.

Mineral Commodities' **Xolobeni** project (Eastern Cape) is a medium sized ilmenite project. Mineral Commodities had hoped to develop the HM Project since 2001, but its conditional mining rights were revoked in 2011 for environmental reasons. Land claims and environmental issues will undoubtedly be a factor in the planning of developments in Eastern Cape and KwaZulu-Natal.

The occurrences **Bowker's Bay**, **Morgan Bay** and **Nickolas** in Eastern Cape are not well explored and so far have uneconomic resources.

**Cape Vidal**, **St Lucia** and **Tojan** in KwaZulu-Natal, although large in size, will not be mined owing to environmental restrictions. Resistance from environmental groups can be expected for any planned mining activities. The KwaZulu-Natal coastal areas are a very popular holiday destination in South Africa and some of the occurrences and deposits have been sterilised by touristic developments.

The **Tormin Mineral Sands Project** of Mineral Commodities Pty Ltd in the Western Cape could be a new zircon mine in the next years. The currently reported resources of Tormin have a minor content of VHM and can be classified as small with a mine life of only four to five years. It will be interesting to see whether MRC can achieve any exploration targets there. If so, then Tormin can be a medium-sized deposit for zircon with an additional mine life of five years. Ilmenite plays only a minor role in the Tormin-project. Industrial production is planned for 2014.

The **Kamiesberg Mineral Sands Project** of Zirco Resources Ltd is located in the Northern Cape region. A prefeasibility study is scheduled for 2013. It is a medium sized occurrence of zircon and only of small size for ilmenite. Project risks are the low VHM content, lack of infrastructure, and processing.

The occurrences **Wallekraal**, **Soutfontein** and **Alexander Bay** in Northern Cape are too small according to current knowledge. Additionally, due to the diamond mining concessions the possibility for HM mining in that area is restricted. But the feasibility of exploiting these heavy minerals in conjunction with the diamond mining should be assessed. The **diamond mining dumps** of the onshore diamond mining operations in Northern Cape could be an interesting source of HM. Up to now, only limited attempts have been made to estimate the VHM grade of the sands and the feasibility of extracting the minerals.

The **Bothaville** project of Southern Mining Corporation in Free State apparently has large ilmenite and very large zircon resources, though not JORC compliant. However, studies in 1998 showed the mineralogy of Bothaville to be quite complex and additional processing advances would be required for optimal exploitation. The Bothaville deposits are difficult to beneficiate owing to the presence of excessive amounts of goethite, silica and chromite.

Currently little is known about the occurrences **Gravelotte** rock and Gravelotte sands & pebbles as well as **Letsitele** rock and sand occurrence. Neither of these occurrences has been extensively explored or mined in the past.

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## 5.2 Rare-earth elements

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### 5.2.1 Definition, mineralogy and sources

#### Definitions and mineralogy

The rare-earth elements (REE, metals) comprise a set of sixteen elements (fifteen lanthanides plus yttrium; promethium does not occur in natural minerals). All REE have rather similar chemical properties and generally occur mixed in ore deposits. The lanthanides are commonly grouped into a cerium group (light rare-earth element (LREE); Lanthanum to Samarium) and an yttrium group (heavy rare-earth elements (HREE); Europium to Lutetium and Yttrium).

Rare-earth minerals and REE-bearing minerals mentioned in this report have the following chemical formula:

Aeschnynite	$[(\text{Ce,Ca,Fe,Th})(\text{Ti,Nb})_2(\text{O,OH})_6]$
Allanite	$[(\text{Ce,Ca,Y})_2(\text{Al,Fe}^{2+},\text{Fe}^{3+})_3(\text{SiO}_4)_3(\text{OH})]$
Fluorapatite	$[\text{Ca}_5(\text{F}/(\text{PO}_4)_3)]$
Bastnaesite	$[(\text{Ce,L a,Y})\text{CO}_3\text{F}]$
Britholite	$[(\text{Ce,Ca})_5(\text{SiO}_4)_3(\text{PO}_4)_3(\text{OH,F})]$
Cheralite	$[(\text{Ca,Ce,Th})(\text{P,Si})\text{O}_4]$
Fluocerite	$[(\text{Ce,L a})\text{F}_3]$
Leucoxene	mixture of Fe-Ti oxides
Monazite	$[(\text{Ce,L a,Nd,Th})\text{PO}_4]$
Synchysite	$[\text{Ca}(\text{Ce,L a})(\text{CO}_3)_2\text{F}]$
Xenotime	$[\text{YPO}_4]$
Zircon	$[(\text{Zr,REE})\text{SiO}_4]$

#### Sources of rare-earth elements

Rare-earths deposits occur in magmatic or sedimentary environments.

**Magmatic deposits:** Carbonatites (>50 % of primary carbonate minerals), associated magnetite-olivine-apatite-phlogopite rocks as well as pyroxenites are the most common host rocks of REE deposits. Mineralisation in alkaline intrusive rocks (e.g. nepheline syenite) contains a large number of elements of economic interest (REE, Y, Zr, Ta, Nb), but commonly at rather low concentrations. The world's largest sources of REE are represented by the hydrothermal iron deposit at Bayan Obo (China) and the Tomtor Massif (central carbonatite complex; Arctic Siberia, Russia).

**Sedimentary deposits:** Heavy mineral sand deposits containing REE- and thorium-bearing monazite and xenotime occur in alluvial to coastal REE placers. However, the cost of handling and disposing radioactive material is a serious impediment to the economic extraction of the more radioactive REE-rich minerals, in particular monazite (Long et al. 2010). Ion-adsorption clays represent a valuable source of HREE; this is of great importance, because HREE are not enriched in carbonatites.

Commonly, the ores of REE are characterised by a chemical and mineralogical complexity and by elevated or strong radioactivity (U, Th). To date, REE production has largely resulted from single-mineral-phase deposits, such as Bayan Obo, Inner Mongolia (bastnaesite), Mountain Pass, USA (bastnaesite), and heavy mineral placers (monazite). However, REE minerals are commonly mined as by-products or co-products of other mineral commodities (e.g. Bayan Obo-iron ore; heavy mineral sands in India and Malaysia-ilmenite, zircon, rutile, cassiterite).

It is expected that "with continued global growth of the middle class, especially in China, India and Africa, the demand for REE will continue to grow" (CHO 2012). Rare-earths are important because they provide critical functionality in a wide variety of applications (DU & GRAEDEL 2011; Tab. 5.2.2). Owing to the fact that no qualified substitution materials are available for many applications of REE, the demand for REE reacts highly inflexible on short term price changes.



## 5.2.2 Specifications and use

The REE market is small and highly specialised (value in 2013: US\$ 4–6 billion (KINGSNORTH 2013)). In 2012, the estimated distribution of REE by end use was for the United States as follows: catalysts, 62 %; metallurgical application and alloys, 13 %; glass polishing and ceramics, 9 %; permanent magnets, 7 %; phosphors, 3 %, and others, 6 % (GAMBOGI 2013). The anticipated composition of REE for the world demand in 2015 is shown in Figure 5.2.1. On a global scale, the major applications are catalysts and magnets, with a possible shift in application towards an increase for magnets and metal alloys.

REE markets are expected to require greater amounts of higher purity mixed and separated products to meet the demand (GAMBOGI & CORDIER 2012). REE are not commodities; they are customer specific chemicals, produced to precise chemical and physical specifications (KINGSNORTH 2013). Furthermore, since REE are generally present in minute concentrations in high technology products, they are rarely recycled.

## 5.2.3 Supply and demand

### Rare-earths producing countries

World production of total rare-earth oxides from 1960 until 2010 (2011) is summarized in Figure 5.2.2 and Table 5.2.1. There are numerous REE projects worldwide currently considered for development (in 2011/2012: >400 REE projects by about 250 companies in 35 countries); however, most of them are enriched in the LREE and would flood the market for lanthanum and cerium if put into production. In contrast, certain REE and especially some of the HREE have very limited reserves and their ores are characterised by causing significant problems during cost-effective processing.

### Rare-earths demand

Key demand drivers for REE are the further development of high-tech applications, and especially electro-mobility (hybrid car motors) and renewable energy technologies (Tab. 5.2.2). Different wind turbine designs need different amounts of REE. Direct-drive turbines (without a gearbox) need up to 10 times more REE (especially neodymium, dysprosium) than conventional turbines based on geared drive trains (VESTAS 2013). According to a study of the Massachusetts Institute of Technology (ALONSO et

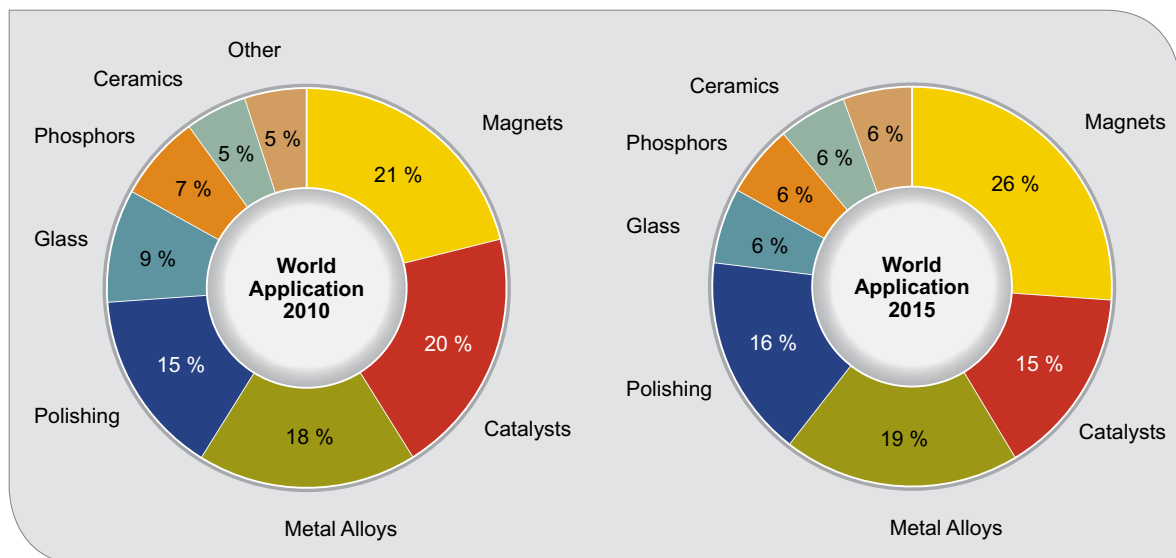
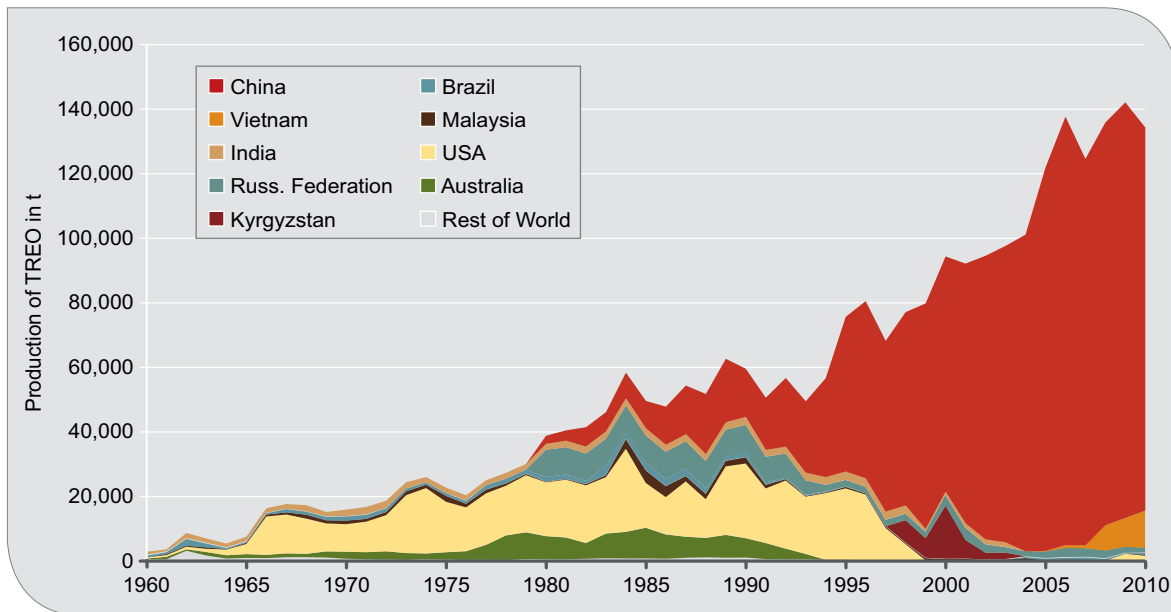


Fig. 5.2.1: REE demand by application (modified from HUMPHRIES 2012; data source: IMCOA 2011).



**Fig. 5.2.2: World production of total REO (TREO in t) from 1960 until 2010**  
(sources: USGS database; BGR database; et al.).

al. 2012), the demand particularly for these REE (neodymium and dysprosium – both materials have exceptional magnetic properties) could increase by 2,600 and 700 % over the next 25 years, respectively.

Based upon IMCOA's analysis of the supply and demand balance for 2016, it is apparent that terbium, erbium and yttrium will be in short supply in that year (KINGSNORTH 2013; Tab. 5.2.3) and, if the demand for wind turbines increases significantly,

**Tab. 5.2.1: World production of rare-earth element minerals from 2001 to 2011 [in tonnes];**  
(sources: USGS database; BGR database; et al.).

	Tonnes	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
<b>USA</b>	Ore						0	0	0	0	0	0
	REO equiv.									2,150	1,483	3,516 <sup>1)</sup>
<b>India</b>	Monazite	2,651	2,856	2,891	149	93	45	0	0	0		
	RE products							35	22	16		
<b>Brazil</b>	Monazite	0	0	0	731	958	958	1,173	834	303	249	290
<b>Russia</b>	Loparite concentrate	12,178	8,897	5,940	7,748	7,435	8,758	9,023	8,564	6,510	5,339	6,147
	REO equiv. <sup>2)</sup>	3,805	2,631	1,680	1,592	2,027	2,935	2,711	2,470	1,898	1,495	1,444
<b>China</b>	REO equiv.	80,600	88,000	92,000	98,300	119,000	133,000	120,000	125,000	129,400	118,900	96,900
<b>Sri Lanka</b>	Monazite										86	
<b>Malaysia</b>	Monazite	643	509	795	1,683	320	894	682	233	25	732	
<b>Vietnam</b>	Monazite <sup>3)</sup>					400	1,520	1,600	13,610	15,517	20,030	22,330

<sup>1)</sup> Including ores from the USA that were processed in Estonia; <sup>2)</sup> exported material only; <sup>3)</sup> based on published data.

the same will be true for neodymium. From 2010 until 2013, a lower production of total REO than the worldwide demand was forecast by IMCOA (highlighted in Fig. 5.2.3 by the diamond symbols).

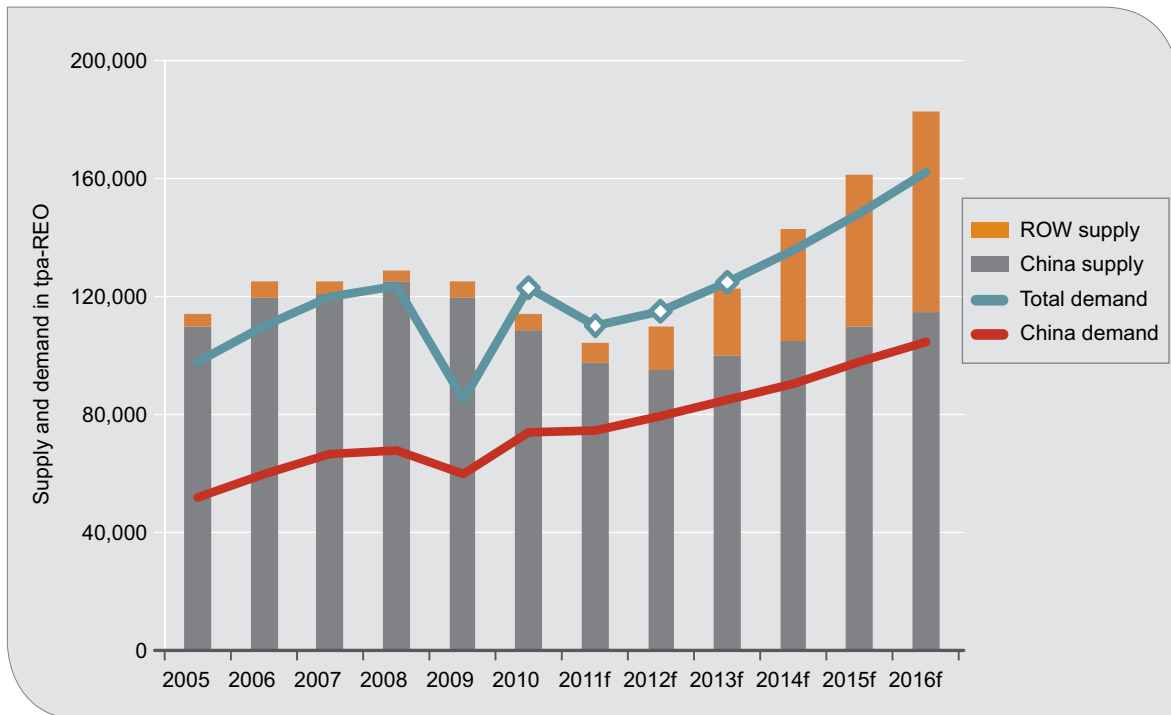
A surplus in total REO supply compared to the worldwide demand is expected for the years after 2013 (a strong increase in rest of world (ROW) supply of REO is predicted starting from 2013).

**Table 5.2.2: Usage, key demand drivers and growth outlook for rare-earths**  
(Source: CURTIS 2012).

Sector	Segment	Subsegments	Growth rate over GDP	Rare-earths used
Conventional energy	Fuel cracking <b>Emissions control</b> Nuclear	FCC <b>Catalysts</b> Material	+2 %	La <b>Ce</b> Gd
Renewable energy	Storage <b>Wind turbines</b>	NiMH batteries <b>Magnets</b>	+10–15 % <b>+25–30 %</b>	La, Nd <b>NdPr</b>
Auto/ Transportation	Emissions control  <b>e-Mobility</b>	Autocat Oxygen sensors <b>Magnets</b> <b>Batteries</b>	+6–8 % 0 % <b>+20–25 %</b> <b>+20–25 %</b>	Ce Y <b>NdPr, Dy</b> <b>La, Nd</b>
Lighting	TC lamps LEDs	Phosphors	+5 %	Eu, Tb, Y, Ce, La
Metallurgy	Special alloys	RE silicides	+10–15 %	CeLa
Electronics	GHD <b>Cameras</b> Displays <b>Capacitors &amp; chips</b>	Polishing <b>Material</b> Phosphors	+2–5 % <b>+5–10 %</b> 0 % <b>0 %</b>	CeLa <b>La</b> Eu, Tb, Y, Ce, La <b>Dy, Nd, Ce</b>
Medical	MRI <b>PET scans</b> Medicines	Magnets <b>Crystals</b> Material	+5–10 % <b>+10–15 %</b> +10–15 %	Gd, NdPr <b>Lu</b> La
Miscellaneous	Defence <b>Decorative ceramics</b> Agriculture	<b>Niches</b>		NdPr, Dy, La <b>Ce, Pr</b> Ce

**Table 5.2.3: Forecast global supply and demand for individual rare-earths in 2016**  
(±20 %; from KINGSNORTH 2013).

Rare-earth oxides	Demand	Supply
<b>Total REO</b>	160,000 tpa	182,500 tpa
<b>Lanthanum</b>	37,500 t REO	50,000 t REO
<b>Cerium</b>	72,000 t REO	79,800 t REO
<b>Praseodymium</b>	6,675 t REO	8,500 t REO
<b>Neodymium</b>	27,725 t REO	28,500 t REO
<b>Europium</b>	425 t REO	450 t REO
<b>Terbium</b>	<b>450 t REO</b>	<b>250 t REO</b>
<b>Dysprosium</b>	825 t REO	1,000 t REO
<b>Erbium</b>	<b>1,000 t REO</b>	<b>500 t REO</b>
<b>Yttrium</b>	<b>9,600 t REO</b>	<b>7,000 t REO</b>
<b>Ho-Tm-Yb-Lu</b>	250 t REO	1,000 t REO



**Fig. 5.2.3: Rare-earths supply and demand data until 2016 based on IMCOA estimates for the years 2011–2016 (data after KINGSNORTH 2013). Diamond symbols indicate years with higher demand than total REE production worldwide. ROW – Rest of World.**

**Tab. 5.2.4: Rare-earth prices from Metal Pages compiled by Frontier Rare Earths (updated 1 December 2013).**

	One year average \$/Kg	Current China FOB price \$/Kg	Current China domestic price \$/Kg
Lanthanum	8	6	4
Cerium	8	6	4
Praseodymium	91	118	86
Neodymium	71	68	47
Samarium	15	9	3
Europium	1,188	975	698
Gadolinium	47	47	25
Terbium	985	825	546
Dysprosium	552	480	265
Yttrium	27	22	10

### Prices

The Table 5.2.4 refers to 99 % purity RE oxides except for europium which is the price for 99.9 % purity and yttrium which is quoted at 99.999 % purity. All prices shown are FOB China except for China domestic column.

### Consumption of REE in Germany

Owing to the fact that there is no primary REE production or significant REE recycling in Germany, the REE consumption is best described using the published import and export data for REE metals and REE-bearing products. The most recent available data come from the report Deutschland-Rohstoffsituation 2012 (HUY et al. 2013). The report states imports of 290 t, 553 t and 4,155 t and exports of 10 t, 165 t and 534 t for REE metal, cerium compounds and non-organic and organic REE compounds, respectively.

The apparent consumption of REE in Germany was estimated at about 5,000 t REO in 2012.

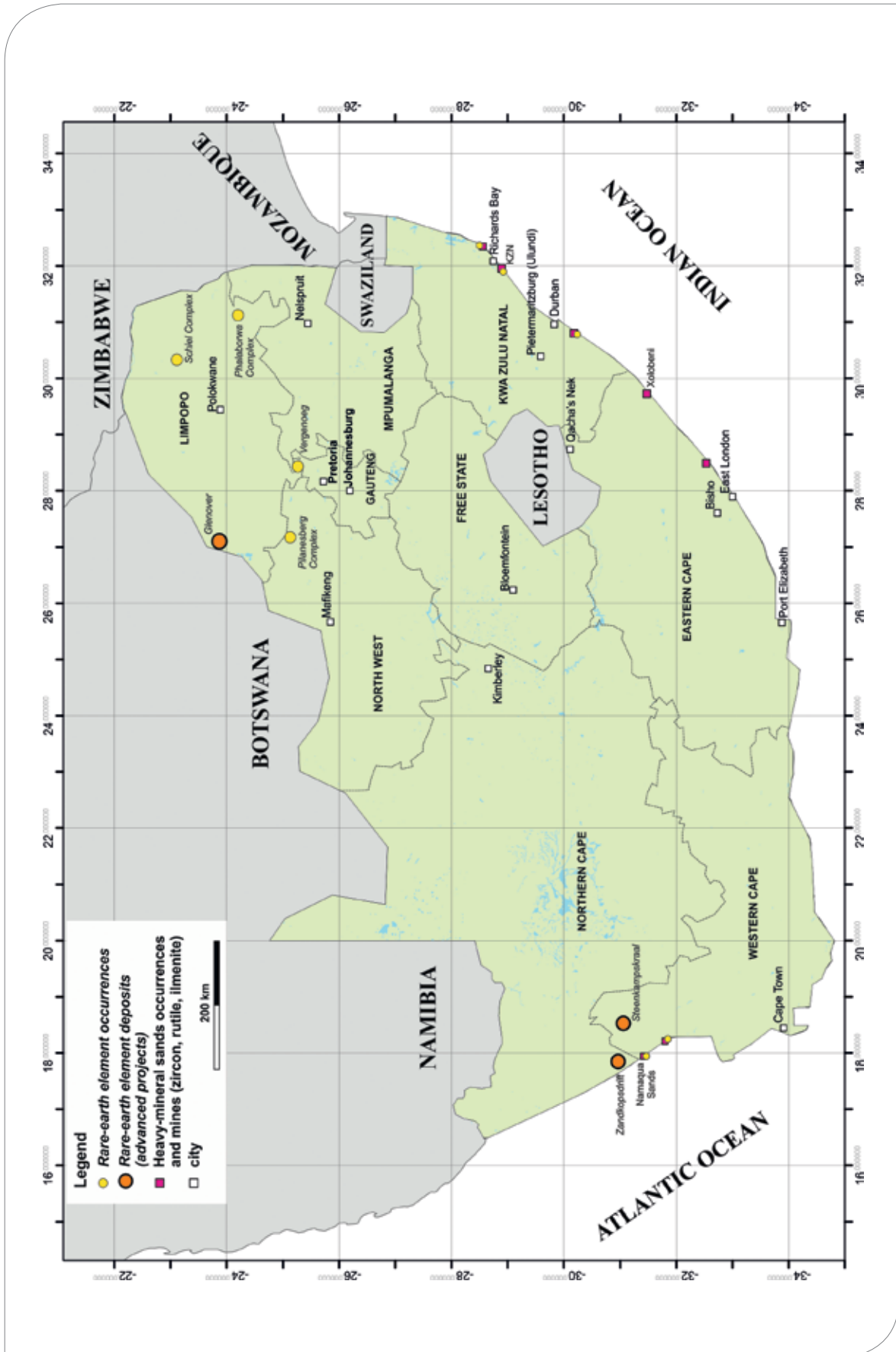


Fig. 5.2.4: Occurrences and deposits of rare-earth elements in the Republic of South Africa.

## 5.2.4 Resources in South Africa

### 5.2.4.1 Steenkampskraal (Western Cape)

#### Location and owner

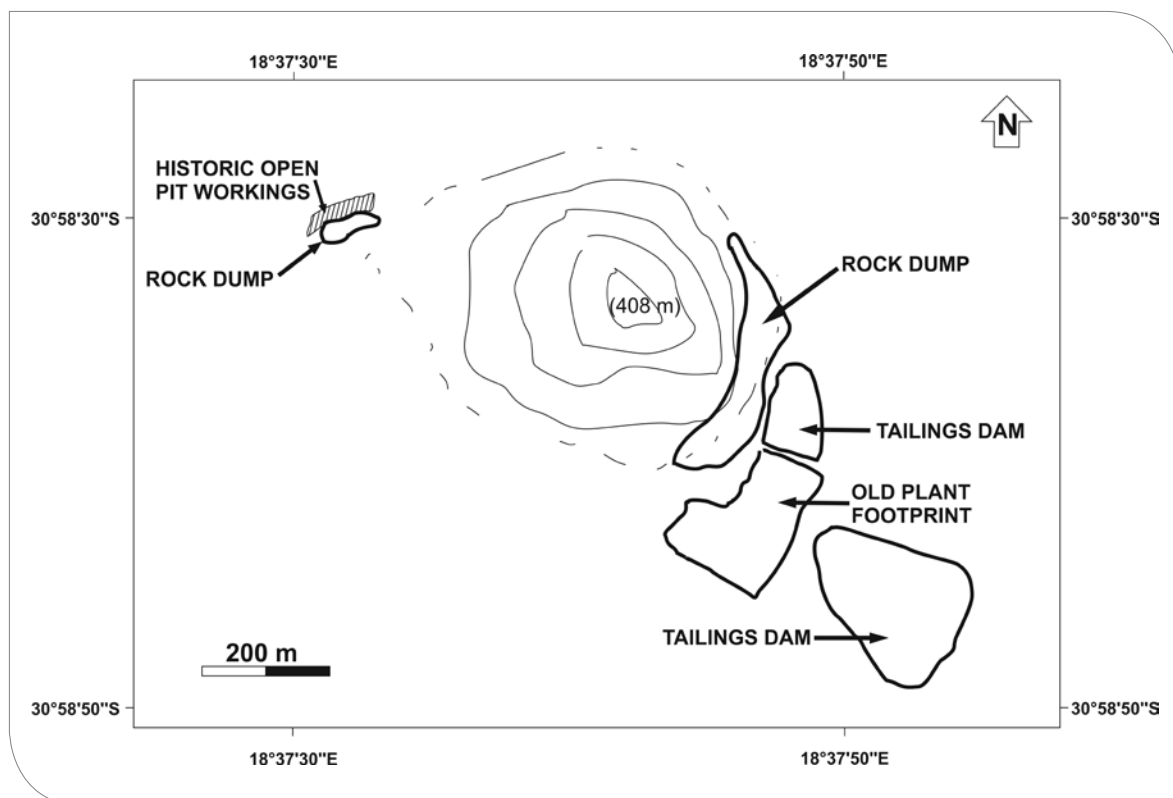
Coordinates: (Centre of rock dump) 30°58'37.57"S; 18°37'51.26"E; 391 m above mean sea level (amsl)

The Steenkampskraal Monazite Property in the Western Cape Province of South Africa, situated some 70 km northeast of Vanrhynsdorp and 30 km south of Kliprand, is presently held by Steenkampskraal Monazite Mine (Pty) Ltd (SMM), a subsidiary of Rareco (the latter is a 100 %-owned subsidiary of Great Western Minerals Group Ltd (GWMG)). Between 1952 and 1963, the monazite mineralisation was mined by Monazite and Mineral Ventures (Proprietary) Limited. Since then, the mining operation has been suspended (Fig. 5.2.5).

All data summarised in this chapter are from the publicly available NI 43-101 compliant Resource Estimate and Technical Report on the Steenkampskraal property (HANCOX & JONES 05/2012; updated JONES et al. 12/2012, JELICOE 11/2013), the announced results from a Preliminary Economic Assessment (PEA; McKECHNIE et al. 12/2012) and internet resources of GWMG (and linked sites). Additional field and analytical work have not been carried out for this report.

#### Geology

Steenkampskraal is a massive, quasi-planar ore body of monazite located in the Mesoproterozoic Namaqua crustal province. The mineralised body has a strike extent of over 1,000 m as an E-W striking band of fine-grained monazite-dominated ore, with an average thickness of ~1 m (Fig. 5.2.6). The stepped, lenticular, dyke-like monazite ore body dips from 0° to 60° to the S, extending down-dip for at least 300 m in Namaquan granitic gneiss. Historical mine development extended down to the 300 level, which is about 90 m below the surface.



**Fig. 5.2.5:** Simplified map of the Steenkampskraal mine site with the historic open pit, the rock dump and tailings dams (redrawn after HANCOX & JONES 05/2012).





**Fig. 5.2.6:** Cross-sectional view of the surface exposure of the monazite, facing east (from <http://www.techmetalsresearch.com/wp-content/uploads/2011/03/SKK13.jpg>).

Based on underground exposures and on drill core intercepts, the ore consists of a phosphate-rich assemblage (REE-enriched monazite, apatite, chalcopyrite, magnetite), and to a lesser extent of a magnetite-rich assemblage of similar minerals. The monazite ore is variably intermixed with and diluted by feldspar and quartz (xenoliths), sulphides and magnetite (KNOPER & JELICOE 2013). Intruding the Namaquan granitic gneiss in the immediate vicinity of the ore body are monazite-bearing alkali-granite dykes, which are traceable into the ore body itself. The ore body is postulated to have originated by igneous processes during emplacement of the alkali-granite dykes at ~1,045 Ma. Post-emplacement multi-temporal deformation is characterised by brittle-ductile and ductile shearing resulting in deformation of the ore body on a local scale, and by later normal faults that offset the ore body. Monazite contains >90 % of the total REE in the deposit (KNOPER & JELICOE 2013).

#### Rare-earth element potential

The REE potential of the Steenkampskraal mine site consists of two parts: firstly, mining of the monazite-mineralised zones from the existing under-

**Tab. 5.2.5:** Grade and relative distribution of in-situ rare-earth oxides (REO; wt %) for the Steenkampskraal deposit. All data are from the TMR ADVANCED RARE-EARTH PROJECTS INDEX 2013.

	Grade of In-situ REO (wt %)	Relative distribution of In-situ REO (wt %)
La <sub>2</sub> O <sub>3</sub>	2.907	20.762
CeO <sub>2</sub>	6.340	45.283
Pr <sub>6</sub> O <sub>11</sub>	0.717	5.123
Nd <sub>2</sub> O <sub>3</sub>	2.517	17.980
Sm <sub>2</sub> O <sub>3</sub>	0.402	2.874
Eu <sub>2</sub> O <sub>3</sub>	0.009	0.068
Gd <sub>2</sub> O <sub>3</sub>	0.274	1.954
Tb <sub>4</sub> O <sub>7</sub>	0.030	0.217
Dy <sub>2</sub> O <sub>3</sub>	0.140	0.998
Ho <sub>2</sub> O <sub>3</sub>	0.020	0.143
Er <sub>2</sub> O <sub>3</sub>	0.041	0.294
Tm <sub>2</sub> O <sub>3</sub>	0.004	0.028
Yb <sub>2</sub> O <sub>3</sub>	0.018	0.129
Lu <sub>2</sub> O <sub>3</sub>	0.002	0.013
Y <sub>2</sub> O <sub>3</sub>	0.579	4.135
<b>TREO</b>	<b>14.001</b>	<b>100</b>

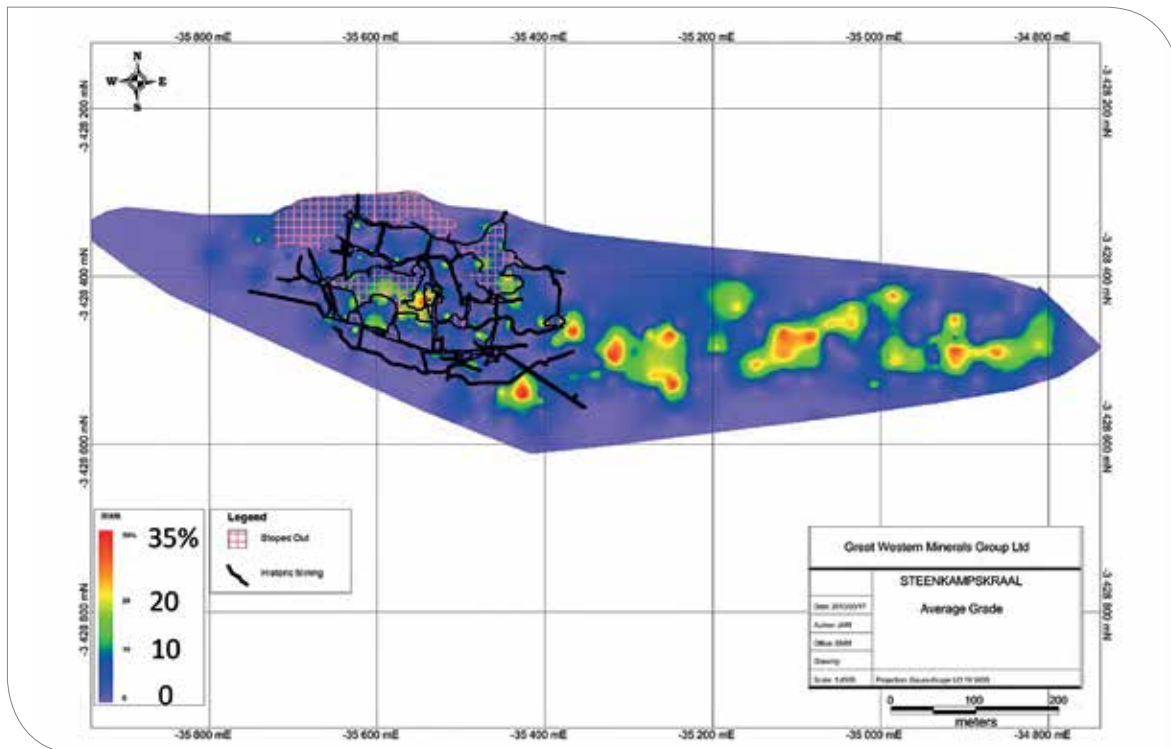


Fig. 5.2.7: Plotted assay results – average grade (from KNOPER & JELICOE 2013).

Tab. 5.2.6: Summary of data for the Steenkampskraal Monazite Property (e.g. from PEA (McKECHNIE et al. 12/2012); JONES et al. 2012; JELICOE 2013; TMR ADVANCED RARE-EARTH PROJECTS INDEX 2013).

<b>Total mineral resource (1 % cut-off grade)</b>	Combined <i>In-situ</i> : Measured+indicated: 559,000 t @ 14.95 % TREO Inferred: 20,000 t @ 12.77 % TREO; 40,000 t @ 9.30 % TREO  Combined tailings: Indicated: 46,000 t @ 7.18 % TREO
<b>Contained TREO</b>	93,100 t
<b>Planned annual production</b>	5,000 t TREO
<b>Mining</b>	30,000 to 44,000 (ore tpa)
<b>Estimated mine life</b>	11 years +
<b>Mining method</b>	Underground and reprocessing of tailings
<b>RE separation plant</b>	Operated by GWGQD (joint venture of GQD with GWMG) <sup>1)</sup> ; site: Vredendal, Western Cape (~100 km from mine site)
<b>Average RE separation plant recovery</b>	93.62 %
<b>Risks (for mining, processing and mine waste storage)</b>	High radioactivity of monazite ore (thorium); permission for handling and long term storage of radioactive material (COR <sup>2)</sup> ; 2004 and 2011)
<b>Start of mining/hydrometallurgy</b>	Commencement of development not before late 2013 or early 2014
<b>REO basket price</b>	31 US\$/kg

<sup>1)</sup> GWGQD – Great Western GQD Rare Earth Materials Proprietary Limited;

Ganzhou Qiandong Rare Earth Group Ltd (GQD) holds 25 % of the shares of GWGQD.

<sup>2)</sup> COR - Certificate of Registration in terms of the South African National Nuclear Regulator (NNR).

ground mine (Monazite Mine Area; Exploration Area) and, secondly, reprocessing of tailings (information from PEA for GWMG Ltd (McKECHNIE et al. 12/2012)). Table 5.2.5 summarises the grade and relative distribution of REO for the deposit.

Five phases of drilling and other sampling activities were completed between 09/2011 and 03/2013, which expanded the resource along strike from 450 m to 1,100 m and tripled the in-situ resource. The average grade of the plotted assay results are shown in Figure 5.2.7.

Significant highlights of the Steenkampskraal monazite deposit are summarised in Table 5.2.6. These include mineral resource data, mine design, risks and data for the REE separation plant.

#### 5.2.4.2 Zandkopsdrift (also Zandkops Drift, Sandkopsdrift) (Northern Cape)

##### Location and owner

Coordinates: (Zandkopsdrift Mine) 30°51'57"S; 17°57'57"E; ~200 m amsl

The Zandkopsdrift property in the Northern Cape Province of the Republic of South Africa is situated 450 km north of Cape Town and ~80 km southwest of Garies (Fig. 5.2.8). The owner of the prospecting right is Sedex Minerals (Pty) Ltd (Sedex); Sedex is a 74 %-owned subsidiary of Frontier – the remaining 26 % of the share capital is owned by South African individuals.

All data summarised in this chapter are sourced from publicly available NI 43-101 compliant resource estimates and technical reports on the Zandkopsdrift property (VENTER et al. 10/2010), the Preliminary Economic Assessment (PEA; HARPER et al. 12/2011) and website resources of Frontier Rare-Earth Ltd; additional field and analytical work have not been carried out for this report. Figure 5.2.8 gives an overview of the planned Zandkopsdrift rare-earth operations and infrastructure.

## Geology

The Zandkopsdrift carbonatite complex represents a REE-enriched carbonatitic breccia pipe. The pipe occurs as a circular intrusive, roughly 1,000 m in diameter, rising some 40 m above the surrounding area. REE mineralisation is related to a complex series of vertical to subvertical REE-enriched dykes, dykelets and vein swarms that have intruded a pre-existing REE-bearing carbonatitic phlogopite breccia phase (Fig. 5.2.9). The host carbonatitic phlogopite breccia, along with these later stage REE-enriched carbonatite dykes, have undergone several stages of alteration and deep weathering resulting in the development of a series of variable and deeply weathered supergene-enriched REE-bearing mineralised horizons (HAYWARD 2013).

## Rare-earth element potential

The REE potential of the Zandkopsdrift prospect consists of open-cast mining of higher grade zones of the Zandkopsdrift carbonatite intrusion (areas with TREO contents exceeding >2.0 % TREO have been defined and have been termed

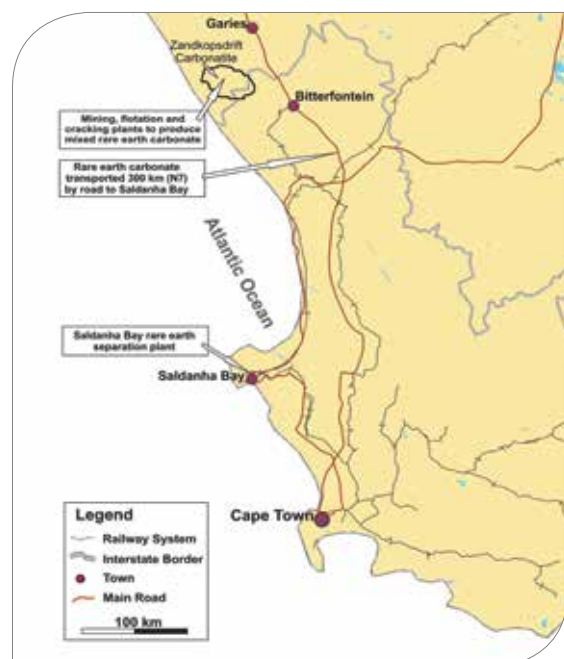
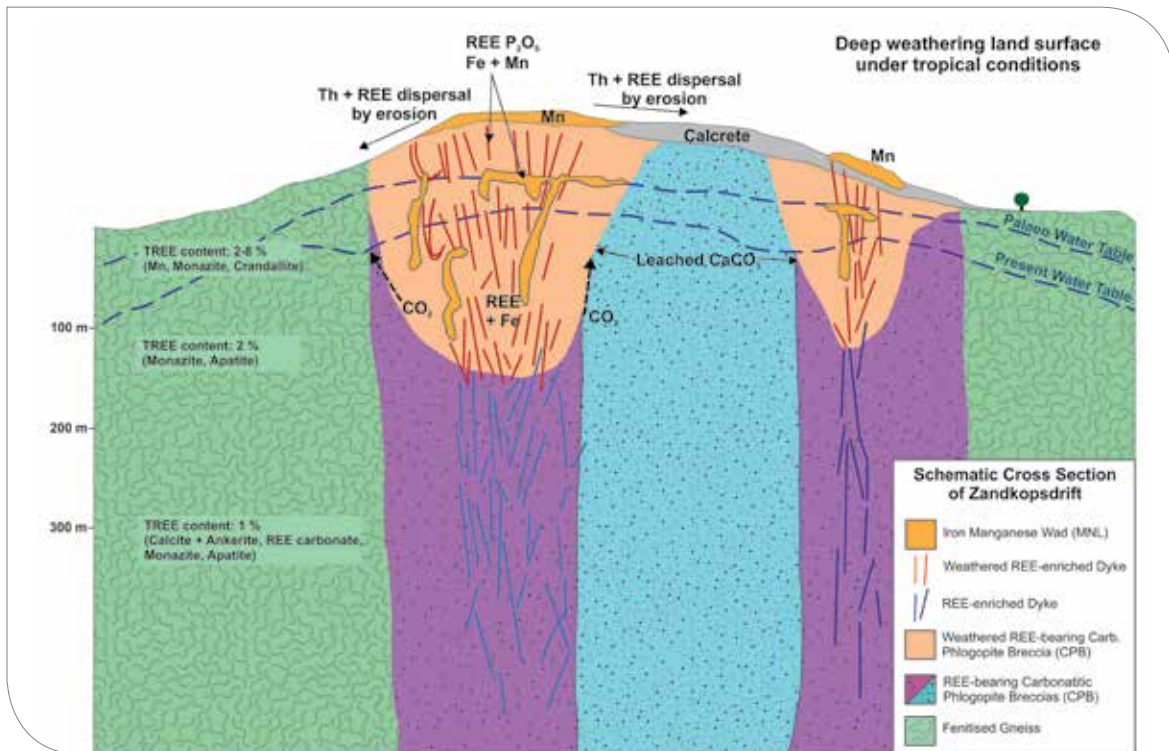


Fig. 5.2.8: Planned Zandkopsdrift rare-earth operations and infrastructure (modified from KENNY 2012).



**Fig. 5.2.9: Current geological model for the Zandkopsdrift Complex (redrawn from HAYWARD 2013).**

the Central Zone by Frontier; information from PEA for Frontier (Harper et al. 12/2011)). Table 5.2.7 summarises the grade and relative distribution of REO for the deposit.

Important key figures of the Zandkopsdrift deposit are summarised in Table 5.2.8. These include mineral resource data, mine design, risks, costs and data for the REE separation plant.

**Tab. 5.2.7: Grade and relative distribution of in-situ rare-earth oxides (REO; wt %) for the Zandkopsdrift deposit. All data are from the TMR ADVANCED RARE-EARTH PROJECTS INDEX 2013.**

	Grade of In-situ REO (wt %)	Relative distribution of In-situ REO (wt %)
La <sub>2</sub> O <sub>3</sub>	0.566	25.370
CeO <sub>2</sub>	0.983	44.050
Pr <sub>6</sub> O <sub>11</sub>	0.103	4.620
Nd <sub>2</sub> O <sub>3</sub>	0.354	15.880
Sm <sub>2</sub> O <sub>3</sub>	0.051	2.270
Eu <sub>2</sub> O <sub>3</sub>	0.013	0.590
Gd <sub>2</sub> O <sub>3</sub>	0.032	1.420
Tb <sub>4</sub> O <sub>7</sub>	0.004	0.170
Dy <sub>2</sub> O <sub>3</sub>	0.017	0.780
Ho <sub>2</sub> O <sub>3</sub>	0.003	0.130
Er <sub>2</sub> O <sub>3</sub>	0.007	0.320
Tm <sub>2</sub> O <sub>3</sub>	0.001	0.040
Yb <sub>2</sub> O <sub>3</sub>	0.005	0.220
Lu <sub>2</sub> O <sub>3</sub>	0.001	0.030
Y <sub>2</sub> O <sub>3</sub>	0.092	4.120
<b>TREO</b>	<b>2.233</b>	<b>100</b>



**Tab. 5.2.8: Summary of data for the Zandkopsdrift Property from PEA (HARPER et al. 12/2011) and update on PFS (available at [www.frontierrareearths.com](http://www.frontierrareearths.com) 03/2013).**

<b>Total mineral resource (2 % cut-off grade; Central Zone)</b>	Indicated: 16.01 Mt @ 3.09 % TREO Inferred: 4.53 Mt @ 2.85 % TREO
<b>Contained TREO (2% cut-off grade; Central Zone)</b>	~624,000 t
<b>Total mineral resource (1 % cut-off grade)</b>	Indicated: 32.35 Mt @ 2.28 % TREO Inferred: 10.13 Mt @ 2.08 % TREO
<b>Contained TREO (1% cut-off grade)</b>	~948,000 t
<b>Planned annual production</b>	20,000 t separated rare-earth oxides
<b>Target annual mining rate (ore)</b>	1.0 million tpa (Central Zone material)
<b>Estimated mine life</b>	>30 years
<b>Mining method</b>	Open pit with single entry access ramp
<b>Average stripping ratio</b>	1:1
<b>RE separation plant</b>	Operated through Odvest 196 (Pty) Ltd ("Sepco"); located at Saldanha Bay (~250 km south of mine site)
<b>Recovery rate (metallurgical test work)</b>	The overall TREO recovery of the 'Flotation and Cracking' option selected for the PEA is 67 %
<b>Risks (for mining, processing and mine waste storage)</b>	Potential environmental risks have been identified and can be managed or successfully mitigated
<b>Production start-up</b>	2016
<b>Total estimated Construction Capex</b>	910 m US\$
<b>Start-up costs</b>	27 m US\$
<b>Total estimated cash operating costs</b>	13.08 US\$/kg of separated REO
<b>REO basket price</b>	32 US\$/kg

### 5.2.4.3 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; 1,105 m amsl

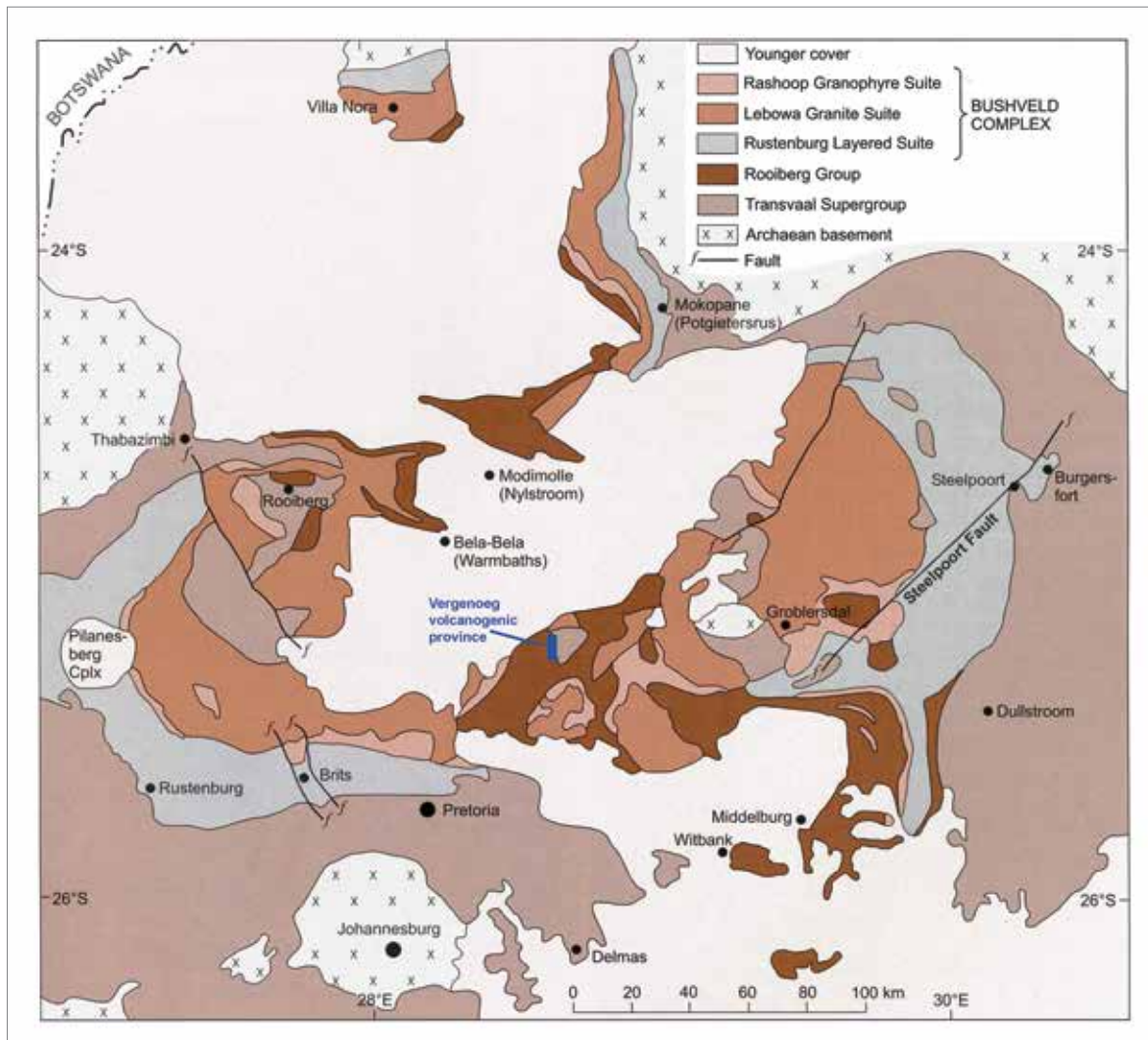
The Vergenoeg fluorspar mine, situated 125 km northeast of Johannesburg, is presently (since September 23, 2009) owned by Minerales Y Productos Derivados S.A. ("Minersa") which holds 85 % of the issued ordinary share capital of Vergenoeg. All data summarised in the Chapter 5.2.4.3 are sourced from publicly available 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 tarred road. The Vergenoeg fluorite deposit is easily accessible via the D567 tarred 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 ~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 water-course 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<sup>3</sup>) and the Flood Diversion Dam (built in 1975; storage capacity: 1,065,865 m<sup>3</sup>; 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).



**Fig. 5.2.10: Simplified geological map of the Bushveld Complex indicating the position of the Vergenoeg volcanogenic province (modified from BUCHANAN 2006).**

### Geology

The Vergenoeg Igneous Complex (Fig. 5.2.10) is located in the Rooiberg Group. 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 ( $2,061 \pm 2$  Ma (WALRAVEN 1997)). The last-mentioned formation overlies the intracratonic Transvaal Supergroup. The oval-shaped (900 m x 600 m) Vergenoeg 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). Furthermore, siderite lenses and metallur-

gical fluorspar ("metspar") plug-like bodies occur throughout the pipe. The genesis of this deposit is still a matter of debate (e.g. CROCKER 1985; BORROK et al. 1998; GOFF et al. 2004).

### Mining

Vergenoeg mine represents one of the largest fluorite deposits globally with a fluorite resource in excess of 174 million tonnes at 28.1%  $\text{CaF}_2$  (GOFF et al. 2004). In addition, a statement in 2009 resulting from joint research of the Council for Geoscience and the Japan Oil, Gas and Metals National Corporation (JOGMEC) suggests an "excellent potential of the Vergenoeg fluorite deposit as a source of rare-earth elements" (WATANABE et al. 2009).



According to data of ISCOR (1999), Vergenoeg also contains an iron resource in the order of ~195 million tonnes at 42 % Fe.

Presently, mining of fluorite is mainly restricted to the hematite-fluorite gossan (open pit; Fig. 5.2.11). Fluorite grades decrease from ~40 % in the magnetite-fluorite unit to ~10 % in the fayalite unit (GOFF et al. 2004); however, fluorite resources are present to a depth of 600 m below surface (data from drill core).

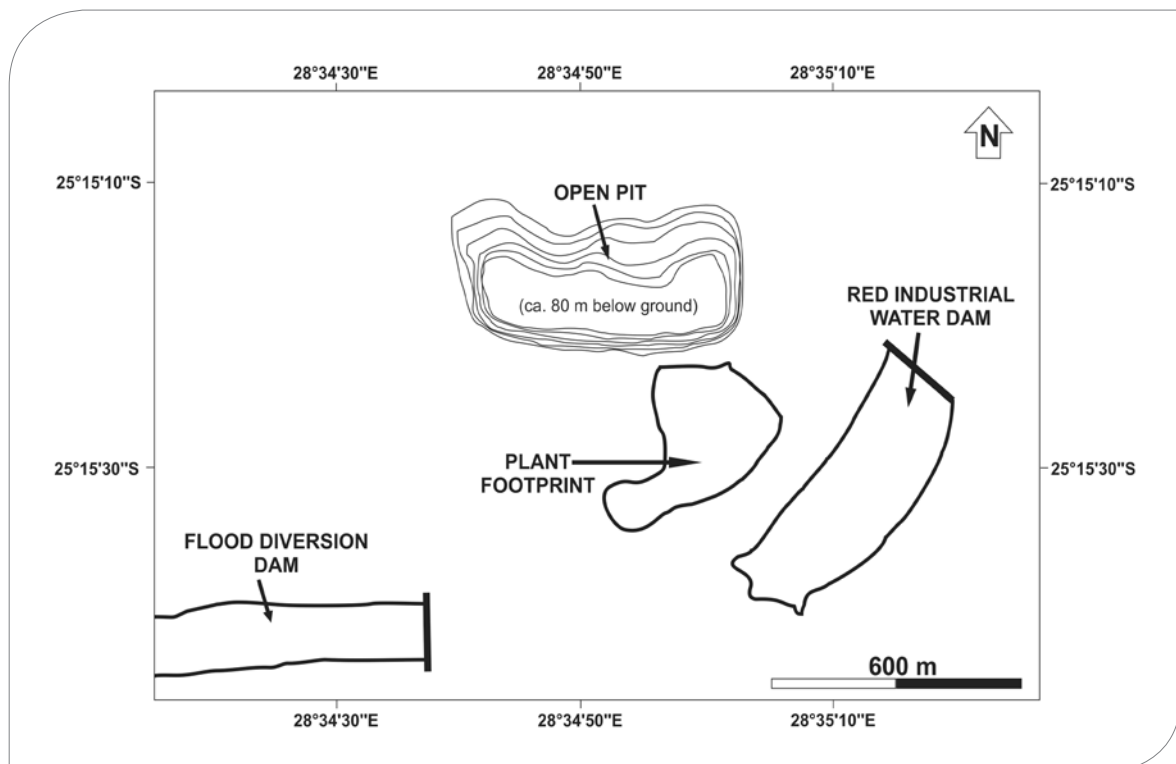
### Rare-earth element potential

The statement of the CGS/JOGMEC research group concerning an excellent potential of the Vergenoeg deposit for REE is supported by published scientific data. According to GOFF et al. (2004), the Vergenoeg pipe units have unusually high REE contents, similar to carbonatite-related rocks. The REE concentrations reach values up to 2 %. Interestingly, the above mentioned authors found whole-rock chondrite-normalised REE distribution patterns significantly different from carbonatites. A gentle slope from LREE towards

HREE and a strongly negative Eu anomaly is common; however, strong HREE enrichment was found occasionally (chondrite-normalised La/Yb ratio: 0.07 to 4.2 (GOFF et al. 2004)). Neodymium and dysprosium contents vary between 11 and 5,900 ppm and 4 and 1,500 ppm, respectively (GOFF et al. 2004; Tab. 5.2.9). Niobium values are also elevated in the Vergenoeg pipe (60–300 ppm; GOFF et al., 2004).

FOURIE (2000) describes an association of the REE (Y, La, Ce and Nd in decreasing order) with monazite and xenotime throughout the volcanic pipe and in some pyroclastic rocks. Furthermore, the REE minerals fluorocerite, bastnaesite and allanite are described for Vergenoeg (CROCKER 1985; BORROK et al. 1998). Anomalous Th and U values are found for purple fluorite (FOURIE 2000).

TAKAGI (2012) expects significant separation problems for REE minerals during conventional physical processing of ore from Vergenoeg for REE. This is inferred from the very fine grain size of the REE-bearing phosphates (monazite, xenotime) and the related iron oxides in the deposit.



**Fig. 5.2.11: Simplified map of the Vergenoeg fluorspar mine site with the open pit, the processing plant and the water dams.**

There is no resource estimate for REE and yttrium available at present; however, the high heavy-REO contents in some of the Vergenoeg ores (HREO; Tab. 5.2.9) are important owing to the expected high demand for some of the HREO in the future. A heterogeneous distribution of REO in the lithological units of the Vergenoeg pipe is expected; phosphate-rich zones seem to be especially rich in REO (probably because of a frequent occurrence of REE phosphates; Tab. 5.2.9).

#### 5.2.4.4 Glenover carbonatite project (Limpopo)

##### Location and owner

Coordinates: (Centre of open pit) 23°52'07.02"S; 27°09'46.11"E; 910 m amsl

The Glenover carbonatite (phosphate, RE) project, situated 85 km north of Thabazimbi,

**Table 5.2.9: Vergenoeg fluorspar mining operation. Rare-earth compositions of whole-rock ore samples and ore concentrates (all values are in ppm unless otherwise stated). Data are from (1) Goff et al. (2004) for ore compositions and (2) Schürmann (1992) for the composition of an ore concentrate.**

Sample	Rock samples								Concentrate
	Hematite-fluorite unit – sample 21	Hematite-fluorite unit – sample 7	Fayalite unit – sample 12	Fayalite unit – sample 13	Magnetite-fluorite unit – sample 15	Magnetite-fluorite unit – sample 16	Magnetite-fayalite unit – sample 18	Magnetite-fayalite unit – sample 19	Magnetite concentrate GFJ 19
Data source	1	1	1	1	1	1	1	1	2
P <sub>2</sub> O <sub>5</sub> (%)	0.17	0.55	0.64	<b>1.46</b>	0.31	<b>2.26</b>	0.66	0.02	
La	236	2,186	511	1,261	748	3,741	872	72.9	381
Ce	702	5,058	1,366	3,737	2,077	11,237	2,370	195	792
Pr	99.2	627	171	495	278	1,517	308	23.5	118
Nd	391	<b>2,343</b>	626	1,926	1,097	<b>5,896</b>	1,169	80.7	449
Sm	85.7	<b>493</b>	133	433	264	<b>1,368</b>	268	15.6	86
Eu	2.59	<b>16.2</b>	2.51	9.2	6.43	27.5	5.47	0.66	2.1
Gd	71.9	474	128	409	271	<b>1,304</b>	266	14.2	95
Tb	12.7	85.3	22.8	74.9	50.3	236	48.6	2.66	17
Dy	84.7	575	156	485	330	<b>1,543</b>	329	20.6	116
Y	970	<b>4,031</b>	997	2,760	2,321	<b>8,495</b>	2,364	169	
Ho	18.4	<b>121</b>	33.0	104	72.4	<b>321</b>	69.8	5.72	25
Er	57.5	<b>358</b>	108	299	213	<b>888</b>	206	27.3	82
Yb	64.2	<b>349</b>	145	282	199	<b>634</b>	176	110	69
Lu									
ΣREE	2,806	16,775	4,419	12,324	7,962	37,340	8,484	747	2,232 <sup>1)</sup>
TREO	<b>3,415</b>	<b>20,295</b>	<b>5,340</b>	<b>14,885</b>	<b>9,647</b>	<b>45,112</b>	<b>10,282</b>	<b>898</b>	<b>2,651<sup>1)</sup></b>
HREO <sup>2)</sup>	<b>46.88</b>	<b>36.74</b>	<b>36.92</b>	<b>36.74</b>	<b>44.54</b>	<b>36.85</b>	<b>41.84</b>	<b>48.13</b>	<b>17.57<sup>1)</sup></b>
Nd <sub>2</sub> O <sub>3</sub> <sup>3)</sup>	<b>13.4</b>	<b>13.5</b>	<b>13.7</b>	<b>15.1</b>	<b>13.3</b>	<b>15.2</b>	<b>13.3</b>	<b>10.5</b>	<b>19.7<sup>1)</sup></b>
Eu <sub>2</sub> O <sub>3</sub> <sup>3)</sup>	<b>0.09</b>	<b>0.09</b>	<b>0.05</b>	<b>0.07</b>	<b>0.08</b>	<b>0.07</b>	<b>0.06</b>	<b>0.09</b>	<b>0.09<sup>1)</sup></b>
Dy <sub>2</sub> O <sub>3</sub> <sup>3)</sup>	<b>2.85</b>	<b>3.25</b>	<b>3.35</b>	<b>3.74</b>	<b>3.93</b>	<b>3.93</b>	<b>3.67</b>	<b>2.63</b>	<b>5.02<sup>1)</sup></b>

<sup>1)</sup> data for yttrium concentrations were not available for this sample;

<sup>2)</sup> HREO = 100\* total HREO/TREO; total HREO = ΣEu<sub>2</sub>O<sub>3</sub> to Lu<sub>2</sub>O<sub>3</sub> + Y<sub>2</sub>O<sub>3</sub>; <sup>3)</sup> % of TREO.

is presently owned by Fer-Min-Ore (Pty) Ltd (FMO) and Galileo Resources Plc. Between 1963 and 1984, the apatite breccia was mined for phosphate by Goldfields South Africa. Since then, the mining operation has been suspended.

**Local infrastructure:** The Glenover project area can be accessed via the tarred P16/2 provincial road. The major regional town of Lephalale (old name Ellisras; northeast of Glenover) is connected with the Glenover site via tarred roads (distance about 70 km).

A replenishing water borehole is in operation at the existing site and it is proposed that an expansion or similar new borehole field will supply the water requirements of the project. Riverbed wells or a borehole field could be developed at Matlabas River and connected to the site via a ~7 km pipeline.

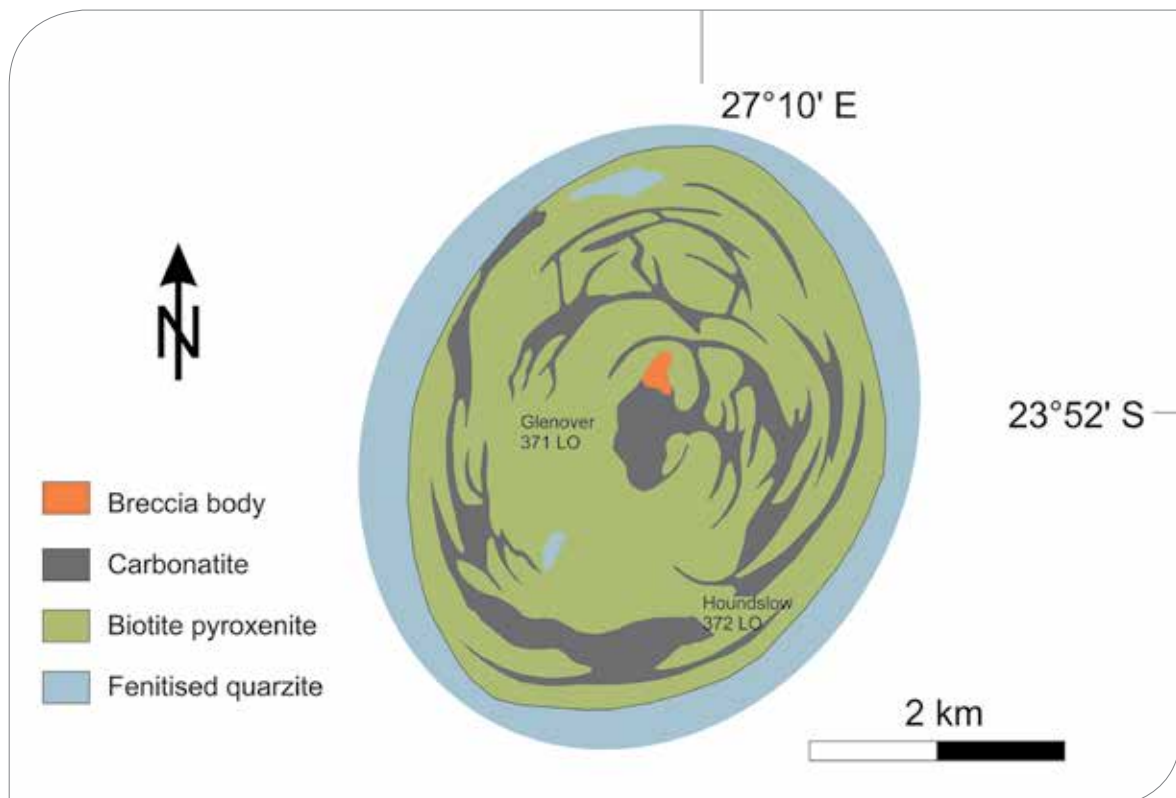
Utilities including power, coal and fuel can be sourced from local providers. Infrastructural data are mostly from a PEA-Executive Summary on the Glenover Rare-Earth Project (FAIRHALL et al. 2013).

## Geology

The carbonatite/pyroxenite plug hosting the RE-bearing phosphate deposit was discovered in 1953 (oval-shaped, ~3.5 km x ~3.0 km; Fig. 5.2.12). Its host rocks are sedimentary rocks of the Waterberg Formation. Fenitised quartzites surround the intrusion. The entire complex is located within an east–west-trending structural graben structure.

The pyroxenite is variably altered to phlogopite-rich varieties. The rock is magnetite rich and contains low-grade phosphate mineralisation (5 %  $P_2O_5$ ; apatite). The carbonatite intruded the pyroxenite as a series of dykes and cone sheets. It shows harrisitic textures. XRD analysis indicated that the carbonate is predominantly dolomite with lesser amounts of calcite and ankerite. Minor amounts of apatite, magnetite and pyrite also occur.

The central part of the complex is formed by an iron-rich apatite-hematite breccia. The rock contains martite or hematite (formed from magnetite), vermiculite and a matrix of apatite. This rock type was mined by Goldfields SA in the open pit and was stockpiled in the area.



**Fig. 5.2.12: Geology of the Glenover Complex (simplified from VERWOERD 1967).**

### Rare-earth element potential

The REE potential for the Glenover site consists of two parts: Firstly of remnant material in the open pit (Fig. 5.2.13) and, secondly, of surface stockpiles of high-, medium- and low-grade ore (Fig. 5.2.14). Surrounding carbonatite and pyroxenite rocks were excluded from further consideration because of their low REE contents (MINING JOURNAL 2013; GALILEO RESOURCES PLC 2013).

The REE are present in the ore in five distinct phases (GALILEO RESOURCES PLC 2012a):

1. REE phosphates, mainly monazite,
2. REE calcium-rich fluorocarbonate, probably synchysite,
3. REE calcium-poor fluorocarbonate, probably bastnaesite,
4. REE titano-niobate with similarities in composition to the mineral aeschynite, and
5. REE-bearing apatite.

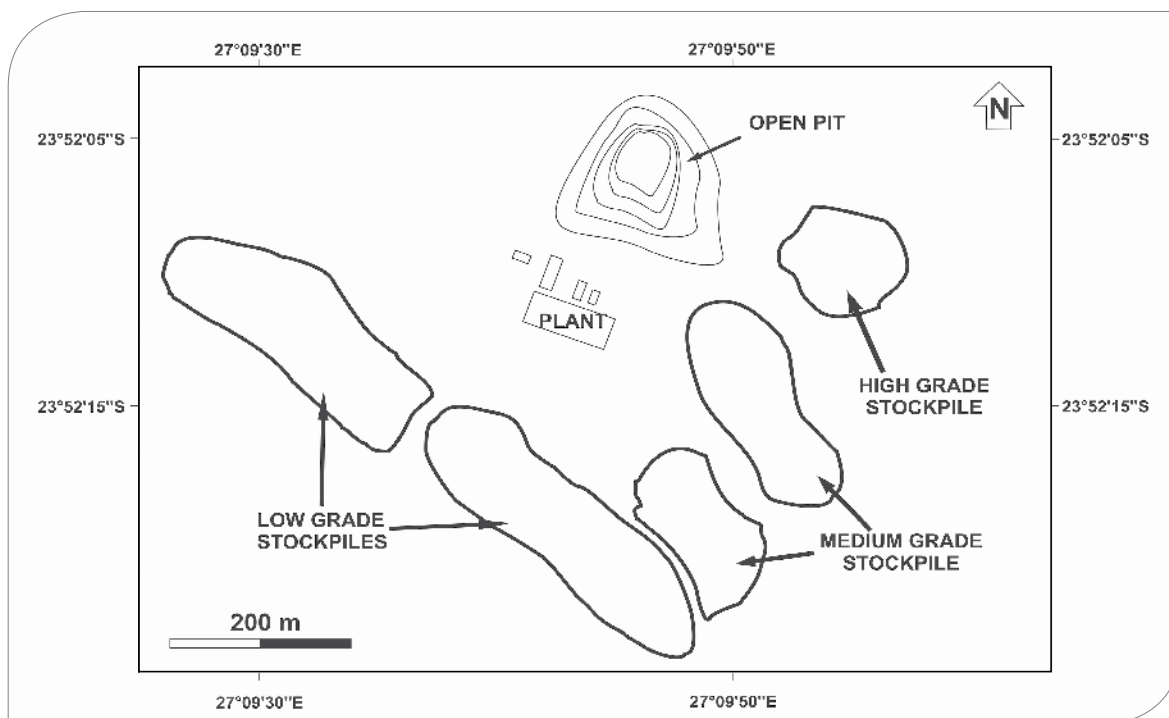
Mean REO grade and relative distribution in ore from the Glenover carbonatite project are shown in Table 5.2.10 (data source: TMR ADVANCED RARE-EARTH PROJECTS INDEX 2013). The economically relevant ore types are characterised by LREE >> HREE; however, significant contents of Nd oxide form an economically important part of the project.

Bulk rock chemistry data for REE-bearing rock samples (pick samples;  $\leq 1.5$  kg each) from the inactive Glenover open pit (samples Gle1 to Gle6), taken during the BGR/CGS field campaign in Glenover in September 2012, are given in Table 5.2.11.

The BGR/CGS samples contain TREO contents in the same order of magnitude ( $\sim 0.2$  to 6.3 wt % TREO; mean: 1.57 wt % TREO) compared to the TREO data for in-situ material as released by the project owner (Tab. 5.2.12). The analytical work carried out in the BGR labs also confirm elevated concentrations of  $\text{Nd}_2\text{O}_3$  (mean of samples Gle1 to Gle6 in Tab. 5.2.11: 22.82 % of TREO) and  $\text{Eu}_2\text{O}_3$  (mean: 0.92 % of TREO) in the ore from Glenover, when compared to ore from several other advanced REE projects (ANDERSON 2012).



**Fig. 5.2.13:** East-northeast view into the inactive open pit of the Glenover carbonatite project. The dimensions of the open pit are  $\sim 210$  m x  $\sim 230$  m (Photo BGR).



**Fig. 5.2.14: Contours of the 2011 Orbital survey and positions of the main stockpiles of the Glenover project (simplified from VAN DER WALT et al. 04/2012).**

The classified SAMREC-compliant mineral resources for in-situ remnant pit resources and stockpile material of the Glenover project are given in Table 5.2.12. The original resource statement was compiled by Geo-Con-

sult International (Pty) Ltd on behalf of Glenover Phosphate (Pty) Ltd (VAN DER WALT et al. 2012). The mineral resource estimate for the surface stockpiles was updated in a PEA Update (GALILEO RESOURCES PLC 2012b).

**Tab. 5.2.10: Grade and relative distribution of In-situ REO (wt %) for the Glenover project. All data are from the TMR ADVANCED RARE-EARTH PROJECTS INDEX (2013).**

	Grade of In-situ REO (wt %)	Relative distribution of In-situ REO (wt %)
La <sub>2</sub> O <sub>3</sub>	0.359	16.845
CeO <sub>2</sub>	0.956	44.827
Pr <sub>6</sub> O <sub>11</sub>	0.122	5.747
Nd <sub>2</sub> O <sub>3</sub>	0.473	22.182
Sm <sub>2</sub> O <sub>3</sub>	0.075	3.525
Eu <sub>2</sub> O <sub>3</sub>	0.019	0.889
Gd <sub>2</sub> O <sub>3</sub>	0.043	2.034
Tb <sub>4</sub> O <sub>7</sub>	0.004	0.206
Dy <sub>2</sub> O <sub>3</sub>	0.016	0.772
Ho <sub>2</sub> O <sub>3</sub>	0.002	0.105
Er <sub>2</sub> O <sub>3</sub>	0.004	0.193
Tm <sub>2</sub> O <sub>3</sub>	0.000	0.019
Yb <sub>2</sub> O <sub>3</sub>	0.002	0.091
Lu <sub>2</sub> O <sub>3</sub>	0.000	0.009
Y <sub>2</sub> O <sub>3</sub>	0.054	2.556
<b>TREO</b>	<b>2.132</b>	<b>100</b>



**Table 5.2.11: Chemistry of bulk rock analysis of REE-rich rocks from the Glenover open pit. All analyses carried out by BGR.**

Chemistry		Gle1	Gle2	Gle3	Gle4a	Gle5	Gle6
		Carbonatite (low RE)	Breccia	Breccia	"Carbonatite" flow <sup>3)</sup>	Breccia	High-grade apatite ore
XRF analysis, all data are in wt %	SiO <sub>2</sub>	0.57	20.88	5.41	3.01	11.56	0.27
	TiO <sub>2</sub>	0.007	1.97	0.67	2.52	1.79	0.22
	Al <sub>2</sub> O <sub>3</sub>	0.07	1.36	0.15	0.82	0.43	0.33
	Fe <sub>2</sub> O <sub>3</sub>	0.90	30.01	13.65	41.58	23.76	6.16
	MnO	0.53	0.13	0.24	0.71	0.08	0.03
	MgO	2.65	0.35	0.29	1.60	0.75	0.06
	CaO	50.92	23.60	42.22	25.76	27.46	52.10
	Na <sub>2</sub> O	<0.01	0.06	0.04	0.03	0.01	<0.01
	K <sub>2</sub> O	0.02	0.023	0.008	0.031	0.19	0.007
	P <sub>2</sub> O <sub>5</sub>	2.39	17.53	30.02	18.65	19.86	37.73
	(SO <sub>3</sub> )	0.12	0.01	0.73	0.04	0.03	0.03
	(F)	0.24	0.95	2.26	1.04	1.74	2.82
	LOI	40.65	2.17	1.86	2.20	3.52	0.86
	<b>Total</b>	<b>99.09</b>	<b>99.04</b>	<b>97.55</b>	<b>97.99</b>	<b>91.18</b>	<b>100.60</b>
XRF analysis, all data are in ppm	Ba	768	55	15,620	191	399	1,142
	Nb	69	478	2,560	3,868	15,900	123
	Ta	<5	7	<6	<8	13	<6
	Th	27	217	113	335	1,010 <sup>4)</sup>	33
	U	<4	18	17	30	157	5
	Zr	21	1,180	73	888	611	145
ICP-MS analysis, all data are in ppm	La	415	993	988	1,546	9,275	225
	Ce	1,032	2,830	1,810	3,641	23,779	601
	Pr	123	384	361	535	3,034	84.2
	Nd	462	1,529	1,428	2,091	11,562	346
	Sm	65.0	265	244	316	1,794	56.8
	Eu	15.2	67.9	63.0	77.3	454	14.4
	Gd	38.7	186	158	197	1,094	37.7
	Tb	3.61	17.5	14.3	17.9	110	3.89
	Dy	14.1	70.2	53.6	63.9	403	16.1
	Y	47.2	211	155	193	621	58.2
	Ho	1.94	9.38	6.63	8.24	44.0	2.22
	Er	4.08	17.8	12.1	15.5	70.3	4.49
	Tm	0.44	1.64	1.10	1.41	5.18	0.44
	Yb	2.29	7.12	4.70	6.09	15.6	2.16
	Lu	0.30	0.82	0.55	0.73	1.38	0.24
	TREE	2,225	6,590	5,300	8,710	52,262	1,453
	TREO	<b>2,670</b>	<b>7,900</b>	<b>6,326</b>	<b>10,430</b>	<b>62,642</b>	<b>1,741</b>
HREO <sup>1)</sup>	<b>5.73</b>	<b>8.91</b>	<b>8.83</b>	<b>6.64</b>	<b>5.30</b>	<b>9.65</b>	
Nd <sub>2</sub> O <sub>3</sub> <sup>2)</sup>	<b>20.2</b>	<b>22.6</b>	<b>26.3</b>	<b>23.4</b>	<b>21.5</b>	<b>23.2</b>	
Eu <sub>2</sub> O <sub>3</sub> <sup>2)</sup>	<b>0.66</b>	<b>1.0</b>	<b>1.15</b>	<b>0.86</b>	<b>0.84</b>	<b>0.96</b>	
Dy <sub>2</sub> O <sub>3</sub> <sup>2)</sup>	<b>0.61</b>	<b>1.02</b>	<b>0.97</b>	<b>0.70</b>	<b>0.74</b>	<b>1.06</b>	

<sup>1)</sup> HREO = 100\* total HREO/TREO; total HREO = Σ(Eu<sub>2</sub>O<sub>3</sub> to Lu<sub>2</sub>O<sub>3</sub> + Y<sub>2</sub>O<sub>3</sub>); <sup>2)</sup> % of TREO; <sup>3)</sup> in the flow dark lenses and crystals occur in sizes up to several centimeters, which contain high Nb (31,700 ppm), Th (1,520 ppm), Zr (1,400 ppm) and TREE+Y (15,400 ppm) - XRF and ICP-MS data; <sup>4)</sup> ICP-MS and ICP-OES data.



In two press releases (MINING JOURNAL 2013; GALILEO RESOURCES PLC 2013), Galileo Resources Plc announced that following the strategic review of the PEA, it will focus on the development of the REE-bearing phosphate-rich breccia resource (apatite-hematite breccia (indicated resource) and surface stockpiles (inferred resource); Tab. 5.2.12) of 10.4 Mt at 2.13 % TREO+Y<sub>2</sub>O<sub>3</sub> and 18.8 % P<sub>2</sub>O<sub>5</sub> at Glenover. This

makes the Glenover REE project a smaller, but higher grade operation.

Significant highlights of the Glenover project are summarised in Table 5.2.13. The data are mainly sourced from the PEA-Executive Summary (FAIRHALL et al. 2013). This table includes mineral resource data, mine design, risks and REE separation test work.

**Table 5.2.12: Classified mineral resources for the Glenover project. Data are from VAN DER WALT et al. (2012) and the TMR ADVANCED RARE-EARTH PROJECTS INDEX (2013).**

Rock type	Resource class	Tonnage (Mt)	TREO + Y <sub>2</sub> O <sub>3</sub> (%)	P <sub>2</sub> O <sub>5</sub> (%)	Nb <sub>2</sub> O <sub>5</sub> (%)	Sc <sub>2</sub> O <sub>3</sub> (ppm)
Apatite-Hematite Breccia	Measured	–	–	–	–	–
	Indicated	7.407	2.20	17.57	0.46	179.5
	Total measured + indicated	7.407	2.20	17.57	0.46	179.5
	Inferred <sup>2)</sup>	0.274 <sup>2)</sup>	2.16 <sup>2)</sup>	15.83 <sup>2)</sup>	0.46 <sup>2)</sup>	167.9 <sup>2)</sup>
Surface stockpiles	Measured	–	–	–	–	–
	Indicated	–	–	–	–	–
	Total measured + indicated	–	–	–	–	–
	Inferred	2.940 <sup>3)</sup>	2.08 <sup>3)</sup>	23.71 <sup>3)</sup>	–	–
Total <sup>1)</sup>	Measured	–	–	–	–	–
	Indicated	7.407	2.20	17.57	0.46	179.5
	Total measured + indicated	7.407	2.20	17.57	0.46	179.5
	Inferred	2.940 <sup>3)</sup>	2.08 <sup>3)</sup>	23.71 <sup>3)</sup>	–	–
<b>Total Resource<sup>1)</sup></b>		<b>10.4</b>	<b>2.13</b>	<b>18.80</b>	<b>–</b>	<b>–</b>
Carbonatite <sup>2)</sup>	Measured	–	–	–	–	–
	Indicated	9.374 <sup>2)</sup>	0.86 <sup>2)</sup>	3.50 <sup>2)</sup>	0.18 <sup>2)</sup>	63.8 <sup>2)</sup>
	Total measured + indicated	9.374 <sup>2)</sup>	0.86 <sup>2)</sup>	3.50 <sup>2)</sup>	0.18 <sup>2)</sup>	63.8 <sup>2)</sup>
	Inferred	0.453 <sup>2)</sup>	0.80 <sup>2)</sup>	4.24 <sup>2)</sup>	0.15 <sup>2)</sup>	66.3 <sup>2)</sup>
Pyroxenite <sup>2)</sup>	Measured	–	–	–	–	–
	Indicated	–	–	–	–	–
	Total measured + indicated	–	–	–	–	–
	Inferred	8.735 <sup>2)</sup>	0.66 <sup>2)</sup>	5.31 <sup>2)</sup>	0.11 <sup>2)</sup>	71.6 <sup>2)</sup>

<sup>1)</sup> updated resource estimate 05/2013 (REE-Phosphate breccia resource; GALILEO RESOURCES PLC 2013); <sup>2)</sup> not included in REE-Phosphate breccia resource at Glenover; <sup>3)</sup> updated resource for the surface stockpiles (GALILEO RESOURCES PLC 2012b)

**Tab. 5.2.13: Summary of data for the Glenover Property (e.g. GALILEO RESOURCES PLC (2012a); PEA-Executive Summary (FAIRHALL et al. 2013); TMR ADVANCED RARE-EARTH PROJECTS INDEX (2013)).**

<b>Total mineral resource (1 % cut-off grade) <sup>1)</sup></b>	Indicated: 7.41 Mt @ 2.20 % TREO Inferred: 2.94 Mt @ 2.08 % TREO <sup>2)</sup>
<b>Contained TREO</b>	~221,000 t; additional contents of Sc <sub>2</sub> O <sub>3</sub> , P <sub>2</sub> O <sub>5</sub> , Nb <sub>2</sub> O <sub>5</sub>
<b>Planned annual production</b>	7,400 t of REO
<b>Mining</b>	400,000 tpa (ore, "RoM")
<b>Estimated mine life (LOM)</b>	18 years (24 years)
<b>Mining method</b>	Processing of surface stockpiles; extending and deepening of original open pit
<b>Average stripping ratio</b>	1.5:1
<b>RE separation plant</b>	–
<b>Recovery rate</b>	Metallurgical test work by Maelgwyn Minerals Services Ltd (South Africa) finished in 10/2012; ongoing work by Dorfner ANZAPLAN (Germany) and GRINM (China) + overall REE recovery of 80 %
<b>Risks (for mining, processing and mine waste storage)</b>	Radioactivity of the ore (low uranium and thorium)
<b>Project development plans</b>	Complete PFS Q4 2013
<b>Total estimated operating costs</b>	20.38 US\$/kg REO
<b>REO basket price</b>	41 US\$/kg

"RoM" – run-of-mine material from both the stockpiles and extension of the existing open pit;

<sup>1)</sup> updated resource estimate 05/2013 (REE-Phosphate breccia resource; GALILEO RESOURCES PLC 2013);

<sup>2)</sup> updated resource for the surface stockpiles (GALILEO RESOURCES PLC 2012b)

### 5.2.4.5 Schiel Complex (Limpopo)

#### Location and owner

Coordinates: (Centre of the eastern part of the Schiel Complex) 23°10'24.69"S; 30°27'20.01"E; 726 m amsl

The Schiel Complex is situated within the Limpopo Province of Southern Africa approximately 55 km east-southeast of Louis Trichardt (Makhado). There is presently no ongoing exploration activity; however, thorough investigation of the phosphate mineralisation was carried out by Phosphate Development Corporation Ltd (Foskor) in the 1960s and 1970s. Technocom Mineral Development Services (Pty) Ltd evaluated the economic potential of the mineralisation in 1981 (PRINS et al. 1981).

**Local infrastructure:** Water, electricity and railway facilities for the Schiel area were evaluated in detail in the feasibility study mentioned before

(PRINS et al. 1981). The nearest rivers are the Luvuvhu River 8 km north and the Middle and Small Letaba Rivers 8 km south of Schiel. All three rivers are water-bearing during the rainy season only. The Nandoni Dam (old name Mutoti Dam), located on the Luvuvhu River ~25 km northeast of Schiel Farm, has a height of 43 m and a capacity of 164 million cubic metres. It was opened in 2004 (source: WIKIPEDIA). The Middle Letaba Dam, situated ~14 km southwest of "Schiel Farm" (close to the confluence of the Middle and Small Letaba Rivers), has a height of 38 m and a capacity of 173 million cubic metres (source: WIKIPEDIA). It was opened in 1984.

In 1981, the nearest power connection point was at Sibasa (~8 km from Schiel; PRINS et al. 1981). Currently, a power line from Louis Trichardt to Giyani is present to the north of Schiel Farm.

The nearest railway connections are at Bandelierkop and Makhado (Louis Trichardt) to the west of Schiel Farm. A railway line from the Bandelierkop area passes through Duiwelskloof and Tzaneen, approximately 60 km southwest of Schiel Farm.

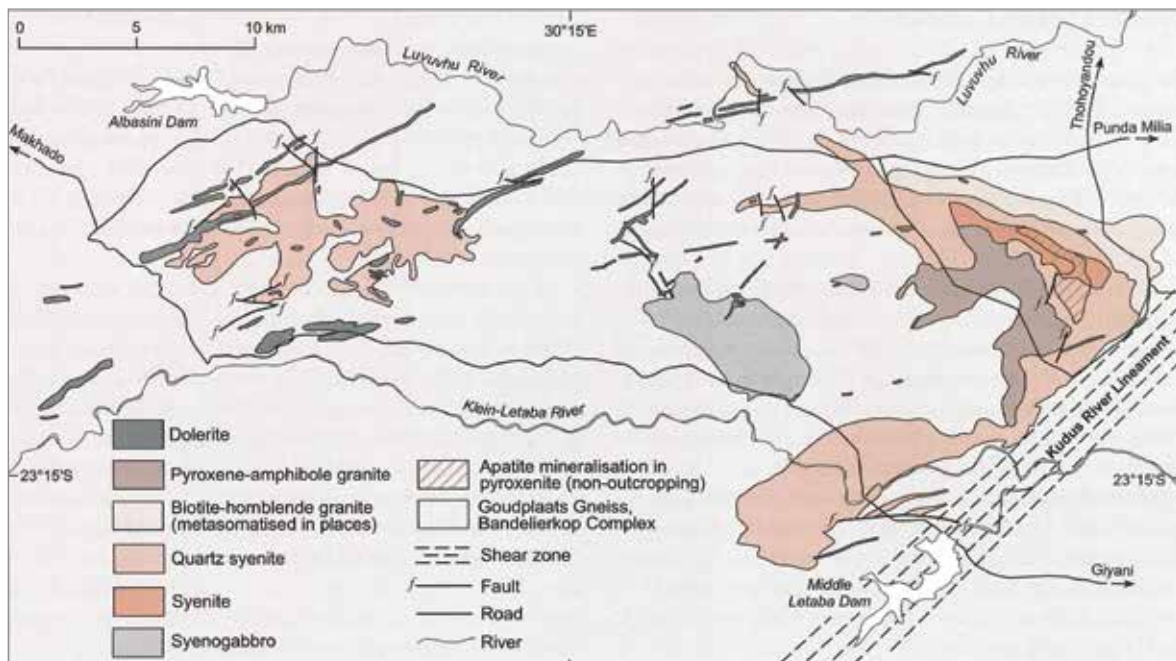
Road access from Schiel Farm to the railway connections at Bandelierkop would probably be easier than towards the Duiwelskloof area. Most of the road from Schiel Farm to Makhado (Louis Trichardt; distance: ~83 km) is paved, as is the road from Schiel Farm to Bandelierkop (distance: ~75 km). Gravel roads connect the numerous villages in the surrounding area.

## Geology

The 2,060 Ma old (WALRAVEN et al. 1992) Schiel Complex intrudes the Goudplaats Gneiss close to the northeast-oriented Kudus River Lineament (Fig. 5.2.15). The mineralised (see below) eastern part of the complex is composed of four to five intrusive phases (DU TOIT et al. 1983; STETTLER et al. 1993). The unexposed elliptical central core of the complex with pyroxenites and carbonatite-type rocks forms the first intrusive phase. The later intrusive phases include a plug-like syenogabbro, a quartz syenite (forming >60 % of the complex), a pyroxene-amphibole granite and a biotite-hornblende granite (VERWOERD & DU TOIT 2006; see Figs. 5.2.15 and 5.2.16). In places, the older rocks were fenitised by the alkaline intrusions.

Apatite, magnetite and vermiculite mineralisation is restricted to the first intrusive phase. Irregular bodies of glimmerite, phoscorite and later carbonatite veins intrude pyroxenite of this phase (data from drill core to 400 m depth). Apatite occurs in lenticular and tabular bodies, separated by more or less frequent syenite dykes. Greater amounts of injected syenitic material result in a decrease in the  $P_2O_5$  content (apatite) in the ore bodies towards the southeast (Joubert 1964). The vermiculite-apatite-magnetite rocks also contain minor diopside, tremolite, zircon and alteration products, e.g. montmorillonite and chlorite (Joubert 1964). Investigations of the ore mineralisation were carried out mainly in the 1960s by trenching and by diamond and percussion drilling (Foskor (Pty) Ltd; total footage of drilling: 17,192; 10 diamond drill sites (45°); Joubert 1964; Viljoen 1966).

**Rare-earth element potential:** According to data of the National Institute of Advanced Industrial Science and Technology of Japan (AIST; Watanabe 2008) ~170,000 t of REE (oxide conversion) are contained in the apatite produced annually in the world; apatite is the main raw material for agricultural fertilizers. Further research needs to be carried out to test if the REE could be recovered during the production process of phosphoric acid from apatite.



**Fig. 5.2.15: Regional setting of the Schiel Complex in the Southern Marginal Zone of the Limpopo Metamorphic Province (from VERWOERD & DU TOIT 2006).**

For a discussion of the REE potential of the Schiel Complex, two parts of the mineralised system have to be considered, firstly, the primary apatite mineralisation (hidden weathered and fresh phosphate rocks) and, secondly, the near-surface secondary formations (soils; Fig. 5.2.17) resulting from weathering of rocks of the first intrusive phase.

(1) For the primary apatite mineralisation, there were no outcrops with fresh material available during present field work. In addition, all drill cores from exploration work in the 1960s and 1970s carried out by Foskor appear to have been discarded. Consequently, no apatite or phosphate concentrate samples from the primary Schiel mineralisation were available for analysis at the BGR to determine their TREO concentrations and the relative distribution of the individual REE. However, KLEMD (2013) determined TREO+Y<sub>2</sub>O<sub>3</sub> concentrations ranging from 1.80 to 4.55 wt % (average 2.9 wt %) for apatite from two fresh rock samples from the central Schiel pluton

(data were produced using *in-situ* laser-ablation ICP-MS analysis).

Technocom Mineral Development Services considered apatite to be the only economic mineral in the Schiel Complex; magnetite and vermiculite were not regarded as potential by-products of mining of phosphate (PRINS et al. 1981). Consequently, the REE potential of the primary mineralisation has to be assessed as a by-product of the production of phosphoric acid. As part of an "Order of Magnitude Feasibility Study", PRINS et al. (1981) calculated a minimum of 27.2 million tonnes of reserves of phosphate ore for the weathered zone of the Schiel phosphate mineralisation, assuming an average thickness of 30 m for this zone (underneath the top layer) and an average grade of 5.0 % P<sub>2</sub>O<sub>5</sub> (~12 % of apatite/t of ore). The estimated average grade of ore concentrates was 39.5 % P<sub>2</sub>O<sub>5</sub>. Data for TREO concentrations in the ore or in ore concentrates, as well as the relative distributions of individual REE in both, were not presented in this feasibility study.



**Fig. 5.2.16:** Northeast view at the eastern part of the Schiel Complex from the Middle Letaba Dam. The island hills are formed by quartz syenite, biotite-hornblende granite and pyroxene-amphibole granite (Photo BGR).



Based on the estimated phosphate ore reserves from the above mentioned feasibility study (PRINS et al. 1981) and the minimum REO+Y<sub>2</sub>O<sub>3</sub> contents of apatite from fresh rocks from the central Schiel pluton, KLEMD (2013) estimated minimum resources of TREO+Y<sub>2</sub>O<sub>3</sub> for the eastern ore body of the Schiel phosphate deposit of ~40,000 t (Note: the apatite REE data of KLEMD (2013) are from various rock types). The preliminary calculations are based on an 85 % recovery rate of apatite from the phosphate ore and an 80 % recovery rate of the mixed REO during further processing. The mineralisation will have to be more intensively investigated prior to any economic assessment or mine planning.

(2) The top layer consisting of a top soil layer with underlying rubble has an average thickness of about 3 m and its average phosphate content was estimated at 3.8 % P<sub>2</sub>O<sub>5</sub> (PRINS et al. 1981). No REO+Y<sub>2</sub>O<sub>3</sub> data are given in the above feasibility study for the topmost unit of the weathering profile. REE concentrations and relative distribu-

tions of individual REE in four samples from two locations on top of hidden apatite-mineralised bodies (Fig. 5.2.17) are given in Table 5.2.14. The major-element compositions of these samples are highly variable (e.g. SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, CaO (apatite)). However, the TREO concentrations are much more uniform; they are in the range from 2,100 to >3,600 ppm in the soil samples and the underlying syenitic rubble. The proportions of individual REO, potentially in high demand in the future, are (relative to TREO): neodymium oxide 17–20 %; europium oxide 0.6–0.8 %; dysprosium oxide 0.9–1.0 % (Tab. 5.2.14). Furthermore, the contents of uranium and thorium in the soil and rubble vary between 16 and 50 ppm and 137 to 449 ppm, respectively.

For an assessment of the REE potential of the top soil layer overlying the hidden apatite-mineralised bodies at Schiel, further information on the methods applicable for extraction of the REE from the soil is needed. These include additional mineralogical and REE extraction experimental work.



**Fig. 5.2.17: Soil sampling in the centre of the eastern part of the Schiel Complex (Lombard's exploration camp from the 1930s). The apatite mineralisation does not crop out at all (Photo BGR).**

**Tab. 5.2.14: Chemistry of bulk rock and soil analysis of samples from the eastern part of the Schiel Complex. All analyses carried out by BGR.**

Chemistry		Schiel2	Schiel4	Schiel4a	Schiel5	Schiel5a
		Syenite (margin of complex)	Soil sample from mineralised area	Coarse fragments (>2 mm) from sample Schiel4	Soil sample from mineralised area	Syenitic rubble underlying soil sample Schiel5
XRF analysis, all data are in wt %	SiO <sub>2</sub>	67.18	24.78	17.24	46.81	55.68
	TiO <sub>2</sub>	0.29	0.77	1.45	0.66	0.45
	Al <sub>2</sub> O <sub>3</sub>	15.99	8.44	5.57	15.41	17.16
	Fe <sub>2</sub> O <sub>3</sub>	1.50	23.56	50.65	15.03	8.57
	MnO	0.03	0.25	0.40	0.18	0.18
	MgO	0.09	5.77	4.19	1.14	0.11
	CaO	0.88	13.61	7.67	1.71	0.21
	Na <sub>2</sub> O	2.91	0.13	0.04	0.62	1.14
	K <sub>2</sub> O	9.36	1.56	1.04	8.23	11.10
	P <sub>2</sub> O <sub>5</sub>	0.09	10.61	5.99	1.85	0.54
	(SO <sub>3</sub> )	0.01	<0.01	<0.01	<0.01	<0.01
	(F)	<0.05	0.25	<0.05	<0.05	<0.05
	LOI	1.09	9.11	4.85	6.77	3.47
	<b>Total</b>	<b>99.46</b>	<b>98.92</b>	<b>99.11</b>	<b>98.41</b>	<b>98.62</b>
XRF analysis, all data are in ppm	Ba	1,949	1,826	1,217	7,164	6,695
	Nb	38	35	25	50	88
	Ta	<4	<6	<8	<5	12
	Th	99	209	137	383	449
	U	8	20	16	37	50
	Zr	433	1,326	703	1,136	1,090
ICP-MS analysis, all data are in ppm	La	110	576	334	476	337
	Ce	406	1,275	728	1,039	858
	Pr	18.4	157	91.0	112	89.0
	Nd	55.0	621	363	415	314
	Sm	7.39	120	66.0	72.0	52.7
	Eu	1.59	24.9	13.6	15.3	11.6
	Gd	4.71	83.9	44.0	47.6	33.0
	Tb	0.51	8.12	4.39	5.13	3.86
	Dy	2.34	32.9	18.1	22.0	17.5
	Y	8.50	120	67.8	88.5	72.6
	Ho	0.36	4.56	2.59	3.19	2.69
	Er	0.91	9.48	5.33	7.11	6.51
	Tm	0.12	1.01	0.58	0.85	0.85
	Yb	0.80	5.20	3.13	4.90	5.27
	Lu	0.10	0.67	0.39	0.66	0.70
	TREE	617	3,040	1,742	2,309	1,805
	TREO	<b>747</b>	<b>3,644</b>	<b>2,088</b>	<b>2,773</b>	<b>2,171</b>
	HREO <sup>1)</sup>	<b>3.21</b>	<b>9.58</b>	<b>9.21</b>	<b>8.49</b>	<b>8.59</b>
Nd <sub>2</sub> O <sub>3</sub> <sup>2)</sup>	<b>8.59</b>	<b>19.9</b>	<b>20.3</b>	<b>17.5</b>	<b>16.9</b>	
Eu <sub>2</sub> O <sub>3</sub> <sup>2)</sup>	<b>0.25</b>	<b>0.79</b>	<b>0.75</b>	<b>0.64</b>	<b>0.62</b>	
Dy <sub>2</sub> O <sub>3</sub> <sup>2)</sup>	<b>0.36</b>	<b>1.04</b>	<b>0.99</b>	<b>0.91</b>	<b>0.93</b>	

<sup>1)</sup> HREO = 100\* total HREO/TREO; total HREO = Σ(Eu<sub>2</sub>O<sub>3</sub> to Lu<sub>2</sub>O<sub>3</sub> + Y<sub>2</sub>O<sub>3</sub>); <sup>2)</sup> % of TREO.



### 5.2.4.6 Phalaborwa Complex (Foskor pyroxenite mining operation) (Limpopo)

#### Location and owner

Coordinates: (Centre of Foskor (northern) open pit) 23°57'58.67"S; 31°07'29.98"E; 385 m amsl

The Phalaborwa phosphate mining operation, situated 160 km north of Mbombela (until 2009 Nelspruit), is presently owned by Foskor (Pty) Ltd.

The Phalaborwa Complex in the Limpopo Province is located south of the town of Phalaborwa (also Palabora; 250 km northeast of Johannesburg) and close to the Kruger National Park. It

is presently mined for *copper* (Palabora Mining Company (PMC); Loolekop Pipe (Fig. 5.2.18) – underground mining), *vermiculite* (Vermiculite Operations Department (VOD); VOD pit, P.P. & V. pit, rock and tailings dumps; Figs. 5.2.18 and 5.2.19) and *phosphate* (Phosphate Development Corporation, Foskor). Foskor has the exclusive rights for phosphate in the entire complex.

**Local infrastructure:** Water, electricity and railway facilities for the Phalaborwa industrial (mining) area are good to excellent; however, the REE-bearing precipitates (e.g. phospho-sludge) discussed later are primarily produced in the Acid Plant of the Foskor Group in Richards Bay, Kwa-Zulu-Natal. Richards Bay is located in an area well-known for its huge industrial development and harbour export facilities.

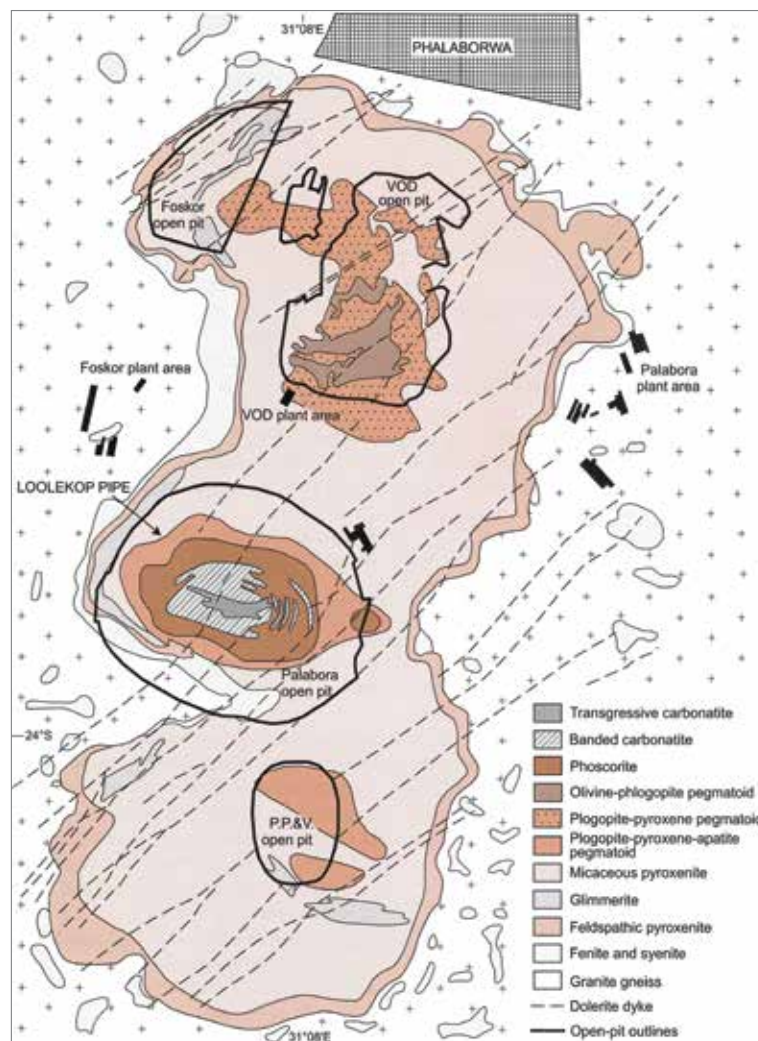


Fig. 5.2.18: Simplified geology of the Phalaborwa Complex (from VERWOERD & Du TOIT 2006).

## Geology

The three pipe-like intrusions of the Phalaborwa Igneous Complex, with their coalescent cores aligned in a north–south direction (VERWOERD 1967; Fig. 5.2.18), cover an area of about 16 km<sup>2</sup>. The host rocks of the intrusions are granite and gneiss. Formation of the complex occurred during the older of the two carbonatite and alkaline intrusive events verified for the Kaapvaal Craton (a similar age like the Schiel Complex). A precise U-Pb age (baddeleyite) indicates an emplacement at 2,060 ± 0.5 Ma (REISCHMANN 1995).

The various rock types of the complex show a well-developed zonal distribution around the three cores. The most widespread member of the suite is clinopyroxenite (70 %) with highly variable apatite contents (VERWOERD & DU TOIT 2006). The copper-rich central intrusion, the Loolekop Pipe, exhibits an outer zone composed of phlogopite-pyroxene-apatite pegmatoid, a transitional structural unit of phoscorite (serpentinised olivine-apatite-magnetite rock) and banded magnetite-rich sövite (carbonatite) and, finally, a core made up by sövite (carbonatite). The core of the southern intrusion is composed of phlogopite/ver-



**Fig. 5.2.19:** Satellite image of the Phalaborwa mining operations with the four open pits (northern: Foskor open pit, VOD open pit, central: Palabora open pit (inactive), southern: P.P. & V. open pit), the processing plants and the tailings dams (Photo courtesy of SATELLITE IMAGING CORPORATION).

miculite-pyroxene-apatite-rich pegmatoid (South Pyroxenite phosphate deposit). The core of the northern intrusion is composed of olivine-phlogopite pegmatoid, with the North Pyroxenite phosphate deposit (Foskor open pit) located to the northwest of the core.

Apatite, the dominant phosphate mineral in the Phalaborwa operations, was initially derived from pyroxenite ores from the North Pyroxenite deposit (Foskor open pit; Fig. 5.2.18). However, copper mining in the carbonatite of the Loolekop Pipe

(PMC) produced large amounts of apatite-bearing phosphorite surrounding the carbonatite intrusion. Consequently, Foskor processed mainly ore from this source during the operation of the Palabora Open Pit. Foskor re-activated and extended its mining in the North and South Pyroxenite deposits within the Phalaborwa Complex after the closure of the open pit mining of the Loolekop Pipe.

**Rare-earth element potential:** For a general assessment of the potential of economic phosphate (apatite) mining, processing and

**Table 5.2.15: Foskor phosphate mining operation in Phalaborwa. Rare-earth compositions of whole-rock ore samples, apatite concentrates and Foskor's phosphate products (all values are in ppm). Data are from (1) HORNIG-KJARSGAARD (1998; ICP-AES) for the ore compositions, (2) RUSSELL (1977) and (3) SCHÜRMANN (1992) for apatite and mixed concentrates and (4) ROUX et al. (1989) for Foskor's final phosphate product compositions.**

Sample	Ore samples			Concentrate samples					Phosphate products	
	Banded magnetite sövite (PA1-Loolekop)	Sövite with Cu mineralisation (PA2-Loolekop)	Phosphorite (PA3-Loolekop)	Apatite concentrate (sövite ore-sample PA1)	Apatite concentrate (phosphorite ore-sample PA3)	Apatite concentrate (phosphorite ore)	Apatite concentrate (pyroxenite ore)	Mixed pyroxenite-apatite-biotite concentrate	Foskor's phosphate product Palfos 80M	Foskor's phosphate product Palfos 88
Data source	1	1	1	1	1	2	2	3	4	4
La	213	296	204	1,150	1,030	882	1,330	197		
Ce	397	609	529	3,140	2,340	1,856	2,426	420		
Pr	58	82	75	399	311	181	310	68		
Nd	249	382	299	<b>1,840</b>	<b>1,290</b>	<b>1,380</b>	<b>1,843</b>	300		
Sm	47.7	66.8	63.2	<b>327</b>	<b>236</b>	184	<b>596</b>	47		
Eu	11.8	10.1	14.4	<b>78.1</b>	<b>52.5</b>	36	<b>94</b>	10.7		
Gd	28.6	33.0	38.8	168	131	83	165	37		
Tb	3.08	2.93	4.56			6	9	3.8		
Dy	12.9	11.0	17.6	63.8	53.9	44	70	15		
Y				223	228	102	172			
Ho	2.13	1.48	2.59	8.33	7.08	7	9	1.6		
Er	4.31	2.77	5.05	12.6	10.9	5	7	3.2		
Yb	1.57	1.39	1.83	4.28	4.24	<9	<9	1.3		
Lu	0.15	0.11	n.d.	0.62	0.44	<9	<9			
TREE	1,030 <sup>1)</sup>	1,498 <sup>1)</sup>	1,256 <sup>1)</sup>	7,415	5,695	4,766	7,031	1,105 <sup>1)</sup>		
TREO	<b>1,228<sup>1)</sup></b>	<b>1,790<sup>1)</sup></b>	<b>1,500<sup>1)</sup></b>	<b>8,883</b>	<b>6,826</b>	<b>5,695</b>	<b>8,383</b>	<b>1,317<sup>1)</sup></b>	<b>5,100</b>	<b>5,800</b>
HREO <sup>2)</sup>	<b>6.06<sup>1)</sup></b>	<b>4.07<sup>1)</sup></b>	<b>6.52<sup>1)</sup></b>	<b>7.54</b>	<b>8.63</b>	<b>5.95</b>	<b>7.48</b>	<b>6.35<sup>1)</sup></b>		
Nd <sub>2</sub> O <sub>3</sub> <sup>3)</sup>	<b>23.7<sup>1)</sup></b>	<b>24.9<sup>1)</sup></b>	<b>23.3<sup>1)</sup></b>	<b>24.2</b>	<b>22.0</b>	<b>28.3</b>	<b>25.6</b>	<b>26.6<sup>1)</sup></b>		
Eu <sub>2</sub> O <sub>3</sub> <sup>3)</sup>	<b>1.11<sup>1)</sup></b>	<b>0.65<sup>1)</sup></b>	<b>1.11<sup>1)</sup></b>	<b>1.02</b>	<b>0.89</b>	<b>0.74</b>	<b>1.30</b>	<b>0.94<sup>1)</sup></b>		
Dy <sub>2</sub> O <sub>3</sub> <sup>3)</sup>	<b>1.21<sup>1)</sup></b>	<b>0.71<sup>1)</sup></b>	<b>1.35<sup>1)</sup></b>	<b>0.82</b>	<b>0.91</b>	<b>0.90</b>	<b>0.95</b>	<b>1.31<sup>1)</sup></b>		

<sup>1)</sup> data for yttrium concentrations were not available for this sample;

<sup>2)</sup> HREO = 100\* total HREO/TREO; total HREO = Σ(Eu<sub>2</sub>O<sub>3</sub> to Lu<sub>2</sub>O<sub>3</sub> + Y<sub>2</sub>O<sub>3</sub>); <sup>3)</sup> % of TREO.



**Table 5.2.16: Chemistry of ore and concentrate samples from the North (Foskor pit) and South Pyroxenite deposits of the Phalaborwa Complex. All analyses carried out by BGR.**

Chemistry		Phb12-1	Phb12-5	Phb12-1a
		Pyroxenite (Foskor pit)	Apatite-poor pyroxenite (southern deposit)	Apatite concentrate from pyroxenite Phb12-1 (Foskor pit) <sup>3)</sup>
XRF analysis, all data are in wt %	SiO <sub>2</sub>	8.73	48.32	0.64
	TiO <sub>2</sub>	0.27	0.26	0.009
	Al <sub>2</sub> O <sub>3</sub>	1.77	0.17	0.06
	Fe <sub>2</sub> O <sub>3</sub>	1.99	2.58	0.09
	MnO	0.027	0.056	0.009
	MgO	4.22	15.58	0.18
	CaO	45.11	27.47	55.47
	Na <sub>2</sub> O	0.04	0.14	0.01
	K <sub>2</sub> O	1.67	0.09	0.04
	P <sub>2</sub> O <sub>5</sub>	32.50	3.98	40.25
	(SO <sub>3</sub> )	0.09	0.03	0.02
	(F)	1.56	0.18	1.82
	LOI	1.36	0.83	0.54
	<b>Total</b>	<b>99.35</b>	<b>99.68</b>	<b>99.16</b>
XRF analysis, all data are in ppm	Ba	83	392	86
	Nb	5	3	6
	Ta	<5	<5	<6
	Th	134	27	207
	U	17	<4	18
	Zr	16	16	9
ICP-MS analysis, all data are in ppm	La	921	113	1,270
	Ce	2,223	283	3,066
	Pr	295	40	403
	Nd	1,268	170	1,730
	Sm	254	36	348
	Eu	45.6	7.01	62.1
	Gd	160	25	241
	Tb	14.4	2.34	19.9
	Dy	52.6	8.54	71.6
	Y	162	26.6	222
	Ho	6.69	1.08	9.14
	Er	11.7	1.87	16.0
	Tm	1.00	0.16	1.37
	Yb	4.23	0.71	5.56
	Lu	0.47	0.08	0.64
	TREE	5,420	715	7,466
	TREO	<b>6,489</b>	<b>856</b>	<b>8,939</b>
	HREO <sup>1)</sup>	<b>8.44</b>	<b>10.24</b>	<b>8.66</b>
Nd <sub>2</sub> O <sub>3</sub> <sup>2)</sup>	<b>22.8</b>	<b>23.2</b>	<b>22.6</b>	
Eu <sub>2</sub> O <sub>3</sub> <sup>2)</sup>	<b>0.81</b>	<b>0.95</b>	<b>0.80</b>	
Dy <sub>2</sub> O <sub>3</sub> <sup>2)</sup>	<b>0.93</b>	<b>1.14</b>	<b>0.92</b>	

<sup>1)</sup> HREO = 100\* total HREO/TREO; total HREO = Σ(Eu<sub>2</sub>O<sub>3</sub> to Lu<sub>2</sub>O<sub>3</sub> + Y<sub>2</sub>O<sub>3</sub>); <sup>2)</sup> % of TREO; <sup>3)</sup> apatite concentrate hand-picked from ~0.5 kg of pyroxenite sample.

phosphoric acid production to generate significant amounts of REE-rich by-products, see the chapter on the Schiel Complex (e.g. publication by AIST; Watanabe 2008). Any discussion of an REE potential of the Phalaborwa phosphate ore is based on (1) phosphoric acid production from the mined apatite ore and (2) possible re-processing of precipitates from this acid production process to extract the REE.

Average REE concentrations in different ore types from the Phalaborwa Complex, in fluorapatite concentrates deriving from carbonatite, phoscorite and pyroxenite ores as well as in Foskor's final phosphate products (concentrates) are summarised in Table 5.2.15. The data sets from the different sources are rather consistent and indicate TREO contents of ~6,000 ppm in phoscorite-

derived apatite concentrates and slightly higher values of ~8,000 ppm for carbonatite- and pyroxenite-derived apatite concentrates (excluding the apatite-poor mixed concentrate). The data for a hand-picked pyroxenite-derived apatite concentrate analysed within this study, confirm these observations (Tab. 5.2.16). The proportions of individual REO potentially in high demand in the future are (relative to TREO in ores and concentrates): neodymium oxide 22–28 %; europium oxide 0.7–1.1 %; dysprosium oxide 0.7–1.3 % (Tabs. 5.2.15 and 5.2.16).

Precipitates produced in the process of phosphoric acid production:

1. Phospho-gypsum: apatite concentrates are dissolved in a mixture of sulphuric

**Table 5.2.17: Preliminary estimates of recoverable REO within the Phalaborwa Complex based on mineral reserve and mineral resource data (SAMREC Code) as of March 31, 2012 (FOSKOR (PTY) LTD 2012).**

Geological area	Reserves category	Reserves (Mt)	Average grade P <sub>2</sub> O <sub>5</sub> (%)	Totals P <sub>2</sub> O <sub>5</sub> (Mt)	Concentrate with 36.5 % P <sub>2</sub> O <sub>5</sub> in Mt (Palfos 80M)	REO in phosacid sludge in t (20 % of total precipitates) <sup>1)</sup>	Recoverable REO in t (90 % of REO contents in sludge)
<b>Mineral reserves as of March 31, 2012 (Foskor)</b>							
<b>North Pyroxenite pit</b>	Proved	418.0	7.0	29.3	80.2	96,200	86,600
	Probable	98.0	6.7	6.6	18.0	21,600	19,400
<b>South Pyroxenite pit</b>	Proved	973.0	6.9	67.1	183.9	220,700	198,700
	Probable	64.3	6.5	4.2	11.5	13,700	12,400
<b>Mineral resources as of March 31, 2012 (Foskor)</b>							
<b>North Pyroxenite pit</b>	Measured	664.0	7.2	47.8	131.0	157,200	141,500
	Indicated	509.0	7.0	35.6	97.6	117,100	105,400
	Inferred	296.0	6.7	19.8	54.3	65,200	58,700
<b>South Pyroxenite pit</b>	Measured	2,248.0	6.7	150.6	412.6	495,200	445,700
	Indicated	1,148.0	6.3	72.3	198.1	237,800	214,000
	Inferred	1,491.0	6.3	93.9	257.4	308,800	277,900
<b>PMC<sup>2)</sup> active tailings dam</b>	Measured	238.3	6.7	16.0	43.7	52,500	47,200
	Indicated	48.8	6.6	3.2	8.8	10,600	9,500
	Inferred	9.9	6.4	0.6	1.7	2,100	1,900

<sup>1)</sup> an average REO content of 0.6 % in the Foskor phosphate products was assumed (based on Roux et al. (1989) and compositional data in Tables 5.2.15 and 5.2.16).

<sup>2)</sup> PMC - Palabora Mining Company

acid and recycled dilute phosphoric acid. Bulk of the REE in the feed (70–85 %) associate with the phospho-gypsum formed in the dissolution reaction; however, the REE are not extractable from this material (VAN DER VYVER 1990).

2. Sludges: concentration of the dilute phosphoric acid to a commercial grade produces valuable REE-bearing sludges consisting mainly of calcium sulfate hemihydrates (2–8 % REO); production of ~10,000 t of sludge per year at the Phalaborwa plant alone (GUPTA & KRISHNAMURTHY 2005). Pilot plant testing for the extraction of REE from the phospho-sludge showed promising results (VAN DER VYVER 1989; metallurgical test-work by MINTEK for Sentrachem Ltd (production of purified Ce, Eu, Nd and Sm oxides); VERWOERD 1993; VAN DER MERWE 2010).

Data concerning the concentration of individual REO in the above-described precipitates were not available for this report.

For 1989, the recoverable reserve of TREO from sludges produced during processing of

the Phalaborwa apatite ore was estimated at 3.03 million tonnes by G.P. VAN DER VYVER (1990). 3.37 Mt of TREO were in the sludges, of which 90 % should have been recoverable.

Based on the most recent mineral reserve and resource data published in FOSKOR (PTY) LTD (2012), recoverable rare-earths from the Phalaborwa mine operations were re-estimated for the present report (Tab. 5.2.17). The calculations were carried out using similar assumptions as were applied by VAN DER VYVER (1990); however, a slightly lower average TREO content of 0.6 % in the Foskor final phosphate products was assumed (based on ROUX et al. (1989) and compositional data in Tabs. 5.2.15 and 5.2.16). The updated recoverable REO totals from the sludges are 317,000 t REO for the mineral reserves published for both pits and 1,301,800 t REO for mineral resources in both pits and the PMC active tailings dam (preliminary estimation only).

Produced REO concentrates would be free of thorium and thus acceptable to overseas markets; however, for further details on the recoverable concentration of individual REO, additional data are needed.



**Fig. 5.2.20:** Southwest view at the Zelati tailings impoundment behind the Zelati River valley (Photo BGR).

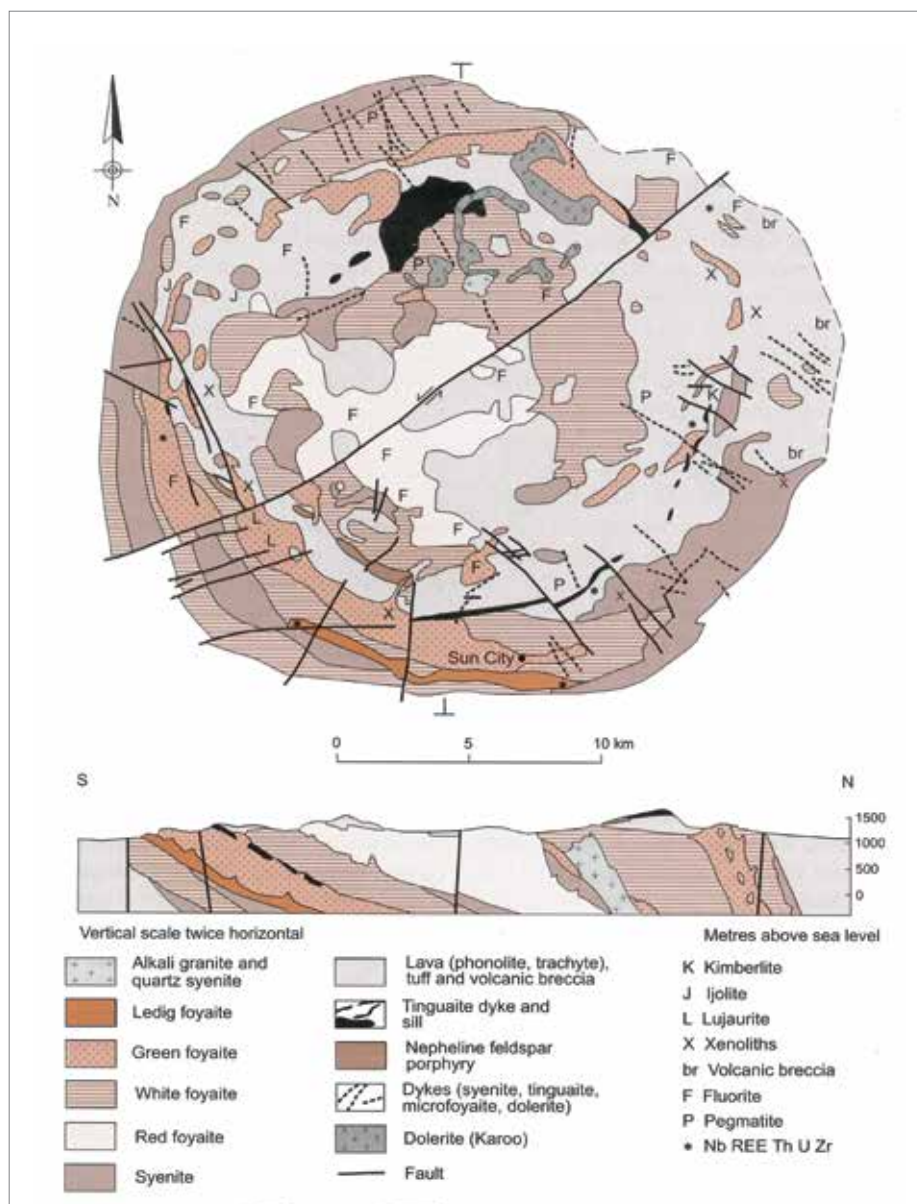


### 5.2.4.7 Pilanesberg Complex (North West)

#### Location

Coordinates: (Centre of complex) 25°14'45"S;  
27°04'00"E; 1,210 m amsl

All the data summarised in this chapter are from work published by Lurie and other authors. The Pilanesberg Complex (Fig. 5.2.21) was the subject of detailed investigations of various localities by Rare Earth Investments (Pty) Ltd and, on behalf of this company, by Rio Tinto, Newmont SA Ltd and JCI Exploration during the period 1970–1976 (LURIE 1986). This work included land-based radiometrics, magnetometrics, sampling and preliminary drilling.



**Fig. 5.2.21: The Pilanesberg Complex (from VERWOERD (2006; after LURIE (1973)). The star symbols in the eastern sector of the complex represent the REE-Th occurrences (i) in the Doornhoek area (southernmost star northeast of Sun City) and (ii) in the Thabayadiotsa/ Rhenosterspruit zones (star near the centre of the eastern sector).**

## Geology

The major-element content of the rocks is typical of alkaline complexes, but potassium and calcium are higher and sodium lower than in complexes of comparable size (LURIE 1986). The contents of rare elements in the major rock types and the overall concentration of these in the complex have been assessed on the basis of 1,500 samples (LURIE 1986). Of the major rock types, the Ledig Foyaite has the highest contents, followed by the green foyaite. These rocks are located on the outer rings of the complex.

Concentrations of REE have been found in the alkaline rocks of the Pilanesberg Complex on Thabayadiotsa (i.e. the farms Houwater 54 JQ and Rhenosterspruit 59 JQ). On Houwater 54 JQ, REE mineralisation occurs as veins in the contact zone between a tinguaitite ring dyke and a younger foyaite, and as disseminated ore in the latter. On Rhenosterspruit 59 JQ, the mineralisation is found in tuff bands intercalated in lava over a distance of ~2 km, and on the farm Saulspoot 38 JQ as veins in white foyaite. The yttrium and REE are concentrated in britholite veins and britholite-bearing foyaite. The high-grade ore consists of britholite (56.36 % REO; 1.56 % ThO<sub>2</sub>) and magnetite, with minor amounts of allanite, apatite, calcite, strontianite, fluorite, aegirine and cheralite (LURIE 1973, 1986; VERWOERD 1986).

### Rare-earth element potential

The Thabayadiotsa occurrence is considered to be a major REE resource. Although the vein material represents the richest ore, ranging from 13.3 % to 48.6 % REO + ThO<sub>2</sub>, the disseminated ore constitutes the significant reserves. The ore requires concentration and removal of contained thorium in order to be saleable (LURIE 1986). Interpolation between surface outcrops and boreholes provides the following estimates of ore tonnages and grades:

- a) Total disseminated ore – 13.5 Mt at 0.7 % REO + ThO<sub>2</sub>,
- b) Subzones ranging in thickness from 0.8 to 2.0 m only (1.28 % to 10.0 % REO + ThO<sub>2</sub>) – 1.2 Mt at 6.54 % REO + ThO<sub>2</sub>,

- c) Exposed vein material – 24,000 t at 10 % REO + ThO<sub>2</sub> (LURIE 1986; VERWOERD 1986).

The Ledig Foyaite has the potential for several hundred million tonnes of low-grade ore containing uranium and niobium with zinc, REE (up to 0.2 %) and zirconium as possible by-products (LURIE 1986). The Ledig Foyaite as a unit requires further research for the solution of metallurgical problems.

The REE resources within the Pilanesberg Complex are listed in the USGS Rare-Earth Report (ORRIS & GRAUCH 2002) and can be found in Mine Search (METALS ECONOMIC GROUP 2012). However, as the Pilanesberg Complex has been declared a National Park in 1979, the chances of its exploitation appear remote. A popular tourist resort (Sun City) is also situated in the Pilanesberg Complex.

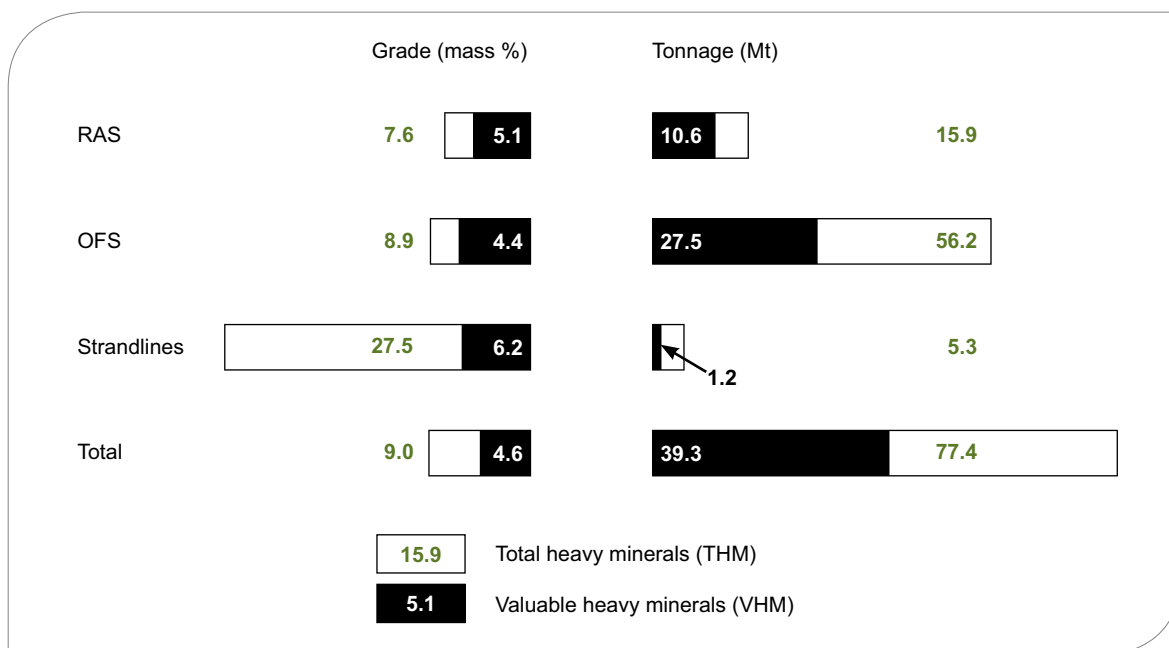
### 5.2.4.8 Heavy mineral sand deposits

The next two chapters focus on the REE potential of the heavy mineral (HM) sand deposits of the western and eastern coastal areas of South Africa. For general information on the geology, mineralogy and infrastructure of the deposits and especially their current production (e.g. zircon and TiO<sub>2</sub>), the reader is referred to Chapter 5.1 of this volume.

#### Western Cape – Namakwa Sands deposit

Except for the Namakwa Sands deposit, information on the lesser known HM sand deposits along the west coast of South Africa is not easily obtainable and likely to be in the hands of the respective prospect rights holders.

Information on the HM potential and especially the REE potential of the Namakwa Sands deposit are given in a number of papers by PHILANDER & ROZENDAAL (e.g. 2009, 2012) and are summarised below. The *in-situ* resource of the deposit is 858 Mt with estimated contents of 3.3 % ilmenite, 0.8 % zircon, 0.2 % rutile, 0.3 % leucoxene and 0.02 % monazite. The total HM (THM) contents in the units of the deposit (RAS – Red Aeolian Sand unit; OFS – Orange Feldspathic Sand unit; STR – strandline deposits) are shown in Fig. 5.2.22. The total HM content is decreasing upwards in



**Fig. 5.2.22: Total heavy minerals (THM), valuable heavy minerals (VHM) and tonnage of mineral resources of the geological units of the Namakwa Sands ore body (data are from PHILANDER & ROZENDAAL 2009).**

the sequence, however, the grades of zircon and monazite are improving.

**Rare-earth element potential:** Common minerals in the deposit that also bear significant TREO concentrations are monazite, metamict zircon, leucoxene and garnet of the almandine-pyropite group. The distribution of these minerals in the units is shown in Table 5.2.18.

**Leucoxene** (alteration product of Fe-Ti oxides) hosts variable and often elevated U, Th and REE concentrations (Tab. 5.2.19). The poor-quality

leucoxene with high concentrations of contaminant elements including U, Th and REE is presently discarded to non-magnetic rejects.

**Zircon** is the chief contributor to the HREE component together with Y (Fig. 5.2.23). Impure zircon hosts REE in greater concentrations than pure, optically clear zircon (Tab. 5.2.20). About 75 % of the Namakwa Sands zircon consists of pure zircon upgraded to a secondary and a primary zircon product delivered to the chemical and ceramics industries, respectively. The remaining 25 % of impure zircon containing sig-

**Tab. 5.2.18: Distribution of REO-bearing minerals in the units of the Namakwa Sands deposit (in %). The data are from PHILANDER and ROZENDAAL (2009, 2012).**

	RAS		OFS		STR	
	In-situ grade	Percentage of THM	In-situ grade	Percentage of THM	In-situ grade	Percentage of THM
<b>Leucoxene</b>	0.25	3.6	0.34	4.7	0.31	1.9
<b>Zircon</b>	1.03	17.3	0.69	9.7	0.83	3.8
<b>Monazite</b>	0.05	0.36	0.03	0.23	0.01	0.08
<b>Garnet</b>	0.89	6.7	1.93	21.7	5.31	25.2

RAS – Red Aeolian Sand unit; OFS – Orange Feldspathic Sand unit; STR – strandline deposits;  
THM – total heavy minerals

**Tab. 5.2.19: Uranium, thorium and total REE concentrations of REO-bearing minerals of the Namakwa Sands deposit [in ppm].**  
All data are taken from PHILANDER & ROZENDAAL (2012).

Mineral	n	U	Th	Σ REE
Leucoxene	87	94	302	2,013
Zircon	694	666	350	4,018
Monazite	32	45	27,910	568,685
Garnet	80	<1	<1	1,013

**Tab. 5.2.20: Average trace-element chemistry of zircon types of the Namakwa Sands deposit [in ppm]. Modified from PHILANDER & ROZENDAAL (2009).**

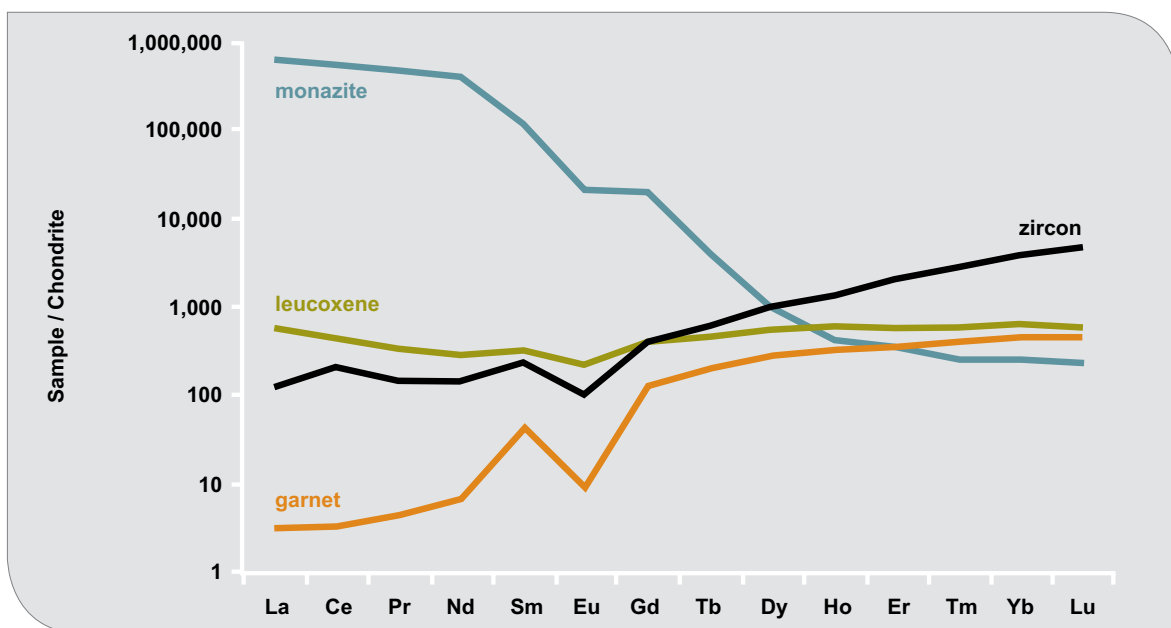
	Clear (n = 231) <sup>1)</sup>	Coloured (n = 201) <sup>2)</sup>	Metamict (n = 225) <sup>2)</sup>
Th	127	288	785
U	209	608	1,248
Y	949	1,838	3,969
Σ REE	757	1,551	3,992

<sup>1)</sup> optically clear zircon - pure zircon with low Fe, U and Th; <sup>2)</sup> impure zircon

nificant REE concentrations (Tab. 5.2.20) and additional rejects end up as a non-magnetic waste fraction.

The LREE-enriched **monazite** hosts ~80 % of the REE of the Namakwa deposit (PHILANDER & ROZENDAAL 2012). Its average major oxide chem-

istry is typical of a monazite-(Ce): CaO 2.66; P<sub>2</sub>O<sub>5</sub> 32.03; La<sub>2</sub>O<sub>3</sub> 15.15; Ce<sub>2</sub>O<sub>3</sub> 32.20; Nd<sub>2</sub>O<sub>3</sub> 9.10; ThO<sub>2</sub> 2.07; SiO<sub>2</sub> 8.72 (n=136; PHILANDER & ROZENDAAL 2009). The low monazite concentrations in the deposit (Tab. 5.2.18) are upgraded by a factor of 50 in the beneficiation process. During mineral separation, it finally reports to the non-magnetic



**Fig. 5.2.23: Chondrite-normalised REE distribution pattern for HM with significant REO concentrations in the Namakwa Sands deposit (modified from PHILANDER & ROZENDAAL 2012).**

rejects. Monazite-(Ce) hosts thorium at percentage level, which requires strict regulations worldwide for its mining, ore processing and waste storage.

**Garnet** hosts very low U and Th, but also moderately enriched REE concentrations. Yttrium dominates the REE values, which are, furthermore, characterised by HREE>LREE (Fig. 5.2.23). In the ilmenite beneficiation process, more than 99 % of the garnet fraction is rejected.

**Summary:** The Namakwa Sands ore body hosts REE below the 0.1 % level. The total estimated REE resource amounts to ~250 kt for the deposit of which 80 % is LREE mainly from monazite-(Ce) and the HREE fraction as well as yttrium from zircon (PHILANDER & ROZENDAAL 2012). However, the high Th concentrations commonly observed in monazite have eliminated this mineral as a significant source of REE in most parts of the world. Up to 10 % of the total REE, particularly the HREE, present in the Namakwa Sands, report to saleable rutile and zircon products in refractory form and the bulk is rejected as by-pro-

ducts (stockpiled). The presently underutilised REE resources could potentially increase the *in-situ* value of the entire Namakwa Sands ore deposit (PHILANDER & ROZENDAAL 2012); however, a revision of the nuclear legislation may be required for further development past the conceptual stage.

Exxaro Sands and Base Metals GM Trevor Arran said, the company was looking strategically at its monazite production, but hadn't reached a decision on what to do with it yet (Mining Weekly.com, May 26, 2011).

### **Richards Bay (KwaZulu-Natal)**

Recent information on the REE (+U+Th) potential of HM sand deposits along the east coast of South Africa is not obtainable and likely to be in the hands of the respective prospect rights holders. Rare-earth data are only available for Richards Bay and, to a much smaller extent, also for Umgababa. However, these data are mostly older than 25 years and have already

**Tab. 5.2.21: ICP-MS minor- and trace-element results for zircon and monazite concentrates from Richards Bay [in ppm]; (Richards Bay Minerals; from PIETERSEN (1992)).**

	Zircon		Monazite
	ZC-B91	ZCP-892	MP-892
<b>Y</b>	1,030	990	10,000
<b>La</b>	10.20	47.90	73,600
<b>Ce</b>	36.00	123.00	148,000
<b>Pr</b>	4.13	15.00	19,000
<b>Nd</b>	14.60	63.50	68,800
<b>Sm</b>	9.69	23.60	13,500
<b>Eu</b>	2.19	4.44	315.00
<b>Gd</b>	24.20	41.60	9,200
<b>Tb</b>	8.99	14.00	914.00
<b>Dy</b>	89.80	126.00	2,940
<b>Ho</b>	35.20	41.20	396.00
<b>Er</b>	143.00	194.00	658.00
<b>Tm</b>	27.60	39.40	45.90
<b>Yb</b>	245.00	372.00	296.00
<b>Lu</b>	50.30	67.10	35.20
<b>Th</b>	141.00	182.00	41,200
<b>U</b>	312.00	381.00	2,770

Sample ZC-B91 was a non-magnetic zircon concentrate taken in November 1991. Samples ZCP-892 and MP-892 are from a zircon concentrate and a monazite product, respectively; both were taken in August 1992.



been evaluated in SCHÜRMANN & HARMER (1998). Consequently, just the most recent concentrate REE chemistry data sets by PIETERSON (1992) that are available are given here (Tab. 5.2.21). Mineral Separation Plant tailings containing monazite, unrecovered zircon and rutile are stockpiled.

Sample ZC-B91 was a non-magnetic zircon concentrate taken in November 1991. Samples ZCP-892 and MP-892 are from a zircon concentrate and a monazite product, respectively; both were taken in August 1992.

### 5.2.5 Requirements and evaluation

Key data for the above discussed rare-earth projects in South Africa are presented in Figures

5.2.24 and 5.2.25 as well as are summarized in Tables 5.2.22 and 5.2.23.

Limiting factors for direct comparison (ranking of projects) and an economic evaluation of the project data are:

- the very different stages of development of the REE projects (advanced projects with PEA or PFS versus almost undeveloped REE occurrences)
- the extreme variability in the nature of the REE sources (for a summary cf. Tab. 5.2.22)
  - the potential for REE in the different projects is either contained in
    - (i) In-situ resources,
    - (ii) stockpiles or tailings dams, or
    - (iii) precipitates resulting from the processing of apatite concentrates,

**Tab. 5.2.22: REE potential of rare-earth projects in South Africa.**

Name	Owner	RE potential	Part of project	Data source
<b>Glenover</b>	Fer-Min-Ore (Pty) Ltd (FMO); Galileo Resources Plc	<i>In-situ</i> resource	Mining of apatite-hematite (REO-Phosphate) breccia resource in old pit	VAN DER WALT et al. 04/2012; updated GALILEO RESOURCES PLC 05/2013
		Stockpiles	Processing of historical surface stockpiles	
<b>Phalaborwa Complex</b>	Foskor (Pty) Ltd	Precipitates from processing of apatite concentrates	Re-processing of REO-bearing sludges from phosphoric acid production for REE extraction	VAN DER VYVER, 1990; GUPTA & KRISHNAMURTHY, 2005
<b>Schiel Complex</b>	none	<i>In-situ</i> resource	Mining of REO-bearing top layers (soil+rubble) overlying primary ore bodies	PRINS et al., 1981; KLEMD, 2013
		Precipitates from processing of apatite concentrates	Mining of weathered phosphate-rich rocks for phosphoric acid production and subsequent re-processing of REO-bearing sludges from acid production for REE extraction	
<b>Steenkamps-kraal</b>	Great Western Minerals Group Ltd	<i>In-situ</i> resource	Underground mining of monazite mineralisation (Monazite Mine Area; Exploration Area)	McKECHNIE et al., 2012
		Tailings dams	Processing of the resources from the two tailings dams	
<b>Zandkops-drift</b>	Frontier Rare Earths Ltd	<i>In-situ</i> resource	Open-cast mining of the REO-enriched carbonatite	HARPER et al., December 15, 2011
<b>Namakwa Sands deposit</b>	Tronox Ltd	<i>In-situ</i> resource	Mining of placer deposits	PHILANDER & ROZENDAAL, 2012
		Stockpiles	Processing of surface stockpiles (non-magnetic rejects)	

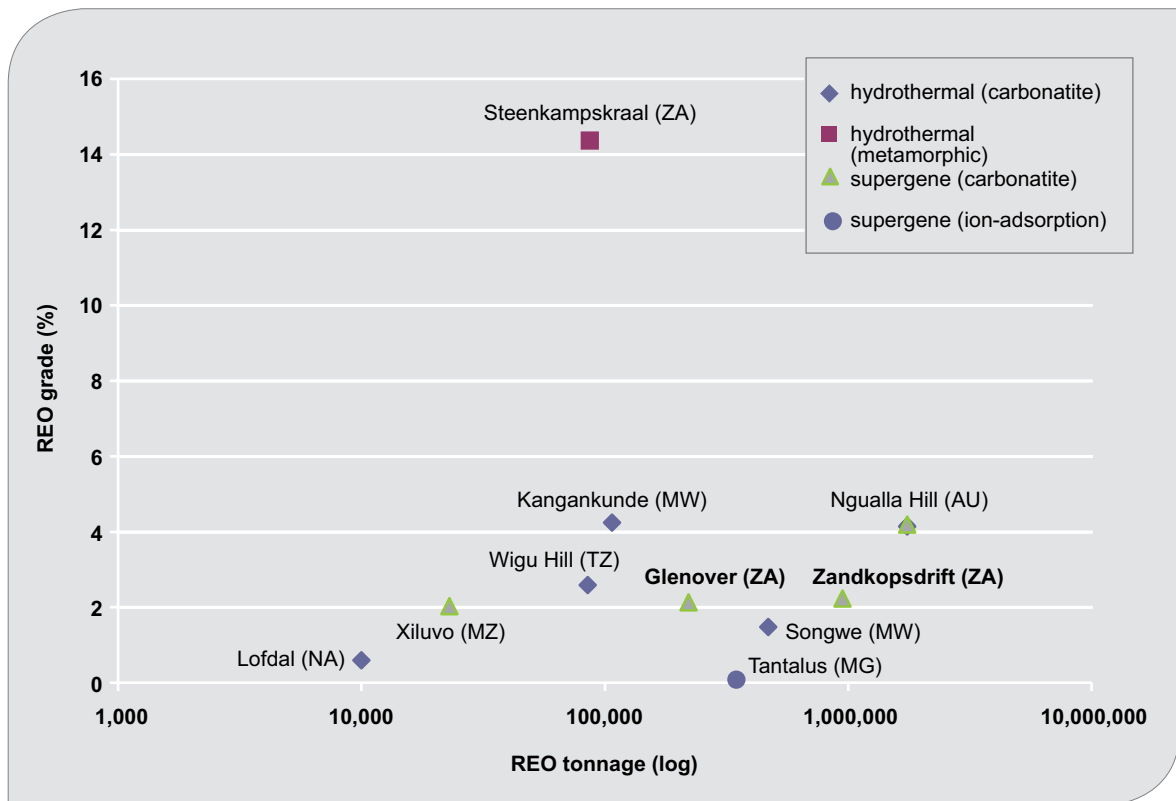
- the fact that the infrastructure in the regions under consideration is developed at very different levels and needs significant development.

**Relative contribution of the different REE in the projects**

As pointed out in the introductory section, the prices for different individual rare-earth oxides differ by orders of magnitude. Consequently, the relative contributions of the different REE to the total resource of a deposit must be assessed in addition to the reported REO grades and tonnages (Tab. 5.2.23 and Fig. 5.2.24), for a final ranking of the individual REE projects. The global forecast of the supply and demand balance for 2016 (cf. before) shows striking differences for the individual REE. Consequently, REE that are expected to be in short supply in 2016 are highlighted with pinkish bars in Figure 5.2.25, which summarizes the REE distributions in the South African Rare -Earth projects (grayish bars stand for REE in high demand for high-tech applications (cf. before)).

All three advanced REE projects in South Africa (viz. Steenkampskraal, Zandkopsdrift, Glenover) show a clear predominance of the LREE over the HREE (Fig. 5.2.25). The highest relative value contribution to their REE products comes from the strong Nd<sub>2</sub>O<sub>3</sub> contents in the ore concentrates (33.6 to 40.2% of TREO value; REO prices from June 2013 (HARMER 2013)) followed by Dy<sub>2</sub>O<sub>3</sub> and Eu<sub>2</sub>O<sub>3</sub> (Eu<sub>2</sub>O<sub>3</sub> is lower for Steenkampskraal). Monazite, the major carrier of the REE in the Namakwa Sands heavy mineral deposit, is also clearly dominated by LREE and the same holds true for the relative contribution of the different REE in apatite concentrates from the Phalaborwa apatite deposit.

The only presented location in South Africa with a significantly increased relative contribution of the HREE to the total rare-earth content is the Vergenoeg fluorspar mine (Fig. 5.2.25). However, all data summarized in the Vergenoeg chapter of this guidebook are sourced from publicly available scientific publications/reports and these sources neither contain information on REE reserves/resources nor on the treatment of REE-rich ores.



**Fig. 5.2.24: Grade-tonnage diagram for African advanced REE projects.**  
 Data source: TMR ADVANCED RARE-EARTH PROJECTS INDEX (2013).  
 Country codes after international standard ISO-3166-ALPHA-2.

Consequently, the evaluation of an economic REE potential at this mine site is impossible at the present stage.

### Environmental aspects

A. The first aspect to be considered here is the common occurrence of radioactive materials in REE ores. The projects in South Africa may be grouped into three types: (i) sites with highly Th- and U-bearing REE minerals, (ii) sites with moderate radioactive ores, and (iii) REE-bearing materials without elevated radioactivity.

#### (i) Highly radioactive ores

**Steenkampskraal Monazite Mine** (moderate  $U_3O_8$  and very high  $ThO_2$  in the monazite ore) holds a Certificate of Registration ("COR"), granted by the South African National Nuclear Regulator (NNR) which grants the necessary authority for the handling and the long term storage of radioactive material including Th at the Steenkampskraal mine site.

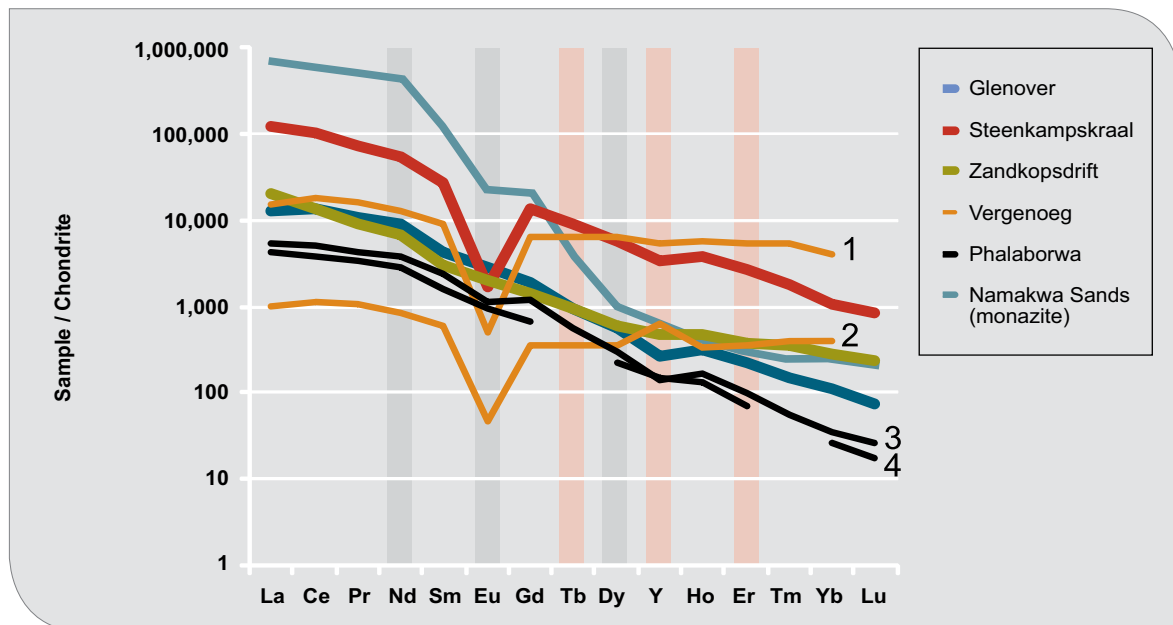
### Heavy mineral sand deposits of the western (and eastern) coastal areas of South Africa:

About 90 % of the total REE present in the Namakwa Sands is rejected as U, Th and REE-enriched by-products (stockpiled). Relaxing or revising the tight regulatory nuclear legislation is, however, required to further develop these REE potentials past the conceptual stage.

#### (ii) Moderate radioactive ores

**Glenover REE project:** Owing to the presence of low levels of U and Th in the deposit (e.g. 540 ppm  $ThO_2$  in the apatite breccia; ANDERSON 2012) Glenover is in possession of a NNR Certificate. In compliance with the terms of the certificate the prescribed radiation warning signage is displayed on the property and radiation monitoring procedures are in place.

**Zandkopsdrift REE deposit:** U and Th are both present at relatively low concentrations compared to many other carbonatite REE deposits being developed worldwide. The average grades of U and Th in the area, in which the resource



**Fig. 5.2.25: REE distribution for South African REE projects.**

**Data sources:** TMR ADVANCED RARE-EARTH PROJECTS INDEX (2013); Vergenoeg deposit: GOFF et al. (2004) - high- (1) and low-REE-bearing (2) rocks from the hematite-fluorite and the magnetite-fluorite units; Phalaborwa: HORNIG-KJARSGAARD (1998) and BGR data – apatite concentrates from pyroxenites (3) and phoscorites (4); Namakwa Sands deposit: PHILANDER & ROZENDAAL (2012). REE that are expected to be in short supply in 2016 are highlighted with pinkish bars; grayish bars stand for REE in high demand for high-tech applications.

has been defined, vary between 60–70 ppm and 215–235 ppm, respectively (HARPER et al. 2011).

(iii) *REE-bearing materials without elevated radioactivity*

**Phalaborwa apatite deposit:** Produced REO concentrates would be free of Th and thus acceptable to overseas markets.

B. The REE resources within the Pilanesberg Complex occur in an area which has been declared a National Park in 1979; consequently, the chances of its exploitation appear remote.

**Evaluation of grade and tonnage data of the REE projects:**

For the advanced REE projects and the Namakwa Sands deposit, grade and tonnage data are summarized in Figure 5.2.24 and Table 5.2.23. Compared to international

REE projects the projects in South Africa are considered as follows:

The Zandkopsdrift deposit – is a moderate to large sized deposit with moderate REO grades.

The Steenkampskraal deposit – is a small to moderate sized deposit with very high REO grades.

The Glenover deposit – is a moderate sized deposit with moderate REO grades.

The Namakwa Sands heavy mineral deposit – has a moderate sized REO resource (data are preliminary estimations only).

The Phalaborwa phosphate deposit – has a large sized REO resource (data are preliminary estimations only).

The Schiel phosphate-REE occurrence – has a small sized REO resource (data are preliminary minimum estimations only).

**Table 5.2.23: Summary of resources in advanced rare-earth projects in South Africa.**

Name	Owner	Resource class	Cut-off grade (TREE)	Part of project	MR (Mt)	TREO (wt %)	TREO (Mt)	Data source
Glenover	Fer-Min-Ore (Pty) Ltd (FMO); Galileo Resources Plc	Indicated	1 %	<i>In-situ</i> resource	7.41	2.20	0.221	VAN DER WALT et al. 2012; updated GALILEO RESOURCES PLC (2012b, 2013)
		Inferred	n.a.	Surface stockpiles	2.94	2.08		
Phalaborwa Complex	Foskor (Pty) Ltd							No data available for RE
Schiel Complex	none							No data available for RE
Steenkampskraal	Great Western Minerals Group Ltd	Measured + Indicated	1 %	<i>In-situ</i> resource	0.559	14.95	0.084	JELICOE, November 14, 2013
		Inferred	1 %	<i>In-situ</i> resource	0.060	9.30 –12.77	0.006	
		Indicated	1 %	Combined tailings	0.046	7.18	0.003	
Zandkopsdrift	Frontier Rare Earths Ltd	Indicated	1 % 2 %		32.35 16.01	2.28 3.09	0.739 0.495	HARPER et al. December 15, 2011
		Inferred	1 % 2 %		10.13 4.53	2.08 2.85	0.210 0.129	
Namakwa Sands deposit	Tronox Ltd	–	–	Ore bodies and surface stockpiles			0.250 (TREE)	PHILANDER & ROZENDAAL 2012

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## 5.3 Antimony

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### 5.3.1 Definitions, mineralogy and sources

#### *Definitions and characteristics*

Antimony (Sb) is defined as a crystalline semi-metal (or metalloid) and exhibiting poor conductivity of electricity and heat. Unlike typical metals, antimony is not malleable, but hard and brittle and can be crushed to a powder. Along with the other semimetals (silicon, germanium, arsenic and tellurium), antimony is positioned in the Periodic Table along the boundary between the metals and the nonmetals. Key characteristics and physicochemical properties of antimony are listed in table 5.3.1.

From an economic point of view, the most important ore mineral and principal source for the production of metallic antimony is stibnite ( $Sb_2S_3$ ), with 71.7 wt.-% antimony. Stibnite is the most important ore mineral and is the principal source in economic antimony mining. Although stibnite is widely distributed, high grade concentrations are not common. In major antimony deposits such as the Chinese Xikuangshan deposit, Central Hunan, and the antimony line in the Murchison Belt, South Africa, stibnite is the dominant ore mineral.

**Tab. 5.3.1: Physicochemical properties of antimony.**

Symbol	Sb (antimony)
Atomic number	51
Atomic weight	121.75
Density	6.697 g · cm <sup>-3</sup>
Hardness (Mohs scale)	3.15
Melting point	630.63 °C (903.78 K)
Boiling point	1,587 °C (1,860 K)
Principal valences	Sb(V), Sb(III)
Ionic radii	0.245 nm (–3); 0.062 nm (+5); 0.076 nm (+3)

## Mineralogy

A wide variety of antimony minerals occur in natural systems. More than 264 different antimony-bearing mineral phases have been defined so far. Antimony tends to concentrate in sulphide ores along with copper, lead and silver. Stibnite has a gray colour and metallic luster. It reaches a hardness of 2 on the Mohs scale and its density is about 4.6 g/cm<sup>3</sup>. Beside stibnite the most important antimony minerals are berthierite (FeSb<sub>2</sub>S<sub>4</sub>), boulangerite (Pb<sub>5</sub>Sb<sub>4</sub>S<sub>11</sub>), stephanite (Ag<sub>5</sub>SbS<sub>4</sub>), jamesonite (Pb<sub>4</sub>FeSb<sub>6</sub>S<sub>14</sub>), bournonite (PbCuSbS<sub>3</sub>), tetrahedrite (Cu<sub>12</sub>Sb<sub>4</sub>S<sub>13</sub>), freibergite (Cu,Ag)<sub>12</sub>Sb<sub>4</sub>S<sub>13</sub>, gudmundite (FeSbS), ullmannite (NiSbS), dyscrasite (Ag<sub>3</sub>Sb), breithauptite (NiSb), kermesite (Sb<sub>2</sub>S<sub>2</sub>O), and valentinite/senarmontite (Sb<sub>2</sub>O<sub>3</sub>) (see Tab. 5.3.6).

## Sources of antimony

Antimony occurs in different types of ore deposits of all ages, from the presently forming fumarole precipitates of active volcanoes, e.g. in New Zealand, to deposits in the Archaean volcanic strata of greenstone belts, e.g. in Canada and South Africa (Tab. 5.3.2). Generally, economically exploitable deposits of stibnite are small and discontinuous.

In decreasing order of significance, antimony-rich deposits are represented by greenstone-hosted quartz-carbonate epithermal-style vein-type deposits, carbonate replacement deposits, polymetallic base-metal vein deposits, granite-related tin-base metal deposits, pegmatite deposits and precipitates from hot springs.

Mines with antimony-bearing ore are in production on all continents. Large deposits are located in China, Bolivia, Russia, South Africa, Tajikistan, Canada, and Australia. Currently, the most important deposits are in China, Bolivia, South Africa, and Russia. More than 88 % of the world's antimony production comes from China, where the vast majority of antimony is produced at the Xikuangshan deposit.

## Major deposit classes

Antimony deposits have a distinct, but not exclusive, hydrothermal origin (OBOLENSKY et al. 2007). Three main antimony deposit types can be distinguished based on fluid generation and metal source: (i) Low-temperature hydrothermal (epithermal) origin in shallow crustal environments and in association with magmatic-hydrothermal fluids, (ii) metamorphogenic hydrothermal origin in consolidated crustal environments and formed from crustal fluids, eventually mobilised by, and with contributions of magmatic heat and expelled fluids, and (iii) reduced intrusion-related gold systems. Antimony deposits can also be distinguished by their metal and mineralogical composition, with (i) simple stibnite (plus gold) deposits, and (ii) much more complex polymetallic deposits with variable contents of elements of the epithermal suite including gold, silver, tellurium, selenium, mercury, arsenic, antimony, and thallium and, locally, base metals (copper, lead, bismuth, zinc). Key characteristics and examples of the major types of antimony deposits are given in table 5.3.3.

**Tab. 5.3.2: Size and grade of the major types of antimony deposits (grades and tonnages are very variable between deposits and figures given are indicative only).**

Deposit type	Deposit size range (metric tonnes)	Typical grade (% Sb <sub>2</sub> S <sub>3</sub> )	Antimony metal content of known deposits (metric tonnes)
Gold-antimony (Epithermal) vein-Type	10,000 – 1,000,000	0.1 – 3.5	580,000
Carbonate replacement	1,000,000 – 100,000,000	1.5 – 25	2,500,000
Reduced-magmatic	1,000,000 – 100,000,000	0.1 – 1.5	320,000
Polymetallic base metal Vein	10,000 – 1,000,000	0.1 – 0.5	175,000
Hot springs	10,000 – 1,000,000	0.1 – 0.2	2,500
			<b>3,577,500</b>

Tab. 5.3.3: Key characteristics and examples of the major types of antimony deposits.

Deposit type	Brief description	Features	Examples
<b>Gold-antimony (epithermal) vein-type</b>	Medium to large, low-grade stockwork-type quartz-stibnite (tetrahedrite) veinlets and disseminations in shale, calcareous shale, limestone, quartzite, volcanic, granite (or metamorphic equivalents) in greenstone belts of a potential subduction zone and island arc setting.	Deposits lack significant copper, lead, zinc, and nickel sulphide and sulfosalt minerals; Sb-As-Hg-Au-Ag-Te assemblage of the high low-sulfidation subtype in epithermal environments; veins of quartz cored by massive stibnite; wall rock equilibration of magmatic fluids; transitions to meso-zonal (orogenic) deposits.	Antimony line (South Africa), Hemlo (Canada), Olimpiada (Russia)
<b>Reduced-Magmatic</b>	Regional arrays of sheeted auriferous quartz-carbonate veins in the carapace and volcanic surroundings of causative plutons; small to intermediate size proximal As-Sb-Au veinlets. Weak post-collisional extension behind a thickened continental margin.	Deposits occur in a mineral system with an outward zonation of an Au-Bi-Te-W-As-Sb-Ag-Pb-Zn assemblage; skarn-like and replacement bodies and veins; associated with volatile-rich quartz monzonite melts.	Tintina Au province (USA, Canada), Timbarra, Kidston, (Australia), Niuxinshan (China)
<b>Carbonate Replacement</b>	Numerous but small to intermediate size, <0.1 to 2.0 million tonnes high-grade vein-stockwork deposits of almost pure stibnite in sedimentary or metasedimentary (limestone) sequences. Syn- to post-collisional tectonic settings.	Deposits are characterized by lenticular bodies of quartz and stibnite within limestone, at contacts with overlying shale, near high-angle faults; silicification extends tens of meters into the host limestone.	Xiguanshan (China), Kadamdzhay (Russia)
<b>Polymetallic Base Metal Vein</b>	Small to medium polymetallic deposits; structurally controlled in postcollisional vein breccia zones of clastic meta-sedimentary or magmatic-dominated terranes; mineralization by basinal brines.	Polymetallic base metal and Ag-rich ores; densely intergrown ore minerals (telescoping); Sb hosted by stibnite, tetrahedrite and a variety of simple and complex sulphosalts; quartz-carbonate gangue.	Cobalt district (Canada), Bolivian Sb belt, Bau district (Malaysia)
<b>Hot spring exhalative</b>	Siliceous precipitates deposited by hydrothermal fluids, hot springs, fumaroles; volcanic activity.	Low temperature fluids forming sulphide and sulphosalt segregations in altered intermediate to felsic wall rocks; Sb co-enrichment with As and Hg (Te, Se, Au, Ag).	Shallow marine hydrothermal vents and magmatic fumaroles at Kudryavyi, Kuril islands (Russia), Merapi (Indonesia), Taupo volcanic zone



### 5.3.2 Specifications and use

The main antimony products in international trade are stibnite and subordinate stibnite-berthierite and tetrahedrite ores and concentrates, antimony metal, antimony trioxide, and antimonial lead. Highest antimony ore concentrates are mined in South Africa and Bolivia and contain up to 60 % Sb. Chemical grade ores are sufficiently pure to be used directly in the production of antimony trioxide, antimony chloride or other compounds. The total impurity level must not exceed 0.25 %, with arsenic and lead concentrations less than 0.1 %. Antimony metal specifications are in excess of 99.80 % Sb and maximum values for arsenic (0.05 %), sulphur (0.10 %) lead (0.15 %) and other elements (0.05 %) for grade A. Grade B metal must have 99.5 % Sb, maximum 0.1 % arsenic, sulphur and other elements, and 0.2 % lead.

A number of antimony compounds are traded on the international markets. The compounds include antimony oxychloride ( $\text{SbOCl}$ ; 70.3 % Sb), antimony pentoxide ( $\text{Sb}_2\text{O}_5$ , 75.3 % Sb), antimony trichloride ( $\text{SbCl}_3$ ; 53.4 % Sb), antimony trioxide ( $\text{Sb}_2\text{O}_3$ ; 83.5 % Sb), antimony trisulphide (stibnite  $\text{Sb}_2\text{S}_3$ ; 71.1 % Sb), sodium antimonite ( $\text{NaSbO}_3$ , 63.2 % Sb), stibine ( $\text{SbH}_3$ ; 97.6 % Sb).

Antimony trioxide is the most important antimony compound. It has a molecular weight of 291.5, a melting point of 656 °C, and a boiling point of 1,550 °C. Crude antimony trioxide grades below 98 %  $\text{Sb}_2\text{O}_3$ ; commercial grades contain 99.2 to 99.5 %  $\text{Sb}_2\text{O}_3$ , with variable quantities of impurities such as arsenic, iron and lead. Suppliers trade various grades of antimony trioxide based on tinting strength which increases with decreasing particle size. The main grades produced are high-tint (average particle size of 1.0–1.8  $\mu\text{m}$ ), low tint (2.5–5.0  $\mu\text{m}$ ) and ultra fine (0.2–0.4  $\mu\text{m}$ ). The antimony trioxide is supplied in low-melt bags for direct charge, bulk tank trucks for discharge into silos and bulk bags for reduced dusting and direct discharge.

### Uses and consumption

The unique properties of antimony make it a vital component in a diverse range of products and applications. These properties include:

- low melting point enhancing workability at low temperatures
- stability in air at room temperature and in cold water up to 250 °C
- resistance to most cold acids
- dissolution in some hot acids and in aqua regia

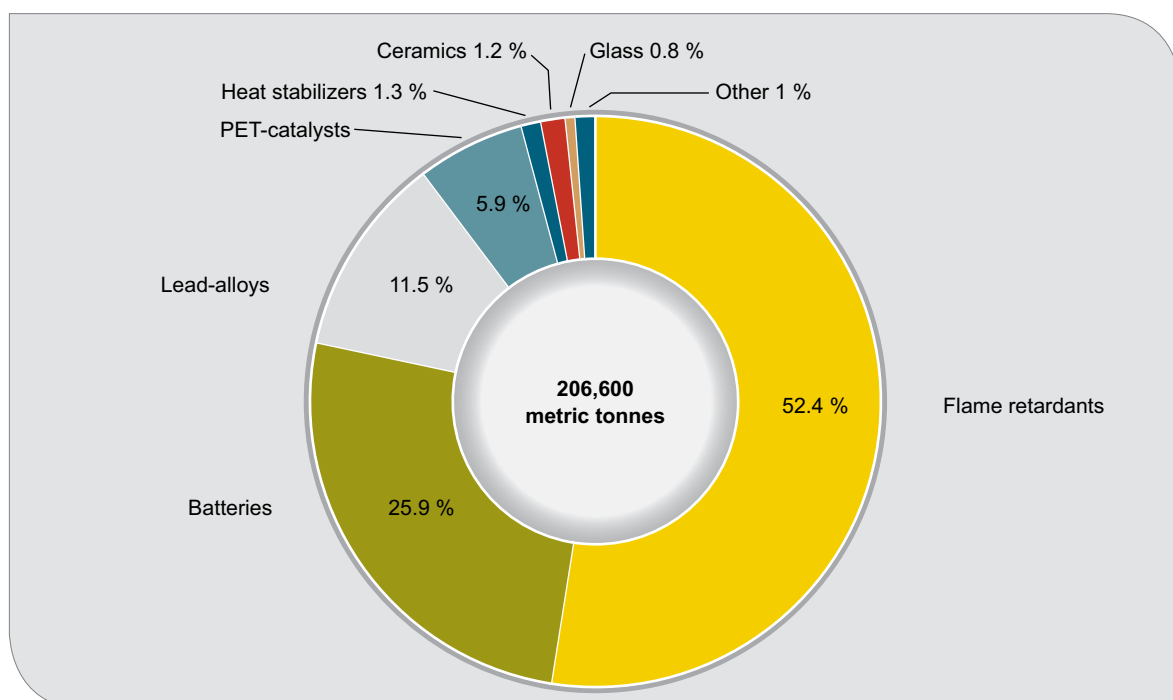


Fig. 5.3.1: End-uses of antimony in 2011 (modified after ROSKILL INFORMATION SERVICE LTD 2012)

- incompatibility with strong oxidising agents, chlorine, fluorine
- reaction with materials that do not react with hydrochloric and nitric acids separately
- metastability at rapid cooling, providing exothermic reaction
- high density but weak bonding, leading to low hardness and brittleness
- two allotropic forms of antimony: stable metallic and amorphous gray
- low electrical and thermal conductivity
- expansion on freezing (density anomaly) similar to silicon, bismuth, gallium and germanium

Antimony is consumed in the following forms:

- antimony trioxide, used mainly in flame retardants
- sodium antimonite, used mainly in cathode ray tube glass
- primary metal, used mainly in lead-acid batteries
- antimonial lead, mainly recycled from and re-used in lead-acid batteries

The most important uses and the development from 2011 are shown in figure 5.3.1.

### 5.3.3 Supply and demand

China is the major antimony producer (mine and refined production) worldwide. The known producers of antimony worldwide by company country and annual capacity are listed in table 5.3.4.

#### Antimony market

The development of the historic supply-demand balance shows a worldwide excess of supply of antimony from 2000 to 2003. In 2003, the excess was about 4,500 tonnes, i.e. approximately 3 %. Since 2006, the demand exceeds the supply of antimony (supply shortage). ROSKILL INFORMATION SERVICE LTD (2012) recorded a supply deficit in the year 2011 of approximately 2,840 tonnes (i.e. 1.4 %). In the past, production had always to be adjusted and therefore was demand driven.

#### Extraction

Of the 18 countries that have produced primary antimony in the past decade, the most important have been, in order of decreasing production, China, Tajikistan, Russia, Myanmar, Canada,

**Tab. 5.3.4: Global antimony producers in 2011 (SCHMIDT 2013).**

Company	Country	Capacity (t/year Sb)
Various (Hsikuangshan Twinkling Star)	China	128,017
Various (GeoProMining, Novoangarsk, Khara Shibirsky)	Russia	8,400
Village-Main-Reef (former Metorex)	South Africa	3,175
Various (Shwe Zin Htut, Thu Ya Kan Chun, Htut Khaung, Myint Myat San)	Myanmar	7,048
Beaver Brook (China-Non-Ferrous)	Canada	5,766
Comsup (former Anzob GOK)	Tajikistan	9,825
Various (Emusa, COMISAL, Bernal Hermanos, CBPA)	Bolivia	3,947
Mandalay Resources	Australia	1,576
Various (Cengiz & Özdemir Antimuan Madenleri)	Turkey	1,320
Kazzinc	Kazakhstan	709
Various (Hong Xin, Siam)	Thailand	1,000
Kadamdzhai	Kyrgyzstan	480
Various (SRS, Sin Rung Roj)	Laos	1,456
US Antimony	Mexico	5
Various	Peru	120
Various	Pakistan	24
Various	Other Asia	400
<b>Total</b>		<b>173,200</b>

Bolivia, South Africa and Australia (SCHMIDT 2013). Antimony mining in those countries is dominated by a single or only a few stibnite-rich deposits, with possible by-products of gold, silver, tungsten and mercury. A number of small mines contain irregular and scattered orebodies that cannot be readily exploited by large-scale mining methods.

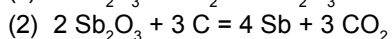
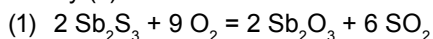
These mines are entered by a shallow shaft or short adit, developed by drifting in the vein, and stoped by simple methods between raises driven on the footwall of the ore. One of the world's major antimony-producing mines, the underground Consolidated Murchison (Cons Murch) Mine in South Africa, uses variations of shrinkage stoping.

On the surface, the waste is separated from the high-grade ore, and trucked to a mill for the separation and concentration of gold and antimony. Flotation methods used to concentrate low-grade stibnite ores can produce a concentrate that contains more than 60 % antimony, with recovery rates of up to 95 %.

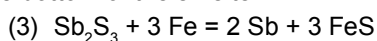
### **Processing, beneficiation and conversion to metal**

Techniques for the antimony recovery encompass the entire range of traditional hand sorting, conventional flotation to technologically advanced mineral processing. Primary production may be characterised by both plentiful and cheap labour, and by capital-intensive techniques. Mineral processing generally includes primary conventional crushing and grinding, followed by combined gravity concentration and flotation.

Elemental antimony is recovered from stibnite ores by a reduction process. The ore is heated and oxidised in a current of air (1) and then the stibnite oxide is reduced by charcoal to the metallic antimony (2).



An alternative recovery method is melting the stibnite ore with iron in a furnace. The iron combines with the sulphur and generates a layer of molten iron sulphide (3). The liquid elemental antimony has a higher density and is removed at the bottom of the smelter.



## **5.3.4 Resources in South Africa**

The Republic of South Africa is the seventh largest antimony producer (after China, Tajikistan, Russia, Myanmar, Canada and Bolivia) in the world. Antimony in the Limpopo Province occurs in the Murchison Greenstone Belt as well as the Barberton Greenstone Belt in the Mpumalanga Province (no production; Fig. 5.3.2).

### **5.3.4.1 Consolidated Murchison Mine, Murchison Greenstone Belt (Limpopo)**

#### **Location and owner**

Coordinates: (Athens shaft) 23°53'52.00"S; 30°41'09.00"E; 561 m amsl

The Consolidated Murchison Mine ("Cons Murch Mine") is located approximately 7 km east of the Village of Gravelotte, and covers a mining right area of approximately 1,580.65 ha, as well as a converted prospecting right area of 9,544.75 ha. Since 1932, the Consolidated Murchison antimony deposits (Alpha/Gravelotte, Beta, Athens, and Monarch) have produced more than 550,000 t of antimony in concentrate and more than 25 t of gold.

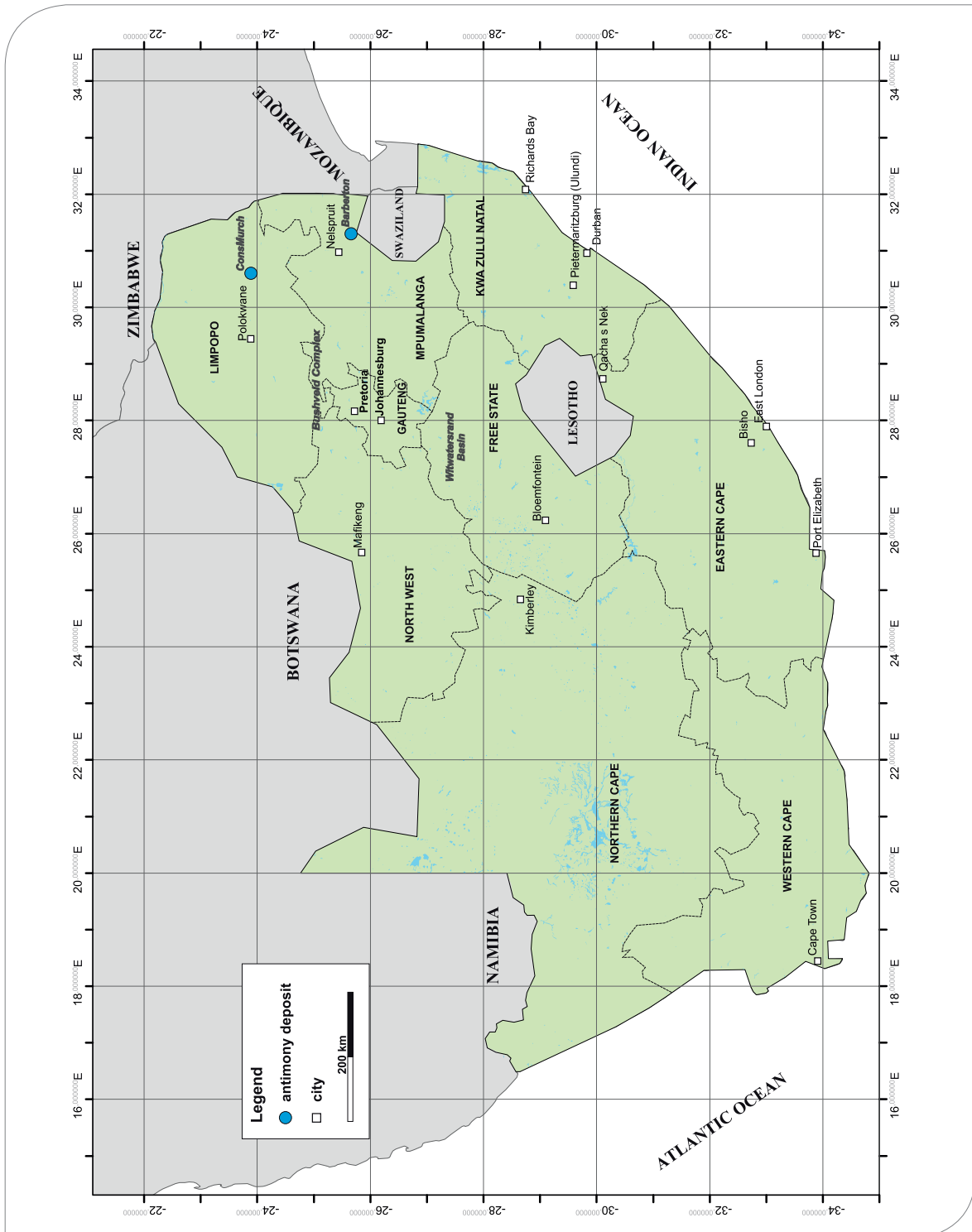
In March 2011, Village Main Reef Limited acquired Consolidated Murchison for a total consideration of R 40 million after a period of non-profitable production under Metorex Limited and "To The Point" (Proprietary) Limited ownership. With current strong commodity prices, Consolidated Murchison has operated profitably since acquisition and, with the current strong antimony prices and the focus on increased antimony production from the operations, the company is expected to achieve payback of the purchase price in less than 12 months which will contribute significantly to its free cash flow during the current financial year. Current activities focus on improving the ore body flexibility and ramping up the production as more mining areas become available. The planned upgrade of the plant will improve recoveries and operating efficiencies.

**Local infrastructure and climate**

Infrastructural development and access to the antimony deposit in the Murchison Greenstone Belt is well developed with a regular supply of power, water and labour. Access to the property

is via a well-maintained tar road which adjoins the National Road R 21, which runs between Tzaneen and Gravelotte.

The deposit area is characterised by a relatively flat to gently undulating topography averaging 500



**Abb. 5.3.2: Distribution of antimony occurrences and deposits in South Africa.**







**Fig. 5.3.4:** *Left: Primary mineralization of stibnite within a quartz-carbonate vein in the Athens shaft (920 m below ground; photo BGR). Right: head gear of the Athens shaft (Photo DERA).*

**Tab. 5.3.5:** *Historical Exploration of the Cons Murch Mine.*

Year	Detail
1870	Two prospectors report having found gold in what was later named the Murchison Range.
1886	Start of a gold rush led by French Bob and the area was soon proclaimed a public digging.
1890	A township is laid out around French Bob's camp, given the name of Leydsdorp.
1890–1928	Numerous small mines are worked for gold. All encounter metallurgical difficulties, with the refractory ore extracted from a certain depth below surface and are forced to close down.
1914–1918	Antimony ore first produced for export from the Murchison area. The deposit at Union Jack is treated for gold trying both cyanidation and other leaching processes. These are not successful and production soon ceased.
1928	Exploitation of antimony as a by-product of gold is considered worthwhile and the revival of the area begins.
1934	Consolidated Murchison (Transvaal) Goldfields and Development Company Limited merged with Anglovaal. The purpose of this company is to prospect and exploit the mineralised area to the east of Leydsdorp on the Murchison Range.
1972	The company name is changed to Consolidated Murchison.
1940–1946	Mercury mined is at Harrington Kop east of Monarch Shaft, by a company known as Monarch Cinnabar (Pty) Ltd which is purchased by Consolidated Murchison Limited in 1956.
1966	Eskom power is made available to the mine.
1972	Antimony Products Limited is formed.
1974	First phase of the plant is commissioned.
1985–1988	The McGeanRohco plant is commissioned in 1985 and ceases production in February 1988.
1988–1996	Johannesburg Consolidated Incorporation (JCI) takes over Cons Murch Mine and sells it in 1996 to METOREX Ltd.
1996–2011	METOREX constructs new parts of the ore processing plant and sells the mine to Village Main Reef in 2011, which formed the company Cons Murch Mine (Pty) Ltd.



**Fig. 5.3.5: Flotation of stibnite ore in the processing plant at Athens shaft (Photo DERA).**

Gold was discovered in the Murchison Range towards the end of the nineteenth century, and was mined on a small scale for many years, with antimony as a by-product. Larger-scale mining started in 1937 and has continued to the present day without any marked interruption.

**Metallurgical operations/processing:** Ore is mined by sublevel open sloping and hoisted to the concentrator where it is crushed. Once the

ore is crushed and milled, an antimony mineral concentrate is produced by flotation (Fig. 5.3.5). In general, this concentrate is then roasted to form crude antimony oxide, which has approximately 85 % Sb. However, the roasting plant has not been in operation since 2008. Therefore, the final product is a stibnite mineral concentrate with approximately 60 to 65 % Sb. The concentrate is dried and bagged. Gold is recovered in a gravity circuit and a number of leach and carbon absorption stages.

**Tab. 5.3.6: Sb-bearing minerals from the Murchison greenstone belt (DAVIS et al. 1986).**

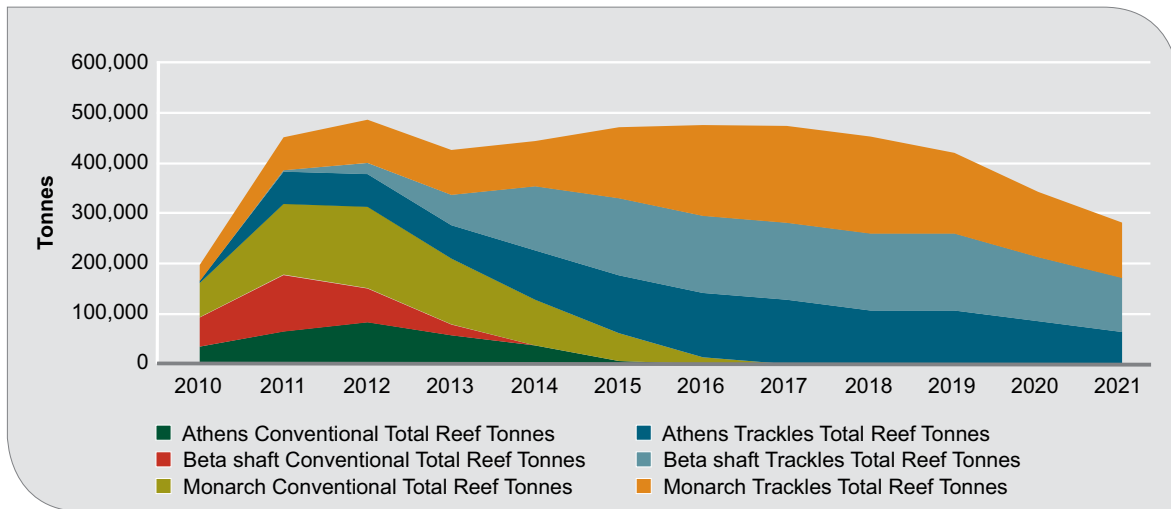
Mineral Name	Chemical composition	% Sb
Stibnite	$Sb_2S_3$	71.68
Berthierite	$FeSb_2S_4$	56.94
Gudmundite	$FeSbS$	58.07
Native antimony	$Sb$	100
Cervantinite	$Sb^{3+} Sb^{4+}O_4$	79.19
Valentinite	$Sb_2O_3$	83.53
Senarmontite	$Sb_2O_3$	88.39
Breithauptite	$NiSb$	67.47
Aurostibite	$AuSb_2$	55.28
Famatinitite	$Cu_3SbS_4$	27.63
Jamesonite	$Pb_4FeSb_5S_4$	35.39
Kermesite	$Sb_2S_2O$	75.31
Livingstonite	$HgSb_4S_7$	51.58
Ullmannite	$NiSbS$	57.29

**Tab. 5.3.7: Resources of Sb and Au, annual production and other key notes.**

<b>Total mineral reserves (proved and probable)</b>	24,420 t Sb
<b>Total mineral resource (1 % Sb cut-off grade)</b>	Measured and indicated: 62,950 t Sb
<b>4 shafts: Athens, Beta, Monarch, Alpha/Gravelotte</b>	Measured, indicated and inferred: 204,673 t Sb
<b>Contained Sb %</b>	1.53 – 2.83 % av.: 2.18 %
<b>Production Sb concentrate (financ. year 2012–2013)</b>	5,326 t Sb
<b>Total mineral reserves (proved and probable)</b>	115,280 oz Au
<b>Total mineral resource (1 g/t Au cut-off grade)</b>	Measured and indicated: 320,92 oz Au
<b>4 Shafts: Athens, Beta, Monarch, Alpha/Gravelotte</b>	Measured, indicated and inferred: 709,960 oz Au
<b>Contained Au g/t</b>	2.43 g/t
<b>Production Au (financial year 2012-2013)</b>	308 kg
<b>Mining (ore tpa)</b>	135,000 t
<b>Estimated mine life at current production rates</b>	10 years
<b>Mining method</b>	Underground – open stoping
<b>Average stripping ratio</b>	1.5:1
<b>Sb, Au plant</b>	Milling, flotation, (the roasting plant is currently not working)
<b>Recovery rate</b>	80 % Sb; 65 % Au
<b>Risks (for mining, processing and mine waste storage)</b>	
<b>Large-scale production since</b>	1934
<b>Sb basket price (US\$/t)</b>	10,000

Source: VILLAGE MAIN REEF (2013) Integrated Annual Report; t: metric tonnes; oz: troy ounces.

**Fig. 5.3.6: Stibnite concentrate packed in 1 metric ton big packs for export (Photo DERA).**



**Fig. 5.3.7: Cons Murch Mine antimony LoM, by the Competent Persons' Report on the Consolidated Murchison Mine, Limpopo Province, South Africa, prepared by MINXCON (PTY) LTD (with kind permission of Village Main Reef and Umbono).**

**Current mining activities, production and reserves/resources:** Village Main Reef (Village) is a South African-based, mining and development company, with its ordinary shares listed for trading on the main board of the Johannesburg Stock Exchange (JSE) under the share code VIL. Village took control of Cons Murch in March 2011 and currently owns 76.6 % of the mine. The remaining 23.4 % of the issued share capital is held by a broad-based black economic empowerment (BBBEE) employee share trust. BBBEE partner, Umbono Capital, holds some 12 % of Village and Xelelwa a further 7 %. Village is an established mid-tier mining group that is focused on gold, antimony and platinum production and runs five active mining projects in South Africa. The company operates underground mining at Cons Murch Mine in the Murchison Greenstone Belt in the following three shafts:

- Athens
- Beta
- Monarch

The mine primarily extracts stibnite, with gold and minor arsenopyrite, from stibnite reefs. The annual production is about 5,300 tonnes of antimony concentrate (Tab. 5.3.7). The antimony and gold mineralisation at the Cons Murch Mine is hosted in rocks of the Rubbervale Formation, Murchison schists (comprising the Weigel and

MacKop Formations) and La France Formation of the Gravelotte Group.

The ores occur within fractured or brecciated massive, competent, siliceous carbonate rocks as mineralised reefs, stibnite disseminations or irregular veins and stringers of stibnite-quartz-carbonate (NELL & SCHLEGEL 2006). Sb bearing minerals from the Cons Murch Mine are listed in table 5.3.6.

A number of exploration targets surrounding the existing operating areas have been identified. Consolidated Murchison has a total antimony resource base of 205,000 t of which more than 10 % is in the reserve category. The 2013 mineral resources and reserves for the underground operations and the production capacity of antimony and gold as a by-product, as well as the estimated life-of-mine are listed in table 5.3.7. The investigation results of the potential of the Consolidated Murchison Tailings Dump in resources are described in chapter 5.3.4.2.

**In situ mineral resources in life-of-mine plan:**

At the current planned production rates, Cons Murch Mine will have a life-of-mine ("LoM") of 10 years. The LoM plan was supplied to an independent auditor by the mine and has been audited and reviewed by Minxcon. Figure 5.3.7 illustrates the mine's LoM reef tonnes per shaft and per mining method.



### 5.3.4.2 Consolidated Murchison tailings dumps, Murchison Greenstone Belt (Limpopo)

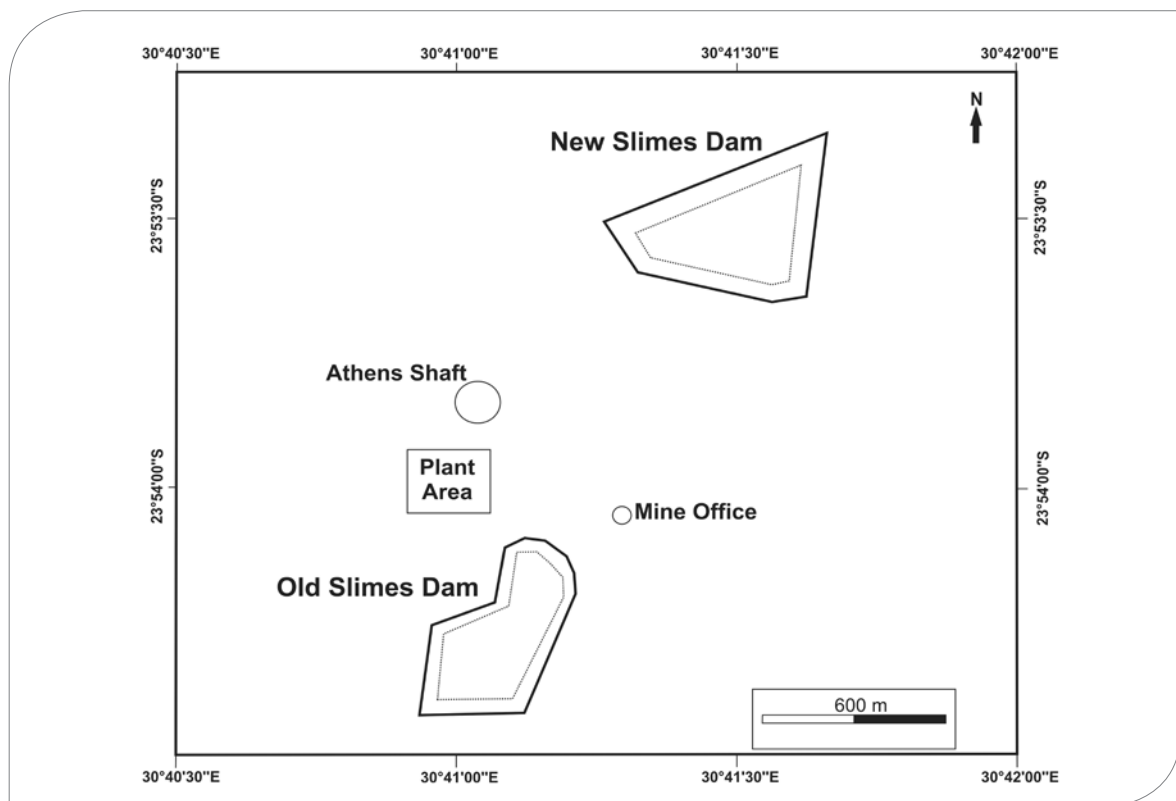
#### Introduction

A tailings recovery project (the so-called "Cons Murchison Project") at the tailings at the Ath-

ens shaft, located 10 km northeast of the town of Gravelotte, was carried out as an Independent Competent Persons' Report by KING (2010), mineral resources manager of Minxcon (Pty) Ltd. The report is fully compliant with the South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves (2007) (the SAMREC Code), the South African Code for the Reporting on Mineral Asset Valuations (2008) (the SAMVAL Code) and Section 12 of the Johannesburg Stock Exchange listing requirements.



**Fig. 5.3.8:** Old slimes dam (OSD) at the Athens shaft (view from the main road to the north, to the southern margin of the OSD; photo DERA).



**Fig. 5.3.9:** Location of the old slimes dam (23°54'15"S/30°41'10"E) and the new slimes dam (23°53'30"S/30°41'30"E) at the Consolidated Murchison Operation (modified after KING 2010).



The commodities of extractable interest in the project are gold and antimony.

There are two tailings dams in the area of the Athens shaft at the farm Josephine 777 LT the Old slimes dam (OSD) and the new slimes dam (NSD; Fig. 5.3.9). The OSD has a footprint of 18.264 ha and contains tailings material from beneficiation of ores from the United Jack, Athens, Gravelotte, Alpha and Monarch shafts of the Cons Murch Mine. The footprint of the new slimes dam (NSD) is 23.323 ha and also contains fine-grained tailings materials (Fig. 5.3.10) from the Athens, Beta and Monarch shafts. The material of the OSD has a stratified structure, as a result of variations in grade throughout the layers. The OSD has been evaluated regarding its content of Sb, Au as well as As (KING 2010).

## Methods

### Sampling method

The OSD was investigated in two time periods from the 1970s to the mid-1980s and in 2010.

Two major drilling campaigns were carried out in 1984/85 and February 2010.

A dry drilling method was performed, using a fully portable hydraulic drill rig comprising a rotating spiral auger drill encased in a stainless steel core barrel/rod. The upper 20–30 cm of tailings material was removed. The extension rods and spiral augers have three lengths, namely 1.5 m, 3.0 m and 4.5 m. This facilitates the extraction of 1.5 m samples, averaging between 2 and 4 kg in weight. The typical drilling cycle comprises the following:

- The initial sample is drilled with a 1.5 m spiral auger/sample tube, after which the first sample is extracted. The subsequent sample is drilled with a 3.0 m auger/sample tube and the 1.5 m sample is extracted.
- Thereafter, a 4.5 m spiral auger/sample tube is used and the sample is extracted. The succeeding samples are extracted from the 4.5 m spiral auger plus a 1.5 m extension rod, followed by a 3.0 m extension rod and then a 4.5 m drill rod. This succession is repeated until the floor of the tailings dam is intersected or the hole can no longer be



**Fig. 5.3.10: Fine-grained, sandy to silty material of the new slimes dam (NSD; photo DERA).**



**Fig. 5.3.11: Collar positions for 1984/1985 (old drill holes) and February 2010 (new drill holes) drilling campaigns on the OSD (modified after KING 2010).**

**Tab. 5.3.8: Consolidated Murchison OSD descriptive statistics for the combined data set (KING 2010; with kind permission of Village Main Reef and Umbono).**

	Units	Valid	Mean	Min.	Max.	Std. Dev.	Skewness	Kurtosis
Au	ppm	1,219	0.46	0.01	3.95	0.45	2.50	9.51
Sb	ppm	1,219	7,337.15	700.00	30,400.00	3,478.56	1.67	5.01
As	ppm	1,205	1,158.20	100.00	9,200.00	775.12	3.50	22.54

**Note:** 1. Valid – Valid Samples; 2. Std. Dev. – Standard Deviation.

**Tab. 5.3.9: Cons Murchison Mine tailings dams OSD and NSD measured antimony, gold and arsenic resources (VILLAGE MAIN REEF 2013 Integrated Annual Report, KING 2010 (with kind permission of Village Main Reef and Umbono).**

Tailings Dams	Volumen (Mio. m <sup>3</sup> )	tonnes (Mt)	grade			content		
			Au (ppm)	Sb (wt:%)	As (wt:%)	Au (t)	Sb (t)	As (t)
OSD	3.94	6.18	0.46	0.752	0.116	2.843	46,474	7,169
NSD	7.47	11.73	0.50	0.240	n.d.	5.865	28,152	n.d.
<b>Summary</b>	<b>11.41</b>	<b>17.91</b>	<b>0.48</b>	<b>0.500</b>	<b>0.116</b>	<b>8.708</b>	<b>74,626</b>	<b>7,169</b>

**Notes:** 1. Mineral Resources are inclusive of Mineral Reserves; 2. Gold content conversion: 1 kg = 32.15076 oz; 3. SG = 1.57 t/m<sup>3</sup>; 4. Cut-off (gold equivalent) = 1:36,308 Au:Sb; 5. Optimistic Operating Cost (including Plant Operating) ZAR60/t; 6. Mine Call Factor = 100 %; 7. Recovery rate: Gold = 70 %; Antimony = 30 % (min.)

advanced. Extra 4.5 m sample tubes are utilized to speed up the drilling process.

The samples are analyzed for antimony utilizing a four acid digest and ICP-OES determination.

### Key technical factors

1. Number of drill holes: 43 drill holes drilled (1984/1985) in the first phase of the historical drilling campaign and a total of 13 holes were drilled as twins to selected 1984 drill holes.
2. Resources of 6.18 Mt at 0.46 g/t with a gold content of 91,000 oz and antimony grade of 7,518 ppm and content of 46,474 tonnes.
3. No mine plan.

### Domaining methodology

Data interrogation and statistical analysis lead to the conclusion that the OSD comprises distinct vertical zones based on grade distribution. The drill holes were filtered on the assay results and viewed in vertical section. A wireframe surface was built from points and strings created on the estimated contact between two zones of differing grades. The wireframe surfaces were translated to the extents of the domains to create a wireframe solid for each domain. A summary of the domains modeled for Sb estimated for the Consolidated Murchison OSD was carried out. The domains were individually estimated and modeled.

## Results

### Statistics, grades and resources

Table 5.3.8 shows the descriptive statistics of geochemical data for the drill core samples for the historical and new data sets.

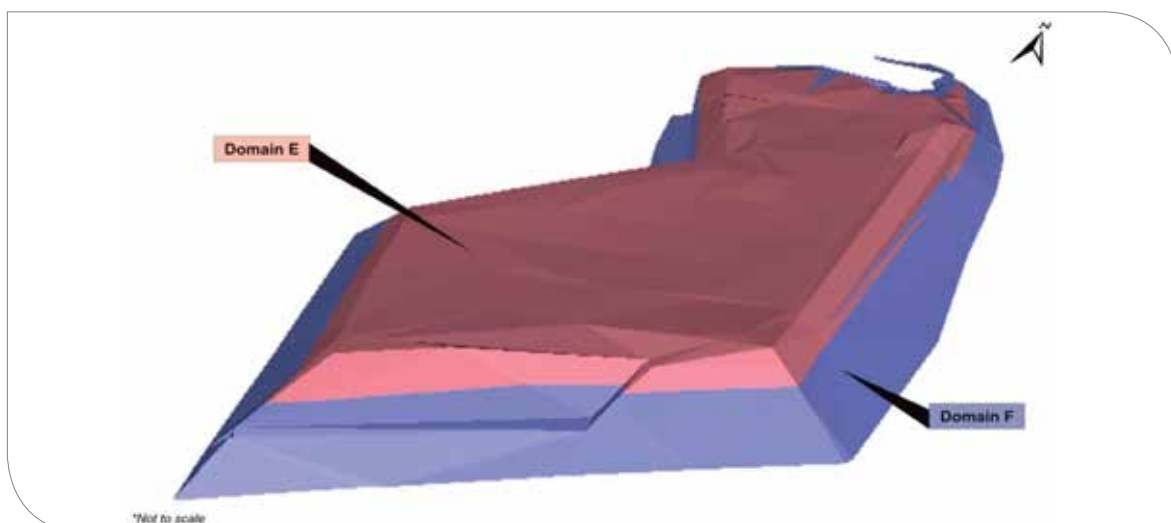
### Domains of OSD

Figure 5.3.12 displays the lateral domaining of the OSD into two layers based on different antimony grades. The two domains are named Domain E and Domain F. The differentiation between the two domains is visible in a 3-D model of the OSD.

The top 11 m of the OSD is low grade with a Sb mean of 0.549 % and has been named Domain E. The remaining lower zones of the OSD display a higher grade, with an Sb mean of 0.837 %. The lowermost portion of the Domain F to the east, in the vicinity of the drill holes J1, J2 through to A1, A2V and A2, displays higher Sb grades of approx. 1.1 %.

Minxcon reached the following conclusions regarding the project:

The Consolidated Murchison old slimes dam contains measured gold resources that are estimated to be 6.18 Mt at Au 0.46 g/t and Sb of 0.752 % and an arsenic content of 0.112 %.



**Fig. 5.3.12: Consolidated Murchison OSD vertical antimony domains (source: KING 2010, with kind permission of Village Main Reef and Umbono).**

### 5.3.4.3 Mali and Amo Antimony Mine, Barberton Greenstone Belt (Mpumalanga)

#### Location and owner

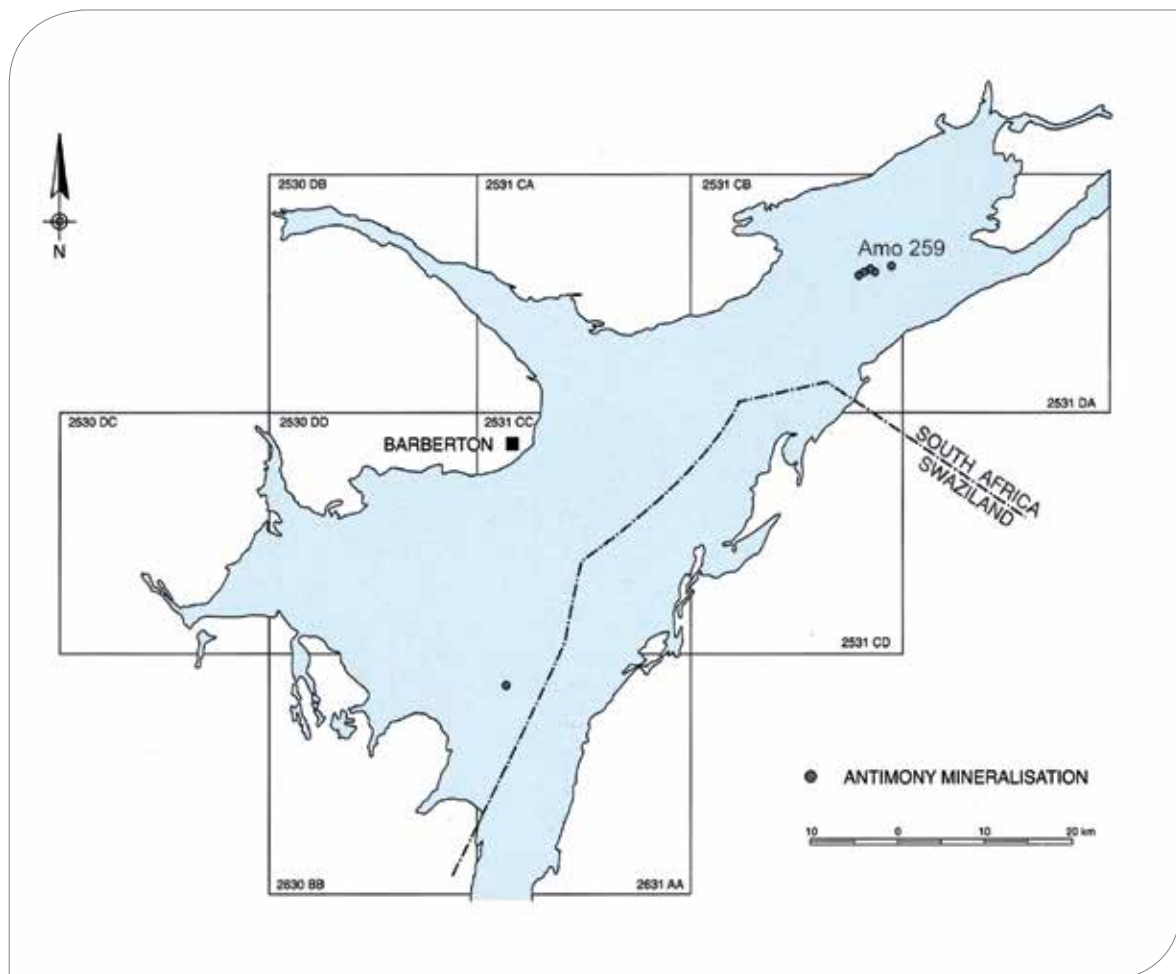
The Mali Antimony Mine, situated in Onverwacht greenstones west of Msauli, was worked in the early years of the 20<sup>th</sup> century for a reported production of only a few tonnes of stibnite (GROENEVELD 1975).

The Amo Antimony Mine, formerly known as the Morning Mist Mine, is situated some 13 km south-southwest of Malelane in the eastern part of the Barberton Greenstone Belt. The mineralisation occurs associated with a 200-m-wide zone of cherty, micaceous, talc-carbonate schists which represents an eastern extension of the Scotsman

fault. Common rock types include chlorite-talc-carbonate schist, fuchsite-sericite-quartz schist, and massive greenish-grey banded chert. Secondary silicification is widespread, especially in areas of intense carbonatisation.

#### Geology

The Barberton Greenstone Belt is a granite greenstone terrain, formed in the mid-Archean (3600 – 3100 Ma). It covers an area of 120 to 50 km, is situated south to southeast of Nelspruit and is a strongly folded, ENE-trending volcanosedimentary remnant, entirely surrounded by a variety of granitoids of the Kaapvaal Craton (ANHAEUSSER et al. 1969). The Barberton Supergroup comprises three major lithostratigraphic units: the Onverwacht Group, the Fig Tree Group and the Moodies Group (JOHNSON et al. 2006).



**Fig. 5.3.13:** The area of the Barberton Greenstone Belt showing a significant distribution of stibnite occurrences (source: WARD 1999).

Native antimony and antimonial sulphides are often present as minor accessory minerals in the refractory gold ores of the Barberton Greenstone Belt (DE VILLIERS 1957, BARTON 1982). In recent exploration ventures, antimony, together with arsenic, has been used as a standard path-finder element in geochemical prospecting for gold in the Barberton region. At just one gold deposit, the Belvue Gold Mine underlying Weltevreden 712 JU in the Montrose area, the sulphide mineralisation was enriched enough in stibnite for it to be classified as antimomal gold ore. The antimony concentration in the gold ore was too low for the metal to be extracted as a by-product. Only two discrete occurrences of stibnite have been sufficiently concentrated as a potential source of antimony ore. These small-scale operations were known as the Mali Antimony Mine, underlying the farm Soodorst 2 IU in the Komati River Valley, and the Amo Antimony Mine, on Amo 259 JU in the Malelane area. The siliceous dolomitic host rock to the massive and disseminated stibnite mineralisation is very similar to orebody host rocks exposed along the antimony line in the Murchison Greenstone Belt.

### Mining and history

The only record of production is that of 15 t of hand-cobbed stibnite ore which was mined in 1935 from a short central adit linked to a shallow 15-m-long open pit, and the occurrence is reported also to have been a gold prospect (GROENEVELD 1975). During the 1970s, Johannesburg Consolidated Investment Co. Ltd (JCI) undertook extensive surface geological exploration of the Amo antimony mineralisation, including some diamond drilling. Four exploration priorities were established along a 2.5 km strike. Diamond drilling and underground sampling at the original Morning Mist deposit established an inferred resource of 5 – 10,000 t of stibnite ore grading 5 % Sb.

### 5.3.5 Requirements and evaluation

An evaluation of the Cons Murch Mine and the Cons Murch tailings was carried out by two points: first regarding the size of the deposits, after PETROW et al. (2008) and, second, by preparing a grade tonnage diagram regarding the most important Sb-producing mines worldwide.

According to PETROW et al. (2008), the size of the primary Cons Murch deposit with Resources of 206,000 tonnes of Sb content would be classified into the category “large” and the tailings dams (OSD + NSD with 74,000 tonnes) would be ranged within the category “medium”.

To demonstrate the global significance and the mine value, the Cons Murch Mine and its tailings project were classified into a grade-tonnage equation (regarding the total resource; Fig 5.3.14). After this valuation, the Cons Murch deposit lies, because of its relatively high Sb grade of 2.19 % (Tab. 5.3.10), in a valuable position, compared to most of the other deposits with Sb grades lower than 1 %. Regarding the widely unknown reserve base of the Barberton occurrence and the very small exploration and mining activities in that area an evaluation of that deposit is not possible.

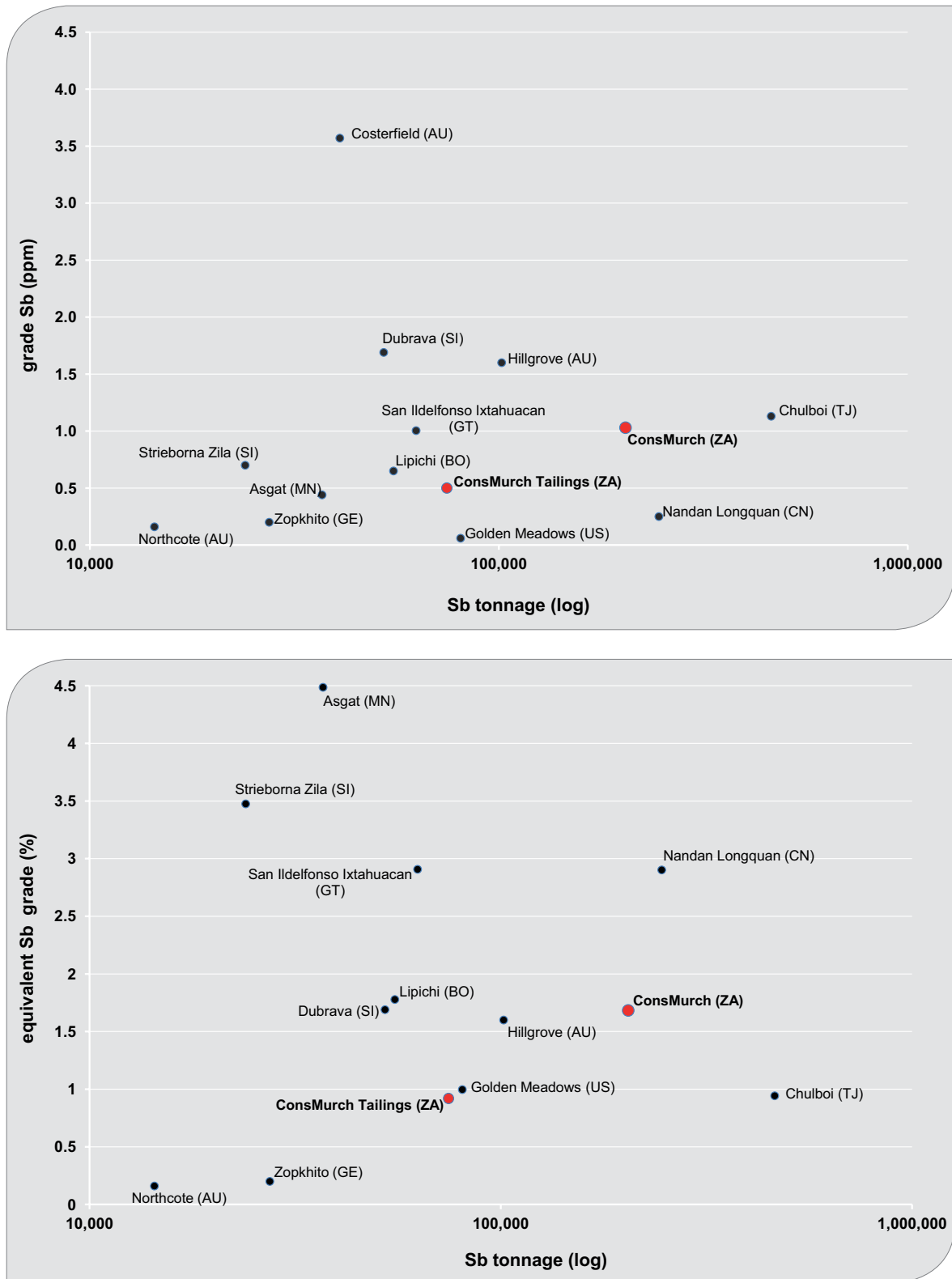
Antimony is generally produced as a by-product of other produced commodities, in particular gold, but also silver, copper, lead, zinc and tin. Thus, it is essential to calculate the equivalent value of all commodities relative to the price of antimony. A recovery rate of approximately 80 % is also considered within the calculation. Therefore a second diagram is shown, demonstrating the equivalent Sb content, relative to the total measured, indicated and inferred reserves.

After this evaluation, the Cons Murch primary deposit with its three producing shafts lies within the upper mid-range, compared to other projects worldwide. Asgat (MO) and Strieborna Ziela (SI) show a much higher value owing to their high proportion of primary commodities.

**Tab. 5.3.10: Size of antimony deposits according to the classification of PETROW et al. (2008).**

	Unit	Small	Medium	Large	Very large
<b>Sb content</b>	1,000 t	< 50	50 – 100	100 – 300	> 300





**Fig. 5.3.14: Grade-tonnage diagrams (total Sb resources on X-axis) to evaluate the values of different Sb producing mines worldwide. Top: Under consideration with Sb grades only; Bottom: calculation considers other produced commodities: gold, silver (Asgat, Strieborna Zila, Nandan Longquan), copper (Asgat, Strieborna Zila), lead, zinc and tin (Nandan Longquan). Country codes after international standard ISO-3166-ALPHA-2.**

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