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Book

The HiTi feedstock market - rutile, leucoxene and others

Deutsche Rohstoffagentur
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The HiTi feedstock market – rutile, leucoxene and others

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DERA Rohstoffinformationen

The HiTi feedstock market – rutile, leucoxene and others

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Executive Summary

Titanium is a common element in the Earth's crust and all common titanium minerals are oxides. This study presents the mineralogical and chemical properties of economically important titanium minerals with an elevated titanium content (HiTi feedstock minerals) i. e. rutile, leucoxene and HiTi, a mixture of rutile and leucoxene.

Total global titanium mineral production (in TiO_2 units) is estimated to have been about 7.4 million tonnes in 2019. Approximately 89 % of all natural titanium minerals (ilmenite, leucoxene, rutile) extracted worldwide are used for the production of TiO_2 (titanium dioxide) based white pigments. 6 % is used for the production of titanium metal and 5 % for coating welding electrodes and others.

Natural rutile is the highest quality titanium mineral and is used in three major areas:

- Manufacturing of TiO_2 white pigments with a market share of about 60 – 65 %.
- Manufacturing of titanium metal with a market share of about 10 – 15 %
- Sheathing of stick welding electrodes as well as filling of flux-cored wire electrodes and manufacture of flux powder for arc welding. These welding applications are estimated to have a market share of about 25 – 30 %.

Additionally, minor amounts of natural rutile are used as a protective TiO_2-based coating for repairing damaged blast furnaces, in the production of special glasses for pharmaceuticals, for staining pottery and in glazes.

Leucoxene is formed by weathering of ilmenite and contains 68 – 92 % TiO_2. Virtually all leucoxene produced worldwide is used for the production of TiO_2 white pigments while HiTi, containing anything between 70 and 95 % TiO_2, is used for the same applications as natural rutile.

Demand data for HiTi feedstock minerals are available from a few titanium mineral producers, but especially from TZMI, a consulting company based in Australia. TZMI has forecasted rising demand for HiTi feedstock for many years which, coupled with strongly decreasing supply, will result in supply deficits and rising prices.

In 2019 about 890,300 tonnes of HiTi feedstock minerals (containing 820,300 tonnes of TiO_2) were produced globally of which 752,400 tonnes were rutile, 106,700 tonnes were leucoxene and 31,200 tonnes were HiTi. The most important producing countries in decreasing order of tonnage were Australia (53 % less production than in 2012), China (+83 %), Sierra Leone (+45 %), Republic of South Africa (–22 %), Kenya (production since 2013), and Ukraine (– 25 %), followed by USA, Vietnam, India, Senegal, Mozambique, Malaysia, Brazil, Sri Lanka, Thailand, Russia and Indonesia.

In the coming years until 2025 – which is the last year this study looks at – global HiTi feedstock mineral production will probably rise to 1,213,400 tonnes (+36 %) containing some 1.1 million tonnes of TiO_2. Of this quantity, 1,109,300 tonnes will be rutile (+47 %), 59,100 tonnes leucoxene (–45 %) and 45,000 tonnes HiTi (+44 %). The largest increases in production will be seen in Australia (+82 %), Sierra Leone (+53 %) and China (+32 %) while the strongest decrease will probably be reported from Ukraine (–47 %).

In stark contrast to TZMI's projections, the BGR/DERA demand-supply scenarios show a massive oversupply of natural rutile in the world market of at least 25,000 tonnes TiO_2 content and more probably as much as 100,000 tonnes by 2019. This oversupply is likely to more than triple to 337,000 tonnes TiO_2 content by 2023 before declining to 304,000 tonnes in 2025.

While the BGR/DERA demand-supply scenarios are based on publicly available TZMI demand data and company-based rutile production forecasts, they do not take into account the effects of the COVID-19 pandemic which may be enormous

Chapter 7 describes the global titanium metal market until 2018. Meanwhile this description is of historic interest only as, due to the COVID-19 pandemic, the commercial aerospace market has collapsed completely. Close to 50 % of all titanium metal produced in recent years was used for commercial aerospace production.

Information on all HiTi feedstock-producing companies in all countries is provided in Appendix A.

Appendix B provides comparative statistics for the majority of all commercially available leucoxene, rutile and HiTi concentrates while Appendix C lists the raw analytical data.

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Wonnerup Mine, formerly Cristal Mining Ltd., Australia
Keysbrook Mine, formerly MZI Resources Ltd., Australia

1 Introduction

In 2010 the German Mineral Resources Agency (DERA) was founded within the Federal Institute of Geosciences and Natural Resources (BGR), a government agency of the German Ministry of Economics and Energy (BMWi). Two of the functions of DERA are to observe changes in worldwide prices and demand and provide advice to German companies on all aspects of mineral resources supply.

In 2013 DERA published a market study on zircon on the question of whether zircon was in short supply and whether it was even possible to talk of a “peak zircon situation” as postulated by the major international consultant TZ Minerals International Pty Ltd. (TZMI). A clear result of the DERA study was that zircon deposits are abundant, and that zircon supply would be sufficient within the foreseeable future. Zircon prices fell considerably shortly following publication, proving the results of the study to be correct. Within the DERA study it was also able to obtain, analyse and compare samples of most of the commercial zircon concentrates available in the international market. These data proved helpful both for German and for international zircon processing and trading companies.

Back in 2013 zircon was the most widely discussed topic among market participants. This has recently been replaced by HiTi feedstock. While there is an accepted opinion that there is enough titanium feedstock in the world in general, demand for feedstock with elevated TiO_2 contents is rising. Leucoxene, natural rutile and HiTi – a mixture of leucoxene and natural rutile – synthetic rutile and titanium slag produced from ilmenite are used as a preferred feedstock in many titanium-based products. While demand is strong, supply is apparently decreasing as one of the leading TiO_2 pigment producers (Tronox Ltd.) has decided no longer to sell its HiTi feedstock on the open market but to keep it for internal consumption.

Once again, DERA decided to look into the details and produce its own evaluation. Very similar to the market study on zircon and numerous other commodity studies published by DERA in recent years, this study concentrates on the supply side of HiTi feedstock, putting a strong emphasis on obtaining as precise as possible data on past, present and probable future worldwide production. Additionally, DERA has attempted to obtain as many different commercial leucoxene, rutile and HiTi concentrates as possible for its own in-house analysis.

A chapter on titanium metal was added on special request of the German Ministry of Economics and Energy.

In early 2020 shortly before this study was scheduled to be published, the COVID-19 pandemic hit the world with dramatic consequences for the titanium market. The precise effects of the pandemic are still not clear and therefore were not modelled in this study. However, a general decrease of > 10 % in both supply and demand can be estimated for the years 2020 and 2021.

Due to the restrictions caused by the COVID-19 pandemic, DERA was unable to host a workshop for German companies on HiTi feedstock and titanium metal as initially planned, and for German readers this study therefore includes a chapter in German on the supply and demand of HiTi feedstock in Germany.

2 Mineralogy and chemistry of titanium minerals

There are well over 400 known different minerals containing titanium but only few of them occur commonly in the natural environment and even fewer have any commercial use. The most important Ti minerals are:

- Ilmenite, $FeTiO_3$, ideally containing 31.56 % Ti
- Pseudorutile, $Fe_2Ti_3O_9$, ideally containing 35.97 % Ti, a weathering product of ilmenite
- Leucoxene, a weathering product of pseudorutile, containing 40.77 – 55.15 % Ti
- Rutile, TiO_2, together with the two other crystal modifications of titanium dioxide, i.e. anatase and brookite, containing up to 59.94 % Ti
- Nb-bearing rutile (ilmenorutile), $(Ti,Nb,Fe)O_2$, an important (Ta-)Nb mineral, ideally containing 35.18 % Ti
- Ta-bearing rutile (struverite), $(Ti,Ta,Fe)O_2$, a formerly important Ta mineral, ideally containing 24.48 % Ti
- Loparite, $(RE,Na.Ca)_2(Ti,Nb)_2O_6$, an important RE mineral, ideally containing 23.27 % Ti
- Titanite (sphene), $CaTiSiO_5$, no commercial use, ideally containing 18.16 % Ti
- Perovskite, $CaTiO_3$, no commercial use, but tested for high-tech applications, ideally containing 35.22 % Ti

Pure **ilmenite** has the following characteristics:

Formula	$FeTiO_3$
Chemistry	52.66 % by mass TiO_2, 47.34 % by mass Fe_2O_3
Density	4.72 g/cm^3
Mohs hardness	5 – 5½
Colour	black to black-brown
Magnetic property	intensely paramagnetic
Electrostatic property	conductive

Ilmenite is the most common titanium mineral in the Earth's crust. It is the most important dispersed accessory mineral in almost all intrusive and extrusive rocks. It has overriding significance as a titanium mineral in norites, gabbros and anorthosites. There is seamless miscibility at high temperatures (>600 °C) between ilmenite and hematite (Fe_2O_3). Part of the Fe can be replaced by Mg, Mn and Al, and part of the Ti by Mg in the mixed crystals though. As the temperature drops, hematite and ilmenite become segregated forming titano-hematite: here thicker or thinner lamellae of hematite in varying amounts are intercalated with ilmenite.

Another important mineral is titanium magnetite. The two spinels magnetite ($Fe^{2+}Fe_2^{3+}O_4$) and ulvite (Fe_2TiO_4) are seamlessly miscible at high temperatures. Furthermore, part of the Fe^{2+} can be replaced isomorphously by Ti, Mg, Mn and other elements and part of the Fe^{3+} can be replaced by Ti, Al, V and Cr in the magnetite. As the temperature declines, there is segregation into magnetite, ilmenite and ulvite. Complete segregation into pure magnetite and ulvite does not take place. In addition, ilmenite is precipitated in the form of fine lamellae on the octahedral faces of the magnetite. The slower the cooling, the coarser the segregation structure.

Due to the preferred intercalation of Fe instead of Ti, the TiO_2 content in ilmenite can be far below the stoichiometric value of 52.66 % by mass. The numerous possibilities for the incorporation of impurity ions in ilmenite also partly explain the difference in the chemical analyses of ilmenite concentrates. Impurities due to the incorporation of mineral impurities in solution cavities or by insufficient processing are common. The lower the TiO_2 content of the ilmenite, the lower its commercial value (cf. Chapter 3).

Figure 1 shows the FeO-Fe_2O_3-TiO_2 system in a triangle chart (Garnar 1978). This also includes the weathering sequence of ilmenites from solid rocks (A) to ilmenites from sediments (B and C) and to leucoxenes from sediments (D) and finely crystalline secondary rutile (E).

After it is released from solid rocks, the ilmenite is subject to weathering. Particularly under humid tropical conditions, iron increasingly dissolves and titanium becomes relatively enriched. The final member in the weathering process is the mineral mixture **leucoxene** which predominantly consists of Ti oxides and, to a far lesser degree, Fe oxides. The process of weathering is therefore called leucoxenization. Leucoxenization only occurs above groundwater level. The influence of humic acids plays an important role. As the TiO_2 content of ilmenites is of outstanding significance in an economic-geological and processing context, the process of leucoxenization has been thoroughly

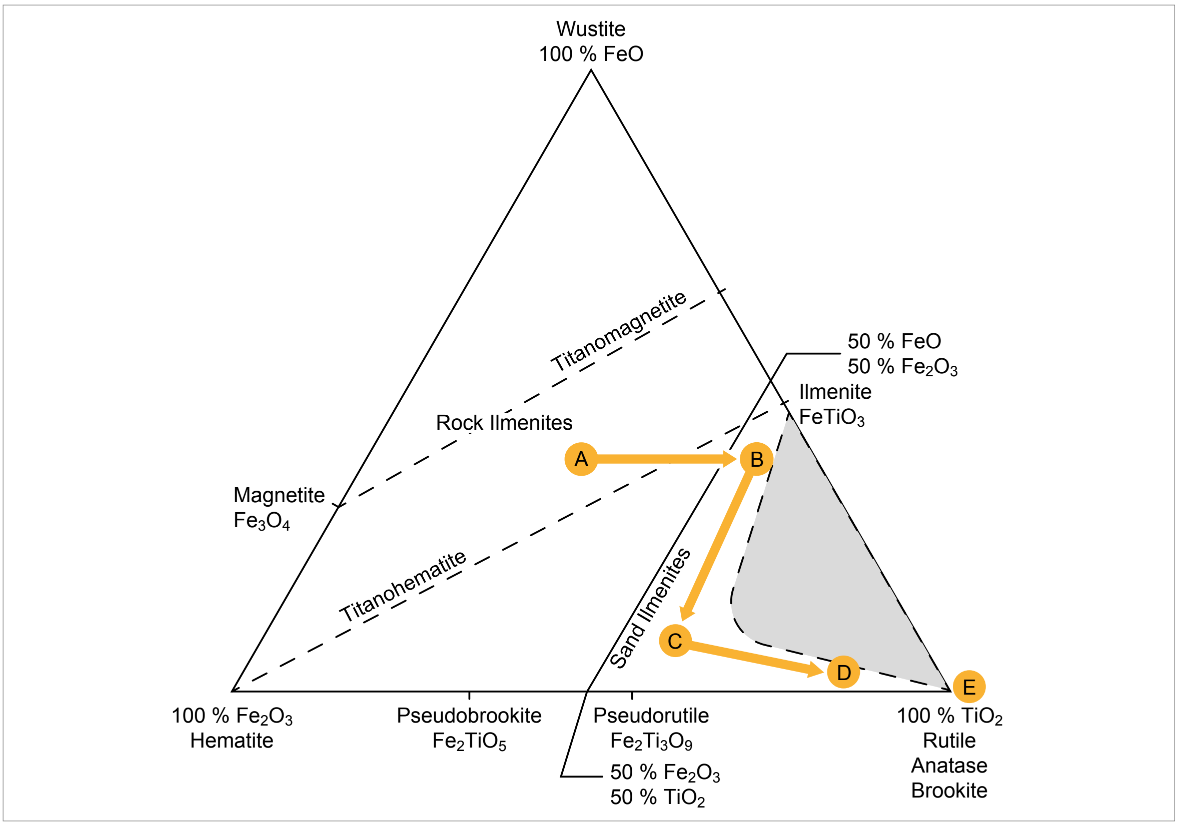


Figure 1: Representation of the FeO-Fe_2O_3-TiO_2 system in a triangle chart according to Garnar (1978). There are no known analyses of titanium minerals in the dark field.

investigated (e.g. Dimanche & Bartholome 1976). Disintegration of the ilmenite structure and formation of an amorphous iron/titanium oxide mixture occurs starting at the grain and structural boundaries. FeO is increasingly oxidized to Fe_2O_3 and Fe oxides dissolve. The amorphous TiO_2 recrystallizes as fine crystalline rutile or more rarely as anatase or brookite. This fine crystalline mineral mixture consisting predominantly of TiO_2 is called leucoxene.

The dissolution of the iron oxides induces the relative increase in TiO_2 and the reduction of magnetic susceptibility. Mücke & Chaudhuri (1991) were able to very closely define the minerals of the ilmenite → leucoxene conversion series in a mineralogical and crystallographic context for the first time: ilmenite ($FeTiO_3$) → leached ilmenite → pseudorutile ($Fe_2Ti_3O_9$) → leached pseudorutile ($FeTi_3O_6(OH)_3$) → leucoxene.

Meinhold (2010) reviews findings about rutile in different rocks and states that leucoxene is essentially a mixture of pseudorutile and rutile.

According to Temple (1966), the inherent colour of "leucoxene" depends directly on its TiO_2 content (cf. Table 1).

Table 1: Dependence of the colour of "leucoxenes" on their TiO_2 content (Temple 1966).

TiO_2 (%)	Colour
52–63	dark grey
63–68	reddish grey
68–75	auburn
75–80	yellowish-brown
80–85	yellow orange
85–90	yellowish-grey
90–95	yellowish-white
95–100	white

According to Garnar (1980), ilmenites and partially weathered ilmenites are opaque and completely soluble in sulphuric acid when their TiO_2

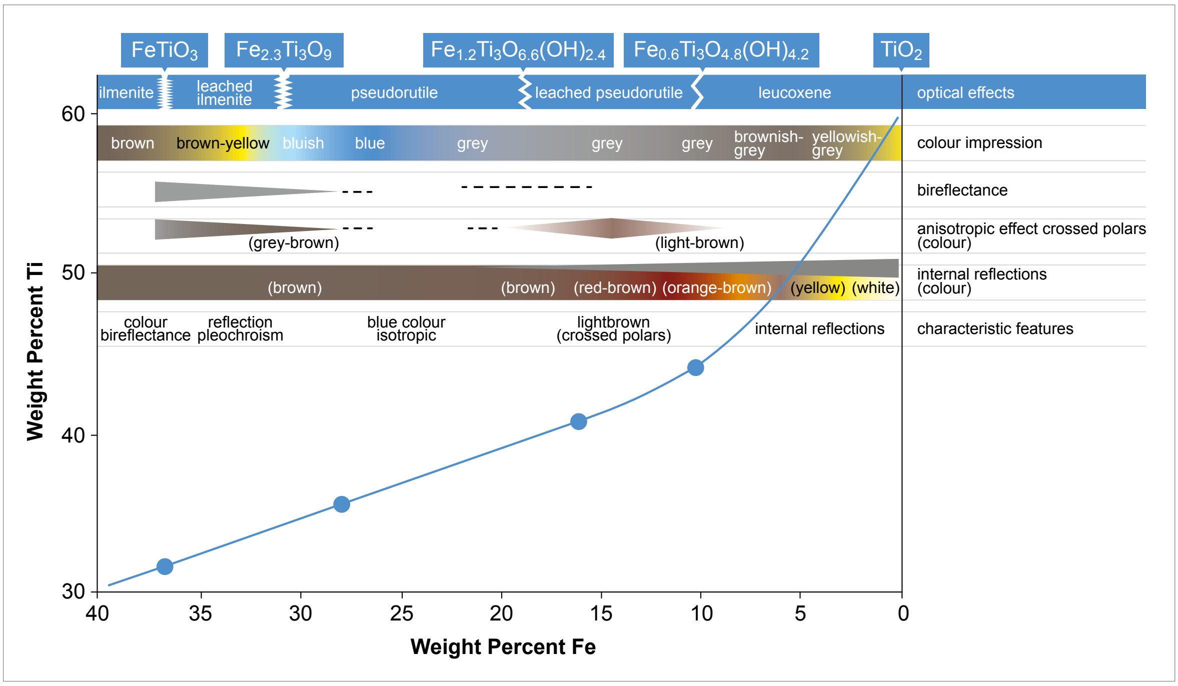


Figure 2: Microscopic ore behaviour of ilmenite and its alteration products as related to the composition presented in a Ti:Fe diagram. Taken from Mücke & Chaudhuri (1991).

Table 2: Changes in chemical and magnetic properties with increasing weathering of ilmenite (Garnar 1985).

Name of the mineral	TiO_2 (%)	Density (g/cm³)	Magnetic susceptibility
Ilmenite	40	4.7	very strongly paramagnetic
Ilmenite	50	4.7	strongly paramagnetic
Ilmenite	60	4.2	paramagnetic
Weathered ilmenite	70	4.1	slightly paramagnetic
Leucoxene	85	3.5	very slightly paramagnetic
Rutile	95	4.2	nonmagnetic

content lies between 45–65 %. Leucoxenes are also opaque, have TiO_2 contents between 68–92 %, a light grey colour when heated to 550 °C under the influence of oxygen and are not completely soluble in sulphuric acid. Rutiles are reddish brown and translucent and have a TiO_2 content of 92–98 % (see below).

As there is still no commonly agreed-upon chemical composition of leucoxene, Garnar's definition of a leucoxene containing 68–92 % TiO_2 was adopted in this study. By comparison, Iluka Resources Inc., one of the largest HM producing companies in the world, defines leucoxene as a Ti feedstock with a TiO_2 content of 65–90 %.

Garnar (1985) (cf. Table 2) and Elsner (1992) (cf. Table 2) listed further distinguishing properties of ilmenite, leucoxene and rutile.

Table 3: Differentiation of ilmenite, leucoxene and rutile in industrial use (Elsner 1992).

Mineral	Density	Magnetic susceptibility
Ilmenite	> 4.1 g/cm³	magnetic
Leucoxene	< 4.1 g/cm³	nonmagnetic
Rutile	> 4.1 g/cm³	nonmagnetic

Of the three crystal modifications of natural titanium dioxide (rutile, anatase and brookite), rutile is the most important from an economic perspective.

Pure **rutile** has the following characteristics:

Formula	TiO_2
Chemistry	100 % by mass TiO_2
Density	4.23 g/cm^3
Mohs hardness	6–6½
Colour	brown, foxy red, yellowish, grey beige, bluish, violet black to black-brown
Magnetic property	non-magnetic
Electrostatic property	conductive

Microcrystalline rutile is also the end member of leucoxenization. It is no longer very resistant to the processes of physical weathering and therefore an indicator for in situ weathering under humid tropical conditions.

Brookite is very rare and of no economic significance. Anatase can be created by the transformation of rutile in placers but is also rare in these cases. However, anatase is a common accessory mineral in some Brazilian carbonatiteswhere perovskite has weathered to anatase which is finely intergrown with quartz.

The colour diversity of rutile and anatase is thought to be attributable to different quantities of trace elements built into the crystal lattice. Nb, Ta, V, Cr and Fe can be built into the crystal lattice particularly well, but Meinhold (2010) also lists Al, Zr, Sn, Sb, Hf, Mo, Sc, Y, Mg, Mn, Zn, W, and U as possible trace elements. According to Martin (1985), the colouring of rutiles stands in direct relation to the ratio of the components FeO-Cr_2O_3-Nb_2O_5 whereas the proportions of Mg, Mn, V, Cu etc. do not play a part here. Rutiles particularly rich in Fe are called nigrines.

Nb-bearing rutile (ilmenorutile) and Ta-bearing rutile (struverite) are (end) members of the solid solution series of Nb-Ta-Fe^{2++} bearing rutiles. They are relatively rare in nature and only recovered commercially from “amang” in SE Asia. In the Filipino language, “amang” means a heavy mineral concentrate, which is recovered as a by-product of alluvial tin mining. The chemical composition of Ta-Nb-Fe^{2++} rutile varies widely and was given by Hassan (1994) as 40–77 % TiO_2, 9–17 % Nb_2O_5, 5–26 % Ta_2O_5, 5–13 % FeO, 2–7 % SnO_2, 0.5–1.0 % WO_3, 0.2–2.0 % MnO_2 and 0.0–0.2 % ZrO_2. “Pure” struverite from Malaysia was found to contain 12–13 % Ta_2O_5, 12–13 % Nb_2O_5, 56–57 % TiO_2 and 4–5 % SnO_2 (Krauss et al. 1982b). Nb-Ta-bearing rutiles are used exclusively for the recovery of tantalum, but not titanium.

3 Applications and specifications

3.1 Applications of ilmenite, leucoxene, rutile and HiTi as well as synthetic rutile and titanium slag as intermediate products

The significance of ilmenite, as the most important rock-forming titanium mineral, is not due to the extraction of titanium metal but the production of titanium dioxide TiO_2. TiO_2 is easily the most important white pigment in the world and is used in paints and varnishes, printing inks, plastics, rubber, linoleum, artificial fibres, paper, glass, enamel, and ceramics etc. TZMI estimates that at present approximately 89 % of the natural titanium minerals (ilmenite, leucoxene, rutile) extracted worldwide are used for the production of TiO_2 pigments. With only a few exceptions, the white materials in almost all applications worldwide owe their "colour" to TiO_2 pigments.

There are two industrial processes for the manufacture of TiO_2 pigments.

The older *sulphate process* requires either ilmenite with a TiO_2 content of at least 44 % or a titanium slag (cf. below) with 70–80 % TiO_2 as initial raw materials. However, McCoy et al. (2011) point out that in all processes "often not just one feedstock is used, but a simultaneous blend of up to three very different materials".

The sulphate process for manufacturing titanium dioxide was developed in 1915 and has been applied industrially since 1919. It is still important today in countries such as China, Vietnam, Russia, and Ukraine although it has been replaced by the chloride process in many plants in the western world due to its environmental burden. In the sulphate process, the finely ground and enriched titanium ore is dissolved in concentrated sulphuric acid. The iron oxide contained in the ore reacts to become iron sulphate while the titanium ore becomes titanium oxysulphate.

$$FeTiO_3 + 2H_2SO_4 \rightarrow FeSO_4 + TiOSO_4 + 2H_2O$$

During this process, large quantities of sulphur dioxide are produced which is largely neutralized with caustic soda solution so that nowadays only a relatively small amount of sulphuric dioxide is released into the environment. The iron sulphate is separated from titanium sulphate by crystallization. Due to its superior solubility in water, the iron sulphate crystallizes out as green iron (II) sulphate ("green salt"), which can then be removed. Titanium oxysulphate is broken down into titanium oxide hydrate relatively easily by boiling in large vats of water, which results again in the parallel production of large quantities of "dilute acid" as an undesirable by-product.

$$TiOSO_4 + 2H_2O \rightarrow TiO(OH)_2 + H_2SO_4 \text{ ("dilute acid")}$$

The titanium oxide hydrate is annealed to pure white titanium dioxide in large rotating kilns at temperatures of between 800 and 1000 °C following a lengthy washing process.

$$TiO(OH)_2 \rightarrow TiO_2 + H_2O$$

To improve the optical and physical properties, the fine pigment particles are post-treated using different substances and processes (e.g. renewed washing, grinding or vapour depositing a coating onto the pigment particles).

For each tonne of TiO_2 produced using the sulphate process, approx. 1.7–2.5 tonnes of low-grade ilmenite (45 % TiO_2) and 4.4 tonnes of sulphuric acid, or 1.0–1.4 tonnes of titanium slag (80 % TiO_2) and 2.4 tonnes of sulphuric acid are required. In addition to 4.5 tonnes of iron sulphate ("copperas"), around 6–9 tonnes of dilute acid with a sulphuric acid concentration of up to 23 % by volume are produced. This dilute acid cannot be processed further due to its low sulphuric acid content. The dilute acid is also usually contaminated with heavy metal salts such as lead or chromium salts. Thus, nowadays most manufacturers apply a subsequent process in which the acid content is increased and the metal salts – predominantly the iron sulphate – are crystallized out. However, this subsequent process consumes relatively large amounts of energy. The higher concentrated sulphuric acid produced in this way can then be recycled back into the process. The iron sulphate is used in wastewater treatment as "green salt". It converts phosphate salts in the wastewater from fertilizers and detergents into iron phosphate that is insoluble in water. This can then be extracted from the water using the usual separation methods in sewage treatment plants. The iron oxides produced during TiO_2 production are in part recycled or dumped in landfills (cf. Table 4).

The more recent *chloride process* requires intensely weathered ilmenite of > 58 % TiO_2, leucoxene, natural rutile, synthetic rutile (cf. below) or a titanium slag (cf. below) with > 85 % TiO_2 as the basic raw materials. The demand for high-grade titanium feedstock, i.e. mainly high-grade (chloride-grade) ilmenite has risen in line with the demand for TiO_2 pigments as more and more companies worldwide switch from the sulphate process to the chloride process.

The chloride process was developed in 1959 by E.I. du Pont de Nemours and Company (DuPont) for the use of high-grade titanium minerals from their newly exploited Trail Ridge placer deposit in Florida. In this process, ore rich in TiO_2 is initially mixed with coke and then with chloride gas at approximately 1000 °C in a fluidized bed furnace particularly resistant to chloride. The chloride reacts with the titanium dioxide in the ore and the added carbon to form gaseous titanium tetrachloride, carbon monoxide and carbon dioxide (chlorination) according to the formula:

$$2TiO_2 + 3C + 4Cl_2 \rightarrow 2TiCl_4 + 2CO + CO_2$$

Table 4: Average emmissions in the production of TiO_2 using the sulphate and the chloride process (EU 2007).

Substance	Sulphate process	Chloride process
Liquid substances		
Fe in the wastewater (kg/t TiO_2)	18	2.3
Hg in the wastewater (mg/t TiO_2)	799	8.56
Cd in the wastewater (mg/t TiO_2)	310	57.6
Other metals (Mn, V, Ti, Zn, Cr, Pb, Ni, Cu, As) in the wastewater (kg/t TiO_2)	3	1.334
HCl in the wastewater (kg/t TiO_2)		16
Suspended solids in the wastewater (kg/t TiO_2)	12	5
Chlorides in the wasterwater (kg/t TiO_2)		164
Sulphates in the wastewater (kg/t TiO_2)	274	
Solid substances		
Solids mostly from neutralization (kg/t TiO_2)	5796	397
Gaseous substances		
Dust (kg/t TiO_2)	0.446	0.660
NO_x (kg/t TiO_2)	0.03	1.528
NO_2 (kg/t TiO_2)	0.6	
Cl_2 (kg/t TiO_2)		0.003
CO (kg/t TiO_2)		159
COS (kg/t TiO_2)		2.39
CO_2 (kg/t TiO_2)		923
SO_2 (kg/t TiO_2)	3.97	1.28
HCl (kg/t TiO_2)		0.7037
H_2S (kg/t TiO_2)	0.003	
Acid mist (kg/t TiO_2)	0.65	

Iron (II) chloride produced by chlorination is dissolved in water and separated out. At the same time, hydrochloric acid is produced as a result of the reaction between the chloride with the residual moisture contained in the raw ore and is leached out and can be sold as a raw material. Following this, the gaseous titanium tetrachloride is condensed into a solid substance and this is treated repeatedly by distillation to remove impurities.

After re-condensing, pure titanium tetrachloride is produced that can be supplied to the next processing step. Pure titanium dioxide is produced by heating the titanium tetrachloride to high temperatures and adding pure oxygen:

$$TiCl_4 + O_2 \rightarrow TiO_2 + 2Cl_2$$

In doing so, the titanium tetrachloride oxidizes to form titanium dioxide, and pure chlorine is released again, which is returned to the reaction process.

The major advantage of the chloride process is the fact that no sulphur dioxide and no dilute acid are produced because the chlorine released is recycled back into the chlorination process. The reaction furnace for the chlorination has a lifetime of approximately one year before it needs to be renewed. This work takes several months. The manufacture of one tonne of TiO_2 using the chloride process requires approx. 1.1 – 1.2 tonnes of rutile, 0.1 – 0.2 tonnes of chlorine, 0.3 – 0.4 tonnes of coke and 0.4 – 0.5 tonnes of oxygen (Lynd & Lefond 1983). The process produces approx. 0.9 tonnes of 20 % iron chloride solution as a by-product. When using more low-grade titanium slag, the chlorine requirement increases up to 0.7 – 0.9 tonnes and more iron chloride is also produced. The latter product is used in wastewater treatment, amongst other things.

Currently approx. 43 % of the 6.2 million tonnes of TiO_2 pigment produced worldwide is produced using the chloride process.

Customers in the paints and varnishes, printing inks, and plastics industries prefer TiO_2 pigments produced via the chloride process for technical reasons, while TiO_2 pigments generated via the sulphate process are used more often in the production of paper, ceramics, rubber, chemical fibres, comestibles, and cosmetics.

Low-grade titanium ores can be processed to form titanium slag or synthetic rutile using various processes to increase their primary TiO_2 content in a secondary manner.

Titanium slag can be formed by reducing ilmenite with carbon in an electric furnace at temperatures of between 1650 – 1700 °C. Low-grade ilmenites are the preferred feedstock for smelting because the high iron content provides suitable thermodynamic conditions. *Pig iron* is always generated in large quantities as a valuable by-product. The basic reaction is:

$$FeTiO_3 + C \rightarrow Fe + TiO_2 + CO$$

Due to their differing densities, the slag floats on the iron and mainly consists of unreacted ilmenite, titanium oxides and other impurity oxides. The slag is most often used by pigment manufacturers as feedstock in the sulphate process (sulphate slag > 75 % TiO_2) and chloride process (chloride slag > 85 % TiO_2) although some companies use it in titanium sponge production. The fines produced when crushing chloride slag are called “chloride fines” and can be used as feedstock in the sulphate pigment industry. The final quality of the slag is highly dependent on the quality of the ilmenite as virtually all the impurities, together with any impurities in the reductant report to the slag. Table 5 summarizes the production data from several titanium slag producers, the comparative compositions of the feedstock and the titanium slags extracted from them. Sun et al. (2012) give details on titanium slag production technologies. Van Dyk et al. (1999) compare the chemical compositions of titanium slags with those of synthetic rutiles (cf. below).

Synthetic rutile (SR) serves as one of the possible basic raw materials in the chloride process and is therefore also suitable for metal production using the Kroll process (cf. below). The process for the manufacture of synthetic rutile consists of the complete or partial reduction of the iron bound up in the ilmenite in a rotary reduction kiln at 1050 – 1150 °C and subsequent leaching and separation from the titanium dioxide. One tonne of ilmenite yields approx. 0.6 tonnes of SR. The process is not suitable for low-grade ilmenite because the silicate gangue will remain in the synthetic rutile thus decreasing its tenor in titanium. Numerous special processes have been developed to produce syn-

Table 5: Global production of titanium slag for pigment production.

Country/Location/ Company	Feedstock	Slag properties (average values)	Capacity Production
Canada Allard Lake QIT-Rio Tinto	Ilmenite-hematite-ore (Ø 32.7 % TiO_2, 37.0 Fe_{total})	Sorelslag (Ø 80 % TiO_2, 9.7 % FeO) RTCS slag (Ø 90 % TiO_2) "upgraded slag" (UGS) (Ø 94.5 % TiO_2, 1.5 % Fe_2O_3)	1.25 Mt/year 0.70 Mt (2016)
South Africa Richards Bay RBM-Rio Tinto	Placer ilmenite (Ø 49.7 % TiO_2, 36.6 % FeO, 11.1 % Fe_2O_3)	RBM slag (Ø 85.5 % TiO_2, 10.8 % FeO)	1.05 Mt/year 563,264 (2019)
South Africa Namakwa Tronox	Placer ilmenite (Ø 48 % TiO_2)	Namakwa chloride slag (Ø 86 % TiO_2, 9 % FeO) Namakwa sulphate slag (Ø 82 % TiO_2, 10 % FeO)	190,000 t/year 172,000 t (2019)
South Africa Fairbreeze, Tronox	Placer ilmenite (Ø 47 % TiO_2)	KZN slag (Ø 86 % TiO_2, 12 % FeO)	220,000 t/year 167,000 t (2019)
Norway Tellnes Eramet	Titanium magnetite ore (Ø 44.4 % TiO_2, 34.0 % FeO, 12.5 % Fe_2O_3) Placer ilmenite (Ø 51 % TiO_2)	Tinfos slag (Ø 80 % TiO_2, 9 % Fe)	230,000 t/year 189,000 t (2018)
China 70 – 80 different	Hard-rock ilmenite (Ø 39.6 % TiO_2, 32.3 % FeO, 7.2 % Fe_2O_3) Placer ilmenite (50 – 55 % TiO_2)	up to 92 % TiO_2	> 2 Mt/year 700,000 t (2014)
Saudi-Arabia Jazan City, AMIC-Tronox	Placer ilmenite	Jazan slag (85 – 92 % TiO_2)	500,000 t/year not in production
Iran Kahnuj, IMIDRO-EcoAtom	Placer ilmenite (Ø 52 % TiO_2)	Khanuj slag	70,000 t/year n.a.
India Chhatrapur Saraf Agencies	Placer ilmenite (Ø 50 % TiO_2)	Odisha slag (Ø 85 % TiO_2)	36,000 t/year n.a.
Vietnam Thừa Thiên-Huế Province HUMEXCO	Placer ilmenite (Ø 52 % TiO_2)	HUMEXCO slag (Ø 92 % TiO_2)	10,000 t/year closed since 2017
Vietnam Bình Định Province BIMICO	Placer ilmenite (Ø 51 % TiO_2)	BIMICO slag (Ø 85 % TiO_2)	19,000 t/year closed in 2019
Vietnam Thai Nguyen Province Mountainous Rural	Placer ilmenite	VCK slag	20,000 t/year n.a.
Vietnam Bình Định Province Biotan	Placer ilmenite (Ø 52 % TiO_2)	Biotan slag	12,000 t/year closed in 2019
Vietnam My Thanh Village, SQC	Placer ilmenite (Ø 52 % TiO_2)	SQC slag (Ø 93 % TiO_2)	24,000 t/year closed since 2017
Vietnam Bac Chu Lai, DQCL	Placer ilmenite (Ø 52 % TiO_2)	DQCL slag	25,000 t/year closed in 2019
Vietnam Binh Thuan Province Hai Tinh International	Placer ilmenite	Hai Tinh slag	24,000 t/year n.a.

Table 6: Global production of titanium slag for titanium sponge production.

Country/Location/ Company	Primary feedstock	Slag properties (average values)	Capacity Production
Ukraine Zaporozhye ZTMC	Placer ilmenite (Ø 54–63 % TiO_2)	ZTMC slag (Ø 62 % TiO_2)	120,000 t/year 27,100 t (2015)
Russia Berezniki VSMPO	Placer ilmenite (Ø 54–63 % TiO_2)	n.a.	n.a.
Japan Amagasaki/Wakamatsu Osaka Titanium	Natural and synthetic rutile Placer ilmenite (Ø 55 % TiO_2)	OTC slag (Ø 90 % TiO_2)	n.a.
Japan Chigasaki Toho Titanium	Natural and synthetic rutile Placer ilmenite	n.a.	n.a.

thetic rutile. Most of them even allow the amount of minor contaminants to be reduced (Schmidt et al. 1980, Van Dyk et al. 1999). However, low-impurity ilmenite is still the preferred feedstock as the removal of contaminants, with the exception of iron and manganese, requires costly additional acid-leaching steps. Table 7 summarizes the capacity/production data from several synthetic rutile producers, the comparative compositions of the feedstock and the synthetic rutile extracted.

Table 7: Global production of synthetic rutile for pigment or titanium sponge production.

Country/Location/ Company	Feedstock	Product	Capacity Production
Australia Capel, WA Iluka Resources	Cataby ilmenite (Ø 60 % TiO_2)	Standard SR: 85–88 % TiO_2 Premium SR: 91–93 % TiO_2 Enhanced SR: 94–95 % TiO_2	250,000 t/year 196,200 t (2019)
Australia Chandala, WA Tronox	Cooljarloo ilmenite (Ø 62 % TiO_2)	SR: 89–92 % TiO_2	220,000 t/year 211,000 t (2018)
India Edayar, Kerala Cochin Minerals	Chavara ilmenite (Ø 58 % TiO_2)	SR: 96 % TiO_2	45,000 t/year n.a.
India Sahupuram, Tamil Nadu DCW	Manavalakurichi ilmenite (Ø 55 % TiO_2)	SR: 95 % TiO_2	42,000 t/year n.a.
India Sankarmangalam, Kerala KMML	Kerala ilmenite (Ø 51 % TiO_2)	SR: 92–93 % TiO_2	55,000 t/year n.a.
China Shandong Xingyuan	Mozambique/Australia ilmenite (Ø 53 % TiO_2)	SR: 85–90 % TiO_2	50,000 t/year n.a.
China Guangxi Maoming Ubridge	Ilmenite from imported HMC	n.a.	150,000 t/year n.a.
China Jiaozuo, Henan Lomon Billions	Panzhihua ilmenite (Ø 46 % TiO_2) Ilmenite from imported HMC	n.a.	300,000 t/year n.a.

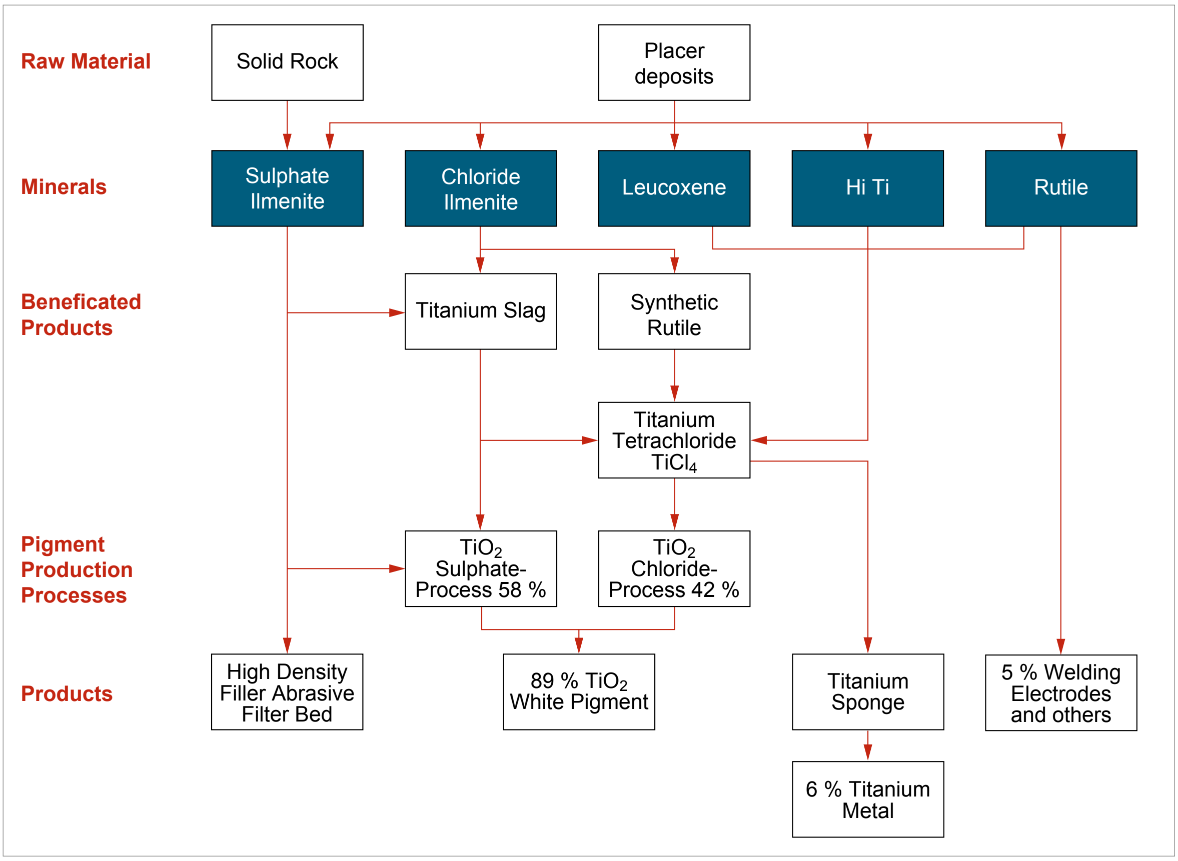


Figure 3: Structural overview of the titanium mineral processing industry from the raw material to the final product. Data in the products category refer to the final uses of titanium minerals.

Figure 3 and Table 8 show the structure of the titanium mineral processing industry and the possibilities for the further processing of different titanium raw materials depending on their TiO_2 content.

Titanium dioxide is the most popular white pigment worldwide. Its advantages are:

– high refractive index of 2.55 or 2.70 for high opacity (covering power),
– high reflectivity causes luminosity and whiteness,
– inertness and chemical stability (insoluble in acids, bases, organic solvents and air pollutants),
– high resistance to UV degradation (colour retention),
– non-toxicity (despite current discussions in the EU to classify TiO_2 as a cancerogenic substance)
– high thermal stability.

TiO_2 pigments are available in two crystalline textures: rutile and anatase. The rutile texture is denser than the anatase texture and therefore has a higher refractive index. Due to its higher chemical stability, the rutile texture is preferred for use in exterior paints, plastics, printing inks and in cosmetics. The anatase texture has a bluish base tone and is less resistant. It is used in interior paints, paper, textiles, rubber products, soaps and medicines. Table 9 compares the physical properties of the two TiO_2 crystalline textures.

Due to its outstanding properties and non-toxicity, TiO_2 has displaced many other formerly common white pigments, e.g. lead oxides.

White pigments must scatter the emitted light as much as possible. The optimum light dispersion capability of TiO_2 pigments is achieved at particle sizes of 0.2–0.3 µm (200–300 nm). The particle size distribution curve must also be as narrow as possible. Pure TiO_2 is a colourless, pure white

Table 8: Use of titanium raw materials as a function of their TiO_2 content. Updated from Harben (2002).

Raw material	TiO_2 (%)	Use
Ilmenite concentrate of ilmenite/magnetite or ilmenite/ hematite rock, e.g. Tellnes/Norway, Allard Lake/Quebec	33–45	Sulphate process or titanium slag
Ilmenite from placers, e.g. India, Vietnam, South Africa and Sri Lanka	47–53	Sulphate process, titanium slag, refractory industry
Ilmenite from placers, e.g. Australia, India and Ukraine	54–63	Sulphate process, synthetic rutile, titanium slag
Weathered ilmenite from placers, e.g. Western Australia and SE USA	> 60	Chloride process, synthetic rutile
Leucoxene, e.g. Western Australia and Florida	> 68	Choride process, welding rods
Titanium slag from Quebec by melting ilmenite/hematite rocks	80	Sulphate process
Titanium slag through melting ilmenite from Richards Bay in South Africa	85	Sulphate and chloride process
Anatase concentrate from carbonatites in Minais Gerais/Brazil	90	Chloride process
Upgraded Slag (UGS) from Quebec through melting and concentrating ilmenite/hematite rocks	95	Chloride process
Synthetic rutile through reduction of iron and chemical leaching of ilmenite from Australia and India	85–96	Chloride process
Natural rutile from placers, e.g. from Australia, Sierra Leone, South Africa, Ukraine, Sri Lanka and India	> 92	Chloride process, welding rods and coatings, titanium metal
HiTi, a mixture of natural rutile and leucoxene, from Australia and Florida	70–95	Chloride process, welding rods and coatings, titanium metal

Table 9: Properties of TiO_2 pigments (Harben 2002).

	Rutile-TiO_2	Anatase-TiO_2
Appearance	Pure white powder	Pure white powder
Apparent density (g/cm^3)	4.2	3.9
Mohs hardness	6–7	5½–6
Refractive index air	2.70	2.55
Refractive index water	2.1	1.9
Refractive index oil	1.85	1.7
Specific heat (kJ/°C kg)	0.7	0.7
Dielectric constant (powder)	114	48
Melting point (°C)	1855	Turns into rutile
Brightening properties (Reynolds)	1650–1900	1200–1300
Relative light scattering ability	800	600

powder with a refractive index that exceeds all other colourless substances (including diamond). It therefore has such a high light dispersion capacity that it can reflect almost all of the light at any wavelength.

The application of TiO_2 pigments in the form of highly concentrated, pourable, pumpable suspensions (*slurries*) which can be metered volumetrically has increased in recent times. These slurries contain up to 75 % TiO_2 and are rheologically designed to prevent the formation of sediments, even after longer periods of storage. They represent a dust-free form of TiO_2 pigment application.

This study focusses on the high-titanium feedstock market, i.e. on titanium feedstock > 68 % TiO_2 and the global pigment market is not discussed in detail here.

Only approx. 6–7 % of the titanium minerals extracted worldwide is used for the production of **titanium metal**. All present-day industrial producers use the Kroll process (Nagesh et al. 2008), which was invented in 1938 but has only been used on a large industrial scale since 1946. Feedstock for this process is titanium tetrachloride previously produced from natural rutile, synthetic rutile or titanium slag using the chloride process. It is based on the principle of the separation of the titanium from titanium tetrachloride by means of magnesium:

$$TiCl_4 + 2Mg \rightarrow Ti + 2MgCl_2$$

The reduction of the TiCl4 is performed using argon to create an inert atmosphere, since titanium as a relatively base metal has a high affinity to atmospheric gases. The process is carried out in a reactor made of steel or chromium-nickel steel. Its interior walls must be brushed clean. Depending on the size of the reactor, 1.5–7 tonnes of titanium sponge is produced in each batch. Magnesium is melted in the reactor at the beginning of the process. $TiCl_4$ is then continually added dropwise over the course of several days or fed from above into the reactor in gaseous form. The magnesium chloride is liquid and sinks to the reactor floor due to its higher apparent density compared to titanium and magnesium. The liquid $MgCl_2$ therefore accumulates below the magnesium melt and can be extracted discontinuously. The titanium sponge, however, precipitates in the reactor and forms a solid crust above the magnesium melt. The magnesium rises through the porous titanium sponge to its surface due to capillary action where it further reacts with the gaseous $TiCl_4$. The addition of TiCl4 is stopped when the magnesium placed in the reactor at the beginning has been consumed. Afterwards, the titanium sponge must be cleaned of magnesium and $MgCl_2$ residues. The production of 1 t of titanium sponge typically consumes 4.4 t of titanium tetrachloride.

Today, this process is usually performed by vacuum distillation. A vacuum bell connected via a vacuum line to a second reactor is set on top of the reduction reactor. A vacuum of around 10^{-3} mbar and a temperature between 900 and 1000 °C is generated in the reduction and distillation reactors. Under these conditions, the impurities (metal chloride, mainly magnesium chloride and titanium tetrachloride and , as well as magnesium) pass into the gaseous state. They are transferred to the second distillation reactor that serves as a condenser where they condense leaving behind the cleansed titanium sponge in the reduction reactor. Condensed magnesium and $MgCl_2$ constitute two separate phases in the condenser and can thus be removed separately.

The titanium sponge cake is removed mechanically from the reactor and crushed into large lumps and then into smaller pieces afterwards. As impurities from minor components differ from piece to piece, all pieces are thoroughly mixed and blended to produce a uniform quality. The minimum titanium content of standard-quality titanium sponge is 98.5 % (or more often 99.2 %), which is used for production of airframes and non-rotating parts of aircraft engines, as well as in non-aerospace industrial applications such as equipment for desalination, nuclear power plants, chemical processing equipment, medical implants, and other products. Premium quality > 99.7 % Ti (CIS: TV-90 Grade, China: Grade #0), which is commonly referred to as “rotor grade,” is used in rotating engine parts in the aerospace industry. In “rotor grade” titanium sponge the levels of Ti, nitrogen, hydrogen, carbon, and heavy metals, especially Cr and Ni, are strictly controlled. As contamination from the stainless steel of the vessel is possible, only sponge from the centre of each sponge batch is used for subsequent “rotor grade” titanium metal production.

Due to its porosity and remaining impurities, the titanium sponge is typically melted down into blocks or ingots. This is usually done in a high vacuum arc furnace with consumable electrodes made from titanium sponge and water-cooled copper crucibles. Since titanium reacts readily with oxygen, nitrogen and carbon, the melting process is performed in a vacuum or inert atmosphere. Induction or arc furnaces with cooled tungsten or carbon electrodes are used to a lesser degree. Titanium scrap can be added during the smelting process which normally takes place in two or even three steps to ensure even quality (Kosemura et al. 2002, Turner et al. 2001). The sole use of scrap as a raw material for the production of titanium metal (ingot) reduces energy consumption and CO_2 emissions by 95 % (Corby 2018).

There are eleven commercially pure (CP) grades of titanium with differing contents of N, C, H, Fe, O, Pd, Ru, Mo, and Ni, respectively. The two most popular CP grades, CP1 and CP2, only differ in their contents of C (0.10 %/0.08 %), Fe (0.20 %/0.30 %), and O (0.18 %/0.25 %) (Roskill 2019). On the other hand the most popular titanium alloy is Ti-6Al-4V with 5.5 – 6.75 % Al and 3.5 – 4.5 % V.

Titanium metal is valued for three main properties:

- Low apparent density (4.507 g/cm³). Volume for volume, titanium is 43 % lighter than steel (7.85 g/cm³) and only 66 % heavier than aluminum (2.70 g/cm³). This means that a 1 m² steel sheet metal has the same weight as a 1.75 m² titanium sheet metal of the same thickness.
- Titanium and its alloys have close to the same strength properties as steel at room temperatures and therefore generally higher strengths than light alloys. During continuous stress at elevated temperatures of up to around 500 °C, the relationship between strength and apparent density is particularly advantageous.
- The corrosion resistance of titanium – particularly in oxidizing and chloride-ion containing media – enables it to be applied in different economic areas

Other outstanding properties are:

- high melting point: 1668 °C
- good thermal conductivity: 21.9 W/m · K
- small coefficient of expansion: 8.36 [10^{-6} K^{-1}]
- high electrical resistivity: 54 µΩ · cm
- non-toxicity and non-irritation of human skin (biocompatibility)
- forgeability, formability, castability, machinability and joinability.

These properties make titanium metal and its numerous alloys (with Fe, Nb, Mo, Sn, V, Al, Zr, Mn, Ni, Cr, Cu, Si, Y, Ru, Pd) suitable for use in the following areas:

- Aircraft engineering: landing gear support beams, engine supports, fuselage, engine blades, rotor blades, compressor disks, spacers, suspensions, bolts, exterior skin, exterior skin jacking points, spars, spar frames, wing spar box, undercarriage components
- Helicopter engineering: gearbox, boom, rotor hub, tail rotor driveshaft, fasteners, exterior skin and floor pan components, rotor leading edge
- Spacecraft: helium and nitrogen tanks, hydrogen tanks, jet components, rings, bracers in the propulsion area, spars, spar frames
- Drive systems: connecting rods, valves, butterfly valves, rocker arms, water jet propulsion systems, maglevs, batteries, fuel cell separators
- Chemical and industrial plant engineering: pumps and valves and fittings, chemical and seawater pipes, bleach tanks in paper mills, hydrogen tanks, anodes in chlorine, chlorate and hypochloride production, catalysts, nuclear fuel canisters, plate heat exchangers
- Ocean civil engineering: ocean platforms, ship hulls, bridges, rigs
- Building: roofs, air conditioning systems, curtain-walls
- Defence: submarine cladding, weapons systems
- Means of transport: bikes, motorcycles, engine parts
- IT & electronics: semiconductor-grade sputtering targets, supercomputers, cryo-electronics, superconductor systems
- Casting and molding: rotors, suction covers, housing components for plate valves and y-valves, ball valves, valve plates

- Jewelry, watches and cameras: wrist watches, rings, combs, eyeglasses, body piercing jewelry, cameras
- Sports: golf clubs, tennis rackets, baseball bats, racing bike frames, billiard cues
- Medicine: prostheses, surgical implants and devices, dental technology, pacemaker covers, wheelchairs

Titanium outperforms all other architectural metals as a building material and is gaining rapid acceptance among designers. Due to its mechanical and physical properties, corrosion resistance to all modern pollutants and attractive appearance, it is used for exterior cladding, roofs, fascia, canopies and many other building purposes. Because it is totally immune to corrosion in all environments, including marine and industrial, titanium is the ultimate choice when lifecycle and maintenance costs are considered. Commercially pure (CP) titanium, ASTM Grades 1 or 2, are most often specified for architectural applications.

In the automotive industry, factors such as fuel economy, emissions legislation and longer warranties are compelling engineers to consider titanium as a “value engineering” solution. Evaluations in commercial engines have demonstrated that titanium valve trains can improve fuel efficiency by 4 % and they are being evaluated in several engines. Suspension springs, engine springs, exhaust systems and brake pads are also all being investigated. Effort is also being made in the sports car and motorcycle markets where titanium is used for mufflers, fuel tanks and engine parts, i.e. valves, valve springs, rocker arms, retainers, bodies, connecting rods and frames. In electric car production, a titanium underbody is used in the Tesla Model S and graphite-coated titanium coils are used for separators in hydrogen fuel cell vehicles (FCV) in the Toyota Mirai.

Titanium metal powder is used in pyrotechnics and serves as the initiator for the inflation of airbags. It is an alloying agent in the manufacture of magnets and a deoxidizer. In recent years titanium metal powder, in the form of pure Ti metal or Ti alloys, e.g. TiAl alloy, has increasingly been used in additive manufacturing (3D-printing, above all of medical devices, automotive and aerospace parts). Additive manufacturing requires spherical metal particles with 15–100 µm diameter, which also need to be ultraclean. This requires special production equipment and atmospheres (Busch 2018). Current global demand for Ti metal powder is estimated at 500–700 t and is anticipated to grow to 2500 t by 2025. Thus, despite projected strong growth, Ti metal powder will nevertheless remain a niche market compared to other Ti metal applications (cf. Chapter 7). Roskill (2019) estimates current global titanium metal powder capacity at 15,200 tpa, meaning production capacities are already more than sufficient.

Other areas of application for titanium and titanium dioxide are:

Fillers:
Ultra fine (20–40 µm) TiO_2 particles should still be viewed as relatively coarse. They are not effective in dispersing light and are highly transparent in various media (metallic paints, cosmetics). Special paint effects can be achieved when mixed with aluminum flakes.

Nanotechnology:
Ultra fine TiO_2 (1–50 nm) generates high UV protection in sunscreens, clear wood varnishes and plastic films due to its ability to effectively absorb and disperse UV light. Deposited on glass with a thickness of approx. 15 nm, ultra fine TiO_2 gives the glass self-cleaning properties. Further areas of application are emerging in the areas of electro-ceramics, dye-sensitized solar cells (DSSC), arsenic removal in water treatment, cancer therapies, noise absorption and photocatalysis.

Batteries:
Titanium has been used as an insulator in alkaline batteries for a long time. Recently, it has been used in rechargeable Mn-Ti-Li batteries that use an Li-Mn complex oxide cathode and an Li-Ti oxide anode (e.g. Energizer®). The Li-Ti oxide and cell structure improve electron flow and lead to increased miniaturization, superior charging properties and excellent voltage and overload resistance characteristics.

Chemistry:
TiO_2 is the raw material for various titanium chemicals such as:

– Titanium iodide, TiJ_4, a black-green crystalline powder that is used as a catalyst in the stereo-specific polymerization of butadiene.

- Barium titanate, $BaTiO_3$, a light grey powder with ferro-electric properties and a high dielectric constant, semi-conducting and piezo-electric properties used for special electro-ceramic purposes. Barium titanate works by generating an electric voltage field dependent on the pressure of the substrate. Conversely, the material also changes its form as a function of the electric field acting upon it. Applications in high technology include underwater sonar, guided missiles, sonar mines, ultrasound cleaning, measuring equipment, sound reproduction, filters and ultrasound therapy.
- Strontium titanate, $SrTiO_3$, crystallizes in the cubic perovskite structure (special ceramic material, electronic and electric insulators), can then be cut (microwave utilization, super and semi-conductor substrates, thin films) and polished (synthetic gemstones, optical and piezoelectric applications).
- Titanium tetrachloride, $TiCl_4$, a liquid which is only colourless after distillation, and that fumes strongly upon contact with moist air. This intermediate product of titanium metal, TiO_2 and organic titanium production, changes the structure of aluminum alloys, special glazes for glasses and ceramic products, feedstock for pharmaceuticals.
- Alkyl and butyl titanate, colourless to yellow liquids. Their areas of application are: Catalyzation (polymerization of polyethylene, polypropylene, polybutadiene; esterization of plasticizers and different esters, transesterization of polyesters for fibers, films, casting resins and paint binders); binders between different casting resins; surface modification (leaving a TiO_2 film when heated) to improve surface hardness, adhesion, off-colour effects, iridization, heat and light reflection and/or corrosion resistance (plastics, oils, greases, paint, printing paper, glass treatment, metal treatment, pigmented coatings); adhesion promotion (printing inks, coatings, laminates, demolding enhancers, wire coatings, sealants) and direct use (in sunscreen gels, catalysts, special glass, greases and metal titanate coatings).
- Titanium oxide chloride, $TiOCl_2$, a pearlescent pigment frequently used for coatings, cosmetics and sanitary products, packaging, plastics and printing inks. It is also used in metal treatment and as a feedstock for the manufacturing of barium titanate and inorganic titanates.
- Titanium oxide sulphate, $TiOSO_4$, a colourless to light yellow liquid (barium titanate production, manufacture of polymerization catalysts, pearlescent pigment production for cosmetics)
- Potassium titanate, $K_2O(TiO_2)_{n\ n=4\text{-}7}$, occurs as needles, bars or powder with low thermal conductivity. It is highly reflective between the ultra red and infrared spectrum and possesses good friction properties (high quality welding bars, car brakes, special paints, heat insulation materials). In the modification as extremely fine individual fibres or strings with 0.3–0.6 nm diameter and 10–20 mm length (1/1000 the size of a typical glass fibre), potassium titanate has great strength and form stability, stiffness, abrasion and corrosion resistance, as well as good packing, lubricating and machining properties (reinforcement of special plastics, friction materials in cars and precision filters).
- Titanium disulfide, TiS_2, a black, crystalline solid (Li-TiS_2 batteries), is a substitute for graphite as an anode material with LiCoO as the anode and a suitable low-temperature electrolyte in rechargeable electro-chemical lithium-ion cells that can operate at temperatures <20 °C.
- Titanium hydride, TiH_2, a grey powder that explodes on contact with oxygen. Areas of application: pyrotechnics, manufacture of vacuum tubes, bronzing aids when applying ceramics on metals, titanium feedstock for alloys, reservoir for high purity hydrogen (450 l H_2 in 1 kg TiH_2 powder); foaming agent for expanding aluminum, feedstock for the manufacture of titanium carbide and titanium nitride.
- Titanium carbide, TiC, a hard (Mohs: 9), dense refractory with high thermal shock and abrasion resistance and low friction resistance. Used in powder metallurgy in fittings, cutting tool end fittings, wear parts and high strength coatings; additives for plastic or rubber replacement parts instead of metals; in mixed crystals such as (Ti,W)C, (Ti,Ta,W)C, (Ti,Ta,Nb,W)C for hard metals.
- Titanium nitride, TiN, a yellow brown crystalline solid with a melting point of 2950 °C and Vickers hardness of 2100. Used in crucibles for melting lanthanum alloys, for coatings on cemented carbides and golden yellow colouration on jewelry.

Natural **rutile** is the highest-quality titanium mineral and is used in three major areas:

- The manufacture of TiO_2 white pigments but only using the chloride process (cf. above) with a market share of about 60–65 %. Using rutile instead of ilmenite reduces the demand for ore by 30 %, the demand for chlorine by 85 % and generates 80 % less waste per tonne of pigment (Blackwell 2019).
- The manufacture of titanium metal, similar to ilmenite and leucoxene (cf. above), with a market share of about 10–15 %
- Sheathing of stick welding electrodes for stabilizing the electric arc, for the prevention of oxidation of the slag, for the reduction of the melting viscosity and for the reduction of the surface tension of the metal drops on the electrodes. Similarly, flux-cored wire electrodes and flux powder for arc welding are used for the same purposes. These welding applications are estimated to have a market share of about 25 %. However, in some years this share may be larger, as e.g. in 2013 Iluka Resources estimated the market share of rutile and HiTi for welding to be 33 % (Gibney 2015).

Figure 4: Pharmaceutical glass FIOLAX® amber is coated with TiO_2 produced from natural rutile, photo: Schott AG.

Minor amounts of natural rutile are also used as a lower-cost substitute for Rutilit®, a protective TiO_2-based coating for damaged parts of blast furnaces, in the production of special glasses for pharmaceuticals (as colouring agent and for UV-blocking), for staining of pottery and in glazes (as colouring agent and as opacifier).

Rutilit® is a powder containing some 30 % TiO_2 and 40 % Fe_2O_3 and is generated as a by-product in the production of TiO_2 pigment via the sulphate process. It is injected (2.5 kg per tonne of hot metal) directly in the blast furnace where the molten iron together with carbon and nitrogen reacts with the titanium forming titanium nitrides and titanium carbonitrides. These high temperature resistant compounds clad the inner refractory lining of the blast furnace preventing further destruction of the damaged parts.

The most typical application of natural rutile, apart from the production of TiO_2 pigments and titanium metal, is as a major ingredient in the flux of stick electrodes, in the flux of flux- cored wire electrodes and in the flux of welding powders.

According to The Welding Institute (TWI Ltd.) all stick electrodes consist of a core wire (typically 2.5–6 mm diameter) coated with a flux. The core wire is generally made of low-quality low-carbon (< 0.1 % C) rimming steel with 0.5–0.9 % Si and up to 0.15 % Al added to provide de-oxidation. Alloying elements such as Mn, Cr, Ni and Mo are added to the ingot to provide improved mechanical properties and corrosion resistance. In addition, the steel wires are often copper coated both to reduce corrosion during storage and to improve welding current pick-up in the contact tip. In general, the solid wires are formulated to match the composition of the alloy to be welded.

The composition of the flux sheathing the core wire decisively impacts on the electrodes' behaviour:

- The flux must be capable of providing a protective shield to prevent the atmospheric contamination of the electrode tip, the filler metal, as it is transferred across the arc and the molten weld pool. It generally does this by decomposing in the heat of the arc to form a protective gaseous shield.
- It must be capable of removing any oxide film (failure to do so will result in lack of fusion

defects and oxide entrapment). It does this by reacting chemically with the oxide.
- It should improve mechanical properties by providing clean, high quality weld metal and by transferring alloying elements across the arc.
- It must be capable of providing the desired weld metal composition, again, by transferring alloying elements across the arc.
- It should aid arc striking and arc stability.
- It should produce a slag that will shape the molten pool and hold the pool in place during positional welding if required.
- Any slag should be readily removable and preferably self-detaching.
- It should not produce large amounts of fumes and any that it does should not be harmful to the welder.

Most flux-coated manual metal arc (MMA) electrodes can be conveniently divided into three main groups according to their coating composition. These three main groups are cellulosic (C), rutile (R) and basic (B) coatings. The subgroups are thick rutile (RR), rutile basic (RB), and rutile cellulose (RC), all of which have very specific welding properties making them suitable for specific welding tasks:

Cellulosic (C) electrodes contain a large proportion of cellulose (25 – 40 %) generally in the form of wood flour. This is mixed with rutile (0 – 5 %), manganese oxide (0 – 10 %) and ferro-manganese and bonded onto the core wire with sodium or potassium silicate. The moisture content of these electrodes is quite high, typically 4 – 5 %. The cellulose burns in the arc to form a gas shield of CO, CO_2 and, in conjunction with the moisture in the coating, produces a large amount of H_2, typically 30 – 45 ml hydrogen/100 g weld metal.

The high hydrogen level means that any steel welded with these electrodes should be selected for very high resistance to hydrogen-induced cold cracking. They should not be used without considering the steel composition, restraint and preheating requirement. The characteristics of deep penetration, high deposition rates and the ability to be used vertically downwards means that the main use of these electrodes is for cross-country pipelining although they are also used to a more limited extent for welding storage tanks.

Rutile (R) coatings, as the name suggests, contain a large amount of rutile, typically 30 – 50 %, in addition to cellulose (up to 10 %), calcium carbonate (15 – 25 %), silica (5 – 15 %), mica (0 – 25 %), ferromanganese (0 – 5 %) and some moisture (approx. 1 – 2 %). The binders are either sodium or potassium silicate. The cellulose and the calcium carbonate decompose in the arc to form a gas shield containing H_2 (around 20 ml/100 g weld metal), CO and CO_2. The electrodes have medium penetration characteristics, a soft, quiet but stable arc and very little spatter, making them a ‘welder friendly’ electrode. Striking and re-striking is easy making rutile-coated electrodes preferable for welding short joints. The electrodes produce a dense covering of slag that is easily removed and gives a smooth evenly rippled weld profile.

The presence of cellulose and moisture means that the electrodes produce relatively high levels of H_2, perhaps 20 to 25 ml/100 g weld metal. This restricts their use to mild steels of less than 25 mm thickness and thin section low-alloy steels of the C/Mo and 1Cr 1/2Mo type. They are probably the most widely used general purpose electrode. Rutile coated austenitic stainless steel electrodes can be obtained and used in all thicknesses as cold cracking is not a problem with these alloys.

The term basic’ (B) originates from the chemical composition of the flux coating which contains up to perhaps 50 % calcium carbonate. This decomposes in the arc to form a gas shield of CO/CO_2. In addition to the calcium carbonate, there may be up to 40 % calcium fluoride added to lower the melting point of the carbonate and to reduce its oxidising effect. Deoxidants such as ferrosilicon (5 – 10 %), ferromanganese and ferrotitanium are also added to provide de-oxidation of the weld pool. Other alloying elements such as ferrochromium, ferromolybdenum or ferronickel may be added to provide an alloy steel deposit. The binders may be sodium silicate or potassium silicate.

The penetration characteristics of basic electrodes are similar to those of rutile electrodes although the surface finish is not as good. The slag cover is heavier than rutile electrodes but is easily controlled, enabling the electrodes to be used in all positions. High calcium carbonate coatings have been developed that enable a limited range of electrodes to be used in the vertical-down (PG) position. The weld pool blends smoothly into the parent metal and undercutting is unlikely to occur.

The slag is not as easily removed as with rutile or cellulosic electrodes, but the low melting point means that slag entrapment is less likely. The chemical action of the basic slag also provides very clean, high quality weld metal with mechanical properties, particularly notch toughness, better than that provided by the other electrode types. A further feature of these electrodes is that the welds are more resistant to solidification cracking and tolerate higher levels of sulphur than a rutile or cellulosic electrode. This makes them valuable if it is necessary to weld free cutting steels.

The basic electrode is also known as a low hydrogen rod ('lo-hi''). The coating contains no cellulose and little or no moisture provided the electrodes are correctly handled. However, when exposed to the atmosphere, moisture pick-up can be rapid.

Basic, low hydrogen electrodes are widely used in a variety of applications where clean weld metal and good mechanical properties are required. They can be obtained with alloyed core wires and/or adding ferro-alloys to the coating to provide a very wide selection of weld metal compositions, ranging from conventional carbon steels, creep resistant and cryogenic steels to duplex and stainless steels. Where high quality, radiographically or ultrasonically clean weld metal is required, e.g. for offshore structures and pressure vessels, basic electrodes are used. The low hydrogen capabilities also mean that basic electrodes can be used for welding thick section carbon steels and high strength, high carbon and low alloy steels where cold cracking is a risk.

The basic components in the preparation of coatings for stick welding electrodes and flux powders is listed below in decreasing order of total share (Feytis 2012).

- sodium water glass (also potassium and potassium-lithium water glass)
- bauxite
- magnesium oxide
- magnesium carbonate
- calcium fluoride
- manganese oxide
- rutile sand or finely ground rutile flour
- ferromanganese
- calcium carbonate
- ferrosilicon
- cellulose (wood flour)
- feldspar
- and possibly many others, e.g. mica, quartz, calcium magnesium carbonate, aluminite, cryolite, kaolin, bentonite, wollastonite, ilmenite, iron powder, calcium silicon, talcum, barium carbonate, chromite, diatomaceous earth, diopside, graphite, siderite, iron silicate, lepidolite, lithium chloride, lithium fluoride, magnetite, nepheline syenite, pyrophyllite, zircon (Griffiths 1985) and a variety of other alloys like ferrotitanium, ferrochromium, ferromolybdenum and ferronickel

The substances are weighed accurately and mixed in a dry mixer to achieve a homogeneous blend. Sodium or potassium silicate are added in a correct proportion to bind the wet mix. The wet mix is then pressed to form briquettes in a hydraulically operated press in order to load the flux in the flux cylinder of an extruder.

An extrusion press adds a flux coating by feeding it through a cylinder under pressure. The briquettes are introduced into the extrusion cylinder of the press while the wire is fed from the wire magazine of the electrode press. During extrusion, the core wires are fed one by one from the wire feeder and coated with the flux using a nozzle/die box system incorporated in the extrusion press. The electrodes protruding from the press are tested in an eccentricity tester. The flux is stripped from the rejected electrodes in a flux stripping machine in order that the core wire and the flux can be re-used.

The electrode protruding from the press passes through a conveyor to the brushing machine so that the holding end can be brushed and cleaned for easy striking. Following this, the electrodes are spread on a collecting tray to air dry and after a certain period they are fed into an oven for final drying and moisture reduction which should not exceed 4 %.

Flux-cored wire electrodes are filled with a flux, instead of a flux sheathing the wire. They allow for a high deposition rate, work well outdoors and in windy conditions and create clean, strong welds. Thus, they are widely used in construction because of enabling high welding speed and portability of the welding equipment.

Welding powders are preferentially used for the automatic arc welding of larger components with thicker sheets. Again, the purpose of the powder is the prevention of oxidation of the slag, and the incorporation of hydrogen from the air. The slag prevents the welded joint from cooling too rapidly and thus from possible cracking.

HiTi (= High-Titanium) is a man-made mixture of natural rutile and leucoxene of various compositions. Currently, it is only produced and sold by some Australian heavy mineral mining companies that mine deposits of rutile and leucoxene of grades too low for the separate extraction of rutile and/or leucoxene concentrates. Tests for producing and marketing a HiTi concentrate are also taking place in the US. HiTi may contain anything between 70 and 95 % TiO_2 and is used for the same applications as natural rutile.

3.2 Physical and chemical requirements for leucoxene, rutile, and HiTi

For **titanium slag** manufacture**,** the TiO_2 minimum content in the raw material is 35 %. Because the smelting processes remove little, if any, of the minor impurities in the feedstock, there are the same constraints on the nature of the ilmenite/leucoxene used as primary feedstock as on titanium mineral concentrates used in the sulphate or chloride process directly (Taylor et al. 1998). According to Murphy & Frick (2006), about 20 % of the V_2O_5 and of the Cr_2O_3, 40 % of the SiO_2 and 80 % of the MnO, and all other impurities in their entirety report to the slag. Additionally, a low Cr_2O_3 value of the feedstock is also relevant for the coproduct pig iron.

Regarding impurities, feedstock for TiO_2 pigment manufacture based on the **sulphate process** should have (Harben 2002):

- low Cr, V and Nb contents (act as colour pigments and form toxic waste materials),
- low Ca and P contents (impede optimum crystallization),
- low U, Th and Ra contents (< 500 ppm U+Th).

McCoy et al. (2011) also mention Cu, Ni, and Mn as critical impurities in the sulphate process.

Feedstock for TiO_2 pigment manufacture using the **chloride process** has the following impurity constraints (Harben 2002):

- 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),
- < 0.5 % Cr_2O_3 and V_2O_5 (colour 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_2 (coats grains and impedes the reaction),
- low U, Th and Ra contents of < 500 ppm in total.

McCoy et al. (2011) name particle size distribution, surface area and particle density as important physical characteristics to chloride pigment producers. Typical maximum elutriation sizes of feedstock for commercial fluid bed chlorination are 90 µm for rutile, 100 µm for chloride slag and 115 µm for synthetic rutile. Critical elements to be observed in the chloride process are Fe, Zr, Sb, Nb, Al, As, V, Mn, Si, Ca (< 0.15 % CaO), Mg (1 – 2 % MgO), P, S and U + Th (<< 500 ppm).

Table 10: Relevant impurities in feedstock for the production of TiO_2 pigments, according to Grosz (1987). Critical impurities are shown in bold typeface.

Oxides	Sulphate process (%)	Chloride process (%)
Al_2O_3	0.2–1.2	**0.1–0.6**
Cr_2O_3	**0.01–0.1**	0.1–0.2
V_2O_5	**0.01–0.15**	**0.01–0.3**
Nb_2O_5	**0.04–0.2**	unimportant
P_2O_5	**0.01–0.2**	0.01–0.1
SiO_2	**0.1–0.5**	**0.1–0.5**
MnO	**0.1–3.0**	**0.1–1.0**
CaO	0.01–1.0	**0.01–0.02**
MgO	0.01–?	**0.01–0.04**
ThO_2	< 200 ppm	< 200 ppm
U_3O_8	< 10 ppm	< 10 ppm

Grosz (1987) compiles the chemical specifications for the raw materials required for the manufacture of TiO_2 pigments with the impurities listed in Table 10.

Venkatasubramanian (1994) also lists maximum acceptable impurity levels for titanium mineral feedstock suitable for chlorination:

- 1.0 % for MnO, Al_2O_3, and SiO_2
- 0.5 % for ZrO_2, V_2O_5, Cr_2O_3, Nb_2O_5, P_2O_5, and MgO
- 0.2 % for CaO

Van Dyk et al. (1999) reviews the requirements for rutile substitute materials acceptable as feedstock in the chloride process:

- > 95 % TiO_2 and as little Ca and Mg as possible as these elements form high boiling chlorides which disrupt the operation of the fluidized bed chlorinator
- The particle size should be suitable for fluidized bed chlorination
- Low Fe content to minimize iron chloride disposal problems and chloride consumption
- Minimal Cr and V which affect the toxicity of the iron chloride waste
- Low SiO_2 which could coat titanium minerals grains and so prevent their reaction with chlorine
- Low Sn and As which are difficult to separate in the purification steps and accumulate in the purified titanium tetrachloride
- Minimal U and Th due to their undesirable radioactivity

To be suitable as a raw material in the chloride process, the crushed and ground slag must have a particle size of 50–100 µm. A controlled and narrow particle size spectrum is advantageous because this avoids blow-over effects during chlorination in the reactor and dust loss. Pistorius (2007) provides the chemical requirements for titanium slag in chloride TiO_2 production.

The tin content should be low (< 0.03–0.05 % SnO_2) for the final production of titanium metal as tin makes the metal more brittle.

According to Venkatasubramanian (1994), synthetic rutiles in comparison to natural rutile are measured against the following properties important for their utilization in the chloride process:

- Composition: Natural rutile has the highest TiO_2 content and the lowest levels of impurities.
- Hardness: Insufficient hardness leads to dust losses during chlorination. Natural rutile does not develop dust whereas synthetic rutiles produced by acid solution do.
- Bulk density: Low density leads to elutriation and therefore to dust losses during chlorination. The apparent density of synthetic rutiles produced by the acid solution is only 1.3 g/cm^3.
- Particle size: Particle sizes of the raw material < 50 µm lead to dust losses during chlorination.
- Particle size distribution: A wide particle size band negatively affects the control of the reaction processes.
- Surface area and porosity: High surface area and porosity facilitate chemical reactions. These are very small in natural rutile, but very large in synthetic rutile manufactured by acid solution.

For the reasons above, industry always prefers natural to synthetic rutile or titanium slag as the raw material in the chloride process despite its high price.

According to Hatch (2017) the typical market specifications for "premium grade" rutile are

- > 95 % TiO_2
- < 2.5 % SiO_2
- < 1.5 % Al_2O_3
- < 1.0 % ZrO_2
- < 1.0 % Fe_2O_3
- < 1.0 % MgO
- < 1.0 % MnO
- < 0.8 % CaO
- < 0.65 % V_2O_5
- < 0.25–0.5 % Nb_2O_5
- < 0.03 % S (welding rod specification)
- < 0.03 % P (welding rod specification)
- < 0.05 % SnO_2 (titanium metal specification)
- > 120 D_{50} (µm)

Rutiles used in welding electrodes must meet the following specifications according to Griffiths (1985) and Murphy & Frick (2006):

- ≥ 95 % TiO_2 (exceptions possible)
- ≤ 1 % ZrO_2
- ≤ 1 % Fe_2O_3
- low P and S
- as few other heavy minerals in the rutile concentrate as possible
- narrow particle size band without oversized particles
- consistent quality (particle size distribution and chemical composition).

However, according to some European producers, specifications for rutile in premium welding electrodes are even stricter:

- 94–98 % TiO_2
- ≤ 1.0 % ZrO_2
- ≤ 1.0 % Fe_2O_3
- ≤ 1.0 % Al_2O_3
- ≤ 0.09 % C
- ≤ 0.02 % P
- ≤ 0.02 % S
- ≤ 0.3 % moisture
- < 0.12 % H_2O at 350 °C
- < 0.095 % H_2O at 1025 °C
- ≤ 0.54 Bq/g (≤ 45 ppm Th, ≤ 25 ppm U)
- dark brown colour, ground: dark beige colour

While a minimum TiO_2 content of 95 % in rutile for general welding purposes is accepted in Europe and the US, the cost is more important than quality (Feytis 2012) for welding companies in the emerging BRIC (Brazil, Russia, India, China) countries and they are willing to accept rutile at 92 % TiO_2 and even HiTi at 90 % TiO_2. Some major welding companies in Japan and the US also use a blend of rutile and leucoxene for welding while others try to avoid leucoxene because of possible variations in its composition (Murphy & Frick 2006).

Leucoxene must contain sulphur and phosphor < 0.03–0.05 % to be considered a substitute for rutile. Narrow particle size range, constant chemical composition for each supply and a high TiO_2 content > 92 % also play an important role.

Until 1996 the Defense National Stockpile Center (DNSC) of the US Defense Logistics Agency also stockpiled natural rutile for intended use in the production of titanium metal, welding rod coatings and ferro-titanium (NMAB 1972). The chemical requirements for this rutile were:

- ≥ 95.00 % TiO_2
- ≤ 1.25 % SiO_2
- ≤ 1.00 % ZrO_2
- ≤ 0.75 % Al_2O_3
- ≤ 1.00 % Fe_2O_3
- ≤ 0.75 % Cr_2O_3
- ≤ 0.75 % V_2O_5
- < 0.05 % P_2O_5
- ≤ 0.25 % MgO+CaO
- ≤ 0.75 % Mn
- ≤ 0.03 % S
- ≤ 0.10 % Sn

The specifications for rutile for pharmaceutical glass production are as follows:

- ≥ 94.0 % TiO_2
- < 2.5 % SiO_2
- < 1.2 % ZrO_2
- < 1.0 % Fe_2O_3
- ≤ 0.30 % V_2O_5
- ≤ 0.10 % Cr_2O_3
- < 0.10 % Sn as SnO_2
- ≤ 0,01 % MnO
- ≤ 0.01 % As as As_2O_3
- Cu, Co, Ni, Sb, Th, U as low as possible
- < 0.15 % Moisture

In China there are official standards for natural ilmenite concentrates (standard YB 835-879) and natural rutile concentrates (standard YB 839-87, cf. Table 11). Although these rutile standards are in effect, in reality commercial rutile concentrates are traded at 87 % min. TiO_2, at 90 % min. TiO_2, at 92 % min. TiO_2, and at 95 % min. TiO_2.

Table 11: Chinese standard YB 839-87 for natural rutile concentrates (Wen Lu 1998).

	Grade (%)			
	1	2	3	4
TiO_2	> 93.0	> 90.0	> 87.0	> 85.0
Fe_2O_3	< 0.5	< 0.8	< 1.0	< 1.2
P	< 0.02	< 0.03	< 0.04	< 0.05
S	< 0.02	< 0.04	< 0.04	< 0.05

Unlike industrialized Western countries, Chinese standards prescribe minimum and maximum contents for different rutile grades which the customer then chooses according to the intended use.

4 Demand

The German Mineral Resources Agency (DERA) has no history or intention of establishing its own data on the worldwide demand for any mineral commodity – including rutile and leucoxene.

4.1 Sources of HiTi feedstock demand data

Since 2016 Roskill Information Services Ltd., UK has ceased publishing studies on titanium minerals leaving TZ Minerals International Pty Ltd. (TZMI), Australia as the main consultant to publish reports on both titanium feedstock supply and demand. TZMI, however, was not willing to sell any of its recent reports to BGR/DERA and did not grant permission to use any of its proprietary data for reproduction.

TZMI's data are nevertheless well known in the titanium industry and TZMI's graphs are reproduced and discussed widely in investor presentations and reports by industry participants. BGR/DERA was therefore able to use past and projected numerical demand data sets from these graphs to create its own figures. The graphs contain data on global TiO_2 and chloride TiO_2 demand (i.e. demand for chloride-grade ilmenite, natural rutile, leucoxene, HiTi, synthetic rutile, chloride titanium slag and upgraded titanium slag) as well as global rutile TiO_2 demand.

In addition, demand figures independent of TZMI were taken from various presentations by three major titanium feedstock producing companies, Iluka Resources Ltd., Kenmare Resources plc. and Base Resources Ltd. all of which are available for free download from the websites of these companies.

4.2 Historic HiTi feedstock demand

Historic demand data on titanium feedstock (which are always given in tonnes of TiO_2 content) published by TZMI and by the three HM mining com-

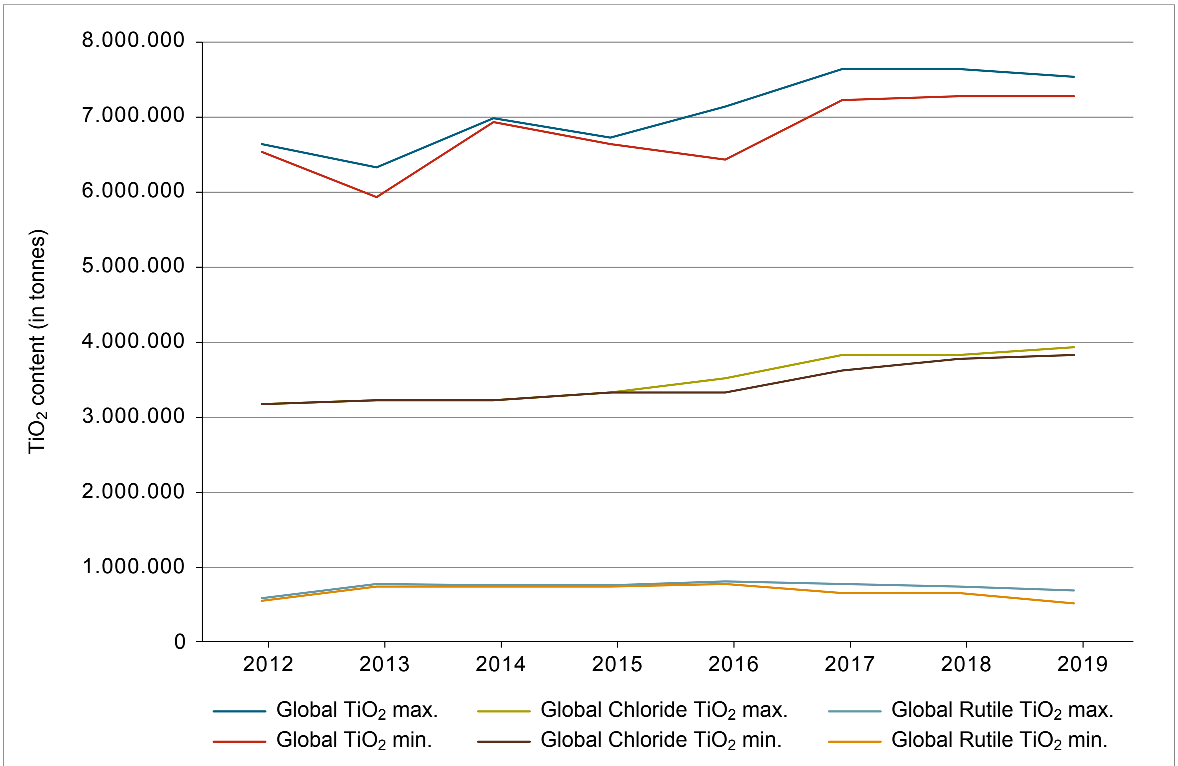


Figure 5: Opinions on historic global demand for titanium feedstock, chloride titanium feedstock and rutile feedstock (TiO_2 content in tonnes) according to Iluka Resources, Base Resources, Kenmare Resources, McCoy (2018, 2019), Perks (2019), Nordic Mining ASA (2020), and TZMI (cited by various HM exploration companies).

panies mentioned above are similar although they do deviate. Even though Iluka Resources and TZMI regularly exchange data, there is a difference of opinion on past global titanium feedstock demand of more than 500,000 tonnes (in 2016). The major industry player Base Resources Ltd. assumes higher global demand figures for chloride TiO_2 (+200,000 tonnes) than TZMI and Iluka. An analysis of past global rutile demand reveals differences in the estimation of demand to be smaller but still existent (up to 75,000 tonnes).

The most recent detailed and publicly available information on historic rutile demand were published by Hatch (2017), Perks (2019), and Nordic Mining ASA (2020). For the 12 years between 2005 and 2016, Hatch gave a compound annual growth rate (CAGR) of rutile demand of 6.9 % of which in 2016, 73 % was used for pigment production, 20 % for welding rod production and 7 % for titanium metal production. Total rutile demand in 2016 was suggested to have been about 800,000 tonnes TiO_2 content which equals about 890,000 tonnes of rutile sand. Perks (2019) assumed global rutile demand to have decreased to about 650,000 tonnes TiO_2 con-tent by 2018, which equals about 680,000 tonnes of natural rutile sand.

4.3 Future HiTi feedstock demand

Calculations/estimates of future titanium feedstock demand in the years up to 2025 are available from the same companies and presentations mentioned above (see Figure 6).

Similar to the data on historic rutile demand, Hatch (2017), McCoy (2018, 2019) and Perks (2019) provide the most detailed information on projected future rutile demand. For 2020 Hatch projected a global rutile demand of about 740,000 tonnes TiO_2 content of which 61 % would be used for pigment production, 26 % for welding rod production and 12 % for titanium metal production. A requirement of approx. 960,000 tonnes TiO_2 content was predicted by 2025 of which 62 % would be used for pigment production, 24 % for welding rod production and 14 % for titanium metal production.

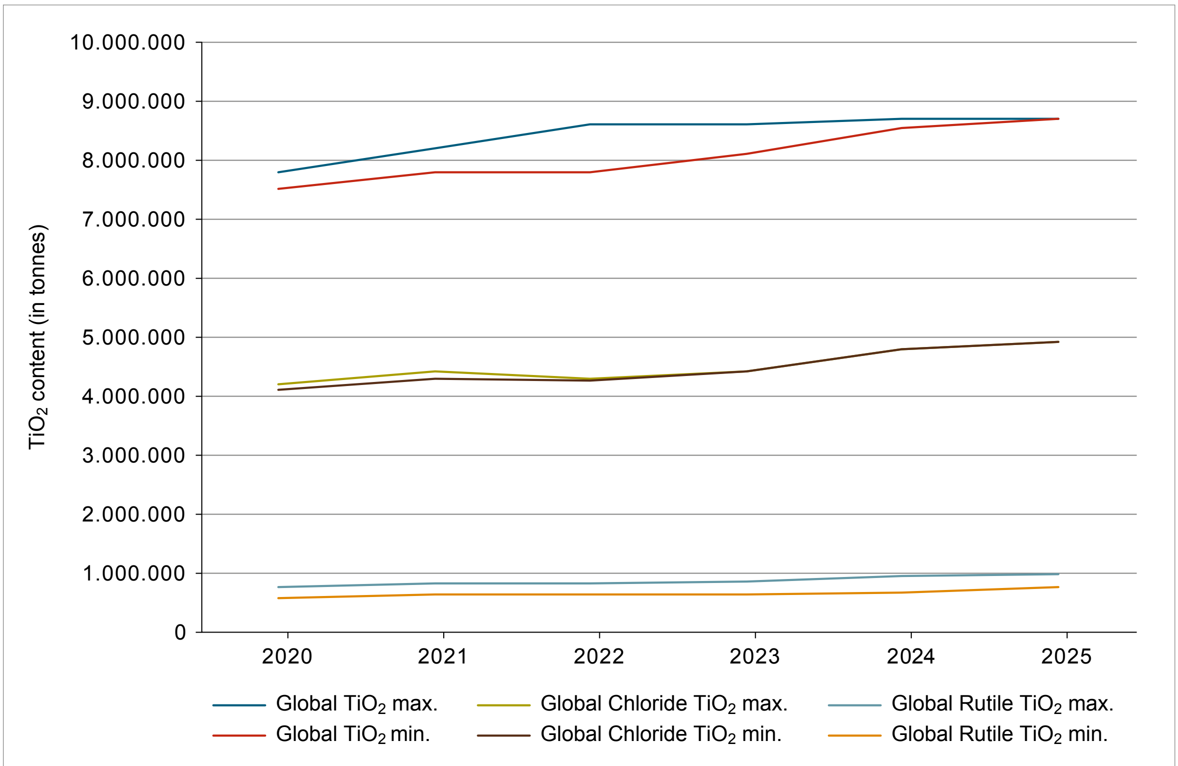


***Figure 6:** Estimates of future global demand for titanium feedstock, global chloride titanium feedstock and rutile feedstock (TiO_2 content in tonnes) according to Iluka Resources, Base Resources, Kenmare Resources, McCoy (2018, 2019), Perks (2019), Nordic Mining ASA (2020) and TZMI (cited by various HM exploration companies).*

In its updated company presentation from February 2020, Nordic Mining ASA cited TZMI and projected distinctly lower global rutile demand of about 560,000 tonnes TiO_2 content in 2020 and 750,000 tonnes TiO_2 content in 2025.

4.4 Comparison of published future demand estimates for HiTi feedstock

Projections for future global chloride-grade titanium feedstock demand which, apart from rutile, leucoxene and HiTi, include high-grade ilmenite and a variety of various upgraded titanium products (cf. Chapter 4.1), differ by 100,000 tonnes/year with Base Resources assuming a higher demand than TZMI.

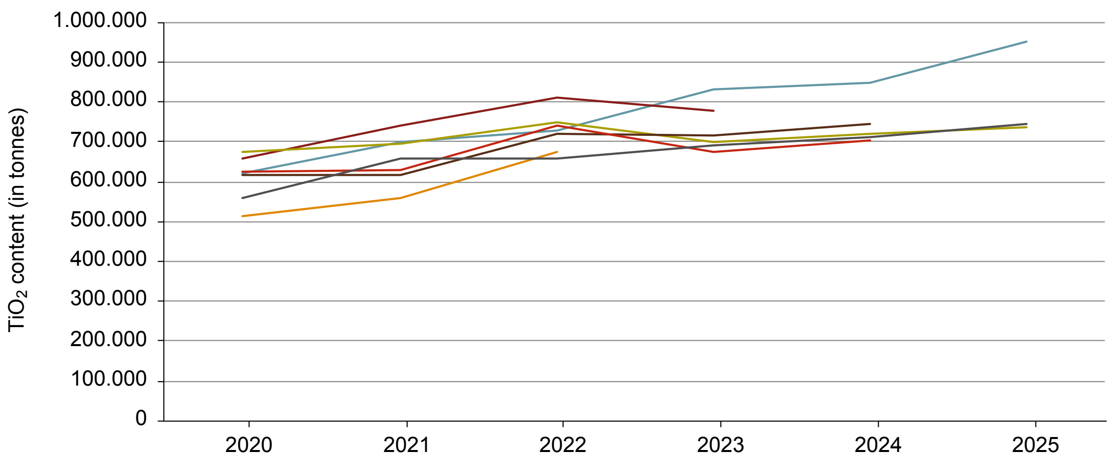
As this study does not include research on upgraded titanium feedstock products, projections of future rutile demand are of more importance, which, on the other hand neglect leucoxene, and HiTi feedstock. All publicly available predictions for future rutile demand are based on TZMI's proprietary data and date back to the period between March 2017 and December 2019.

When plotted along a single graph (cf. Figure 7), it is apparent that rutile demand estimates from TZMI strongly diverge over a short time period. As no background information was available, the reasons for these diverging opinions remain unclear but will continue to be observed by industry participants in the future.

Chapter 6 compares TZMI's demand scenarios with the maximum supply calculations from DERA.

4.5 Influence of substitution

According to discussions with various international titanium feedstock producing companies, the HiTi feedstock market is not worth observing too closely as all chloride-grade feedstock, i. e. chloride-grade ilmenite, natural rutile, leucoxene, HiTi, synthetic rutile, chloride titanium slag and upgraded titanium slag can be substituted with each other with no exceptions.



	2020	2021	2022	2023	2024	2025
3 – 2017	620.000	700.000	730.000	830.000	850.000	950.000
10 – 2017	660.000	740.000	810.000	780.000	780.000	
10 – 2018	675.000	695.000	750.000	700.000	700.000	735.000
3 – 2019	615.000	615.000	720.000	715.000	715.000	
5 – 2019	625.000	630.000	740.000	675.000	675.000	
9 – 2019	515.000	560.000	675.000			
12 – 2019	560.000	660.000	660.000	690.000	690.000	745.000

Figure 7: Future demand for rutile (TiO_2 content in tonnes) according to publicly available information from Sheffield Resources Ltd. and Nordic Mining ASA based on TZMI data and McCoy (2018, 2019) and Perks (2019).

Even assuming that all necessary chemical requirements were fullfilled, only customers who produce chloride-grade TiO_2 pigment or titanium metal via titanium tetrachloride and who do not care about the costs of feedstock, chemicals, operations and environmental issues would be likely to agree with this position.

Producers of welding electrodes are much more particular about feedstock and dependent on natural rutile and sometimes HiTi or even leucoxene but cannot use any upgraded synthetic feedstocks. Synthetic rutile cannot be used for production of welding electrodes as a granular material is required. Also, only ground natural rutile is traditionally used in the production of flux powders.

Looking at substitution in a more general way, the replacement of HiTi feedstock with other mineral resources or chemicals is possible to a limited extent:

– white pigments: zinc sulphide, lithopone (zinc sulphide, barium sulphate), antimony oxide, zinc oxide, lead oxide, kaolin, GCC, PCC (there is no known equivalent substitute for TiO_2)
– metals and alloys: aluminum, magnesium, stainless steel, various super alloys (partially with completely different properties)
– welding electrodes: fluorite, calcite, talc, clays, MnO_2, SiO_2, Fe oxides, silica, siliceous chalk, mica and many others (with inherently completely different properties than rutile)

5 Supply

5.1 Sources of HiTi feedstock production data

Collections of titanium minerals production data of variable quality are available free of charge from the US Geological Survey (USGS), the British Geological Survey (BGS), the Federal Ministry of Sustainability and Tourism of Austria (BMNT) and the German Mineral Resources Agency (DERA). Selected production data can be found in annual reports and stock market information from most of the stock market listed HM producing companies as well as in mineral production data collections of some of the Geological Surveys, Bureaux of Mines, and Central Banks in heavy mineral producing countries.

EITI country reports are good sources of information on titanium mineral production in Madagascar, Mauretania, Mozambique, Ukraine and especially Senegal.

Collections of production data and additional information on titanium mineral uses and supply and demand, both past and future, are also regularly published by TZMI.

BGR/DERA went to great lengths to identify all HiTi feedstock-producing companies worldwide for this report and also to gather the most exact possible information on past HiTi-mineral production since 2012 and future production plans until 2025. HM mines were visited in Australia, South Africa, Mauretania, Mozambique and the US.

Hitherto unpublished production data from former Cristal Mining's operations in Brazil and Australia were kindly made available by both Cristal and Tronox representatives. Production data of companies in Mozambique were provided by the Ministério dos Recursos Minerais e Energia de Moçambique.

Local consultants were commissioned to identify and confirm HiTi feedstock producers in China, India, Sri Lanka, Vietnam, Malaysia and Thailand. Most of them were very successful in not only obtaining up-to-date information (cf. Chapter 5.6) but also rutile and leucoxene samples for analyses (cf. Appendix C).

Fairly precise HiTi mineral production data were available for all countries except Bangladesh, Indonesia, Nigeria, Pakistan and Thailand (cf. Chapter 5.6). Trade data on titanium minerals imports/exports available from the commercial

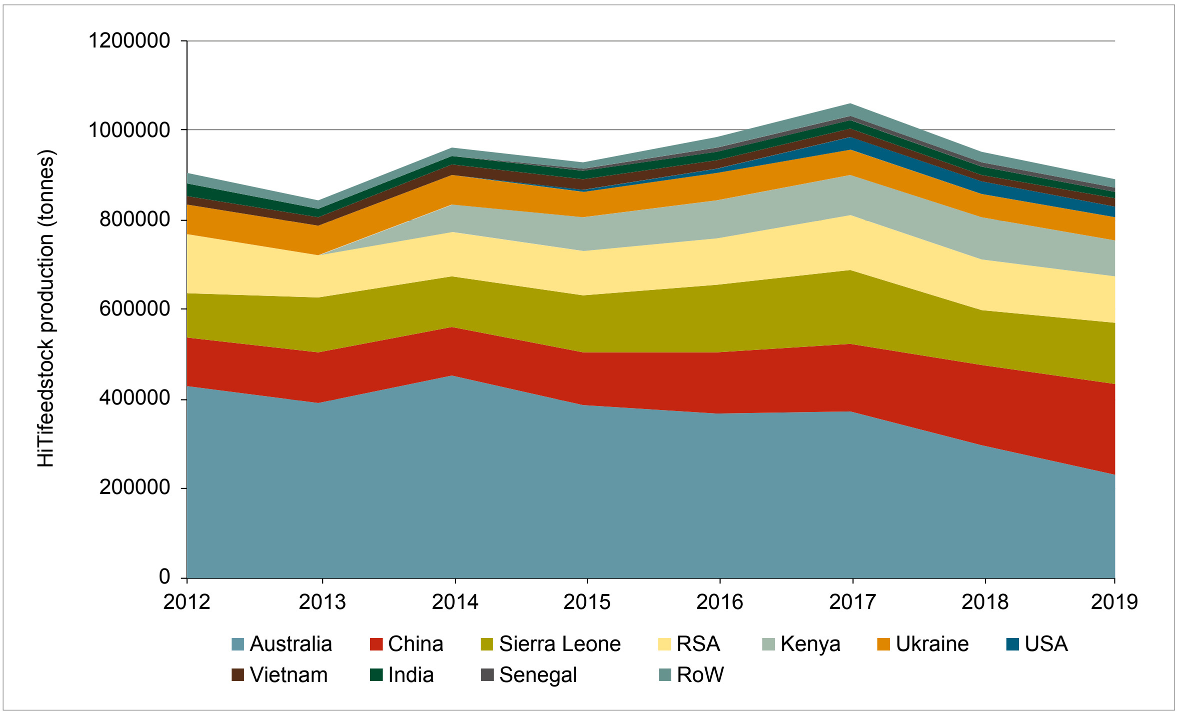


Figure 8: Top 10 HiTi feedstock producing countries 2012–2019. Based on data given in Table 12.

Table 12: HiTi feedstock production (separated products only) in tonnes per country from 2012 to 2019. Sources of data are given in Appendix A.

Country	2012	2013	2014	2015	2016	2017	2018	2019
Australia	427,526	390,436	450,517	388,038	368,069	373,861	298,178	229,000
China	111,200	114,300	108,200	115,800	137,500	147,900	176,850	203,050
Sierra Leone	94,493	120,349	114,163	126,021	148,541	167,600	121,500	137,200
RSA	132,864	93,000	101,000	98,000	103,000	119,000	114,000	103,176
Kenya	0	152	59,348	78,947	87,716	91,456	95,715	78,961
Ukraine	69,100	66,500	64,000	54,200	57,200	57,420	50,936	52,000
USA[2)]	0	0	0	6000	9000	27,000	27,000	27,000
Vietnam	18,800	19,300	23,276	20,497	19,165	17,100	17,100	16,100
India	24,532	19,950	21,572	20,690	21,662	21,551	17,743	13,600
Senegal	0	0	853	5311	9665	9974	9606	10,130
Mozambique	5069	3915	6100	5981	7781	9100	8200	8274
Malaysia	20,008	5983	3069	198	3810	5266	5070	5000
Brazil	2011	2142	1989	2011	2885	2715	3043	3021
Sri Lanka	1590	1406	2111	1808	2237	2174	2319	1959
Thailand[1)]	5568	3539	1583	3877	4569	4368	3832	1222
Russia[2)]	500	500	500	500	500	500	500	500
Indonesia[2)]	100	100	100	100	100	100	100	100
Bangladesh[1)]	20	0	2951	603	0	0	0	0
Total	**913,381**	**841,572**	**961,332**	**928,582**	**983,400**	**1,057,085**	**951,692**	**890,293**
– total rutile	786,745	716,705	836,753	798,981	812,592	867,760	764,507	752,400
– total leucoxene	76,636	86,066	94,879	89,701	124,308	147,525	145,485	106,693
– total HiTi	50,000	38,801	29,700	39,900	46,500	41,800	41,700	31,200
Total (TiO_2 units)	**885,036**	**790,926**	**904,896**	**873,135**	**917,285**	**982,792**	**875,375**	**820,030**

[1)] Export, [2)] Estimate

IHS Markit - Global Trade Atlas® for some of these countries proved to be very helpful although it still only provided rough estimates of production. Despite all the efforts taken in obtaining data from South Africa, Ukraine, the US and Vietnam, some production data for some companies in some years also had to be estimated.

5.2 HiTi feedstock producing countries

Currently (2020), natural rutile is produced in Australia, Brazil, China, India, Kenya, Malaysia, Mozambique, South Africa, Senegal, Sierra Leone, Sri Lanka, Thailand, Ukraine, the US, Vietnam and probably Bangladesh and Indonesia. Leucoxene is produced in Australia, India, Senegal, Thailand, the US, Vietnam and probably Russia. HiTi, a mix of rutile and leucoxene, is produced in Australia and the US only. Within the next few years, production of rutile can also be anticipated in Madagascar and potentially Tanzania.

For many decades, Australia has been the leading producer of HiTi feedstock (with currently five companies), followed by Sierra Leone (one company), South Africa (two companies), Ukraine (two companies) and since 2014 Kenya (one company) (cf. Table 12). However, this summary does not include China which has currently 51 HM separating companies in production. This general situation will stay unchanged until 2025 – the last year this report is looks at – with Ukraine decreasing and China increasing in importance. Other noteworthy countries with HiTi feedstock production are the US, India, Vietnam, Senegal and Mozambique (with much feedstock upgraded in China). Madagascar will become a rutile producer by 2022/23. In all other countries, less than 5000 tonnes of HiTi feedstock are and will be produced annually. In 2019, a production of 5000 tonnes of rutile, leucoxene or HiTi corresponded to a share of worldwide production of only 0.5 %.

5.3 Origin of HiTi feedstock

Close to all HiTi minerals (i. e. rutile and leucoxene) are either separated in dry mills of heavy mineral (HM) mining operations or in discrete HM separation plants (mostly in China) which also produce ilmenite and zircon as well as sometimes monazite, staurolite, sillimanite-kyanite, garnet, xenotime or cassiterite. In SE Asia (i. e. Thailand, Malaysia, and Indonesia) most of the rutile is produced from the tailings (“amang”) of cassiterite mining. In Nigeria, rutile is a by-product of cassiterite-columbite mining. In Russia, small amounts of leucoxene are recovered from oil.

Throughout this study all rutile contained in heavy mineral concentrates imported by and separated in China was counted as Chinese rutile.

Several attempts (e. g. in Chile and China) to produce rutile from hard-rock deposits have met with success only in pilot plants. Nordic Mining ASA has tried to recover rutile from a hard-rock deposit in Norway since 2006. Other hard-rock deposits currently are currently being explored in Canada.

If production of HiTi minerals starts in Canada, it will be from oil sand tailings.

5.4 Assumptions regarding future HiTi feedstock supply calculation

For calculating/estimating the future supply of rutile, leucoxene and HiTi until 2025, published information from established mining companies on the production rates and lifetimes of producing mines, reserves/resources, the planned production rates and lifetimes of future mines were collated. Historic production data for countries without publically reporting companies were averaged to project future production.

In order to evaluate possible future titanium minerals projects, a combination of published information on project economics, project characteristics, assessments by local competitors, personal experience and common sense were used to rank a project as probable or not. In addition, even some probable projects were “postponed for one year” to provide a more realistic picture. This approach is different to many industry consultants who unquestioningly include the proposed start of production in the year reported even by new exploration companies in order not to displease a potential client. The approach adopted in this study may be disproved, at least in some cases, simply by the successful start of the proposed production. However, DERA has observed a trend for many commodities that findings with a negative impact on projects are not reported by junior mining companies in order not to disappoint potential investors.

Projects without any projected start of production were generally not taken into further consideration.

The following assumptions were made for future HiTi feedstock supply calculations (kt = all data in metric kilotonnes of rutile, leucoxene and HiTi):

Australia	
Iluka Resources	Cataby: production of 35 kt rutile in 2020–2022 and 25 kt thereafter Balranald: probable production of 80 kt rutile in 2022 and 170 kt thereafter Jacinth-Ambrosia: production of 40 kt HiTi in 2020ff.
Tronox	Cooljarloo: production of 28 kt rutile and leucoxene in 2020f. Dongara: not probable production of 32 kt rutile and leucoxene but unlikely before 2025 (included in maximum scenario) Wonnerup: production of 7 kt leucoxene in 2020ff. Gingko+Snapper: production of 74 kt rutile and 50 kt leucoxene in 2020 and 2021 and 45 kt rutile and 25 kt leucoxene in 2022 Atlas-Campaspe: production of 70 kt rutile and leucoxene in 2022 and 125 kt rutile and leucoxene in 2023ff.
Sibelco	North Stradbroke Island: no production in 2020ff.
Doral Mineral Sands	Yoongarillup: production of 1 kt leucoxene in 2020, mined out thereafter Yalyalup: production of 1 kt leucoxene in 2022 and 2 kt leucoxene in 2023ff. Keysbrook: production of 40 kt leucoxene in 2020, 35 kt in 2021–2023 and 20 kt in 2024ff.
GMA Garnet	Port Gregory: all rutile content is separated in China
Image Resources	Boonanaring: all rutile and leucoxene content is separated in China
Sheffield Resources	Thunderbird: probable production in 2023 with all HiTi minerals planned to be separated in China
Diatreme Resources	Cyclone: not probable production before 2025 with all HiTi minerals planned to be separated in China
Kalbar Resources	Fingerboards: not probable production before 2025 with all rutile planned to be separated in China
Relentless Resources	Copi and Magic: not probable production before 2025
Strandline Resources	Coburn: not probable production before 2025
VHM	Goschen: not probable production before 2025 with all rutile and leucoxene planned to be separated in China
WIM Resource	Avonbank: not probable production before 2025
Bangladesh	
	probably no production of rutile or leucoxene in 2019ff.
Brazil	
Tronox	Guaju: production of 2.4 kt rutile in 2020, 2 kt rutile in 2021, 1 kt rutile in 2022 and no production thereafter
INB	Buena: production of 0.6 t rutile in 2020, probable production of 0.5 kt rutile in 2021–2014, no production thereafter
China	
All companies	Averaged increase of production between confirmed 2019 tonnage and projected 2025 tonnage, cf. China in Appendix A.
Egypt	
	all rutile content is separated in China

Gambia	
	all rutile content is separated in China
India	
IREL	Chavara: production of 1.5 kt rutile and 0.3 kt leucoxene in 2020ff. Manavalakurichi: probable production of 1 kt rutile in 2020ff. OSCOM: production of 8.0 kt rutile in 2020ff.
KMML	Kerala: production of 2.4 kt rutile in 2020ff.
V.V. Mineral	Tamil Nadu: probably no production of rutile in 2020ff.
Trimex Sands	Srikurmam: probable production of 2 kt rutile in 2021 and 6 kt in 2022ff.
Indonesia	
	probable production of 0.1 kt rutile in 2019ff.
Kazakhstan	
Tioline	Obuhovskoye: all rutile content is separated in China
Kenya	
Base Resources	Kwale: probable production of 75 kt rutile in 2020ff.
Madagascar	
Base Resources	Toliara Sands: probable production of 2 kt rutile in 2023, 8 kt in 2024 and 7 kt in 2025
Malaysia	
	probable production of 5 kt rutile from amang in 2020ff.
Mauritania	
	all rutile content is separated in China
Mozambique	
Kenmare Resources	Moma: production of 8.5 kt rutile in 2020ff.
Africa Great Wall	Deia: all rutile content separated in China
Haiyu Mining	Nagonha: all rutile content separated in China
Mozambique Heavysand	Deia: all rutile content separated in China
Tazetta Resources	Pebane: all contained rutile separated in China
Dingsheng Minerais	Corridor Sands: all rutile content separated in China
Savannah Resources	Mutamba: probable commercial production in 2021, all contained rutile likely to be separated in China
Pakistan	
	all rutile content separated in China
Republic of South Africa	
Richards Bay Minerals	Richards Bay: production of 55 kt rutile in 2020ff.
Tronox	Namakwa Sands: production of 32 kt rutile and leucoxene in 2020ff. KZN Sands: production of 25 kt rutile and leucoxene in 2020ff.
Tormin	all rutile content separated in China

Russia	
Yaregskaya	Yaregskoye: probable production of 0.5 kt leucoxene in 2020ff.
Tuganskyi	Tugansk: all rutile and leucoxene content is separated in China
Senegal	
TiZir	Grande Cote: production of 2.2 kt rutile and 6.5 kt leucoxene in 2020ff.
Astron	Niafarang: all rutile and leucoxene content (“HiTi”) will be separated in China
Sierra Leone	
Sierra Rutile	Gbangbama-Sembehun: production of 170 kt rutile in 2020ff. Sembehun new: probable production of 40 kt of rutile in 2022ff.
Sri Lanka	
Lanka Mineral Sands	Pulmoddai: average production of 2.1 kt rutile in 2020ff.
Tanzania	
Strandline Resources	Fungoni: not probable production of 2 kt rutile in 2021, 3 kt in 2022. 3.5 kt in 2023, 3 kt in 2024 and 2 kt in 2025 (included in maximum scenario)
Thailand	
Various	production of 0.2 kt rutile and 2 kt leucoxene from amang in 2020ff.
Ukraine	
Volnogorsk	Malyshev: probable production of 44 kt rutile in 2020, decreasing 4 kt every following year
Demurinskyi	Volchansk: production of 3.5 kt rutile in 2020ff.
USA	
Chemours	Jesup/Amelia: production of 5 kt HiTi in 2020ff. Mission/Amelia: production of 27 kt rutile and leucoxene in 2020ff.
Vietnam	
MITRACO	Ha Tinh Province: production of 2 kt rutile in 2020ff.
BIMICO	Binh Dinh Province: production of 1 kt rutile in 2020ff.
GPM Asia	Binh Thuan Province: production of 3 kt rutile in 2020ff.
BIOTAN	Binh Dinh Province: production of 2.5 kt rutile in 2020ff.
Song Binh	Binh Thuan Province: production of 1.5 kt rutile in 2020ff.
Hung Tinh	Binh Thuan Province: production of 3.6 kt rutile and leucoxene in 2020ff.
DQCL	Quang Nam Province: production of 0 kt rutile in 2020, 1.5 kt in 2021 and 2.5 kt in 2022ff.
Quang Binh Imexco	Qunag Binh Province: production of 1 kt rutile in 2020ff
HUMEXCO	Thua Thien-Hue Province: no further production of rutile
SQC	Binh Dinh Province: no further production of rutile

5.5 Results of future HiTi feedstock supply calculations

Starting in 2019 there were some major changes in HiTi mineral production in Australia. Tronox took over Cristal and all previous rutile and leucoxene produced by Cristal is now used by Tronox internally for TiO_2 pigment production only. This took 72 kt HiTi feedstock off the market in 2019 and 130 kt in 2020, which on the hand no longer has to be sourced by Tronox externally. Australian HiTi mineral production will be further reduced by some 30–40 kt rutile and leucoxene due to Sibelco having had to close its operations on North Stradbroke Island at the end of 2019 for environmental reasons. While HiTi production at Jacinth-Ambrosia will presumably stay constant, rutile from Iluka's Murray Basin mines was last sourced in 2017. Cataby has taken over some of this rutile production, but the majority of Iluka's Australian future rutile production has to come from the Balranald deposit. In this study it is estimated that Balranald will be commissioned in 2022 and will reach full production capacity of 170 kt rutile in 2023. On the other hand, it is assumed that Dongara will be postponed beyond 2025.

There are also numerous other companies with HM projects in the pipeline in Australia. It is very interesting to note that with a very few exceptions (e.g. Sheffield Resources with its Thunderbird project) most of them have Chinese investors who urge these companies to ship their HM concentrates to China for final separation. Thereby, all contained HiTi (and other!) minerals will only become available on the Chinese domestic market rather than internationally. Out of the many projects, only Kalbar Resources' Fingerboards project and Diatreme Resources' Cyclone project were included in the maximum supply version (Table 14).

The stop of rutile production by Industrias Nucleares do Brasil and Tronox Pigmentos do Brasil S.A within the next years will affect neither the domestic nor the international HiTi feedstock market.

In contrast, the Chinese HiTi mineral market has already started to change considerably and will continue to do so in the future. China has banned HM mining on Hainan Island but buys separated rutile and leucoxene concentrates from all major producing countries. Additionally, rising amounts of HM concentrates and impure ilmenite-rich, zircon-rich and/or monazite-off grade zircon-rich concentrates are imported by China and separated into different heavy mineral products, including rutile. Currently, such concentrates are imported from Australia, The Gambia, Indonesia, Kazakhstan, Liberia, Mauritania, Mozambique, Nigeria, Pakistan, Republic of South Africa, Russia, Senegal, Sierra Leone, Sri Lanka, the US and Vietnam. It is very important to note that neither the zircon concentrates nor the ilmenite concentrates produced by Chinese mining companies abroad are close to being pure. Thus, it is not possible to calculate a zircon or titanium mineral/TiO_2 content from the Chinese import figures of HM concentrates alone. The rutile/leucoxene content of HM concentrates imported by China from Australia will probably rise by 18 kt, and potentially by a further 30 kt, by 2025. The rutile content of HM concentrates imported from Mozambique will also probably rise by some 10 kt, possibly even by up to 50 kt. The rutile supply from South Africa, on the other hand, will drop by some 3 kt.

In India, the rutile output of IREL (India) Ltd. and KMML is expected to remain roughly the same over the next few years. While V.V. Minerals may not resume its operations it is conceivable that Trimex Sands will restart production in 2021 as it has an international and in general better reputation than its private competitors.

Base Resources in Kenya has emerged as a major supplier of rutile on the world market since 2014. According to company announcements, its rutile production will fall by 20 kt until 2025. However, this shortfall will be partly compensated by the company's new mine in Madagascar which will probably deliver some 7 kt rutile by 2025.

Rutile production in South Africa is expected to remain roughly the same with Tronox (KZN Sands and Namakwa Sands) only producing for its internal consumption. RBM's exact production figures between 2013 and 2018 have been kept confidential. But granting that there is no further political unrest, rutile production is estimated to stay more or less constant at about 55 ktpa in the following years.

For Sierra Rutile, the world's single most important producer of rutile, the expected future rutile output which is based on Iluka Resources' public announcements has been adopted. In addition to a consistently high output from the existing Gbangbama mines, additional rutile output of 40 kt from the new Sembehun mine from 2022 on is predicted.

There are doubts about the viability of the Fungoni and other HM deposits in Tanzania, so the announced possible start of Strandline Resources' Fungoni project in 2021 is assumed as not probable and was included in the maximum supply version only.

In Ukraine, there are rumours that the Irshansk mine will run out of resources in the foreseeable future, however, it only produces ilmenite. In recent years, also the Volnogorsk operations have reduced production which stood at 47.9 kt rutile in 2018. Due to a number of problems within Ukraine, this study predicts that rutile output is likely to drop by some 4 ktpa in the coming years in accordance with exports. On the other hand, rutile production by Demurinskyi GZK LLC is not likely to rise above 3.5 ktpa soon.

Close to all rutile and leucoxene produced by Southern Ionics since 2018 has been sold to Chemours, which took over Southern Ionics in mid-2019. Output from the Mission mine cannot rise much further and is limited to 27 kt combined HiTi minerals. For the first time in its long mining history Chemours is planning to sell a HiTi mineral

Table 13: Probable HiTi feedstock production (separated products only) in tonnes per country from 2020 to 2025.

Country	2020	2021	2022	2023	2024	2025
Australia	275,000	269,000	296,000	377,000	417,000	417,000
China	209,000	220,000	231,000	242,000	253,000	268,350
Sierra Leone	170,000	170,000	210,000	210,000	210,000	210,000
RSA	112,000	112,000	112,000	112,000	112,000	112,000
Kenya	75,000	75,000	75,000	75,000	75,000	75,000
Ukraine	47,500	43,500	39,500	35,500	31,500	27,500
USA	32,000	32,000	32,000	32,000	32,000	32,000
Vietnam	14,600	16,100	17,100	17,100	17,100	17,100
India	13,600	15,600	19,600	19,600	19,600	19,600
Senegal	9500	9500	9500	9500	9500	9500
Mozambique	8500	8500	8500	8500	8500	8500
Madagascar	–	–	–	2000	8000	7000
Malaysia	5000	5000	5000	5000	5000	5000
Brazil	3000	2500	1500	500	500	0
Thailand	2200	2200	2200	2200	2200	2200
Sri Lanka	2100	2100	2100	2100	2100	2100
Russia	500	500	500	500	500	500
Indonesia	100	100	100	100	100	100
Total	**979,600**	**983,600**	**1,061,600**	**1,150,600**	**1,203,600**	**1,213,450**
– total rutile	806,500	816,500	918,500	1,031,500	1,099,500	1,109,350
– total leucoxene	128,100	122,100	98,100	74,100	59,100	59,100
– total HiTi	45,000	45,000	45,000	45,000	45,000	45,000
Total (TiO_2 units)	**905,108**	**909,580**	**1,035,022**	**1,133,292**	**1,119,232**	**1,100,174**

concentrate from its Amelia deposit. Production is estimated to have been 5 kt in 2020 and also in the coming years.

It is not possible to get realistic figures of current and even more difficult of future rutile production in Vietnam. However, it is assumed that rutile production in this country will decrease to less than 15 kt in 2020 rising to an average of 17 kt in 2022 and the years thereafter. Most of the rutile contained in Vietnamese HM concentrates is separated in China.

In all other countries with rutile or leucoxene production (i. e. Indonesia, Malaysia, Russia, Senegal, Sri Lanka, Thailand and possibly Bangladesh), production will probably either remain the same or at least not influence the future global HiTi feedstock supply.

If demand for HiTi minerals rises considerably in future, none of the current producers outside China are likely to be able to easily adjust their outputs very much within a short space of time. Additionally, as demand for natural rutile has also been strong in the past, there are no stockpiles available for any unforeseen surges in demand.

Table 14: Additional possible (but rather improbable = maximum) HiTi feedstock production (separated products only) in tonnes per country from 2020 to 2025

Country	2020	2021	2022	2023	2024	2025
Australia	–	–	–	–	32,000	32,000
Tanzania	–	2000	3000	3500	3000	2000
Total	**–**	**2000**	**3000**	**3500**	**35,000**	**34,000**

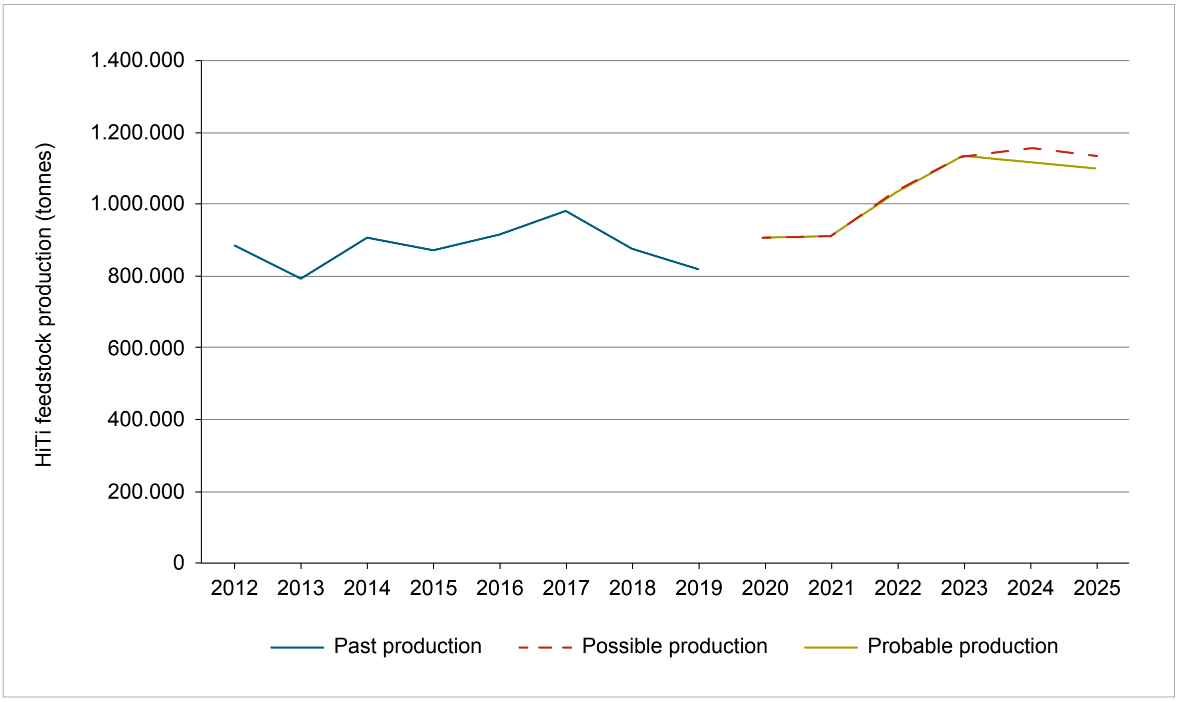


Figure 9: Global HiTi feedstock production 2012–2019 and probable (green line) as well as additional possible (red dotted line) HiTi mineral production between 2020 and 2025.

6 Supply-demand balance

6.1 Supply-demand balance between 2012 and 2019

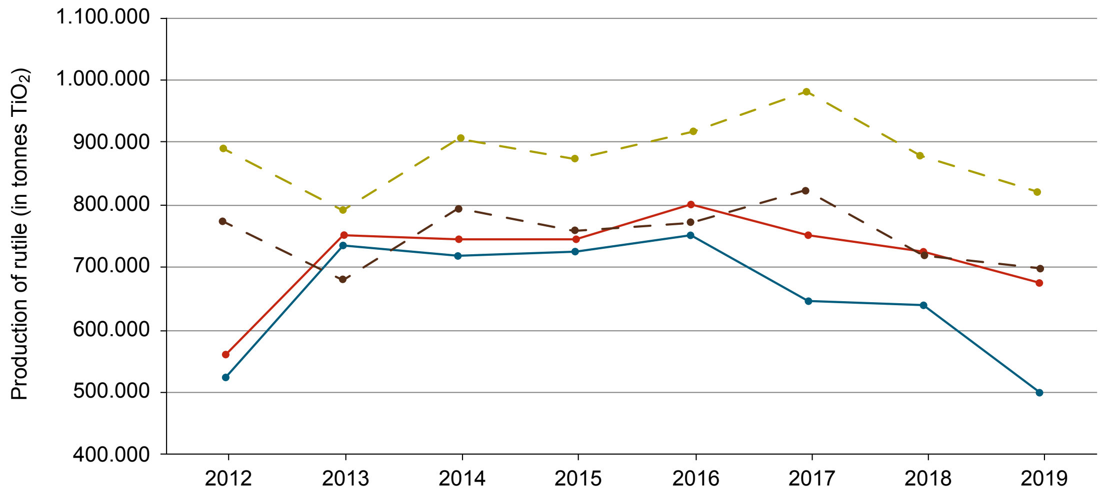
Figure 10 plots the supply data as collated by BGR/DERA (converted into TiO_2 units, cf. Appendix B) against demand estimates for global HiTi feedstock and rutile in TiO_2 units as published by HATCH (2017) and others (cf. Chapter 4.2) for the time interval between 2012 and 2019.

As already outlined in Chapter 4, opinions on future rutile demand vary strongly over time, but, strangely enough, the same is true for past demand data (or rather estimates). The estimates for past global rutile demand (in TiO_2 units) are shown in Figure 10.

In 2012 global the supply of rutile, excluding all other HiTi minerals, surpassed global demand by some +212 kt to +247 kt.

By 2013 this situation had changed considerably resulting in a deficit by the year's end of approx. –55 kt to –70 kt. The reasons for this were strong rising demand (+187 kt to +210 kt) coupled with a decrease in rutile production in South Africa (–40 kt), Australia (especially the Murray Basin, –35 kt) and India (–5 kt). Rutile production in Sierra Leone, however, increased by +26 kt.

In 2014 the world market was in oversupply again. While demand decreased by some +5 kt to +15 kt, rutile production increased by +59 kt in Australia, +8 kt in South Africa and +4 kt in Vietnam. Conversely, production decreased by approx. –6 kt in Sierra Leone. The biggest impact on rutile pro-



	2012	2013	2014	2015	2016	2017	2018	2019
Demand Rutile TiO_2 min.	525.000	735.000	720.000	725.000	750.000	645.000	640.000	500.000
Demand Rutile TiO_2 max.	560.000	750.000	745.000	745.000	800.000	750.000	725.000	675.000
Supply HiTi Feedstock TiO_2	885.036	790.925	904.896	873.134	917.285	982.792	875.375	820.030
Supply Rutile TiO_2	772.072	679.797	793.953	758.757	771.204	823.493	718.580	700.355
Rutile Balance (min. demand)	247.072	–55.203	73.953	33.757	21.204	178.493	78.580	200.355
Rutile Balance (max. demand)	212.072	–70.203	48.953	13.757	–28.796	73.493	–6.420	25.355

Figure 10: Supply of HiTi minerals (rutile, leucoxene and HiTi) and rutile between 2012 and 2019 against demand for rutile for the same time period given in TiO_2 units. Supply data from BGR/DERA converted into TiO_2 units (in accordance with individual product/deposit based TiO_2 grades, cf. Appendix B).

duction was the start of rutile production at Kwale/ Kenya by Base Resources Ltd., however (+59 kt in 2014).

2015 witnessed no change in rutile demand but a decrease in overproduction as a result of less rutile production primarily in Australia (–40 kt) and Ukraine (–10 kt). Rutile production, however, increased by a further +20 kt in Kenya, +12 kt in Sierra Leone and +7 kt in China.

TZMI (McCoy 2018, 2019) saw rutile demand peaking in 2016 and reaching 800 kt TiO_2 units. If this had been the case, there must have been a deficit in balance of close to –29 kt. This again, was caused by a drop in rutile production in Australia – for decades the most important rutile producing country in the world – by some –55 kt, which annulled increases in rutile production in other countries, i.e. China (+22 kt), Sierra Leone (+12 kt), Kenya (+9 kt), and Republic of South Africa (+5 kt).

In 2017, global rutile demand dropped by some –50 kt to as much as –150 kt. while rutile production increased by about +19 kt in Sierra Leone, +16 kt in South Africa, +12 kt in China, +9 kt in the US, and +4 kt in Kenya, resulting in a significant oversupply of anywhere between +73 kt and +178 kt. The latter figure most probably comes closer to the truth.

While in 2018 demand for rutile remained unchanged, Iluka Resources had already halted HM separation in the Murray Basin in October 2017 resulting in a loss of some –93 kt rutile on the world market in 2018. Additionally, rutile production dropped by some –46 kt in Sierra Leone, –7 kt in Ukraine and –5 kt in South Africa but rose by +29 kt in China. In 2018 for the first time in history, China overtook both Australia and Sierra Leone as the most important global rutile producer. The global rutile balance lay somewhere between a deficit of –6 kt and a surplus of +78 kt. The truth may lie somewhere between the two at +45 kt.

In 2019 global rutile production stood at 752.4 kt, equivalent to 700 kt TiO_2 content. Although global rutile demand lay somewhere between 500 kt and 675 kt, the yearly balance must have been strongly positive, i.e. there was an oversupply of between +25 kt and as much as +200 kt rutile TiO_2. Relevant increases in rutile production were reported from China (+26 kt), Sierra Leone (+16 kt), and Senegal (+7 kt), while information on decreases were received from Australia (–26 kt), Kenya (–17 kt) and potentially South Africa (–14 kt).

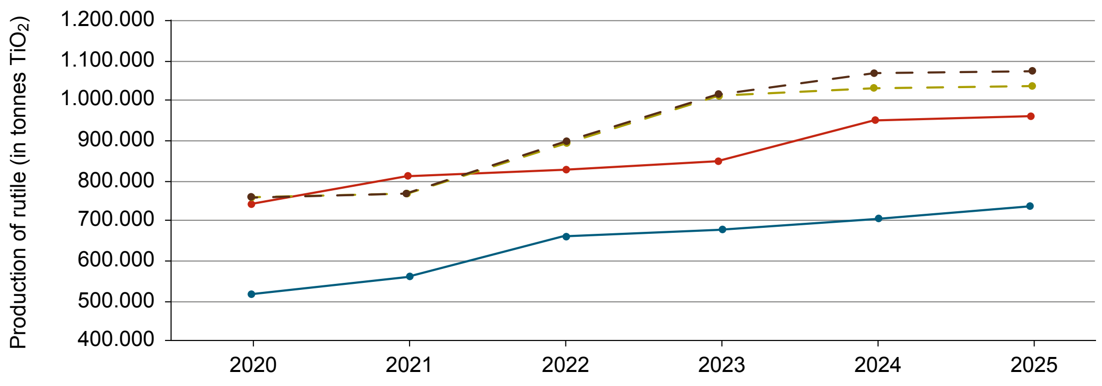
As there are no publicly available data on leucoxene demand, no balances for leucoxene could be calculated. However, it is well known within the industry that close to all global leucoxene available is used for TiO_2 pigment production, especially by the US Chemours Company. In practice, this results in a globally balanced annual leucoxene market.

6.2 Supply-demand balance until 2025

According to the data collated by BGR/DERA, probable production of rutile (in TiO_2 units) will rise by some +58 kt from 700 kt in 2019 to 758 kt in 2020 (not taking into account any COVID-19 effects!). It will continue rising further by some +10 kt to 768 kt in 2021 and more importantly by some +124 kt to 892 kt in 2022. This strong increase in rutile supply in 2022 will result from the opening of Iluka's rutile-rich Balranald HM mine in Australia's Murray Basin which still is scheduled for that year. Global rutile supply will continue to increase in line with Balranald reaching full production capacity in 2023. In addition, the new Sembehun deposit in Sierra Leone is likely to flood the world market with even more rutile, leading to global rutile production of some 1012 kt in 2023. Between 2023 and 2025, rutile production will increase further to around 1039 kt.

Of the many rutile/HM projects in development, which are suggested to be opened until 2025 only two (Fungoni in Tanzania and Dongara in Western Australia) were included in a possible, i.e. maximum rutile supply scenario. Their opening might bring rutile production up to 1075 kt in 2025. Other HM projects in Australia will ship their HM concentrates to China and have been included in China's increasing rutile production.

The experts at TZMI (e.g. McCoy 2018, 2019) express a strongly diverging opinion on future rutile demand which varies from publication to publication by some 300 kt! Most recently, a more pessimistic (realistic?) model has been adopted with projected modest demand of between 600 kt



	2020	2021	2022	2023	2024	2025
Demand Rutile TiO_2 min.	515.000	560.000	660.000	675.000	705.000	735.000
Demand Rutile TiO_2 max.	740.000	810.000	830.000	850.000	950.000	960.000
Supply HiTi Feedstock TiO_2	758.542	767.693	892.255	1.011.645	1.030.985	1.039.264
Supply Rutile TiO_2	758.542	769.573	895.075	1.014.935	1.068.065	1.075.404
Rutile Balance (min. demand)	243.542	207.693	232.255	336.645	325.985	304.264
Rutile Balance (max. demand)	18.542	–43.308	62.255	161.645	80.985	79.264

Figure 11: Supply-demand balance of rutile at probable and possible production scenarios (2020–2025).

to 650 kt between 2020 and 2025. However, these figures may be even lower due to the COVID-19 pandemic.

These two predicitions alone, with a rutile supply of more than 1000 kt against a demand of roughly 650 kt in the same year results in a considerable oversupply of rutile by 2025. Even with a much higher rutile demand than currently projected, there will be an oversupply of rutile in the coming years (cf. Figure 11).

The BGR/DERA scenarios in detail (not taking any COVID-19 effects into account) project a global rutile oversupply of between +18 kt to + 243 kt in 2020 and most probably about +140 kt in TiO_2 units or approx. 150 kt of rutile.

In 2021 the oversupply will remain about the same.

In 2022 the oversupply will further increase to around +232 kt in TiO_2 units or 250 kt of natural rutile.

In 2023 the oversupply will further increase to +337 kt in TiO_2 units or 365 kt of natural rutile.

In 2024 the oversupply will slightly decrease to around +326 kt in TiO_2 units or 350 kt of natural rutile.

In 2025 the oversupply will further decrease to around +304 kt in TiO_2 units or 330 kt of natural rutile.

Interestingly, TZMI (pre COVID-19) comes to a totally different conclusion, predicting a rise in demand for rutile until 2025 (cf. above), together with “existing supply” added by “likely new projects” resulting in “tight supply” with “demand exceeding supply from 2020”. The same is projected for leucoxene in a scenario in which “customers have to switch from rutile and leucoxene to other high-grade feedstocks such as choride slag, synthetic rutile (SR) or upgraded slag (UGS)”.

It should be kept in mind that the forecasts as described here by the BGR/DERA are based on the four main scenarios listed below:

1) Conservative rutile demand as projected by TZMI
2) Commissioning of the Australian rutile-rich Balranald HM project by Iluka Resources Ltd. in 2022
3) Commissioning of the new Sembehun HM mine in Sierra Leone by Iluka Resources Ltd. in 2022
4) Steady increase of rutile production in China based on imported HM concentrates

Should any of these scenarios change, the BGR/DERA will adjust its forecasts accordingly. All other developments in the gobal rutile and HiTi feedstock market should have little influence on the rutile supply-demand balance until 2025.

6.3 Global reserves and resources of HiTi feedstock

As the availability of rutile, leucoxene or HiTi minerals to sufficiently satisfy future demand is disputed, Table 15 summarizes all the available rutile/resource data from Appendix A of this study.

Although data from Ukraine, Vietnam and many African countries with extensive stretches of HM-rich beaches (e.g. Guinea and Somalia) are missing, available data show that most rutile exists in Australia followed by India. With current rutile demand estimated at some 650 ktpa, the current reserves-to-production ratio is about 35 years, while the resources-to-production ratio stands at as much as 198 years.

Vast resources of leucoxene have been reported from India followed by Australia and Russia. With current leucoxene demand estimable at around 125 kt, the current reserves-to-production ratio is about 75 years, while the resources-to-production ratio exceeds 6000 years.

Thus, global reserves and resources of HiTi feedstock should be sufficient for current and any future rises of rutile and leucoxene demand.

Table 15: Global reserves and resources of rutile, leucoxene and HiTi minerals as of 2019 as far as published.

	Rutile (kt)		**Leucoxene (kt)**		**HiTi (kt)**	
	Reserves	**Resources**	**Reserves**	**Resources**	**Reserves**	**Resources**
Australia	8485	55,852	8320	67,908	2947	7609
Bangladesh		98		96		
Brasil	28	738		215		
Cameroon		2849				
Chile[1]		2805				
China	unknown, but limited					
Egypt		7		14		
The Gambia	27					
India		33,950		629,570		
Kazakhstan	53	1410		353		
Kenya	306	2223				
Liberia		84				
Madagascar	419	725	343	593		
Malawi		1876		345		
Mozambique	950	9843				
Norway[2]						
RSA	5610	3076		4218		6900
Russia				43,433		
Senegal	628	655	792	838		
Sierra Leone	3900	9311				
Sri Lanka		2266		3118		
Tanzania	20	606	5	7		
Ukraine	2000	unknown, but extensive				
USA[3]		414		520		
Vietnam					unknown, but extensive	
Total	**22,426**	**128,788**	**9460**	**751,228**	**2947**	**14,509**

[1] in addition to 3000 kt of rutile in solid rock [2] 4927 kt of rutile in solid rock [3] as far as known and permitted

7 The titanium metal market

Due to its low density, its high strength and its high corrosion and temperature resistance, to name just a few of its valued properties, titanium is a very important lightweight metal. It is primarily used in the aerospace and industrial engineering industries (cf. Chapter 3.1).

Titanium currently makes up 13 % of the weight of aerospace raw material in total (771,000 tonnes globally), but 30 % of the value (13 billion US$ globally) (Seiner 2018). The titanium metal market is therefore closely observed by aerospace industry stakeholders, with Airbus and Boeing as its major participants. Due to increasing global air traffic, a backlog in orders for new airplanes and the increasing use of titanium in aircraft frames and engines because of its compatibility with composites, demand for titanium was – prior to the effect of COVID-19 pandemic on the commercial aerospace industry – expected to rise steadily (see Figure 12).

The same holds true for industrial engineering demand which is driven by chemical, petrochemical and power generation industries in Asia. Large orders from the medical and environmental protection sectors in China as well as shipbuilding in China and South Korea currently are also currently bolstering demand for industrial grade titanium. As of 2018, global industrial demand for titanium metal was estimated as 60,400 t (Bruneau 2019). Roskill (2019) assumes the demand for titanium in industrial engineering to have been 80,300 t in 2019, compared with 83,200 t for aerospace and 75,000 t in the steel industry and other alloys production (mainly for ferrotitanium production). Only very small amounts of titanium were used in consumer (8.0 kt), medical (6.1 kt), high-technology (3.8 kt) and non-aerospace military (4.2 kt) applications. On the other hand, in industrial applications low-grade Ti metal always competes with high-performance alloys and duplex stainless steel. An emerging market for titanium metal powder is seen in 3D printing (cf. Chapter 3.1.).

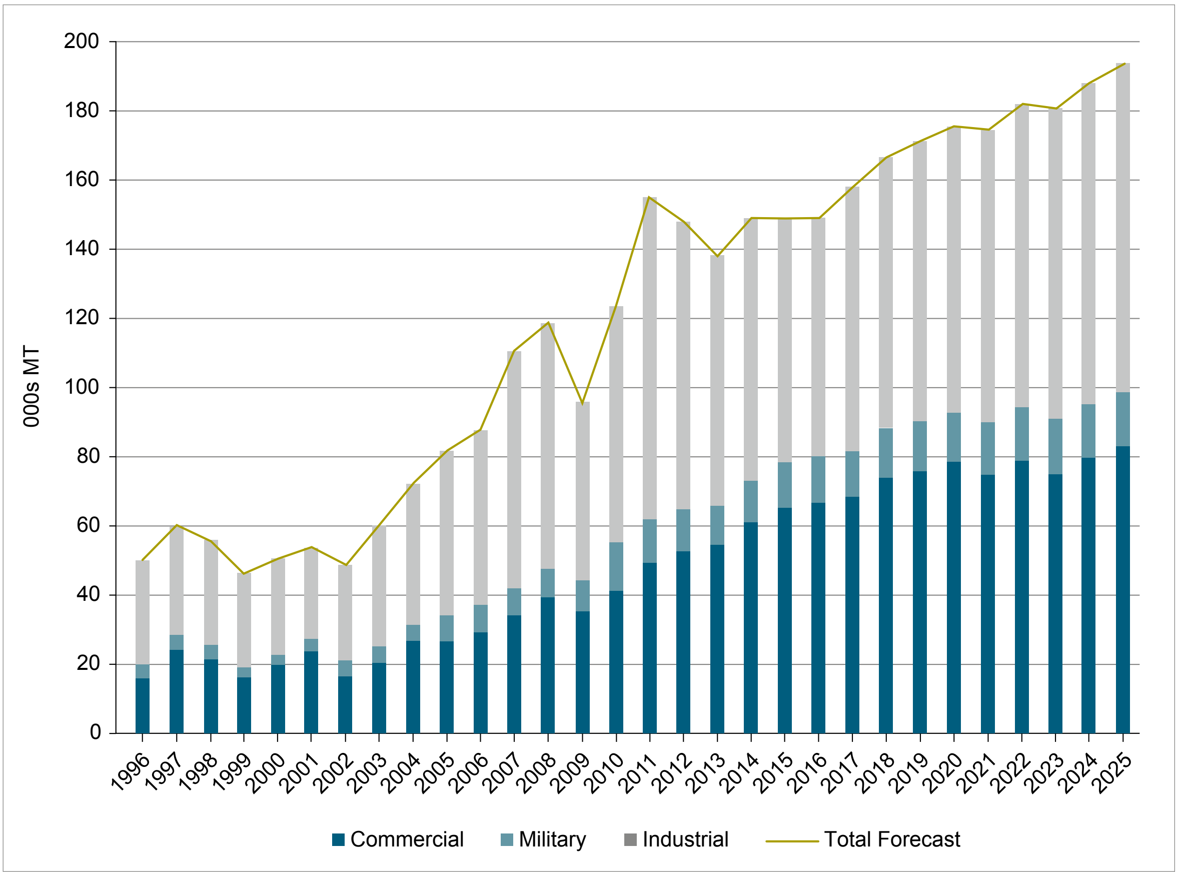


Figure 12: Historic and estimated forecast of titanium metal demand in major applications (Seiner 2018).

There are two main raw titanium metal products:

a) titanium sponge produced from chlorinatable feedstock via titanium tetrachloride as an intermediate product

b) titanium mill products generated by melting down titanium sponge and adding titanium metal scrap to produce ingots or slabs which are further processed into billets, blocks, bars, sheets, tubes, wires and other semi-finished goods by casting, rolling, forging and extrusion.

c) According to Roskill (2019) in 2018, the US consumed about 70 % of world titanium scrap suitable for remelting, and scrap made up 58 % of the feedstock (most of the remainder is natural rutile) in US titanium metal production in the same year. The scrap:ingot ratio in the US in 2017 even was 71:29. Around 80 % of global titanium scrap is estimated to be new scrap produced during the manufacture and processing of titanium sponge.

The primary feedstock in CIS titanium sponge plants according to McCoy (2018, 2019) is mainly chloride-grade titanium slag made from chloride-grade ilmenite with minor amounts of natural rutile and increasing amounts of additional “chloride fines”. Given the limited resources of natural rutile in China, and the high costs of synthetic rutile, titanium slag also dominates feedstock used in Chinese titanium sponge plants. However, the importance of synthetic rutile as feedstock is slowly increasing in China. In contrast to the CIS and China, the two Japanese sponge producers prefer synthetic rutile (imported from India) and upgraded slag but also use small amounts of chloride-grade slag and natural rutile (imported from Kenya, South Africa and Sierra Leone). Total feedstock demand for titanium sponge production is estimated to increase at a compounded annual growth rate of 6.7 % between 2018 and 2023 (McCoy 2019).

Titanium sponge is currently produced by some 26 companies in eight countries (see Table 16). The data in Table 15 may be outdated soon as Chinese producers with minor capacities close or are taken over and major producers expand. Especially in Japan, companies are reporting production at close to full capacities and efforts are being made to raise their capacities and outputs even further. According to Roskill (2019), global titanium sponge capacity in 2019 stood at 317,800 tpa with an average utilization rate of 70 % of which 111,400 tpa was of premium grade quality. Gehler (2019) estimated much lower global titanium sponge capacity of 269,300 tpa in 2018 with an average utilization rate of about 75 %.

According to Argus Media (2019), China's titanium sponge capacity increased to 107,000 tpa in 2018, up by 15 % from 93,000 tpa in 2017. Roskill (2019) estimates Chinese titanium sponge production capacity at 139,000 tpa in 2019 of which 46,400 t was reported idle. However, based on individual company capacity data provided by Asian Metal, China’s titanium sponge capacity already stands at 160,000 tonnes and is set to increase considerably within the next years (Baoji 2018). Liu & Wong (2019) also report a Chinese titanium sponge capcity of 168,500 tpa for 2019. The main hurdles for titanium sponge producers in China are production restrictions, constant fluctuations in titanium sponge prices in the past and, above all, limited availability of titanium tetrachloride feedstock due to lack of chloritinable feedstock, strong competition for suitable feedstock by pigment producers and environmental restrictions. As domestic demand surpasses supply, import volumes of titanium sponge are gradually rising (cf. Table 16).

Most of China’s titanium sponge output is industrial or standard grade for the domestic market, while Japan, Russia and Kazakhstan mainly produce premium grades for aerospace applications and export. Exports of sponge from China are limited and decreasing, but a growing amount of sponge is being converted to mill products which are exported globally with Taiwan, the US, South Korea and Germany (mainly bars, sheets, and plates) being the favourite destinations (cf. Table 17).

Global titanium sponge production data are given in Table 18. However, country data are not consistent and may vary considerably according to reporter. Roskill (2019) projects titanium sponge output in 2019 to be 223,200 tonnes, a considerable increase on 202,800 t in 2018.

Roskill (2019) puts global titanium metal capacity in 2019 at 543,300 tonnes (including about

Table 16: Global producers of titanium sponge as of 2019. Taken from various sources.

Location/ Country	Company	Capacity	Grades
Berezniki Russia	PSC Corporation "VSMPO-AVISMA"	44,000 tpa	Industrial & Aerospace
Solikamsk Russia	OJSC Solikamsk Magnesium Plant	2500 tpa	Aerospace
Ust-Kamenogorsk Kazakhstan	UKTMP Ust-Kamenogorsk Titanium & Magnesium Plant JSC	26,000 tpa	Industrial & Aerospace
Amagasaki Japan	OTC Osaka Titanium Technologies Co., Ltd.	40,000 tpa (7000 tpa add. capacity planned)	Industrial & Aerospace
Wakamatsu Japan	Toho Titanium Co., Ltd.	15,600 tpa	Industrial
Chigasaki Japan	Toho Titanium Co., Ltd.	9600 tpa	Aerospace
Zaporozhye Ukraine	ZTMC Zaporozhye Titanium and Magnesium Combine	20,000 tpa (10,200 tpa, actual capacity)	Industrial & Aerospace
Yanbu Saudi-Arabia	AMIC (65 %) & Toho (35 %) Advanced Metal Industry Co. & Toho Titanium Co.	15,600 tpa (8000 tpa starting capacity planned)	Industrial & Aerospace
Henderson, NV USA	Timet Titanium Metals Corporation	12,600 tpa	Industrial & Aerospace
Salt Lake City, UT USA	HEM Honeywell Electronic Materials Inc.	500 tpa	Electronic
Sankarmangalam, Kerala, India	KMML Kerala Minerals and Metals Ltd.	500 tpa	Industrial & Aerospace
Luoyang, Henan China	Luoyang Sunrui Wanji Titanium Industry Co., Ltd.	30,000 tpa	Industrial
Hami, Xinjiang China	Xinjiang Xiangsheng New Materials Science & Technology Co., Ltd.	30,000 tpa (20,000 tpa starting capacity)	?
Zunyi, Guizhou China	Zunyi Titanium Industry Co., Ltd.	10,000 tpa	Industrial & Aerospace
	Zunbao Titanium Industry Co., Ltd. (subsidiary)	15,000 tpa (5000 tpa actual capacity, 20,000 tpa add. capacity planned)	
Chengdu, Sichuan Panzhihua, Sichuan China	Pangang Group Titanium Industry Co., Ltd. Panzhihua Xinyu Chemicals Co., Ltd.	18,000 tpa (10,000 tpa add. capacity planned) 5000 tpa	Industrial & Aerospace
Chaoyang, Liaoning, China Xiantao, Hebei, China	Chaoyang Baisheng Titanium Co., Ltd. (2 plants)	8000 tpa 15,000 tpa	Industrial & Aerospace
Jinzhou, Liaoning China	Baotai Huashen Titanium Industry Co., Ltd.	12,000 tpa	Industrial & Aerospace

Location/ Country	Company	Capacity	Grades
Chaoyang, Liaoning China	Chaoyang Jinda Titanium Industry Co., Ltd.	10,000 tpa (10,000 tpa add. capacity planned)	Industrial
Lufeng, Yunnan China	Lomon Billions Group Co., Ltd. Yunnan Metallurgical Xinli Titanium Industry Co., Ltd.	10,000 tpa	Industrial
Baoji, Shaanxi China	Baoji Titanium Industry (Baoti) Co., Ltd.	10,000 tpa	Industrial & Aerospace
Sichuan China	Shengfeng Titanium Industry Co., Ltd.	10,000 tpa	?
Anshan, Liaoning China	Anshan Hailiang Nonferrous Metals Materials Manufacturing Co., Ltd.	8000 tpa	Industrial
Linfen, Shaanxi China	Shanxi Zhuofeng Titanium Co., Ltd.	5000 tpa	Industrial
Jinzhou, Liaoning China	CITIC Jinzhou Metal Co., Ltd.	2000 tpa	Industrial
Liaoyang, Liaoning China	Liaoyang Yigong Titanium Co., Ltd.	500 tpa	?
Haixi, China	Qinghai Juneng Titanium Co., Ltd.	30,000 tpa planned	?
Total	**Current actual capacity**	**348,000 tpa**	

Table 17: Titanium sponge and products: imports (excluding re-imports) to and exports from China in tonnes. Taken from IHS Markit – Global Trade Atlas®.

	2012	2013	2014	2015	2016	2017	2018	2019
Imports Ti sponge	130	427	118	82	3106	3824	4918	7139
from Kazakhstan	15	330	0	0	0	1480	2460	4907
from Ukraine	40	80	10	20	2899	1705	2250	1390
from Japan	0	0	0	0	0	3	22	739
from Russia	0	0	108	62	195	368	147	80
from USA	0	0	0	0	0	162	24	4
from others	75	17	0	1	12	106	14	20
Exports Ti sponge	4528	4026	5691	3550	1760	1900	1245	1046
Imports Ti products	4941	3975	4858	5464	5907	7188	8653	8071
Exports Ti products	12,328	9997	11,909	11,850	14,062	15,612	19,057	20,947

150 ktpa capacity used for double and triple melting to reduce impurities in titanium metal for aerospace applications) and output at 257,100 tonnes. The global utilization rate is therefore only around 47 %. Ingot production capacity in China was 163,200 t in 2019.

Table 18: Global titanium sponge production between 2012 and 2018 in tonnes. Taken from various sources.

Country	2012	2013	2014	2015	2016	2017	2018
China	68,700[1)] 79,000[14)] 81,451[3)] 82,120[16)]	75,000[14)] 77,800[2)] 81,171[3)] 82,619[16)]	45,000[2)] 59,550[14)] 67,825[3)] 68,167[16)]	58,762[16)] 59,900[14)] 62,035[3)]	53,000[14)] 66,760[4)] 67,077[3)]	63,800[14)] 71,850[4)] 72,922[3)]	67,830[4)] 74,953[3)] 75,250[15)]
Ukraine	10,000[12)] 10,150[5)]	9220[5)]	7110[5)] 7215[8)]	7610[5)] 7700[8)]	4990[5)]	7180[5)]	7170[15)]
USA[6)]	18,000	12,530	18,530	18,500	10,000	9000	10,000
India[10)]	88	132	138	140	137	161	246
Russia	43,900[9)] 44,150[14)] 46,316[12)]	42,000[9)] 43,650[14)] 45,414[12)]	40,000[15)] 40,697[8)] 41,940[9)] 42,377[12)]	39,980[9)] 40,039[14)] 41,070[8)] 41,833[12)]	37,800[15)] 38,910[8)] 39,000[9)] 41,084[12)]	42,490[15)] 42,584[5)] 44,472[12)]	44,395[15)] 44,445[12)]
Japan	57,700[7)] 63,400[3)]	34,600[7)] 42,178[14)] 47,178[3)]	30,919[3)]	41,885[3)]	54,594[3)]	50,312[3)]	49,284[15)]
Kazakhstan	22,500[5)] 23,700[12)]	9400[5)] 12,000[15)]	6600[5)] 9000[8)]	7300[6)] 8100[5)] 8700[8)] 9200[15)]	7700[8)] 8000[5)]	8500[5)] 8700[15)] 11,000[11)]	15,500 16,500[15)]
Total min.	220,888	182,882	148,297	174,177	168,221	181,443	194,425
Total max.	243,774	209,093	176,346	181,293	185,882	195,047	202,895
Total[3)]	**238,551**	**204,663**	**173,471**	**178,620**	**184,508**	**196,495**	**202,459**

[1)] Asian Metal Annual Titanium Report Top 9 Producers only, [2)] Asian Metal Annual Titanium Report, [3)] Gehler (2019), [4)] Asian Metal Monthly Statistics, [5)] Metz (2018), [6)] USGS Minerals Yearbook, [7)] Imam (2016), [8)] US ITC (2017), [9)] Ministry for natural resources and environment of the Russian federation (various years), [10)] KMML Homepage, [11)] ITA (2018), [12)] ITA (2015), [13)] Sum PSC Corporation VSMPO-AVISMA according to ITA (2015, 2018) and OJSC "Solikamsk Magnesium Works" according to Annual Report (2018), [14)] Roskill (2018), [15)] Roskill (2019), [16)] revised data according to USGS 2016 Minerals Yearbook, n.a. = not available

Table 19: Global titanium metal (ingot and slab) production between 2012 and 2018 in tonnes. Taken from various sources.

Country	2012	2013	2014	2015	2016	2017	2018
China	64,927	62,200	57,000	48,646	60,700 or 66,500	71,022	75,049
Ukraine	1400	1300	1940	2820	2420	2450	2460
USA	68,800	65,900	55,800	61,800	66,200	82,100	85,000
Russia	53,700	54,700	53,400	53,200	51,100	53,300	59,900
Kazakhstan	7794	4970	3855	4193	5304	6240	6860
Japan	24,585	14,872	20,366	23,530	19,986	20,948	22,804
France[1)]	600	950	1300	1200	600	1500	3000
UK[2)]	5300	8800	3800	5200	7000	8000	700
Sweden[3)]	200	400	300	300	400	500	400
Italy[4)]	200	600	300	300	500	700	875
Romania[5)]	n. a.	500	200	200	700	500	500
India[6)]	200	300	300	200	400	400	600
South Korea[7)]	n. a.	2700	3600	2000	2100	2600	2400
Total	**~230,200**	**~218,200**	**~202,200**	**~203,600**	**~220,300**	**~250,300**	**~260,500**

According to Roskill (2019), production of titanium ingot in Essen/Germany by VDM Metals GmbH ceased in 2016.
[1)] Ingot capacity is 3000 tpa, [2)] Ingot capacity is 10,700 tpa, [3)] Ingot capacity is 1000 tpa, [4)] Ingot capacity is 3000 tpa, [5)] Ingot capacity is 1500 tpa. [6)] Ingot capacity is 1000 tpa, [7)] Ingot capacity is unknown

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Appendix A

Supply – Country profiles

AUSTRALIA

Heavy minerals, mineral sands or black sands as they are called in Australia, which include rutile and leucoxene, have been mined in Australia for over a century. Mining started along the east coast but shifted to the west coast some decades ago. Buried fossil strandlines in the South of Australia (Murray Basin, Eucla Basin) currently provide the majority of the Australian rutile output. Leucoxene, on the other hand, is mainly produced in Western Australia.

According to Geoscience Australia (Hitchman 2017), as of 31 December 2016 official proven and probable rutile reserves in Australia amounted to 6.7 million tonnes (Mt) with a reserve life of 22 years. Rutile reserves have doubled over the last 15 years from 3.4 Mt in 2002 to the figure given above in 2016. Official economic demonstrated (measured and indicated) rutile resources (including reserves) in Australia were 33.0 Mt as of 2016, of which 88 % were accessible for mining. Over the last 40 years economic demonstrated rutile resources have increased by 260 % from 9.2 Mt in 1975 to 33.0 Mt in 2016. Additional inferred rutile resources were 34.1 Mt. Peak production of rutile was achieved in 2011 with 470,000 tonnes. This fell to 300,000 tonnes in 2016. [Our figure: 214,000 tonnes]. 217,000 tonnes of rutile concentrate was exported.

Currently, there are five producers of rutile, leucoxene, HiTi or rutile-rich mineral concentrates in Australia mining ten different deposits:

- Iluka Resources Ltd.,
- Tronox Australia Pty Ltd.,
- Doral Mineral Sands Pty Ltd.,
- Image Resources NL,
- GMA Garnet Pty Ltd.

There also are numerous other companies hoping to be able to commission new HM deposits containing rutile or leucoxene in the foreseeable future including:

Astro Resources NL
- Astron Corporation Ltd.
- Broken Hill Prospecting Ltd.
- Diatreme Resources Ltd.
- Image Resources NL
- Kalbar Resources Ltd.
- Murray Zircon Pty Ltd.
- Oresome Australia Pty Ltd.
- Relentless Resources Ltd.
- Sheffield Resources Ltd.
- Standline Resources Ltd., formerly Gunson Resources Ltd.
- Strategic Energy Resources Ltd.
- VHM Ltd.
- WIM Resource Pty Ltd.

Astro Resources NL is based in Sydney and focuses on the exploration of the Governor Broome project located within the Augusta region of south-west Western Australia. As of 2020, Governor Broome contained indicated resources of 52 Mt ore sand at a grade of 4.6 % HM of which 5.4 % is secondary ilmenite, 5.0 % is leucoxene and 1.6 % is rutile in the North Deposit. There is no information about any possible start of mining yet.

The Astron Corporation Ltd. is based in Hong Kong and owns the Donald mineral sands project in the Murray Basin of Victoria, combining the Jackson (formerly known as WIM 200) and Donald (formerly known as WIM 250) HM deposits. As of 2016 resources in the huge Donald project area stood at 5712 billion tonnes of ore sand at an average grade of 3.2 % although very fine HM. The average grade of rutile+anatase within the HM suite is 8 % while the leucoxene grade is 18 %. This is equivalent to a content of 183 Mt of HM or 14.6 Mt of rutile/anatase and 32.9 Mt of leucoxene respectively. The HM concentrate (HMC) produced is processed in China. Many of the approvals necessary for mining have already been granted but metallurgical and geotechnical test work on bulk samples continues.

Broken Hill Prospecting Ltd. (BPL) is based in Sydney and, among engaged in exploration of other commodities, focuses on developing HM deposits in the Murray Basin where it holds very large tenements in Victoria and South Australia. BPL is aiming to establish a sustainable pipeline for high grade, relatively low tonnage HM deposits amendable to processing through mobile plant equipment. So far inferred resources have only been determined for the Jaws and Gilligans deposits with a total of 113 Mt of ore sand at a grade of 1.8 % HM of which 26 % is rutile and 23 % is leucoxene of different magnetic susceptibilities.

Diatreme Resources Ltd. is based in Coorparoo, QLD. Among others the company intends to develop the Cyclone HM deposit in the western part of the Eucla Basin (Western Australia). The Cyclone deposit consists of the Cyclone and the Cyclone Extended deposits with combined resources of 203 Mt of ore sand with 2.3 % HM on average (4.7 Mt HM content) of which 3 % is rutile, 6 % is leucoxene and 26 % is HiTi (i.e. titanium minerals containing 70–95 % TiO_2). Included are probable ore reserves of 138 Mt ore sand with 2.6 % HM on average (3.52 Mt HM content) of which 3 % is rutile, 7 % is leucoxene and 23 % is HiTi.

According to the Definite Feasibility Study (DFS) as of 2018, each year some 147,700 tpa of HMC shall be produced and shipped to China via Port Adelaide for final processing. Average HMC production for the first four years will be approx. 167,500 tonnes, however. It is suggested that on average 9180 tpa of HiTi 87 titanium product (86.6 % TiO_2) will be produced together with 58,790 tpa of zircon and 48,650 tpa of HiTi 67 titanium product (67.3 % TiO_2). The current anticipated mine life is 13.2 years. All necessary approvals are in place. Mining could therefore start any time after financing has been secured following a two-year construction period.

Kalbar Resources Ltd. is based in Bairnsdale, VIC. In 2013, it acquired the Gippsland mineral sands project from Rio Tinto which included the very large Glenaladale deposit in Victoria. Since then, Kalbar geologists have discovered and defined a new, high-value ore body within the Glenaladale deposit that is now the focus of the Fingerboards project. While the Glenaladale resource currently stands at 2,740 Mt of ore sand at a grade of 1.95 % HM of which 13.7 % is rutile and 5.7 % is leucoxene, Fingerboards represents the most economic and mineable ore within the area. As of 2017 the Fingerboards area contained total resources of 1190 Mt of ore sand. Within this resource the probable reserves were 173 Mt of ore sand.

Currently Kalbar Resources is undertaking a Bankable Feasibility Study including further technical and economic studies. Preliminary plans are to mine 170 Mt of ore sand per annum for about 15 years with a production of some 550 kilotonnes per annum (ktpa) of HMC. This concentrate will be processed in China (or Thailand) yielding 21 ktpa of rutile (92 % TiO_2) among others. HM production could start in 2022 with 300 kt of HMC being produced in the first year.

Murray Zircon Pty Ltd., based in Adelaide, is an experienced mineral sands mining company formed in 2011 as a joint venture between Guangdong Orient Zirconic Ind Sci & Tech Co., Ltd. of China (65 %) and Australian Zircon NL (35 %). Murray Zircon's principal asset is the Mindarie mineral sands project located 150 km east of Adelaide. Mindarie was originally mined by Australian Zircon Ltd. from April 2007 to September 2009 when the company went into administration. Mining recommenced in October 2012 and was halted again in March 2015 due to continually falling commodity prices throughout this second operating period. HMC from Mindarie was exported to China for separation into final HM products including rutile. As of 2016, the remaining probable reserves of Murray Zircon at Mindarie and other projects in the Murray Basin amounted to 48.1 Mt of ore sand at a grade of 3.7 % HM of which 5.0 % is rutile and 6.5 % is leucoxene. Resources as of 2016 were 243.9 Mt of ore sand with a content of 7.48 Mt HM of which 5.0 % is rutile and 7.4 % is leucoxene.

Murray Zircon Pty Ltd has also been appointed to manage the well-known WIM 150 project which was the first big HM discovery in the Murray Basin. The WIM 150 project is currently a joint venture between Orient Zirconic Pty Ltd and Million Up Ltd., a Hong Kong based investment fund. The WIM 150 Project is a proposed mineral sand mine and associated processing facility located in the Wimmera region of western Victoria approximately 20 km south-east of Horsham and 280 km north-west of Melbourne. Extensive technical and environmental studies including a Bankable Feasibility Study and subsequent Optimisation Studies have been carried out on the WIM 150 project by the previous owners. As of 2013 WIM 150 contained total resources of 1650 Mt of very fine ore sand at a grade of 3.7 % HM (20–75 µm) of which 11.7 % is rutile and 6.0 % is leucoxene. Within this resource reserves of 582 Mt of ore sand at a grade of 4.3 % HM (24.0 Mt HM content) have been established. The HM assemblage of the reserve contains 11.7 % rutile and 5.9 % leucoxene, among others.

Ozore Resources Pty Ltd. and Oresome Australia Pty Ltd. Oresome Australia is a fully owned subsidiary of Metallica Minerals Ltd. located in East Brisbane while Ozore Resources Pty Ltd. belongs to a private Chinese investor who has provided funding to Metallica Minerals to develop the Cape York for a 50 % share in the project. The Cape York mineral sands project area covers some 2000 km^2 and encompasses the shallow Urquhart Point deposit about 3 km southwest of Weipa. The proven reserves in this deposit are 967 kt of ore sand at 10.6 % HM of which around 13 % is rutile. Probable reserves include an additional 210 kt of ore sand at 4.8 % HM (12 % rutile). Total resources are 3.1 Mt of ore sand containing a total of 184 kt of HM of which 18,700 kt is rutile. It is estimated that the project will produce 87 ktpa of HMC at an average grade of 14.8 % zircon, 17.3 % rutile and 16.2 % ilmenite. The life of mine will be about five years. However, the further development of the Urquhart Point HM project is currently on hold.

Based in Sydney, **Relentless Resources Ltd.** is a potential HM mining company focused on developing HM projects in the Northern Murray Basin. Its flagship project is the Copi deposit in New South Wales which could be developed together with the neighbouring Sunshine deposit and the Sunshine extensions. No reserve figures are currently available but the total indicated and inferred resources of these deposits as of 2019 were 57.4 Mt of ore sand at an average grade of 4.0 % HM of which about 11 % is rutile and 10 % is leucoxene. Relentless Resources aims to start production from the Copi project in mid 2021. The Magic deposit some 50 km north contains inferred resources of 15.0 Mt of ore sand at a grade of 3.7 % HM of which 14 % is rutile and 10 % is leucoxene. The Magic deposit is planned for development in 2022. The Springwood deposit a little further south contains inferred resources of 3.0 Mt of ore sand at 3.0 % HM of which 6.6 % is rutile and 7 % is leucoxene. Development could start after 2024.

Sheffield Resources Ltd. is another company based in West Perth and holds titles over many HM tenements mainly in Western Australia.

Sheffield's flagship project is the zircon-rich Thunderbird mineral sands project which is located on the Dampier Peninsula midway between Broome and Derby in the Canning Basin of Western Australia. Total reserves stand at 748 Mt of ore sand at a grade of 11.2 % HM of which 2.4 % is leucoxene at 70 – 94 % TiO_2 and 2.4 % is HiTi leucoxene at > 94 % TiO_2 while the total mineral resource contains 3230 Mt of ore sand at 6.9 % HM of which 2.9 % is leucoxene and 2.6 % is HiTi leucoxene. Thus, total HiTi resources include 2.7 Mt of leucoxene and 3.0 Mt of HiTi leucoxene. After delivering an Updated Bankable Feasibility Study in July 2019 and fully permitted Sheffield Resources is planning for production in H2 2021 with a 37-year mine life. Products for sale no longer include a HiTi (leucoxene) product (88 % TiO_2, cf. Appendix C for analyses) which now is planned to report to the non-mag concentrate.

The Night Train HM deposit lies 20 km south of the Thunderbird deposit and as of 2019 contained inferred resources of 130 Mt of ore sand at a grade of 3.3 % HM of which 46 % is leucoxene (70 – 90 % TiO_2), 5.4 % is rutile and HiTi leucoxene combined (> 90 % TiO_2). Thus, total inferred resources are around 1.9 Mt of leucoxene and 220 kt of rutile/HiTi leucoxene.

Located near Geraldton in Western Australia's mid-west region, the Eneabba HM project has a combined mineral resource of 193.3 Mt of ore sand at a grade of 3.0 % HM of which 6.8 % is rutile (> 95 % TiO_2) and 4.2 % is leucoxene (85 – 95 % TiO_2). Thus, total HiTi resources include 392 kt of rutile and 242 kt of leucoxene. This project is spread across seven deposits: West Mine North, Ellengail, Yandanooka, Durack, Drummond Crossing, Thomson and Robbs Cross. Sheffield's strategy at Eneabba is to accumulate deposits capable of supporting a sequential mining operation with a flexible mobile plant.

The McCalls HM project, located 110 km to the north of Perth near the town of Gingin, has a mineral resource totalling 5800 Mt of ore sand at a grade of 1.4 % HM of which 2.4 % is rutile and 3.1 % is leucoxene. Thus, total HiTi resources include 2020 kt of rutile and 2570 kt of leucoxene. The McCalls project contains two different deposits, McCalls and Mindarra Springs, and is considered a long-term strategic asset.

Strandline Resources Ltd. (formerly Gunson Resources Ltd.) is a junior exploration company based in West Perth. The company is focused on nickel and HM projects with HM projects under various stages of development in Western Australia and more recently in Tanzania. Located about 700 km north of Perth in Western Australia, the Coburn fossil dune HM deposit lies very remote from any settlements or infrastructure on the edge of the Shark Bay World Heritage area. Although Gunson Resources was required to put the complete project through a lengthy environmental review process two thirds of the major HM deposit, known as the Amy Zone, have governmental approval for mining. As of 2019, this area had reserves of 523 Mt of ore sand averaging 1.11 % HM (5.83 Mt HM content) of which 7 % is rutile and 5 % is leucoxene. Resources including reserves as of 2018, amounted to 1606 Mt of ore sand at an average grade of 1.26 % HM (cut-off grade 0.8 % HM) containing 19.6 Mt of HM (7 % rutile, 5 % leucoxene). However, applying slightly higher cut-off grades, the reserves and resources decrease drastically. Once financing is secured, construction could start with an envisaged average production of 100 ktpa of ilmenite (62 % TiO_2), 24 ktpa of rutile (93 % TiO_2), 34 ktpa of premium zircon and 54 ktpa of zircon-titanium mineral-monazite concentrate. Start of production is currently targeted for 2022. The estimated mine life is 22.5 years.

Strategic Energy Resources Ltd. is an Australian junior exploration company with interests in the HM mining sector. As of 2018 its Ambergate HM deposit south of Busselton in WA held inferred resources of 11.2 Mt of ore sand at an average grade of 5.1 % HM (569 kt HM content) of which 12 % is leucoxene (68 kt).

VHM Ltd. was established in 2014 as an Australian owned and operated unlisted public mineral sands mine development company. It focuses on developing the Goschen HM project in northern Victoria which, as of 2020, held total resources of 1094 Mt of ore sand at a grade of 2.7 % HM (29.7 Mt HM content) of which 9.5 % is rutile and 10.1 % is leucoxene. The main products of the proposed mine will be zircon (24 %) and monazite/xenotime (5 %), however. Probable reserves have been calculated at 230.5 Mt of ore sand at a grade of 3.3 % HM of which 10.1 % is rutile and 8.5 % is leucoxene. Start of production could be in 2023 with a proposed production rate of 2.5 Mt of ore sand or > 210 kt HMC per annum.

WIM Resource Pty Ltd. is a HM project development company based in Sydney. It owns three HM projects in the Murray Basin in Victoria. Avonbank is the most important of the three. As of 2018 Avonbank contained total reserves of 312 Mt of ore sand at 4.3 % HM and is part of a larger total resource of 490 Mt of ore sand at 4.0 % HM of which 16 % is rutile and 8.8 % is leucoxene. This project is currently being modelled to produce > 450 ktpa of HMC over its initial mine life of 30 years. WIM Resource hopes to bring the Avonbank project on line by 2023 with zircon and monazite/xenotime as the main products of interest and all the HMC exported to China for further processing.

The Bungalally HM project lies south of Avonbank and is at an earlier exploration stage with inferred resources of 205 Mt ore sand at a grade of 2.7 % HM of which 17 % is leucoxene and 14 % is rutile/anatase. The Wedderburn project lies much further to the north-west and has a resource estimate of 223 Mt of ore sand at 2.3 % HM of which 16.8 % is leucoxene and 14.2 % is rutile/anatase.

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Based in Perth, Australia, Iluka Resources Ltd. is the world's largest producer of HM (heavy minerals) including rutile. The company was formed in December 1998 following the merger of Westralian Sands Ltd. and Rension Goldfields Consolidated (RGC) Minerals Sands Ltd. At the time of the merger, Westralian Sands owned mining operations at Capel in Western Australia while RGC owned mining and processing operations at Eneabba, Capel, and Narngulu in Western Australia as well as in the US.

In addition to its mineral sand operations, which involve mining and processing, Iluka maintains warehouses in Europe, the US and China. Until 2009, Iluka also had a majority shareholding in Consolidated Rutile Ltd. but sold its stake in this HM mining company to Unimin Australia Ltd. (cf. Sibelco Australia and New Zealand) in May of that year. Iluka acquired Sierra Rutile Ltd., the world's largest rutile producer, at the end of 2016.

Iluka currently mines HM in Western Australia and in the Eucla Basin in South Australia.

Western Australia

Before the start of mining in the Murray and Eucla Basins, Iluka's Australian operations were traditionally in the mid-west and south-west of Western Australia. Until April 2010, the Mid-West operations consisted of integrated mining, processing and upgrading facilities at Eneabba, 85 km north of Perth, and at Narngulu near Geraldton. The Narngulu mineral separation plant (MSP) consists of two separate plants, has a total capacity of 1200 ktpa of HMC and was recently upgraded to be able to process fine HMC from the Eucla Basin as well as coarser material from the new Cataby deposit. The huge Eneabba HM deposit was discovered in 1970 and mining commenced in 1974. In mid-2010, the Eneabba deposit was put on care and maintenance for various reasons but in July 2011, due to better market conditions, it was announced that it would be reopened in December 2011 to produce 25 ktpa of zircon, 25 ktpa of rutile and 140 ktpa of ilmenite for another three years. Mining of additional ore reserves at Eneabba was planned to commence in 2014 (IPL North) and 2016 (South Tails and Allied Tails) which could have extended mine life by approx. another ten years. However, at the end of 2012, the decision was made to idle the Eneabba operations again from March 2013. Mining has not restarted since although there are definite plans to extract monazite and xenotime from the historic tailings. As of 31 December 2019, reserves of this mineral sands recovery project stood at 1.0 Mt of sand at a grade of 82.7 % HM (830 kt HM content) of which 34 % is ilmenite, 26 % is zircon, 19.5 % is monazite and 1.2 % is xenotime.

In addition to Eneabba, 1.4 Mt of HM were mined at Gingin between mid 2005 and May 2009.

Approximately halfway between Perth and Narngulu is the Cataby deposit where Iluka had hoped to commence mining as early as 2014. In fact, mining did not start until June 2019. As of 31 December 2019, the Cataby HM deposit contained reserves of 117 Mt of ore sand at a grade of 5.8 % THM of which 60.4 % is ilmenite, 9.1 % is zircon and 4.1 % is rutile. Resources (including reserves) stood at of 308 Mt of ore sand at 4.5 % THM of which 3.9 % is rutile. The mine is expected to produce 370 ktpa of chloride ilmenite, 50 ktpa of zircon and 30 ktpa of rutile over a mine life of +8.5

Figure 13: Preparation for mining at Cataby in 2018. Source: Iluka Resources Ltd.

years. Access to additional ore reserves could extend mine life by a further four years. Ilmenite sourced from Cataby is transported to Capel (cf. below) for synthetic rutile production (approx. 200 ktpa) and the non-magnetic stream to the Narngulu MSP for final processing into rutile and zircon.

The South-West operations consist of processing facilities and until 2018 mining activities around Capel some 200 km south of Perth. Recently mined HM deposits were the Cloverdale deposit, which was closed in September 2008, followed by the Wagerup deposit in January 2009 and the Waroona deposit in September 2009. They were succeeded by the Tutunup South deposit, which was opened in June 2011 and closed in February 2018. Synthetic rutile production at Capel commenced in 1987 (SR1) followed by a second synthetic rutile kiln in 1997 (SR2). SR1 was idled in 2009 but may be restarted in the future. SR2 was idled between March 2013 and restarted in April 2015. It is currently operating at full capacity and being fed by ilmenite from Cataby. The synthetic rutile from Capel is shipped from the Port of Bunbury 35 km to the north.

Meanwhile, Iluka has some more HM projects in the pipeline in this south-west area comprising the Capel South, Elgin, Scotts, Tutunup and Yarloop deposits with a total of 83.0 Mt of ore sand containing some 74 kt of rutile.

As of 31 December 2019, resources (including reserves) held by Iluka in the Perth Basin of Western Australia stood at 994 Mt of ore sand at 5.6 % HM on average (55.6 Mt HM content) of which 5 % is rutile. At the same time, reserves held by Iluka in the Perth Basin stood at 144 Mt of ore sand at an average grade of 7.2 % HM (10.4 Mt of HM content) of which 3 % is rutile.

Murray Basin

The Murray Basin stretches from South Australia to Victoria and New South Wales. All of Iluka's previous operations were located in the State of Victoria. Iluka started mining in the southern Murray Basin at the Bondi deposits (Bondi Main, Bondi East, and Bondi West) near Douglas (March 2006 – January 2012) followed by the Echo deposit. The Echo mine operated as a satellite deposit adjacent to the bigger and older Douglas operations from March 2010 to September 2011.

The Kulwin HM deposit in the northern part of the Murray Basin was the first to be developed. It commenced production in October 2009 and ceased production in February 2012. Mining and concentrating activities commenced at the Woornack, Rownack and Pirro (WRP) group of deposits in May 2012 and ended in March 2015.

For many years feasibility work has been underway for the potential development of the large rutile-rich Balranald deposit in New South Wales. The Balranald site includes two deposits, West Balranald and Nepean. West Balranald was discovered in 1998 and is a high-grade HM deposit located approximately 12 km from the township of Balranald and 510 km by road from the Hamilton MSP (cf. below). The deposit is approximately 20 km long, between 80 and 300 m wide and is located 50 to 70 m below the surface. The thickness of the ore sand ranges from 5 to 7 m. The Nepean deposit is located approximately 30 km to the north of the West Balranald deposit. Combined resources of both deposits stand at 45.5 Mt of ore sand at an average grade of 33.6 % HM (14.4 Mt HM content) of which 12.4 % is rutile. Based on current estimates, the mining operation is expected to have a potential economic life of at least 10 years if both deposits are developed sequentially. Iluka is pursuing an innovative, unconventional approach to this development with a mining method based on directional drill technology. Advantages of this approach include the ability to access these deep deposits, a minimal environmental footprint versus conventional mining, potentially lower capital intensity, scalable operations and portfolio flexibility. Iluka is currently taking a staged approach to potential production start-up in 2022. Balranald has the potential to produce 170 kt of rutile, 130 kt of zircon and 450 kt of sulphide and chloride ilmenite per annum. Following this, the development of a series of other deposits, referred to as the Euston group of deposits (106.4 Mt of ore sand at 19.7 % HM) is possible.

Output from the former Murray Basin mines of Iluka was transported by road to Hamilton where a mineral separation plant had produced ilmenite, rutile and a premium grade zircon since February 2007. Cassiterite-rich and magnetite concentrates had also been produced as by-products from the southern deposits. Mineral products from Hamilton were trucked to the port of Portland 85 km to the south or in containers to Melbourne. The Hamilton MSP was idled in October 2017 after the last Murray Basin HMC stockpiles had been processed.

As of 31 December 2019, resources held by Iluka in the Murray Basin stood at 195 Mt of ore sand at an average grade of 17.2 % HM (33.4 Mt HM content) of which 17 % is rutile.

Eucla Basin

In November 2009, Iluka produced the first commercial HMC from Jacinth-Ambrosia which was discovered in 2004 and is still the world's highest-grade zircon deposit. Comprising two contiguous deposits, Jacinth and Ambrosia are located in the Eucla Basin of South Australia, approximately 800 km from Adelaide and 270 km from the Port of Thevenard near the township of Ceduna. The average thickness of overburden at Jacinth-Ambrosia is approximately 8 m. The ore thickness ranges from 20–45 m.

Due to subdued demand especially for zircon Jacinth-Ambrosia was idled in April 2016 but resumed operations in December 2017. The HMC from this mine is sent by triple road trains with a capacity of 90 tonnes each to the Port of Thevenard for shipment to Geraldton and Iluka's Narngulu MSP or, if necessary, to the Port of Portland for processing at Hamilton.

As of 31 December 2019, Jacinth-Ambrosia contained resources of 184 Mt of ore sand with an average grade of 2.3 % HM (4.2 Mt HM content) of which 4.7 % is rutile. Reserves included in these resources were 87 Mt of ore sand at 2.9 % HM (2.6 Mt HM content) of which some 47.2 % is zircon but only 4.7 % is rutile.

In addition to Jacinth-Ambrosia, there are some other noteworthy HM deposits in the Eucla Basin which Iluka hopes to develop in the more distant future. The most interesting ones are:

- Tripitaka was discovered in 2005 and contains inferred resources of 39.5 Mt of ore sand at a grade of 2.3 % HM (0.91 Mt HM content) of which 5 % is rutile but 65 % is zircon.
- Typhoon, discovered in 2007 and situated 4 km south-east of Jacinth-Ambrosia, contains inferred resources of 22.0 Mt of ore sand at 6.1 % HM (cut-off grade 3 % HM), i.e. 1.34 Mt HM content of which only 1 % is rutile. The thickness of overburden at Typhoon is between 5 and 27 m.
- Atacama, discovered in 2011 and located about 9 km north-east of Jacinth-Ambrosia, contains resources of 73 Mt of ore sand at 12.0 % HM (8.7 Mt HM content) of which 1.9 % is rutile.

Figure 14: Mining at Jacinth-Ambrosia. Source: Iluka Resources Ltd.

– Sonoran was discovered in 2012 and is located 9 km south-east of Jacinth-Ambrosia. This deposit contains 30.1 Mt of ore sand at 7.3 % HM (cut-off grade 3 % HM) of which 2 % is rutile. The thickness of overburden varies between 20 and 45 m.

As of 31 December 2019, resources (including reserves) held by Iluka in the Eucla Basin stood at 361 Mt of ore sand at an average grade of 4.8 % HM (17.4 Mt HM content) of which 26 % is zircon but only 3 % is rutile. As of 31 December 2019, reserves held by Iluka in the Eucla Basin stood at 87 Mt of ore sand with an average of 2.9 % HM (2.6 Mt HM content) of which 47 % is zircon but only 5 % is rutile.

Currently, Iluka only produces natural high-grade titanium products in its Narngulu MSP, i.e. a standard-grade rutile from Cataby and a Eucla Basin HiTi product (from Jacinth-Ambrosia). A leucoxene concentrate from the former Capel mine and a rutile concentrate from the former Eneabba mine were also available for analyses (cf. Appendix C).

Table 20: Production of natural rutile, HiTi and synthetic rutile by Iluka Resources Ltd. in Australia [in tonnes]. Taken from Iluka Annual Reports/quarterly Reviews December and personal company information. WA = Western Australia, MB = Murray Basin, EB = Eucla Basin

<table>
<tr><th></th><th></th><th>2012</th><th>2013</th><th>2014</th><th>2015</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th></tr>
<tr><td rowspan="2">WA</td><td>Tutunup South (HiTi)</td><td>23,100</td><td>17,000</td><td>200</td><td>8800</td><td>8900</td><td>7100</td><td>3700</td><td>–</td></tr>
<tr><td>Cataby (Rutile)</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>15,600</td></tr>
<tr><td rowspan="3">MB</td><td>Bondi (Rutile)</td><td rowspan="3">170,300</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Kulwin (Rutile)</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Woornack,
Rownack, Pirro (Rutile)</td><td>93,700</td><td>147,500</td><td>96,600</td><td>62,300</td><td>92,700</td><td>–</td><td>–</td></tr>
<tr><td rowspan="2">EB</td><td>Jacinth-Ambrosia (HiTi)</td><td>26,900</td><td>16,300</td><td>29,500</td><td>31,100</td><td>37,600</td><td>34,700</td><td>38,000</td><td>31,200</td></tr>
<tr><td>Capel (synthetic rutile)</td><td>248,300</td><td>59,000</td><td>–</td><td>164,900</td><td>210,900</td><td>210,800</td><td>219,900</td><td>196,200</td></tr>
</table>

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In September 2011 the owners of the former Tiwest JV, Tronox Western Australia Pty Ltd. and Exxaro Australia Sands Pty Ltd. announced a definitive agreement under which the TiO_2 producing company Tronox Ltd. would acquire Exxaro's mineral sands operations in South Africa and Australia. This included Exxaro's 50 % interest in the Tiwest JV. The transaction was completed in June 2012. In February 2017 Tronox Ltd. announced another definitive agreement to also acquire the TiO_2 business of Cristal, a privately held global chemical and mining company with headquarters in Jeddah, Kingdom of Saudia Arabia. This acquisition received all regulatory approvals in April 2019.

Before the takeover of the assets of Cristal Mining Australia (cf. below), Tronox' mineral sands operations in Western Australia (**Northern Operations** as of 2019) comprised:

- a mineral sands mine at Cooljarloo near Cataby, 170 km north of Perth
- a dry separation plant and synthetic rutile plant at Chandala, 60 km north of Perth
- a chloride process TiO_2 pigment plant at Kwinana, 30 km south of Perth
- a storage facility at Bunbury Port and Henderson, 25 km south of Perth
- corporate offices in Bentley near the centre of Perth.

Dredge mining at Cooljarloo began in 1989 with dry mining following from 1996–2015. The life of mine including all extensions is about 38 years. At Cooljarloo two dredges feed one floating wet mill. The HMC is transported from the wet mill 110 km south to a dry separation plant at Chandala. The MSP at Chandala has an annual processing capacity of about 780 kt HMC with ilmenite (62 % TiO_2), leucoxene (92 % TiO_2, 27 ktpa capacity), three different zircon grades (70 ktpa capacity), premium rutile (23 ktpa capacity) and staurolite (7 ktpa capacity) being produced. The capacity of the synthetic rutile (90 % TiO_2) plant at Chandala is about 260 ktpa.

As of 31 December 2019, Tronox reported remaining proven and probable reserves at Cooljarloo of 286 Mt of ore sand at a grade of 1.8 % THM (5.1 Mt HM content) of which 7.6 % is rutile (about 4.4 %) and leucoxene (about 3.2 %). The Kestrel, Harrier and Woolka ore bodies at Cooljarloo West project comprise probable reserves of 130 Mt of ore sand at 2.0 % THM (2.1 Mt HM content) of which 8.3 % is rutile and leucoxene.

Tronox is also the license owner of the Jurien and the Dongara projects with all mining rights in place. Jurien is located 266 km north of Perth, was discovered in 1971 and was partially mined by Western Mining Corp. Ltd. in the mid-1970s. It has been dormant ever since with the exception of some stockpiled tailings which were processed during the 1990s. As of the end of 2011, Jurien contained reserves of 15.7 Mt of ore sand at 7.9 % THM of which 7.5 % is rutile and 2.7 % is leucoxene. Resources at Jurien stood at an additional 25.6 Mt of ore sand at 6.0 % THM. The Dongara project was acquired by Exxaro Resources in 2003 and transferred to the Tiwest JV two years later. The proposed mining area is located approximately 25 km south-east of the town of Dongara and 30 km north of Eneabba. As of 31 December 2019, it had proven reserves of 68 Mt of ore sand at 5.1 % THM (3.5 Mt of HM content) of which 8.9 % is rutile (about 6.9 %) and leucoxene (about 2.0 %).

As of 31 December 2019, HM reserves at Tronox Northern Operations were 484 Mt of ore sand

Figure 15: Floating wet mill at Cooljarloo. Photo BGR.

with an average of 2.3 % HM (10.9 Mt HM content). Included in the in-ground HM reserves were approximately 6.2 Mt of ilmenite, 1.2 Mt of zircon and 890,000 combined tonnes of rutile and leucoxene.

Former BEMAX Resources Ltd. was incorporated in Australia in 1987 and listed on the Australian Stock Exchange in 1990. In 1990 BEMAX also bought RZM Cable Sands which was the first company to produce mineral sands in Western Australia. In 2008 Cristal Australia Pty Ltd., a wholly owned subsidiary of The National Titanium Dioxide Company Ltd. of the Kingdom of Saudi Arabia, acquired all of the shares in BEMAX via an off-market takeover bid and the company was removed from the official list of the Australian Stock Exchange. In October 2012 BEMAX Resources Ltd. became Cristal Mining Australia Ltd. In April 2019 the TiO_2 division of Cristal, including its Australian mining subsidiary Cristal Mining Australia Ltd., was taken over by Tronox Ltd. (cf. above) with internal restructuring still in progress.

The company's operations in the Murray Basin include the Ginkgo and Snapper mines and a min-

Table 21: Production of rutile (including leucoxene) at Cooljarloo and synthetic rutile in Chandala in tonnes by Tronox. Taken from Tronox SEC Filings/Annual Reports.

Northern Ops	2012	2013	2014	2015	2016	2017	2018	2019
Cooljarloo[1)]	48,000	58,000	65,000	57,000	32,000	28,000	24,000	28,000e
Chandala – SR	221,000	232,000	217,000	227,000	233,000	243,000	211,000	240,000e

[1)] The ratio of leucoxene:rutile was about 1:4 in 2018 and was expected to be 1:3 in 2019.

eral separation plant at Broken Hill in western New South Wales (**Western Operations** as of 2019). Located 220 km from Broken Hill, the Gingko mine opened in December 2005 and was the first commercial mineral sand mining operation in the Murray Basin of NSW. Discovered in 1998, the mine exploits a 14 km long, deep-lying HM deposit containing initial reserves of 184 Mt of ore sand at 3.0 % HM of which around 12 % is rutile and 11 % is leucoxene. The former BEMAX Resources Ltd. stated individual mineral reserves to be 2528 kt of ilmenite, 1082 kt of leucoxene, 684 kt of rutile and 546 kt of zircon. Remaining reserves (excl. Crayfish, cf. below) as of 31 December 2018 were 30.0 Mt of ore sand at a grade of 2.0 % HM (586 kt HM content) (Tronox Australia Pty ltd., pers. comm.). Additional initial measured resources were 162 Mt of ore sand at 3.6 % HM which, as of 31 December 2018, had been reduced to 43.7 Mt of ore sand at 2.0 % HM (882 kt HM content). As a result of a major incident involving the Ginkgo concentrator on 15 September 2018, no ore was processed by the concentrator until 11 August 2019.

In February 2006 processing of HMC began at the Broken Hill MSP. Current production at Broken Hill are an ilmenite (BHT at 57 % TiO_2) and a secondary ilmenite (BHI at 63 % TiO_2) product for final sale through Port Adelaide, as well as a zircon/rutile-rich non-magnetic concentrate sent to Bunbury in Western Australia for final processing into zircon, rutile (95 % TiO_2) and leucoxene (69–70 % TiO_2) products. The Gingko mine including its Crayfish extension (2.2 Mt of HM, containing 19 % rutile and 6 % leucoxene), where mining has not commenced yet, is expected to be shut down in 2022.

The Snapper mine is 10 km from the Gingko mine. Initial proven reserves at Snapper were 117 Mt of ore sand at an average grade of 5.0 % HM of which 16 % was rutile and 9 % was leucoxene. Individual mineral reserves stated were more than 2700 kt of ilmenite, 538 kt of leucoxene, 948 kt of rutile and 563 kt of zircon. As of 31 December 2018, reserves were 20.5 Mt of ore sand at 2.8 % HM (566 kt HM content). At the same date resources were 29.2 Mt of ore sand at 3.3 % HM (976 kt HM content) (Tronox Australia Pty Ltd., pers. comm.).

The construction of all mine equipment and facilities was completed by the end of 2010 and operational commissioning commenced in January 2011. The Snapper mine is operated together with the Gingko mine and is expected to be depleted in 2021.

Tronox is planning to establish a further mine in the Murray Basin referred to as the Atlas-Campaspe. Atlas-Campaspe is located 80 km north of Balranald and approximately 270 km south-east from Broken Hill. It is a double ore body deposit with Atlas containing indicated resources of 11 Mt of ore sand at 15.4 % HM, and Campaspe containing 99 Mt of ore sand at 4.7 % HM of which 12 % is rutile. Total reserves of Atlas-Campaspe as of 31 December 2019 stood at 88 Mt of ore sand at 6.5 % HM (5.7 Mt HM content) of which 16.0 % are rutile and leucoxene. Atlas-Campaspe was licensed in 2014 to extract up to 7.2 Mt of ore sand and produce 450 kt of mineral concentrate for each year of its planned mine life of 11–20 years. Mining is planned to start in 2021 at the earliest.

In the past Tronox **Southern Operations** were operated through wholly owned subsidiaries that made up the Cable Sands Group. Many of the operations ran by Cristal Mining or Cable Sands in Western Australia were relatively small and had operating lives of just a few years. Former mines operated by Cristal Mining in that region were the Tutunup and the Ludlow mines. Both were replaced in early 2008 by the Gwindinup mine comprising the Gwindinup North and Gwindinup South deposits and extending through to the Happy Valley North and South deposits. The latter Gwindinup South and Happy Valley South deposits were opened in 2010 and closed at the end of October 2012. The current Wonnerup mine was opened in May 2013 with the Wonnerup South extension opening in November 2017 and the Wonnerup North extension following in May 2019. It is assumed that all mining at Wonnerup will stop in 2027 due to depletion of resources.

The Wonnerup deposit is ilmenite-rich. As of 31 December 2019, the reserves at Wonnerup Central and North were 21 Mt of ore sand, grading 5.5 % HM, i.e. 1155 kt HM, however, of which only 0.8 % was rutile, but 16.1 % was leucoxene. As of the end of 2018 remaining resources were 49.8 Mt of ore sand at 5.0 % HM (2499 kt HM content) (Tronox Australia Pty Ltd., pers. comm.).

The initial measured resource of the Wonnerup South HM deposit was 3.8 Mt ore sand at a grade of 6.0 % HM. The average mineral suite of VHM in Wonnerup South was 73.9 % ilmenite, 6.9 % secondary ilmenite, 7.5 % leucoxene and 9.9 % zircon.

The ores at Wonnerup are extracted using conventional dry mining techniques. The HMC is then transported from the mine to the company's North Shore MSP at Busselton where it is separated into individual constituent mineral products, i.e. two grades of ilmenite (52–55 % TiO_2 and > 60 % TiO_2), leucoxene (> 87 % TiO_2), zircon and monazite-enriched zircon tailings.

The Bunbury MSP currently produces three HiTi products: a rutile from Gingko/Snapper, a leucoxene from Gingko/Snapper and a leucoxene from Wonnerup (cf. Appendix C for analyses).

Besides the titanium minerals ilmenite, leucoxene and rutile, which are entirely used as internal feedstock for the production of titanium dioxide pigment, Tronox also produces various grades of zircon and staurolite, which is used as an abrasive.

Table 22: Production of titanium minerals by former Cristal Mining Ltd. (now Tronox Australia Pty. Ltd.) in the Murray Basin (MB) and in Western Australia (WA) in tonnes. Taken from Broken Hill Mineral Separation Plant Annual Environmental Management Reports, Cristal Mining December Quarterly Reports and pers. communication by Tronox Australia Pty Ltd.

		2012	2013	2014	2015	2016	2017	2018	2019
MB	Total ilmenite (BHI/BHT)	117,162	257,948	382,686	256,570	318,406	364,579	307,688	168,395
	Rutile	80,399	93,997	101,646	94,466	85,303	69,179	78,397	40,000e
	Leucoxene	43,000e	50,125	53,958	53,361	55,312	50,772	49,022	25,000e
WA	Leucoxene	1900e	2110	3260	2783	3929	3831	7600	7000e

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In May 2009 Unimin Australia Ltd., a subsidiary of SCR-Sibelco NV, bought the 51.04 % stake in Consolidated Rutile Ltd. (CRL) formerly held by Iluka Resources Inc. Unimin had previously built up a 19.6 % stake in CRL and, after acquiring Iluka's share, launched a successful takeover bid so that it now wholly owns the company. Meanwhile, Unimin Australia was rebranded Sibelco Australia and New Zealand. As in all countries where SCR-Sibelco is operating, the public relations policy of SCR-Sibelco Australia and New Zealand is very restrictive.

CRL had operated an HM mining operation on North Stradbroke Island off the coast of Brisbane in Queensland since 1966. There are ten HM ore bodies on North Stradbroke Island: Alpha, Amity, Bayside, Enterprise, Gordon, Herring, Ibis, Kounpee, Vance and Yarraman. Production initially used conventional dry mining methods but in 1978 the company commissioned a dredge and concentrator to mine the Bayside orebody. Mining at the Gordon deposit started in 1985 and moved to the Yarraman deposit in 1999. Production at Bayside ended in 1996 and the dredge and concentrator were moved to the Ibis deposit. In 2004 operations at Ibis were moved to the Enterprise orebody.

In 2011 the North Stradbroke Island Protection and Sustainability Act led to the announcement that all HM sand mining on North Stradbroke Island had to end by 31 December 2019. Mining at Yarraman was terminated in August 2015. Mining at Enterprise ended by 31 December 2019 instead of 2027 as initially planned.

The last remaining current operations on North Stradbroke Island consisted of a floating dredge located in an artificial pond at the Enterprise mining site with the dredged sand pumped through pipelines to a floating wet mill. Waste sand was pumped behind the pond and stacked to be reshaped into dunes. Supplementary dry mining by dozers and excavators was used to access small high-grade deposits near the mine. The HMC was sent by barge across Moreton Bay for final separation at an MSP located at Pinkenba near the mouth of the Brisbane River. The Pinkenba plant had a capacity of 230 ktpa of upgraded ilmenite, 110 ktpa of rutile and 90 ktpa of zircon. Bulk products were shipped from Hamilton on the Brisbane River. Sibelco produced up to four grades of rutile, six grades of ilmenite/leucoxene, and three grades of zircon at its Pinkenba Plant. However, only one historic rutile sample from North Stradbroke Island (CRL) was available for analysis (cf. Appendix C).

Table 23: Production of rutile and leucoxene from North Stradbroke Island in tonnes. Taken from Queensland Mineral Production and Coal Industry Statistics and Queensland's metalliferous and industrial minerals 2012–2016.*

	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Rutile*	59,716	50,375	47,184	37,489	39,301	33,127	37,323
Leucoxene	6133	3581	4219	n.a.	n.a.	n.a.	n.a.

* incl. leucoxene

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Doral is an unlisted public company wholly owned by the Iwatani Corporation of Japan. It is an integrated zirconium producer with downstream processing operations that uses its own zircon sand to make high value zirconium products for use in ceramics, coatings and industrial refractories.

Doral Mineral Sands Pty Ltd. (DMS) was established in 2001 to mine and process high slime heavy mineral sands near Dardanup and Bunbury in the southwest of Western Australia. Mining and wet mill concentration at Dardanup, including the mining of the Burekup Western and the Dardanup Southern Extensions, started in June 2002 and ended in December 2015.

In June 2017 production of heavy mineral sands commenced at Yoongarillup, 17 km southeast of Busselton. As this new mine site is rather small, mining will presumably cease in late 2020. Some 256,000 t of HMC (49,676 t HMC in 2017, 116,365 t HMC in 2018) are expected to be produced during Yoongarillups' mine life. As its own HM reserves were limited, in summer 2019 Doral additionally acquired the assets of former MZI Resources Ltd., which had gone into liquidation in spring 2019. The next HM project will be Yalyalup, 6 km from Yoongarillup, to be developed in 2021/2022.

The MSP of Doral is located at Picton near Bunbury. It produces ilmenite, leucoxene (cf. Appendix C for analyses), zircon and a HiTi-monazite-zircon off grade-mix from Doral's operations at Yoongarillup as well as leucoxene and zircon from MZI's former operations at Keysbrook (cf. below).

Formerly known as Matilda Zircon Ltd., MZI Resources Ltd. was a mineral sands company with former mining operations on Melville Island, the eastern island of the Tiwi Islands, some 50 km north of Darwin. The small Lethbridge West deposit was mined here in 2010, followed by the Lethbridge South deposit from January 2012 to January 2013.

In 2011 MZI additionally identified a large inferred HM resource at Kilimiraka in the southwest of Bathurst Island on the Tiwi Islands. The resource comprises four large dunal systems behind the current beach. As of 30 June 2018, this deposit contained 56.2 Mt of ore sand with an average HM content of 1.6 %. The inferred resource had been established at 900 kt of HM. MZI had commenced environmental studies at Kilimiraka to gain permission to commence mining once its (former) Western Australian deposit had been mined out.

Table 24: Production of leucoxene and HiTi by Doral Mineral Sands from operations in Western Australia in tonnes. Based on company information.

		2012	2013	2014	2015	2016	2017	2018
Dardanupp	HiTi	–	5501		no production			
	Leucoxene	3011	3328	2269	2328	3111		
Yoongarillup	Leucoxene						301	2011

Figure 16: View of Doral's Yoongarillup plant in 2019. Photo: BGR.

In October 2015 MZI commissioned the Keysbrook mine located 70 km due south of Perth. The Keysbrook deposit has an unusual HM suite with leucoxene as its major constituent. Expressed in terms of the mineral products produced, the deposit contains 55 % high-grade leucoxene (> 88 % TiO_2), 26 % low grade leucoxene (> 70 % TiO_2), close to 12 % zircon and 7 % non-valuable HM, mainly aluminosilicates.

As of 2018 reserves at Keysbrook were 57.6 Mt of ore sand at 2.2 % HM (1.3 Mt HM content) of which 81.6 % is leucoxene. Latest published resources including reserves were 90.3 Mt of ore sand, at 2.2 % HM (2.01 Mt HM content). The Yangedi deposit west of Keysbrook contained resources of 51.1 Mt of ore sand at 1.5 % HM (790 kt HM content) of which 84.5 % is leucoxene while the small Railway deposit south of Keysbrook held another 13.6 Mt of ore sand at 2.2 % HM (305 kt HM content).

A heavy mineral concentrate (HMC) is produced in a wet mill on site. The HMC is then transported by road to Picton near the port at Bunbury where it is processed into the final products (leucoxene – L88, leucoxene – L70, zircon – containing 11 % rutile/leucoxene) at a mineral separation plant operated by Doral Mineral Sands Pty Ltd. In summer 2019 Doral Mineral Sands took over MZI Resources' Keysbrook deposit. All titanium minerals produced at Picton are sold to The Chemours Company for TiO_2 pigment production.

Table 25: Production of leucoxene and zircon at Keysbrook in tonnes. Taken from MZI Quarterly Activity Reports December.

	2015	2016	2017	2018
Leucoxene – L70	2316	16,449	26,776	27,975
Leucoxene – L80	1795	23,664	27,375	30,150
Zircon	1775	15,907	18,341	21,858

Figure 17: Mined-out area at Keysbrook. Photo: BGR.

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Image Resources NL focuses on the development of its high-grade HM projects in the North Perth Basin. As of 1 December 2019, the Boonanarring deposit contained proven and probable reserves of 10.7 Mt of ore sand at a grade of 8.9 % HM of which 2.5 % is rutile and 3.2 % is leucoxene. As of September 2019, resources at Boonanarring stood at 30.3 Mt of ore sand at 6.0 % HM of which 2.7 % is rutile and 3.6 % is leucoxene. The neighbouring Atlas deposit contained probable reserves of 9.48 Mt of ore sand at 8.1 % HM of which 7.5 % is rutile and 4.5 % is leucoxene. Resources at Atlas stood at 18.1 Mt of ore sand at 6.0 % HM. The intention is to mine the deposits at a rate of 3.7 Mtpa over a projected minimum five-and-half-year mine life. Annual production from the Boonanaring mine was expected to be around 220 ktpa of HMC (in 2019 it was 270.0 kt) containing about 5000 t of rutile and 3000 t of leucoxene to be shipped to China via Bunbury.

Table 26: Boonanarring production and production forecast in kilotonnes as of end 2019. Taken from Image Resources Quarterly Activities Report December 2019.

	2018	2019	2020f	2021f
Ore processed	233	3186	3300–3600	3500–3800
HMC produced	15.9	270.0	300–330	300–330

Table 27: Mineral resources established by Image Resources NL in the North Perth Basin. Taken from Image Resources Investors Presentation October 2018.

	Ore (Mt)	Grade (%)	HM content (Mt)	Rutile (%)	Leucoxene (%)
Gingin North	2.4	5.5	1.26	3.4	10.2
Gingin South	8.1	6.1	4.51	5.2	10.3
Cooljarloo North	15.2	5.3	7.35	4.6	0.0
Red Gully	6.0	5.3	3.39	3.1	8.2
Regans Ford	9.9	7.7	4.96	4.3	9.9
Titan	136.6	1.9	68.85	3.1	1.5
Telesto	3.5	3.8	1.72	5.6	0.7
Calypso	51.5	1.7	27.11	5.1	1.6
Bidaminna	44.6	3.0	26.26	1.0	7.2

Project construction started in April 2018, wet commissioning commenced in October 2018 and first production of HMC in November 2018. The first shipment of HMC to Shantou Natfort Zirconium and Titanium Co., Ltd., China, for separation into individual HM concentrates was in mid-January 2019.

Besides for Boonanarring and Atlas, Image Resources has established mineral resources for many of its other HM projects in the North Perth Basin (see Table 27).

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The GMA Garnet Group comprises the mining and processing operations in the Mid West region of Western Australia (GMA Garnet Pty Ltd.), a garnet mine in Montana, USA, and a subsidiary group regional distribution centres with eight bulk handling, packaging, processing and recycling facilities in Europe, Middle East, the USA and Australasia. The business is owned by the proprietors of the Jebsen & Jessen Group of Companies established in 1895 and Ketelsen Enterprise Pty Ltd.

Since 1981 GMA Garnet has been mining garnet and associated heavy minerals from fossil dune sands near Port Gregory in Western Australia. The pre-concentrated heavy minerals are transported by truck 150 km south to the port city of Geraldton where the GMA Garnet dry mill is located. Various garnet products are produced here for use as abrasives, blast cleaning and water jet cutting, as well as an ilmenite and a zircon/rutile mix. This zircon/rutile mix was formerly sold to Iluka Resources Ltd. for processing in its Geraldton plant but some years ago GMA Garnet decided to sell this mix directly to its Chinese customers.

The zircon/rutile mix from GMA Garnet contains about 30 – 50 % zircon and about 30 % rutile. The remainder mainly comprises kyanite and quartz.

Table 28: Production of zircon/rutile mixed concentrate by GMA Garnet in tonnes. Based on company information.

	2012	2013	2014	2015	2016	2017	2018
Geraldton	2362	3028	2948	1498	1560	1995	1725

Table 29: Summary of published reserves of rutile, leucoxene and HiTi in Australia as of 2019.

Company	Project/ Region	Ore sand [Mt]	HM grade [%]	THM [Mt]	Rutile [kt]	Leucoxene [kt]	HiTi [kt]
Iluka	W. Australia	144	7.2	10.4	312		
	Eucla Basin	87	2.9	2.6			126
Tronox	Northern Ops	484	2.3	10.9	510	380	
	Southern Ops	21	5.5	1.2	9	186	
	Eastern Ops	162	4.5	7.2	785	562	
MZI/Doral	Keysbrook	58	2.2	1.3		1034	
Diatreme	Cyclone	138	2.6	3.5	106	246	810
Image	Boonanarring	11	8.9	1.0	24	30	
	Atlas	9	8.1	0.8	58	35	
Kalbar	Fingerboards	173	~2	~3.4	~460	~190	
Murray Zircon	WIM 150	582	4.3	24.0	2808	1416	
	Others	48	3.7	1.8	89	116	
Ozore/Oresome	Urquhart Point	1	9.6	0.1	13	–	
Sheffield	Thunderbird	748	11.2	83.8	–	2011	2011
Strandline	Coburn-Amy	523	1.11	5.8	403	288	
VHM	Goschen	231	3.3	7.6	768	646	
WIM	Avonbank	312	4.3	13.4	~2140	~1180	
Total		**3732**		**178.8**	**8485**	**8320**	**2947**

Table 30: Summary of published resources of rutile, leucoxene and HiTi in Australia as of 2019.

Company	Project/Region	Ore sand [Mt]	HM grade [%]	THM [Mt]	Rutile [kt]	Leucoxene [kt]	HiTi [kt]
Iluka	W. Australia	994	5.6	55.6	2780		
	Murray Basin	195	17.2	33.4	5678		
	Eucla Basin	361	4.8	17.4			520
Cristal/Tronox	Atlas-Campaspe	110	5.8	6.3	762		
	Wonnerup	54	5.1	2.7	22	205	
Astro	Gov. Broome	52	4.6	2.4	38	120	
Astron	Donald	5712	3.2	182.8	14,623	32,901	
BPL	Murray Basin	113	1.8	2.0	529	468	
Diatreme	Cyclone	203	2.3	4.7	140	327	1074
Image	Boonanarring	30	6.0	1.8	49	65	
	Atlas	18	6.0	1.1	81	49	
	Other	278	1.7–7.7	145.4	4713	4719	
Kalbar	Glenaladale	2740	1.95	53.4	7320	3046	
MZI/Doral	Keysbrook area	155	2.0	3.1		2503	
Murray Zircon	WIM 150	1650	3.7	61.1	7143	3663	
	Others	244	3.1	7.5	374	554	
Ozore/Oresome	Urquhart Point	3	5.9	0.2	19		
Relentless	Murray Basin	75	3.9	2.9	336	291	
Sheffield	Thunderbird	3230	6.9	222.9		6463	5795
	Eneabba	193	3.0	5.8	392	242	
	McCalls	5800	1.4	81.2	2020	2570	
	Night Train	130	3,3	4.2		1900	220
Strandline	Coburn-Amy	1606	1.3	19.6	1372	980	
Strategic Energy	Ambergate	11	5.1	0.6		68	
VHM	Goschen	1094	2.7	29.7	2822	3000	
WIM	Avonbank	490	4.0	19.6	3136	1971	
	Bungalally	205	2.7	5.5	775	941	
	Wedderburn	233	2.3	5.1	728	862	
Total		**25,979**		**978.0**	**55,852**	**67,908**	**7609**

BANGLADESH

There is no HM production in Bangladesh but the HM deposits along its coast, which contain both rutile and leucoxene, have been known since 1961. They have been investigated in great detail since 1967.

The HM deposits of economic interest are concentrated in the south-eastern Cox's Bazar district, some 390 km south-southeast of the capital Dhaka. 17 different mineral sands deposits have been delineated over a 500-km-long coastal stretch at a grade of 23 % HM on average, containing 4.35 Mt HM in total. 98,274 tonnes of these minerals are rutile and 95,979 tonnes are leucoxene. However, of the 17 deposits only eight are big enough to warrant potential mining. Their total content is 1.76 Mt of HM with ilmenite, zircon, rutile, magnetite, leucoxene, kyanite, garnet and monazite identified as valuable (Akon 2016). As the ilmenite is low in TiO_2 (about 43 %), it is of limited value and the Bangladesh government is especially interested in the monazite as it contains uranium which can be concentrated.

More recently Khalil et al. (2016) sampled 14 stable sand bars of the Brahmaputra River over a 120 km^2 area in the Kurigram district, north-eastern Bangladesh. The Brahmaputra River is one of the largest on earth, transporting huge amounts of sediments from the intense erosion of the Himalayas to the Bay of Bengal. During this process, sand and gravel are deposited on the bed of the river to form sand bars. The thickness of the sand deposits is known to reach up to 44 m. Average HM content analysed was 12.4 % varying greatly from less than 8 % to 25 %. Ilmenite and rutile make up 26.2 %–31.0 % and 14.6 %–23.5 % of the HM suite respectively. Potential rutile resources in the Brahmaputra River area therefore may be great, but dredging might be very difficult during monsoon season.

Imports of titanium concentrates from Bangladesh (from unknown origin) to China were 20 t in 2012, 2951 t in 2014 and 603 t in 2015 (Source: Global Trade Atlas).

BRAZIL

In Brazil there are currently two rutile producers:

– Tronox Pigmentos do Brasil S.A. and
– Indústrias Nucleares do Brasil S.A.

In addition to the activities of these two HM mining companies, there are at least three more known projects capable of producing HiTi feedstock in the future:

Rio Grande Mineração S.A. is implementing the South Atlantic HM project in the State of Rio Grande do Sul which includes the individual Retiro, Estreito, Capão do Meo and Bojuro projects. The entire project extends over an area of some 80 km long and 1.5 km wide in the coastal area of the municipality of São José do Norte. The total project resources stand at 979.3 Mt of ore sand at a grade of 3.14 % HM. Estimated resources of the southernmost Retiro project are 531.2 Mt of ore sand with an average of 3.2 % HM of which 2.4 % is rutile and 0.7 % is leucoxene. About 2.5 Mt of ore sand is planned to be processed every year delivering about 272 ktpa of ilmenite, 37 ktpa of titanomagnetite, 37 ktpa of zircon and 10 ktpa of rutile. The latter two products are to be sold to the domestic market. The expected mine life is in excess of 30 years. However, no starting date for production has been announced yet.

Mineral Brasil Pesquisas e Desenvolvimento Ltda. is as subsidiary company of JFE Mineral Co. Ltd. of Japan. It operates a pilot plant for the production of rutile (and possibly other minerals) from five-metre-thick soil covering deeply weathered granites at Seritinga in the south of Minas Gerais. This pilot unit has a feed processing capacity of 5 tph. No further information is known.

The Companhia de Desenvolvimento Econômico de Minas Gerais or **CODEMIG** (Development Company of the State of Minais Gerais) is working on extracting a commercial anatase concentrate from phosphate mining (cf. Appendix C for analyses).

Anatase ore resources in Brasil are estimated at around 2 Bt with an average content of 18 % TiO_2. Some 90 % of these resources are in the State of Minais Gerais (MG) and 10 % in the State of Goiás. The biggest known deposits are the carbonatites of Tapira and Salitre both of which are found in Minais Gerais and Catalão in Goiás. All of them are being mined for phosphate and partly niobium. In these carbonatites perovskite has weathered to anatase, which is finely intergrown with quartz.

A consortium named VALE FOSFERTIL began producing close to 2.9 Mt anatase concentrate at 14.7 % TiO_2 more than 20 years ago. In 2010 the fertilizer production company Fosfertil (Fertilizantes Fosfatados S.A.) was taken over by VALE and in 2018 VALE Fertilizantes was sold to the US Mosaic Company. All the anatase concentrate produced 20 years ago was stockpiled and used for metallurgical testing purposes.

Between 2014 and 2016, Iluka Resources Inc. of Australia also looked into producing a marketable titanium mineral concentrate from Tapira but was not able to do so "using currently known conventional or alternative technological routes."

Table 31: Rutile production in Brazil in tonnes. Taken from the National Department of Mineral Production (DNPM) / Agência Nacional de Mineração (ANM). Note: In most years this data is not consistent with the sum of the production data reported by the individual companies.

	2012	2013	2014	2015	2016	2017	2018
Brazil	1881	2021	1834	1984	not yet available		

Tronox Pigmentos do Brasil S.A.	
Address (Head office)	Av. Roque Petroni Jr., 999 – 12th Floor São Paulo, SP 04707-910 Brazil
Phone	+55-11-3296-1500
Fax	+55-11-3296-1501
Website	www.tronox-al.com.br
Email	kcorreia@tronox.com
Contact person	Kaiser Gamba Correia, Sales Manager
Phone	+55-83-3297-3813

Tronox Pigmentos do Brasil S.A. produces HM at its Guaju mine at Mataraca in the State of Paraiba. The Guaju mine is about 1100 km from the Bahia plant where the ilmenite from the mine is converted into TiO_2 pigment.

The first owner and operator of the mine from 1983 was Rutilo e Ilmenitado Brasil S.A. (RIB), a subsidiary of Titanio do Brasil S.A. (Tibràs), a Brazilian-German joint-venture. In July 1998 US Millennium Inorganic Chemicals took over RIB and subsequently sold it to the Crystal Company, an affiliate of Saudi Arabia's National Industrialisation Company, in May 2007. In July 2013 Millenium Inorganic Chemicals do Brasil changed its name to Cristal Pigmentos do Brasil S.A. which was taken over by Tronox Ltd. in April 2019 (cf. Australia).

During a nationwide exploration programme for HM deposits in the late 1970s, Guaju at Mataraca was identified as the best site for mining. Here, the mineralized fossil dune sands have an average thickness of 30-40 m and reach up to 60 m in thickness. The HM grade varies between 3 and 5 % with the HM composition dominated by ilmenite (74 %), zircon (14 %), rutile (2.3 %), kyanite and other non-valuable HM. Ilmenite was produced for the first time in April 1983 followed by zircon and rutile in 1988 and kyanite in 1998. All products besides ilmenite are sold to the domestic market. The mining operation at Guaju consists of a dredge, a flotation wet mill and a stationary MSP. Mining at Guaju will stop in 2020 due to depleted resources.

At the end of 2009, Mataraca mine last reported official reserves of 1.85 Mt of ilmenite, 411,824 t of zircon and 44,567 t of rutile.

Tronox Pigmentos do Brasil S.A produces one grade of rutile (cf. Appendix C for analysis).

Table 32: Rutile production by former Cristal Pigmentos do Brasil at Guaju in tonnes. Based on company information.

	2012	2013	2014	2015	2016	2017	2018
Guaju	1697	2030	1660	1703	2170	2307	2462

Indústrias Nucleares do Brasil S.A.	
Address (Head office)	Av. João Cabral de Melo Neto, 400 – 101 a 304 Barra da Tijuca Rio de Janeiro, RJ 22775-057, Brazil
Phone	+55-21-3797-1600
Fax	+55-21-3797-1636
Website	www.inb.gov.br
Email	otto@inb.gov.br
Contact person	Adriano Maciel Tavares, Superintendent Mineral Production
Phone	+55-21-3797-1612
Email	atavares@inb.gov.br

Indústrias Nucleares do Brasil S.A. (INB) is a state-owned company. It succeeded its predecessor Nuclebras in 1988, incorporating its subsidiaries Nuclei and Nuclemon in 1994. INB works in the production chain of uranium, from mining to manufacturing the fuel that generates electricity in nuclear power plants.

INB's HM mines (formerly Nuclemon) are located in the States of Bahia (Cumuruxatiba) and Espírito Santo (Boa Vista) but have been closed for many years. Until 2010 the company operated another HM mine located at Buena in the State of Rio de Janeiro. This deposit was also mined out and, as INB was unable to find another suitable deposit, the mining equipment was decommissioned. Following extraction the ore sand was trucked to a nearby MSP where ilmenite, zircon, rutile and monazite were separated. Monazite was sent for further processing to the company's Caldas unit. The other HM produced were sold to supply the domestic market.

INB HM production of has been decreasing for many years due to mine depletion. However, HM concentrates are still being produced from old stockpiles at Buena and Caldas. HM resources contained in the stockpiles were last reported In 2015 and estimated at 24,903 t of ilmenite, 4665 t of zircon, 3335 t of rutile and 4159 t of monazite.

Figure 18: HM mine and MSP of Indústrias Nucleares do Brasil S.A. at Buena, State of Rio de Janeiro. Courtesy of Indústrias Nucleares do Brasil S.A.

Table 33: Rutile production by Indústrias Nucleares do Brasil at Buena in tonnes. Taken from annual company reports.

	2012	2013	2014	2015	2016	2017	2018	2019
Buena	314	112	329	308	715	408	581	621

CAMEROON

Rutile was mined by artisanal miners in Cameroon between 1935 and 1955 with total production surpassing 15,000 t. The government has been trying to restart the production of rutile on its territory since 1994.

All rutile resources are centered around the town of Akonolinga in the central region of Cameroon extending over an area of some 30,000 km^2. Total rutile resources in this region are said to be 2,849 Mt. The rutile-rich mineralized sands occur within river channels, typically, 200–300 m wide and located approximately 25–40 m below the surrounding topography. Most of the river channels are small- to medium-sized but few reach > 1 km in width. The alluvial sands are typically 4–5 m deep but can also reach thicknesses of up to 8 m.

As of 2012 the privately owned Cameroon Rutile Ltd. registered on the British Virgin Islands was trying to develop a major portion of this deposit. Indicated and inferred resources in three of its seven exploration licenses were given as 162.6 Mt of ore at a grade of 1.15 % rutile (approx. 1.87 Mt rutile content in total). Cameroon Rutile had seven exploration licences with Nyong, Lembe, Boulou and Ayos-Akonolinga included in its Akonolinga rutile project. The Edea-Kribi licence was referred to as the Edea rutile project and the Bafia and Nkolkose licences were referred to as the Bafia rutile prospect.

As of June 2013 most of these licenses were said to have been transferred to Sicamines, another privately owned company. Exploration licenses covering the Akonolinga block were obtained by Eramet SA, France in November 2019.

Two totally different areas with rutile potential in southwest Camerron, Nkoteng and Dehane, are currently being explored by the British BWA group.

Product quality of the rutile from Cameroon was established by the French Bureau des Recherches, Géologique et Minière (BRGM) prior to 2002 and is given in Appendix C.

CANADA

While there is currently no production of rutile in Canada, there are some rutile projects:

Société d'Exploration Minière Vior Inc. of Quebec is exploring two rutile showings in Quebec with **Iluka Resources Ltd.** of Australia.

The Big Island rutile prospect lies within the Havre-St-Pierre anorthositic complex where several massive ilmenite showings were identified, including the Lac Tio ilmenite mine currently in operation. Field visits confirmed the presence of rutile associated to ilmenite and selected rock sampling returned TiO_2 values between 44.2 % and 48.4 %. Rutile mineralization is present over a thickness varying from 1 to 6 m with concentration ranging from traces to locally 15 % in the rock.

The Foothills property is located near the town of Saint-Urbain, a historic iron-titanium mining camp located about 100 km east of Quebec City. The Foothills project includes the promising Grand Duc area and covers the Saint-Urbain and Lac Malbaie anorthositic complexes. Here km-scale trains of rutile-rich ilmenite blocks and fragments were delineated in surficial glacial sediments. Ilmenite blocks, which contain visually significant amounts of rutile minerals, yielded assay values for TiO_2 ranging from 42.1 % to 57.6 % with an average value of 52.5 %.

In 2013 **Fancamp Exploration Ltd.**, a Canadian junior mineral exploration company, published results of hydrometallurgical plant tests. The company was able to upgrade titaniferous magnetite ore from its majority owned undeveloped Magpie Fe-Ti-V-Cr deposit east of Sept-Iles containing indicated and inferred resources of 928 Mt of ore at a grade of 42.3 % Fe and 11.2 % TiO_2. The final product achieved was a synthetic rutile containing 94.8 % TiO_2 with a leaching recovery of 88.5 %.

The Athabascan oil sands tailings are also known to contain large amounts of zircon (15.2 % on average) together with other HM including ilmenite (2.8 %), altered ilmenite at 64.3 % TiO_2 (23.0 %), leucoxene at 66.7 % TiO_2 (16.6 %) and rutile (4.0 %) (Oxenford et al. 1999). A HiTi feedstock sample (75.5 % TiO_2) made up of rutile, leucoxene and ilmenite was tested for potential upgrading already many years ago. Applying rather complicated processes, an upgraded rutile concentrate containing 87 – 89 % TiO_2, could be obtained (Chachula & Liu 2003). However, the Titanium Corporation of Canada, the developer of the Athabascan oil sands tailings, has long since decided to focus on separating zircon from this interesting secondary HM resource.

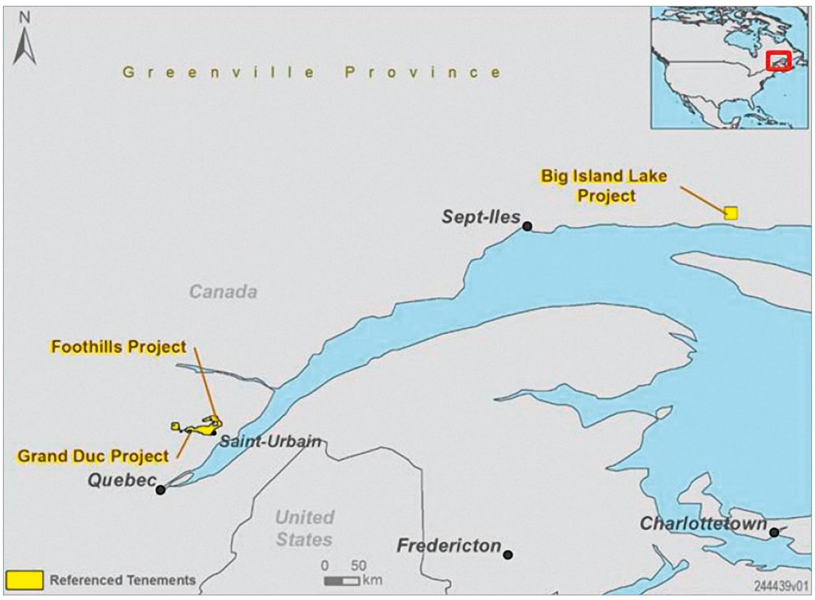


Figure 19: Location of the Big Island Lake, Foothills and Grand Duc projects in Quebec, Canada. Courtesy of Iluka Resources Ltd.

CHILE

HM ore sands are widespread along the 6400 km long coast of Chile. HM deposits at Duna Choapa Norte and La Barca in Coquimbo Province 250 km north of Santiago were first explored 25 years ago. About ten years later Vancouver-based GL Energy and Exploration Inc. took over the majority stake in these projects. Published indicated resources as of 2002 were 100.56 Mt of ore sand at La Barca (38 years mine life) and 45.77 Mt of ore sand at Duna Choapa Norte (17 years mine life). Economic minerals contained in the clean dunal sands are magnetite (9.7 – 10.7 %), rutile (1.62 – 2.05 %), zircon (0.11 – 1.32 %), ilmenite (up to 0.29 %), gold (0.25 – 0.27 ppm), garnierite and monazite. Thus, total rutile resources are 744,000 tonnes at Duna Choapa Norte and 2.061 Mt at La Barca.

Until it went out of business in March 2017, the former US White Mountain Titanium Corporation was exploring possibilities to extract a commercial rutile concentrate from its many hard rock exploration concessions in Chile. Most of them lay in the Cerro Blanco property approx. 39 km west of the City of Vallenar in the Atacama region (Region III) of northern Chile. For every 1 t of rutile, 5 t of feldspar concentrate was intended to be produced as a co-product The production target was 135 ktpa of rutile (95 ktpa standard size at 96.4 % TiO_2, 27 ktpa fine size at 97.2 % TiO_2 and 10 ktpa of ultrafine size at 97.5 % TiO_2) over a mine life of 20 years.

The Ti-mineralization in northern Chile is hosted in albitized gabbro and is composed principally of disseminated rutile, rutile veins, a mixture of disseminated rutile and leucoxene as well as minor disseminated sphene.

As of 2013 the total resources at the Las Carolinas, La Canteras and Eli prospects of the Cerro Blanco property were given at 180.2 Mt of ore at an average grade of 1.60 % TiO_2 (close to 3 Mt rutile content).

CHINA

In China, 86 % of the known rutile is bound up in hard-rock deposits, which still cannot be mined economically, while only 14 % can be found in placer deposits (Wang & Zhao 2013). Almost all placer deposits are found in Hainan Province concentrated in the coastal areas of Wengtian and Jinshan Towns, Wenchang City, on Hainan Island. However, at the end of 2014 Hainan Province stopped the approval of new exploration and mining rights. In 2016 the approval and supervision of mining rights were standardized and extension applications were no longer accepted. Three years later, by the end of 2019, all zircon and titanium mining rights had expired.

All of the HM deposits previously mined on Hainan Island are of aeolian origin, i.e. both coastal and fossil dunes up to 20 m in elevation and up to 3 km inland. The VHM suite in these dunes is dominated by ilmenite followed by zircon, monazite, rutile and cassiterite.

At present, Wenchang's remaining HM concentration companies mainly purchase tailings for processing from quartz sand mining companies as well as crude zircon and titanium ore privately mined by local farmers. Currently, the local production of rutile concentrates in Hainan stands at about 6000 tpa with the various rutile concentrates at grades between 80 – 92 % TiO_2.

Although China is one of the biggest consumers of rutile worldwide, only a very small amount of the rutile demand is satisfied by domestic mining operations (cf. above). Limited domestic reserves, low quality of domestic rutile concentrates and high domestic demand also mean that no Chinese rutile is exported.

To satisfy the rising demand during the last two decades, more than 100 processing and upgrading plants have sprung up all along the Chinese coast specialising in producing rutile, zircon, ilmenite and many other commercial HM concentrates from imported titanium and zircon-rutile mineral pre-concentrates, mixed HM concentrates and even HM tailings.

As hardly any information is publicly available on these Chinese HM separation companies, BGR commissioned Beijing Ruidow Information Technology Co., Ltd. of Beijing to put together all the relevant information on these enterprises. The Ruidow specialists did a very good job and, as of 2020, managed to identify 51 enterprises in operation, four enterprises under construction, but also 53 enterprises which have (temporarily) discontinued their operations. It would appear that the HM separation company market in China is undergoing very rapid change.

Currently operating HM separation companies in rank of importance as of 2019

1. Hainan Wensheng High-Tech Materials Co., Ltd. (Haikou, Hainan Province)

Founded in 2003, Hainan Wensheng High-Tech Materials Co., Ltd. processes, produces and manufactures HM and HM-based products downstream. It is the parent company of numerous mineral processing companies in China including Hainan Winsheen Mining Co., Ltd., Haikou Wensheng Mining Co., Haikou Winsheen Minerals Co., Ltd., Guangxi Winsheen Minerals Co., Ltd., Fujian Winsheen Minerals Co., Ltd., Sichuan Yaanqi Fine Zirconium Minerals Co., Ltd., and Qingyuan Jinsheng Zirconium Minerals Co., Ltd. The company also holds controlling interests in the Fangcheng Wensheng plant, the Fujian Wensheng plant, the Sichuan Yaan Chemical plant, Lao PDR New Material,and above all in Tricoastal Minerals (Holdings) Co., Ltd. Tricoastal Minerals owns the Wensheng Haikou HM Processing Plant and the JinSheng WanNing HM Processing Plant both of which are based on Hainan Island, as well as the Tricoastal Fujian HM Processing Plant in Xiamen, the Wensheng Tianjin Ilmenite Processing Plant, the Wensheng Guangxi Zircon Processing Plant in Guangxi, the JinSheng Qingyuan Zircon Processing & Milling Plant and the Tricoastal Shishan Zircon Milling Plant both of which are in Guangdong.

As of 15 February 2017, Hainan Wensheng High-Tech Materials Co., Ltd. has operated as a subsidiary of Shenghe Resources Holding Co., Ltd.

Hainan Wencheng High-Tech Materials Co., Ltd. is one of the major suppliers of zircon, ilmenite, rutile, kyanite, monazite and various zirconium chemicals in China. Annual production varies considerably mainly due to varying demand rather than lack of resources. Processed material is sourced from various countries with the majority of rutile originating in Australia, Sierra Leone, Mozambique, and Vietnam.

Among others Hainan Wensheng High-Tech Materials buys all the zircon produced by Doral Mineral Sands Pty Ltd. from the Australian Keysbrook HM deposit (cf. Australia) and all the zircon-monazite produced from stockpiles of previous HM mining by Iluka Resources Ltd. in Virginia (USA). Additionally, it sources monazite from the HM operations of The Chemours Company TT, LLC in Georgia (cf. USA) and has also secured future supply of zircon from the Australian Thunderbird_HM project of Sheffield Resources Ltd. (cf. Australia) and of zircon-monazite from the Tanzanian Fungoni_HM project of Strandline Resources Ltd. (cf. Tanzania) and of HMC from the Senegalese Niafarang HM project of Astron Corporation Ltd. (cf. Senegal).

Similar to Shantou Natfort Zirconium and Titanium Co., Ltd. (cf. below) the company also has an off-take agreement for the HMC produced by Image Resources NL from its Australian Boonanarring_HM project (cf. Australia).

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	16,000	18,000	20,000	24,000	28,000	30,000	34,000	43,000	60,000

Hainan Wensheng High-Tech Materials produces three grades of rutile, kindly made available for analyses: Standard Grade (> 85 % TiO_2), Middle Grade (> 90 % TiO_2), and High Grade (> 95 % TiO_2) all produced from Australian concentrates (cf. Appendix C for analysis).

**2. Astron Titanium (Yingkou) Co., Ltd.
(Yingkou, Liaoning Province)**

Founded in 2006, this company is active in the import and export of zircon, rutile, and ilmenite. In 2018 the company established a concentrating mill to focus on rutile concentrating. Its main sources of rutile are Australia and the USA.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	0	0	0	0	0	0	25,000	30,000	48,000

**3. Hainan Dazhou Island New Material Technology Co., Ltd.
(Wanning, Hainan Province)**

Founded in 2012, this company's concentrating mill primarily produces high-quality rutile with the by-products ilmenite, zircon, and monazite. Its main sources of rutile are Australia, Mozambique and Hainan Island/China.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	7000	7500	7500	8000	8000	8000	8500	9000	12,000

**4. Naicher Advanced Material (Yingkou) Co., Ltd.
(Yingkou, Liaoning Province)**

This company was founded in 2006 and mainly produces zirconium tetrachloride, titanium tetrachloride and zircon powder. It also has a titanium-zircon mineral concentrating factory which mainly produces zircon, ilmenite, rutile, etc. The main source of rutile is Australia.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	5000	6000	6500	7000	7000	7000	7500	7800	10,000

Naicher Advanced Material (Yingkou) Co., Ltd. currently produces four grades of rutile, kindly made available for analyses: Standard Grade (> 85 % TiO_2) from Pakistan, two Middle Grades (> 90 % TiO_2 and > 92 % TiO_2 from Australia and USA, and High Grade (> 95 % TiO_2), also produced from Australian concentrates (cf. Appendix C for analysis).

**5. Suixi Jindi Mineral Co., Ltd.
(Zhanjiang, Guangdong Province)**

Founded in 2006, this company is an enterprise active in processing of beach placers and the sale of various mineral products. The main products are zircon, rutile, ilmenite, monazite and kyanite, as well as their by-products and tailings. The main sources of rutile are Australia, Mozambique, the USA and Indonesia.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	5000	6000	6000	6000	6500	6500	6500	7000	9000

Suixi Jindi Mineral Co., Ltd. produces three grades of rutile, kindly made available for analyses: Standard Grade (> 85 % TiO_2) from Vietnamese concentrates, Middle Grade (> 90 % TiO_2) from USA concentrates, and High Grade (> 95 % TiO_2) from Indonesian concentrates (cf. Appendix C for analysis).

**6. Hainan Xiongxiu Mining Co., Ltd.
(Wenchang, Hainan Province)**

This company, founded in 2004, is active in the processing and sales of ilmenite, zircon, rutile, and monazite from Hainan Island/China and various countries in Africa.

Rutile production (tonnes):

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	2000	2000	2300	2300	2300	2300	2500	5000	6700

Hainan Xiongxiu Mining Co., Ltd. produces three grades of rutile, kindly made available for analyses: Standard Grade (> 85 % TiO_2), Middle Grade (> 89 % TiO_2), and High Grade (> 91 % TiO_2), all produced from Hainan HM sands (cf. Appendix C for analysis).

**7. Guangxi Guangbao Mining Co., Ltd.
(Qinzhou, Guangxi Province)**

Founded in 2010, this company has six modern primary concentrating production lines with a production and processing capacity of 100,000 tpa. The average annual output is 15,000 t zircon, 10,000 t rutile, 70,000 t ilmenite and 2000 t monazite. The main source of rutile is Vietnam.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	4500	4000	2500	2000	4000	4500	2500	4500	5000

8. Xiamen King Far East Supply Chain Co., Ltd. (Xiamen, Fujian Province)

Founded in 2010, this company has many holding companies with the businesses including international logistics cloud platform, international freight forwarding warehousing, self-supporting import and export agent, thorough processing of ore and international trade. Since 2017 it has built concentrating mills in Huanghua, Hebei Province and Zhangzhou, Fujian Province to produce zircon, ilmenite and rutile with by-products of monazite and kyanite. The main sources of rutile are Mozambique and Sierra Leone.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	0	0	0	0	0	2000	3500	4200	5600

Xiamen King Far East Supply Chain Co., Ltd. currently produces a rutile concentrate from Sierra Leone (> 95 % TiO_2), kindly made available for analyses (cf. Appendix C for analysis).

9. Guangxi YuanFengda Resources Technology Co., Ltd. (Qinzhou, Guangxi Province)

Founded in 2012, this company, is one of the largest ilmenite and zircon concentrating enterprises in Guangxi with a capacity of 400,000 tpa. The main products are zircon, ilmenite and rutile with the by-products monazite, kyanite etc. The main sources of rutile are Vietnam and Sri Lanka.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	2000	4000	2000	1800	3500	4000	2000	4000	6000

10. Guangxi Liufeng Mining Co., Ltd. (Qinzhou, Guangxi Province)

Founded in 2010, this company is mainly active in ilmenite and zircon concentrating and processing. The main products are ilmenite, zircon, rutile, monazite etc. The main sources of rutile are Vietnam, Indonesia and Sri Lanka.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	5000	3000	2000	1800	3000	3000	2000	4000	4500

Currently Guangxi Liufeng Mining Co., Ltd. produces a rutile concentrate from Vietnam (> 90 % TiO_2), kindly made available for analyses (cf. Appendix C for analysis).

11. Guangxi Jinnianda Mining Co., Ltd. (Qinzhou, Guangxi Province)

Founded in 2008, this company is active in concentration of ilmenite and zircon. Its main products are ilmenite and zircon, as well as rutile, monazite etc. as by-products. It is one of the largest titanium-zirconium concentrating enterprises in Guangxi. The main source of rutile is Vietnam.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	3000	4000	2000	1800	3500	4000	2000	4000	6000

12. Zhangzhou Antai Zirconium Development Co., Ltd. (Zhangzhou, Fujian Province)

Founded in 2002, this company primarily produces zirconium silicate, zircon powder and other zirconium products for ceramics. It owns a mineral-concentrating mill. The main product is zircon, and the by-products are rutile, ilmenite, garnet and monazite. The main sources of rutile are Australia and South Africa.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	3000	3000	3000	3000	3500	3500	3500	4000	5000

13. Leizhou Huayuan Mining Co., Ltd. (Leizhou, Guangdong Province)

Founded in 2006, this company is a beach sand ore concentrating and processing enterprise and was among the first batch of approved associated radioactive mineral development and utilization enterprises in Guangdong Province. The main sources of rutile are Vietnam and Australia.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	2500	3000	3000	3000	3200	3200	3400	3600	4800

14. Zhanjiang Furun Mining Co., Ltd. (Zhanjiang, Guangdong Province)

Founded in 2009, this company is primarily involved in the production of zircon, ilmenite, rutile etc. The main sources of rutile are Vietnam and Australia.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	2000	2400	2500	2500	3000	3000	3500	3500	4000

15. Guangdong Hongpeng New Material Resources Co., Ltd. (Maoming, Guangdong Province)

This company was founded in 2012. The subsidiary company Zhanjiang Dachangdi Mineral Industry Co., Ltd. was founded in 2015 and is mainly involved in the concentration of zircon, ilmenite, rutile, and monazite with the by-products cassiterite and kyanite. The main sources of rutile are Vietnam, Australia and Sri Lanka.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	0	0	0	1900	1500	3000	3000	3500	5000

16. Qinzhou Cedar Industry & Trade Co., Ltd. (Qinzhou, Guangxi Province)

Founded in 2001, this company is primarily involved in the production and processing of zircon, ilmenite, rutile, chrome ore etc. The main sources of rutile are Australia and Vietnam.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	5000	3500	1800	1500	2800	3000	1800	3000	3500

17. Guangdong Leizhou Yuanjia Mining Co., Ltd. (Leizhou, Guangdong Province)

Founded in 1999, this company has businesses active in the processing and sales of zircon, ilmenite, iron ore concentrate, rutile, monazite, tin ore, tungsten ore, bauxite, manganese ore, magnetic powder etc. The main sources of rutile are Australia and Vietnam.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	5000	5000	5000	5000	4000	4000	3000	3000	3500

18. Hainan Zhongtai Mining Co., Ltd. (Wanning, Hainan Province)

Founded in 2004, this company is active in the processing and sales of ilmenite, zircon, rutile and monazite. It is about to build a new large-scale concentrating mill in Yangpu Port of Hainan Province which is expected to be put into operation in 2021. The main sources of rutile are Australia and Liberia.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	2000	2000	2500	3500	4500	5000	4000	3000	6000

19. Fujian Yuanguang Zirconium Co., Ltd. (Quanzhou, Fujian Province)

Founded in 2004, this company is an enterprise integrating the import of zircon and the mineral concentrating, production, processing and sales of zirconium silicate. It is one of the largest manufacturers of zirconium silicate for ceramics in China. It owns a mineral-concentrating mill. The main product is zircon sand and the by-products are rutile, ilmenite, garnet and monazite. The main sources of rutile are Australia, South Africa, and Vietnam.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	2500	2500	2500	2500	2500	2800	2800	3000	4000

20. Tianjin Qingling Advanced Materials & Technology Ltd. (Tianjin)

Founded in 2015, this company is a specialized mineral enterprise integrating mineral import and export trade, zircon-titanium mineral concentrating and processing. Its products include zircon, zircon powder, medium temperature wax, rutile, titanium ores, kyanite and zirconium dioxide. The main source of rutile is Australia.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	0	0	0	0	1500	2000	2500	3000	4000

21. Guangxi Qinzhou Zhonghuang Import & Export Trading Co., Ltd. (Qinzhou, Guangxi Province)

Founded in 2008 this company is primarily active in the concentration and processing of manganese ore, titanium ore, iron ore and chromium ore. The main sources of rutile are Vietnam and Australia.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	4000	3000	1500	1200	2400	2500	1500	2500	3000

22. Fujian Anxi Longmen Zhongquan Glazing Co., Ltd. (Quanzhou, Fujian Province)

Founded in 2000, this company primarily produces zirconium silicate and zircon powder for ceramics. It owns a concentrating mill. The main product is zircon sand and the by-products are rutile, ilmenite, garnet and monazite. The main sources of rutile are Australia, Vietnam and South Africa.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	2000	2000	2000	2000	2300	2300	2400	2500	3300

23. Qingyuan Jinsheng Zr & Ti Resources Co., Ltd. (Qingyuan, Guangdong Province)

Website: www.jinshengzrti.com

QINGYUAN JINSHENG ZR & TI RESOURCES CO.,LTD

Founded in 2008, this company has continued operating in the same fields as its predecessor Hainan Wanning Jinsheng Zr & Ti Resources Co., Ltd. It has a concentrating mill to process zircon concentrates (capacity 40 ktpa) and mainly produces zircon, zirconium silicate, zirconia, zircon powder and fine powder for ceramics. The by-products are ilmenite and rutile. The main sources of the imported concentrates are Australia, South Africa and Indonesia. The company has secured a future supply of zircon from the Australian company Sheffield Resources Ltd.'s Thunderbird_HM project (cf. Australia).

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	1200	1200	1500	1600	1800	2000	2400	2400	3500

Qingyuan Jinsheng Zr & Ti Resources Co., Ltd. produces four grades of rutile: Standard Grade (≥ 87 % TiO_2), Middle Grade (≥ 90 % TiO_2), High Grade (≥ 92 % TiO_2), and Superfine Grade (≥ 95 % TiO_2).

24. Hua'an Rongyi Mineral Co., Ltd. (Zhangzhou, Fujian Province)

Founded in 2004, this company, specializes in the production of zirconium silicate. It owns a mineral-concentrating mill. The main product is zircon and the by-products are ilmenite, rutile and monazite. The main sources of rutile are Australia and Mozambique.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	2000	2000	2000	2000	2200	2300	2300	2400	3200

25. Shandong Yuxiao Zirconium Titanium Mining Co., Ltd. (Rizhao, Shandong Province)

Founded in 2014, this company mainly relies on Jinan Yuxiao Group Co., Ltd. to import raw ore from the mining base in Mozambique. It is primarily involved in the mineral concentration and processing of titanium-zircon ore while producing ilmenite, zircon, rutile, monazite etc. as by-products.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	0	0	0	0	1000	1800	2400	2400	3000

26. Zhanjiang Jieke Metal Industry Co., Ltd. (Zhanjiang, Guangdong Province)

Founded in 2003, this company owns a titanium-zirconium ore concentrating mill: Zhanjiang Changsheng Nonferrous Metals Co., Ltd., which is active in the concentrating of titanium-zirconium ore and chromium ore. Its main products are ilmenite, zircon, rutile, chromite and the by-products monazite, kyanite etc. It is one of the largest titanium-zirconium ore concentrating plants in Guangdong. The main sources of rutile are Australia, Mozambique, and Sri Lanka.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	2000	2000	2500	2500	3000	3000	4000	2000	2000

27. Zhanjiang Dongya Mineral Co., Ltd. (Zhanjiang, Guangdong Province)

Founded in 1989, this company is a specialized corporation integrating the processing and sales of mineral products. Its concentrating mill mainly produces and processes rutile, ilmenite, zircon, monazite and xenotime and has an annual capacity of 120,000 tonnes. The main sources of rutile are Australia, Vietnam and Sri Lanka.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	1500	1500	1600	1600	1700	1800	1900	2000	3000

28. Maoming Ubridge Group Mineral Industry Co., Ltd. (Maoming, Guangdong Province)
Website: www.mmubridge.com

茂名粤桥集团矿业有限公司
MAOMING UBRIDGE GROUP MINERAL INDUSTRY CO, LTD.

Maoming Ubridge Group Mineral Industry Co, Ltd. was established in 1998. Its predecessor, Maoming Mineral Separation Plant was founded in 1989. The group has three factories/companies with a combined capacity of 100 ktpa of HMC containing in general about 60 ktpa of ilmenite, 12 ktpa of zircon and 3 ktpa of rutile (96 % TiO_2). These three factories/companies are Ubridge High-Tech Concentrating Mill, Maoming Mansion Concentrating Mill and Guangxi Ubridge New Material Technology Co., Ltd. (formerly known

as Guangxi Fangchenggang Huachen Mineral Industry Co., Ltd.). All three are active in the reduction of ilmenite for production of synthetic rutile. The group has a provincial engineering centre with an R & D team composed of more than 20 high-tech professionals and holds 41 independent patents. The main sources of rutile are Australia, Vietnam, Mozambique, Sri Lanka and Sierra Leone. In addition, Maoming Yuexi Fruit Development Co., Ltd. manages a eucalypt plantation. Total staff is 486.
Maoming Ubridge Group Mineral Industry Co, Ltd. is presently looking for partnerships or single proprietorship to launch HM projects including exploration, mining and refining in Sierra Leone, Mozambique, Senegal, Madagascar, Nigeria or anywhere else in the world. A first success for the company has been securing a future supply of ilmenite from the Tanzanian Fungoni_HM project operated by Strandline Resources Ltd. (cf. Tanzania).

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	1000	1000	1300	1400	1500	1500	1800	2000	5000

Rutile grades produced by Maoming Ubridge Group Mineral Industry Co, Ltd. include Super Grade (min. 95 % TiO_2), Grade A (min. 93 % TiO_2), Grade B (min. 92 % TiO_2), and Grade 2 (min. 90 % TiO_2).

29. Shantou Natfort Zirconium and Titanium Co., Ltd. (Shantou, Guangdong Province)

Website: www.natfort.com

NATFORT 汕头市国富锆钛实业有限公司 Shantou Natfort Zirconium and Titanium Co. Ltd.

Shantou Natfort Zirconium and Titanium Co., Ltd. is a private company and was founded in 2011. It is a leading enterprise for the concentration and thorough processing of HM from placer deposits. Its main products are zircon (capacity 125 ktpa), ilmenite, rutile, monazite and xenotime with most of the pre-concentrates coming from Australia. The company recently secured future supply of HMC from the Australian Boonanarring HM project operated by Image Resources NL (cf. Australia). Shantou Natfort Zirconium and Titanium Co., Ltd. is one of the few domestic enterprises to have passed inspections and received permission from the provincial, municipal and district land departments as well as the environmental protection department.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	0	0	0	1000	1300	1500	1800	2000	5000

Shantou Natfort Zirconium and Titanium Co., Ltd. produces numerous rutile/leucoxene grades: at min. 70 % TiO_2, min. 87 % TiO_2, min. 90 % TiO_2, min. 92 % TiO_2, min. 93 % TiO_2, min. 95 % TiO_2 and min. 97 % TiO_2.

30. Guandong Suixi Huachen Mining Co., Ltd. (Zhanjiang, Guangdong Province)

Founded in 2005, this company is mainly active in the concentration of titanium and zirconium ores. The main products are zircon sand and ilmenite and the by-products are rutile, monazite, cassiterite and kyanite. The main sources of rutile are Australia, Mozambique, Indonesia and Sri Lanka.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	1500	1600	1600	1800	2800	2000	2000	2000	3000

31. Wenchang Jinshan Dongli Yuandong Mineral Processing Plant (Wenchang, Hainan Province)

Founded in 2001, this company is an enterprise which purchases the products of HM concentrating plants in Wenchang, Hainan Province and carries out thorough processing. Its main products are zircon, rutile, monazite, xenotime, ilmenite etc. Most of the rutile is said to come from Hainan Island/China and Vietnam.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	1600	1600	1600	1700	1800	1800	1900	2000	2000

32. Wanning Zhenye Mining Co., Ltd. (Wanning, Hainan Province)

Founded in 2011, this company processes and sells ilmenite, rutile, zircon, monazite and iron ore. The main sources of rutile are Australia and Sierra Leone.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	800	800	800	1000	1000	1000	1000	2000	2700

33. Dalian Intercontinental New Materials Co., Ltd. (Dalian, Liaoning Province)

Founded in 2013, this company has established three production and processing lines with an annual crude ore processing capacity of 150,000 tonnes. The main products are zircon, zircon powder, ilmenite, kyanite, rutile etc. The main source of rutile is the USA.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	0	0	0	0	0	1800	4000	1800	0

34. Zhanjiang Fanxin Mining Co., Ltd. (Zhanjiang, Guangdong Province)

Founded in 1989, this company is a specialized corporation integrating the processing and sales of mineral products. Its concentrating mill mainly produces and processes rutile, ilmenite, zircon, monazite and xenotime with an annual capacity of 120,000 tonnes. The main sources of rutile are Australia, Sri Lanka and Mozambique.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	1000	1200	1200	1300	1300	1400	1400	1500	2000

35. Maoming Maogang Great Wall Minerals Co., Ltd. (Maoming, Guangdong Province)

Founded in 2009, this company is mainly active in the processing and sales of ilmenite, zircon, rutile and monazite. The main sources of rutile are Vietnam, Australia and Sri Lanka.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	1000	1000	1200	1200	1300	1300	1500	1500	2000

36. Hainan Wanxinfeng Mining Co., Ltd. (Wanning, Hainan Province)

Founded in 2006, this company is a specialized corporation integrating the processing and sales of mineral products. Its products are zircon, rutile, ilmenite, kyanite etc. The main sources of rutile are Mozambique and Australia.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	1200	1200	1300	1300	1300	1400	1400	1500	2000

37. Wanning Ruifeng Mining Co., Ltd. (Wanning, Hainan Province)

Founded in 2008, this company is mainly active in mineral processing with a monthly production capacity of 2,000 tonnes. Its main products are zircon, rutile, kyanite etc. sourced from Sierra Leone, Australia and Pakistan.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	1200	1200	1300	1300	1300	1400	1500	1500	2000

38. Hainan Guoyi Mining Co., Ltd. (Wanning, Hainan Province)

Founded in 2007, this company produces zircon, ilmenite, and rutile, as well as monazite, kyanite, quartz and barite. Its main source of rutile is Mozambique.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	1200	1200	1300	1300	1300	1400	1500	1500	0

39. Hainan Wanning Zhongshun Mining Co., Ltd. (Wanning, Hainan Province)

Founded in 2005, this company mainly produces zircon, ilmenite and rutile with the by-products monazite and cassiterite. The main source of rutile is Mozambique.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	1200	1200	1300	1300	1300	1400	1500	1500	2000

40. Hainan Wenchang New Mingzhu Mining Co., Ltd. (Wenchang, Hainan Province)

Founded in 2004, this company is active in the processing and sales of ilmenite, zircon, rutile and monazite from Vietnamese concentrates.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	1200	1200	1300	1300	1300	1400	1500	1500	1500

41. Qinzhou Qinnan District Boyuan Mineral Processing Plant (Qinzhou, Guangxi Province)

Founded in 2006, this company is mainly active in the production and processing of zircon, ilmenite, rutile etc. The main source of rutile is Vietnam.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	800	800	1000	1000	1100	1100	1200	1200	1500

42. Suixi Ruifeng Mining Co., Ltd. (Zhanjiang, Guangdong Province)

Founded in 2011, this company mainly produces and processes zircon, ilmenite, and rutile with the by-products monazite and kyanite. In 2016 the company passed the environmental impact assessment of the associated radioactive coastal placer ore-concentrating project in Guangdong Province making the environmental protection formalities of the company complete. The main sources of rutile are Australia and Pakistan.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	800	800	800	800	800	900	950	1000	1500

Suixi Ruifeng Mining Co., Ltd. currently produces four types of rutile, kindly made available for analyses: Standard Grade (> 85 % TiO_2) from concentrates from Senegal and Russia, and Middle Grade (> 90 % TiO_2) and High Grade (> 95 % TiO_2) from Australian concentrates (cf. Appendix C for analysis).

43. Wanning Yiyuanfeng Mining Co., Ltd. (Wanning, Hainan Province)

Founded in 2010, this company owns a concentrating mill which mainly produces zircon, rutile and ilmenite and the by-products monazite, cassiterite and kyanite. The main sources of rutile are South Africa and Senegal.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	800	800	800	800	800	900	900	1000	0

Wanning Yiyuanfeng Mining Co., Ltd. currently produces two grades of rutile sourced from Mozambique (> 80 % TiO_2 and > 90 % TiO_2) and kindly made available for analyses (cf. Appendix C for analysis).

44. Shandong Goldsun Zirconium Industry Co., Ltd. (Zibo, Shandong Province)

Founded in 2006, this company is a large-scale enterprise specializing in the production of zirconium silicate and zircon powder for ceramics. It has established concentrating production lines for zircon, ilmenite and rutile with most of the concentrates coming from Australia.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	800	800	800	800	800	900	900	1000	1000

45. Wenchang Hengye Industrial Co., Ltd. (Wenchang, Hainan Province)

Founded in 2006, this company is mainly active in the concentrating of zircon, ilmenite and rutile from sands from Hainan Island/China.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	600	600	600	600	700	700	700	800	500

46. Zhanjiang Gonghe Mining Co., Ltd. (Zhanjiang, Guangdong Province)

Founded in 2018, this new company is active in the processing and sales of various mineral products from Mozambique.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	0	0	0	0	0	0	200	600	1200

47. Qinzhou Xinglian Mining Co., Ltd. (Qinzhou, Guangxi Province)

Founded in 2007, this company is mainly active in the concentrating and processing of ilmenite, manganese ore, iron ore, zircon and rutile. The main source of rutile is Vietnam.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	800	500	300	300	500	500	300	500	600

48. Yulin Jingxi Zirconium Material Factory (Yulin, Guangxi Province)

Founded in 1993, this company has introduced the technology of producing superfine zirconium silicate from zircon imported from abroad. The main product is zirconium silicate for ceramics and the by-product is rutile in small amounts. It has some concentrating equipment. The main sources of rutile are Australia and Mozambique.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	400	400	400	400	400	400	400	500	600

49. Zibo Yonbon Zirconium Co., Ltd. (Zibo, Shandong Province)

Founded in 2002, this company is an enterprise producing zirconium silicate and zircon powder for ceramics. It has also established concentrating production lines for zircon, ilmenite and rutile. Its raw materials are high-quality crude ores imported from Australia, South Africa and Indonesia.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	400	400	400	400	400	400	400	500	6500

**50. Fangchenggang Qihang Mineral Processing Co., Ltd.
(Fangchenggang, Guangxi Province)**

Founded in 2004, this company is an ilmenite and zircon concentrating enterprise with all raw materials imported from Vietnam. Its main products are zircon, rutile, ilmenite, monazite and xenotime.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	700	400	200	200	300	300	200	300	400

**51. Guangdong Zhongcheng Mining Co., Ltd.
(Yunfu, Guangdong Province)**

Founded in 2018, this new company is active in the processing and sales of mineral products from Australia and Nigeria.

Rutile production in tonnes:

Year	2012	2013	2014	2015	2016	2017	2018	2019	2025e
Rutile	0	0	0	0	0	0	0	50	100

Table 34: Summary of rutile production by HM separation companies in operation as of 2019.

No.	Company	2012	2013	2014	2015	2016	2017	2018	2019	2025e
1	Hainan Weng-sheng High-Tech Materials Co., Ltd.	16,000	18,000	20,000	24,000	28,000	30,000	34,000	43,000	60,000
2	Astron Titanium (Yingkou) Co., Ltd.	0	0	0	0	0	0	25,000	30,000	48,000
3	Hainan Dazhou Island New Material Techno-logy Co., Ltd.	7000	7500	7500	8000	8000	8000	8500	9000	12,000
4	Naicher Advanced Materials (Yingkou) Co., Ltd.	5000	6000	5000	6000	6500	7000	7000	7800	7500
5	Suixi Jindi Mineral Co., Ltd.	5000	6000	6000	6000	6500	6500	6500	7000	9000
6	Hainan Xiongxiu Mining Co., Ltd.	2000	2000	2300	2300	2300	2300	2500	5000	6700
7	Guangxi Guangbao Mining Co., Ltd.	4500	4000	2500	2000	4000	4500	2500	4500	5000
8	Xiamen King East Far Supply Chain Co., Ltd.	0	0	0	0	0	2000	3500	4200	5600
9	Guangxi YuanFeng-da Resources Technology Co., Ltd.	2000	400	2000	1800	3500	4000	2000	4000	6000
10	Guangxi Liufeng Mining Co., Ltd.	5000	3000	2000	1800	3000	3000	2000	4000	4500
11	Guangxi Jinnianda Mining Co., Ltd.	3000	4000	2000	1800	3500	4000	2000	4000	6000
12	Zhangzhou Antai Zirconium Devel-opment Co., Ltd	3000	3000	3000	3000	3500	3500	3500	4000	5000
13	Leizhou Huayuan Mining Co., Ltd.	2500	3000	3000	3000	3200	3200	3400	3600	4800
14	Zhanjiang Furun Mining Co., Ltd.	2000	2400	2500	2500	3000	3000	3500	3500	4000
15	Guangdong Hong-peng New Material Resources Co., Ltd.	0	0	0	1000	1500	3000	3000	3500	5000
16	Qinzhou Cedar Industry & Trade Co., Ltd.	5000	3500	1800	1500	2800	3000	1800	3000	3500
17	Guangdong Leizhou Yuanjia Mining Co., Ltd.	5000	5000	5000	5000	4000	4000	3000	3000	3500
18	Hainan Zhongtai Mining Co., Ltd.	2000	2000	2500	3500	4500	5000	4000	3000	6000
19	Fujian Yuanguang Zirconium Co., Ltd.	2500	2500	2500	2500	2500	2800	2800	3000	4000

No.	Company	2012	2013	2014	2015	2016	2017	2018	2019	2025e
20	Tianjin Qingling Advanced Materials & Technology Ltd.	0	0	0	0	1500	2000	2500	3000	4000
21	Guangxi Qinzhou Zhonghuang Import & Export Trading Co. Ltd.	4000	3000	1500	1200	2400	2500	1500	2500	3000
22	Fujian Anxi Longmen Zhongquan Glazing Co., Ltd.	2000	2000	2000	2000	2300	2300	2400	2500	3300
23	Qingyuan Jinsheng Zr & Ti Resources Co., Ltd.	1200	1200	1500	1600	1800	2000	2400	2400	3500
24	Hua'an Rongyi Mineral Co., Ltd.	2000	2000	2000	2000	2200	2300	2300	2400	3200
25	Shandong Yuxiao Zirconium Titanium Mining Co., Ltd.	0	0	0	0	1000	1800	2400	2400	3000
26	Zhanjiang Jieke Metal Industry Co., Ltd.	2000	2000	2500	2500	3000	3000	4000	2000	2000
27	Zhanjiang Dongya Mineral Co., Ltd.	1500	1500	1600	1600	1700	1800	1900	2000	3000
28	Maoming Ubridge Group Mineral Industry Co., Ltd.	1000	1000	1300	1400	1500	1500	1800	2000	3000
29	Shantou Natfort Zirconium and Titanium Co., Ltd.	0	0	0	1000	1300	1500	1800	2000	5000
30	Guangdong Suixi Huachen Mining Co., Ltd.	1500	1600	1600	1800	2800	2000	2000	2000	3000
31	Wenchang Jinshan Dongli Yuandong Mineral Processing Plant	1600	1600	1600	1700	1800	1800	1900	2000	2000
32	Wanning Zhenye Mining Co., Ltd.	800	800	800	800	1000	1000	1000	2000	2700
33	Dalian Intercontinental New Materials Co., Ltd.	0	0	0	0	0	1800	4000	1800	0
34	Zhanjiang Fanxin Mining Co., Ltd.	1000	1200	1200	1300	1300	1400	1400	1500	2000
35	Maoming Maogang Great Wall Minerals Co., Ltd.	1000	1000	1200	1200	1300	1300	1500	1500	2000
36	Hainan Wanxinfeng Mining Co., Ltd.	1200	1200	1300	1300	1300	1400	1400	1500	2000

No.	Company	2012	2013	2014	2015	2016	2017	2018	2019	2025e
37	Wanning Ruifeng Mining Co., Ltd.	1200	1200	1300	1300	1300	1400	1500	1500	2000
38	Hainan Guoyi Mining Co., Ltd.	1200	1200	1300	1300	1300	1400	1500	1500	0
39	Hainan Wanning Zhongshun Mining Co., Ltd.	1200	1200	1300	1300	1300	1400	1500	1500	2000
40	Hainan Wenchang New Mingzhu Mining Co., Ltd.	1200	1200	1300	1300	1300	1400	1500	1500	2000
41	Qinzhou Qinnan District Boyuan Mineral Processing Plant	800	800	1000	1000	1100	1100	1200	1200	1500
42	Suixi Ruifeng Mining Co., Ltd.	800	800	800	800	800	900	950	1000	1500
43	Wanning Yiyuanfeng Mining Co., Ltd.	800	800	800	800	800	900	900	1000	0
44	Shandong Goldsun Zirconium Industry Co., Ltd.	800	800	800	800	800	900	900	1000	1000
45	Wenchang Hengye Industrial Co., Ltd.	600	600	600	600	700	700	700	800	500
46	Zhanjiang Gonghe Mining Co., Ltd.	0	0	0	0	0	0	200	600	1200
47	Qinzhou Xinglian Mining Co., Ltd.	800	500	300	300	500	500	300	500	600
48	Yulin Jingxi Zirconium Material Factory	400	400	400	400	400	400	400	500	600
49	Zibo Yonbon Zirconium Co., Ltd.	400	400	400	400	400	400	400	500	650
50	Guangxi Qihang Mineral Processing Co., Ltd.	700	400	200	200	300	300	200	300	400
51	Guangdong Zhongcheng Mining Co., Ltd.	0	0	0	0	0	0	0	50	100
Estimated additional previous production from Hainan Island		8000	8000	8000	8000	8000	6000	6000	5000	0
Total		**111,200**	**114,300**	**108,200**	**115,800**	**137,500**	**147,900**	**176,850**	**203,050**	**268,350**

HM separation plants under construction as of 2020

**1. Hebei Yuxiao Zr&Ti New Material Technology Co., Ltd.
(Caofeidan Port, Hebei Province)**

The construction of a new concentrating mill in Tangshan, Hebei Province, started in 2019 and is planned to be put into operation in 2021 with an annual production capacity of 500,000 tonnes of crude ore. The main products include ilmenite and zircon with by-products of rutile, monazite etc.

**2. Jiangsu Yuxiao Zr & Ti Mining Co., Ltd.
(Yancheng, Jiangsu Province)**

The construction of a new concentrating mill started in 2020 and is planned to go into operation in 2022 with an annual production capacity of 600,000 tonnes of crude ore. The main products include ilmenite and zircon with by-products of rutile, monazite, etc. The largest shareholder is the same as in Hebei Yuxiao Zirconium Titanium New Materials Co., Ltd. (cf. no 1.).

**3. Shenghe Resources (Lianyugang) New Material Technology Co., Ltd.
(Lianyungang, Jiangsu Province)**

This company is a wholly owned subsidiary of Shenghe Resources Holding Co., Ltd. The new concentrating mill will be constructed in 2020 and put into operation in 2021 with an annual production capacity of 500,000 tonnes of crude ore. The main products include ilmenite and zircon with by-products of rutile, monazite etc.

**4. Maoming Ruifeng Mineral Co., Ltd.
(Maoming, Guangdong Province)**

The construction of a new concentrating mill started in 2020 and is planned to go into operation in 2022 with an annual production capacity of 300,000 tonnes of crude ore. The main products include ilmenite and zircon, with by-products of rutile, monazite etc.

HM separation companies with discontinued or currently no rutile production as of 2020

1. Hainan Jingbang Mining Co., Ltd.
(Wenchang, Hainan Province)

Founded in 2002, out of production as the local reserves are depleted/no extension has been granted.

2. Wenchang Sheng Sheng Mining Co., Ltd.
(Haikou, Hainan Province)

Founded in 2005, out of production as the local reserves are depleted/no extension has been granted.

3. Hainan Guanghaiyuan Mining/Mineral Co., Ltd.
(Haikou, Hainan Province)

Founded in 2006, dry mill in Chengmai County, Haikou, Hainan Province, mainly upgrading ore from Indonesia, currently no rutile production.

4. Hainan Jintai Mining Co., Ltd.
(Wanning, Hainan Province)

Currently no rutile production.

5. Hainan Jinxun Mining Co., Ltd.
(Wanning, Hainan Province)

Currently no rutile production.

5. Hainan Fuxin Titanium Industry Co., Ltd.
(Wanning, Hainan Province)

Founded in 2007, currently no rutile production.

6. Hainan Baichen Mineral Development Co., Ltd.
(Wanning, Hainan Province)

Founded in 2010, currently no rutile production.

7. Hainan Wanning High Titanium Mining Co., Ltd.
(Wanning, Hainan Province)

Founded in 2005, currently no rutile production.

8. Hainan Taixing Mining Co., Ltd.
(Wanning, Hainan Province)

Founded in 2006, currently no rutile production.

9. Hainan Wenchang Haijiang Mining Co., Ltd.
(Wanning, Hainan Province)

Founded in 2006, currently no rutile production.

10. Hainan Wenchang Zhongtai Mineral Processing Plant
(Wenchang, Hainan Province)

Currently no rutile production.

11. Hainan Wenchang Sanhuan Industrial Co., Ltd.
(Wenchang, Hainan Province)

Founded in 1998, currently no rutile production.

12. Hainan Wanxin Mining Dvelopment Co., Ltd.
(Wanning, Hainan Province)

Founded in 1990, currently no rutile production.

13. Hainan Hengxin Industrial Co., Ltd.
(Wenchang, Hainan Province)

Founded in 2001, currently no rutile production.

14. Wanning Jinfeng Mining Co., Ltd.
(Wanning, Hainan Province)

Founded in 2012, dry mill in Wanning, Hainan Province, currently no rutile production.

15. Wanning Jintai Mineral Product Co., Ltd.
(Wanning, Hainan Province)

Founded in 2004, dry mill in Wanning, Hainan Province, currently no rutile production.

16. Wanning Yongxingfa Mining Co., Ltd.
(Wanning, Hainan Province)

Founded in 2006, currently no rutile production.

17. Wanning Jingning Mining Co., Ltd. (Wanning, Hainan Province)

Founded in 2002, dry mill in Wanning, Hainan Province, currently no rutile production.

18. Wanning Guangnan Mining Co., Ltd. (Wanning, Hainan Province)

Founded in 2005, dry mill in Wanning, Hainan Province, currently no rutile production.

19. Wanning Yuehai Industry Co., Ltd. (Wanning, Hainan Province)

Founded in 2004, dry mill in Wanning, Hainan Province, currently no rutile production as the local reserves are depleted/no extension has been granted.

20. Wanning Xinmuan Mineral Processing Co., Ltd. (Wanning, Hainan Province)

Founded in 2011, dry mill in Wanning, Hainan Province, currently no rutile production.

21. Wanning Jincheng Mining Industry Co., Ltd. (Wanning, Hainan Province)

Founded in 1998, dry mill in Wanning, Hainan Province, currently no rutile production.

22. Hainan Wanning Wanhong Mining Co., Ltd. (Wanning, Hainan Province)

Founded in 2010, currently no rutile production.

23. Wenchang Pearl Industrial Co., Ltd. (Wenchang, Hainan Province)

Founded in 2003, currently no rutile production as the local reserves are depleted/no extension has been granted.

24. Hainan Wanning Wanchuan Industrial Co., Ltd. (Wanning, Hainan Province)

Founded in 1994, currently no rutile production.

25. Hainan Junlian Mining Co., Ltd. (Wenchang, Hainan Province)

Founded in 2006, currently no rutile production.

**26. Wanning Fengyuan Mining Co., Ltd.
(Wanning, Hainan Province)**

Founded in 2005, dry mill in Wanning, Hainan Province, currently no rutile production.

**27. Wanning Huanqiu Mining Co., Ltd.
(Wanning, Hainan Province)**

Founded in 2014, currently no rutile production.

**28. Hainan Wanning Wenhai Mining Co., Ltd.
(Wanning, Hainan Province)**

Founded in 2007, dry mill in Wanning, Hainan Province, currently no rutile production.

**29. Hainan Wenchang Sanlian Mining Co., Ltd.
(Haikou, Hainan Province)**

Founded in 2001, currently no rutile production as the local reserves are depleted/no extension has been granted.

**30. Hainan Haiyu Mining Co., Ltd.
(Wanning, Hainan Province)**

Founded in 2007 by a holding enterprise of Hainan Geological Bureau, Hainan International Resources Group Co., Ltd, and Shenzhen Feishang Industrial Group Co., Ltd. Currently no rutile production.

**31. Hainan Honhgai Mining Co., Ltd.
(Wanning, Hainan Province)**

Founded in 2005, dry mill in Wenchang, Hainan Province, currently no rutile production.

**32. Wanning Guoning Mining Co., Ltd.
(Wanning, Hainan Province)**

Founded in 2005, currently no rutile production.

**33. Guangxi Chuangda Mining Investment Group Co., Ltd.
(Qinzhou, Guangxi Province)**

Founded in 2003, currently no rutile production.

**34. Fangchenggang Haohua Mining Co., Ltd.
(Fangchenggang, Guangxi Province)**

Founded in 2010, currently no rutile production.

35. Qinzhou City Dewei Trade Co., Ltd. (Qinzhou, Guangxi Province)

Founded in 2007, currently no rutile production.

36. Qinzhou Kaisheng Mining Co., Ltd. (Qinzhou, Guangxi Province)

Founded in 2005, currently no rutile production.

37. Qinzhou Jiahua Mining Co., Ltd. (Qinzhou, Guangxi Province)

Founded in 1989, currently no HM production.

38. Qinzhou Jieweijia Mining Co., Ltd. (Qinzhou, Guangxi Province)

Founded in 2006, dry mill in Qinzhou, Guangxi Province treating imported ores from Vietnam, currently no rutile production.

39. Fangchenggang Haohua Mining Co., Ltd. (Fangchenggang, Guangxi Province)

Founded in 2011, mainly trading ores from Vietnam, currently no rutile production.

40. Guangxi Jinpan Mining Co., Ltd. (Qinzhou, Guangxi Province)

Founded in 2009, dry mill in Qinzhou, Guangxi Province treating imported ores mainly from Vietnam, currently no rutile production.

41. Guangxi Qinzhou Dongcheng Mineral Factory (Qinzhou, Guangxi Province)

Founded in 2001, dry mill in Qinzhou, Guangxi Province treating imported ores mainly from Vietnam, currently no rutile production.

42. Guangxi Guangxin Mining Co., Ltd. (Qinzhou, Guangxi Province)

Founded in 2003, currently no rutile production.

43. Qinzhou Guangxin Mining Co., Ltd.
(Qinzhou, Guangxi Province)

Founded in 2002, treating imported ores mainly from Vietnam, currently no rutile production.

44. Guangxi HTI Mining Industry Development Co., Ltd.
(Nanning, Guangxi Province)

Founded in 2008, treating imported ores mainly from Vietnam and Indonesia, currently no rutile production.

45. Guangxi Fangchang Nanshun Minerals Co., Ltd.
(Fangchenggang, Guangxi Province)

Founded in 2003, mainly trading ores from Vietnam, currently no rutile production.

46. Zhanjiang Mazhang Dade Mineral Processing Plant
(Zhanjiang, Guangdong Province)

Founded in 2008, currently no rutile production.

47. Zhanjiang Delong Mining Co., Ltd.
(Zhanjiang, Guangdong Province)

Founded in 2013, currently no rutile production.

48. Guangdong Suixi County Yuejin Minerals Co., Ltd.
(Zhanjiang, Guangdong Province)

Founded in 1998, formerly mined mineral sands in Zhanjiang, later treated ore from Australia and other places, currently no rutile production.

49. Foshan Nanhai Jiakun Minerals Co., Ltd.
(Foshan, Guangdong Province)

Founded in 2006, currently no rutile production.

50. Shandong Junan Luguang Zirconium Industry Co., Ltd.
(Linyi, Shandong Province)

Founded in 2002, currently no HM production.

51. Tianjin Aoli Minerals Co., Ltd.
(Tianjin)

Founded in 2001, two dry mills in northern China, currently no rutile production.

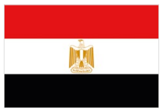
52. Fujian Weiyuan Minerals Co., Ltd. (Tianjin)

Founded in 2012, importing and processing at two dry mills in northern China, currently no rutile production.

53. Fujian Weiyuan Minerals Co., Ltd. (Zhangzhou, Fujian Province)

Fujian Weiyuan Minerals Co., Ltd, previously known as Quanzhou Weiyuan Import and Export Trade Co., Ltd, was established in 2012. The company is mainly active in the import, processing and marketing of minerals and nonferrous metals. Its main products are zircon, ilmenite, rutile, cassiterite, monazite, xenotime, coltan, wolframite/scheelite, kyanite, garnet and spodumene. There is currently no rutile production.

While the previous HMC processing capacity of the company was 80 ktpa it has recently been upgraded to be able to separate the HMC produced and shipped by its new subsidiary Mauritania Titanium Resources Co., Ltd. which began mining HM in Mauritania in February 2017 (cf. Mauritania). Other subsidiaries of Fujian Weiyuan Minerals source raw materials in Egypt (spodumene), Vietnam, Sri Lanka and above all in Malaysia and Nigeria. A subsidiary in Madagascar is in the planning. HMC from Australia and Indonesia and monazite from the HM operations of The Chemours Company TT, LLC in Georgia, USA (cf. USA) are also being imported for processing.



EGYPT

HM placer occurrences extend along the Mediterranean coast of Egypt for about 700 km from Abu Qir in the west to Rafah in the east. Most of the occurrences are present either in the form of storm deposits along the present beaches or in adjoining sand dunes. Well-developed deposits exist in the beach areas of Rosetta, Damietta and north Sinai as well as in the coastal sand dunes of the El-Burullus-Baltim area. HM were mined at Rosetta in the first decades after WW II with an MSP in operation at Alexandria until 1970.

As the Nuclear Materials Authority of Egypt plans to once again exploit the strongly radioactive black sands at Rosetta town and Abu-Khashabah village (east of Rosetta), recently 306 sand samples from that area taken for detailed analyses (Abdel-Karim et al., 2016). Calculated tonnage of raw sand in the area investigated is 15.9 Mt containing 578,760 tonnes of mostly very fine-grained VHM, i.e. the average VHM grade is 3.64 %. Of the 579 kt of VHM, 329 kt is ilmenite (47 – 49 % TiO_2), 182 kt is magnetite, 24 kt is garnet, 21 kt is zircon, 14 kt is leucoxene, 7 kt is rutile and 950 tonnes is monazite. Selected leucoxene grains contained 89.7 % TiO_2 while selected rutile grains contained 95.6 % TiO_2 on average. El-Kammar (2010) published an average TiO_2 grade of 98.4 % in rutile from Rosetta determined by analysing 160 individual rutile grains.

According to Moustafa (2011), a high-grade rutile concentrate assaying 99.3 % rutile with an overall recovery of 88.2 % could be produced easily.

In 2016 the Egyptian Black Sands Company (EBSC) was founded by the Egyptian Military together with the Kafr El-Sheikh governorate, the state-owned National Investment Bank, the Nuclear Materials Authority and the Egyptian Company for Mineral Resource. In 2018 the Nuclear Materials Authority of Egypt awarded a contract to a mineral separation equipment company to develop a DFS for the El Burullus (east of El Burullus Lake) project. A few months later, ESBC signed a deal with Fujian Weiyuan Minerals Co., Ltd. to mine HM sands in that area. In July 2019 the first stage of a new HM mine was opened with a second stage said to be following in October 2019. Total capacity will be 66 ktpa of HMC. Fujian Weiyuan Minerals Co., Ltd. supplied the equipment for the plant in exchange for 30 % of the HMC output for the first five years of operation.

THE GAMBIA

The Gambia is well known to host HM deposits of commercial interest, but their exploitation became the cause for an international scandal in 2008.

HM deposits were first discovered in 1953 on the coast southeast of Banjul, the present capital of The Gambia. Gambian Minerals Ltd., a subsidiary of former British Titanium Products Co. installed a plant to separate the various HM and ship ilmenite and rutile to Britain near the town of Brufut. then. Mining started in 1956 at the Batukunku deposit only, but planned production of 40 ktpa of ilmenite/ rutile never was reached. As the deposit was much smaller than anticipated and international prices for ilmenite were falling, British Titanium's return was small and at the end of 1958, the decision was taken to end all operations. Mining stopped in February 1959 and all equipment was dismantled.

In 2003 the Carnegie Corporation Ltd. of Australia reworked the old zircon-rich stockpiles at Brufut extracting 12,601 t of zircon in 2003 and shipping it to China. In 2006, 437 t and in 2007, 356 t of zircon could finally be extracted (cf. Table 35).

In January 2006 the Carnegie Corporation Ltd. received final government approval to restart HM mining at the Batukunku, Kartung and Sanyang deposits at Brufut through its 45 % owned subsidiary **Carnegie Minerals plc** in an equal joint venture with **Astron Ltd.** of China. The mining license constituted the first mining license granted by the government in more than 50 years. In September 2006 the company announced that it had started mining the Sanyang deposit and that it had shipped the first 1,320 t of HMC to China. The Carnegie Corporation expected to produce about 60 ktpa of HMC by 2007 and 100 ktpa of HMC in 2008.

At the beginning of 2008, all HM operations were halted by request of the Gambia's Geological Department. A little later Carnegie's mining license was terminated and the company's mining assets seized. The mine manager was accused of illegally mining for titanium, iron ore and uranium and imprisoned. He later managed to escape the country.

While there well may have been other causes in the background, the Geological Department stated that its was decision solely based on the regular analyses of HMC provided by Carnegie that revealed the company to be exporting titanium, iron ore and uranium rather than the ilmenite, rutile and zircon for which the license had been granted.

By October 2008 the Gambian Government had decided to sell all of the HM stockpiles and keep the returns for itself.

Carnegie Minerals filed for arbitration with the International Centre for Settlement of Investment Disputes (ICSID) and, in September 2014, the ICSID ruled in favour of Carnegie Minerals. In July 2015 the ICSID awarded almost US$23 million to Astron (which in the meantime had taken over all of Carnegie's assets in The Gambia), which included US$8.6 million in damages for breach of contract. However, in November 2015 the Govern-

Table 35: Import of titanium mineral and zircon concentrates from The Gambia to China in tonnes. Taken from Global Trade Atlas.

	2003	2004	2005	2006	2007	2008	2009	2010
Titanium minerals	0	1086	1233	964	31,353	19,617	58,071	53,444
Zircon	12,601	0	0	437	356	0	0	0

	2011	2012	2013	2014	2015	2016	2017	2018	2019
Titanium minerals	51,870	19,535	34,483	18,595	0	4211	3975	1078	9325
Zircon	0	0	279	0	0	0	0	1145	2684

ment of The Gambia filed a petition with the ICSID for an annulment of the award. Nothing has been heard of this dispute since.

More recently, the Government of the Gambia confirmed that a new license had been issued to a local HM mining company (cf. Table 35).

Total resources at the Batukunku, Kartung and Sanyang deposits are estimated to be 18.8 Mt of ore sand at a grade of 5.2 HM (980 kt HM content). As of 1975 proven reserves were 826,400 t of HM of which 658,800 t were deemed recoverable. The HM assemblage was analyzed and found to be 71.3 % ilmenite (58.2 % TiO_2), 14.6 % zircon and 3.3 % rutile (96.0 % TiO_2). Initial proven rutile reserves were therefore 27,300 t of which 21,700 t were deemed recoverable (Anonymous 1985, 2002, 2007).

GHANA

There is no mining of heavy minerals including rutile in Ghana. However, the Canadian **Hansa Resources Ltd.** is looking into developing potential gold, heavy minerals (especially magnetite, titanomagnetite, and rutile) and sand resources offshore Ghana in a joint venture with private **Poseidon Offshore Minerals Inc.** also based in Canada. The companies are targeting drowned river channels and beach sands of up to 100 m below the surface of the sea.

GUINEA-BISSAU

Russian East Minerals Group holds four mining licenses for HM near Varela on the north coast of Guinea-Bissau through its subsidiary **PÔTO Sarl.** Resources have been established at about 50 Mt of ore sand at an average grade of 5 % HM. VHM of interest are sulfate quality ilmenite, zircon, rutile and monazite, the latter three to be exported as a mixed concentrate. The company received a five-year mining license in 2013, which was suspended in March 2015 for failure to observe environmental regulations, payment of taxes as well as strong opposition from the local population.

According to Global Trade Atlas in 2015, 474 t of zircon concentrate and in 2017, 795 t of ilmenite concentrate from Guinea-Bissau were imported to China.

INDIA

Major HM-rich beach and dune sand deposits occur in India along coastal stretches of the States of Kerala (Chavara), Tamil Nadu (Manavalakurichi, Midalam, Vayakallur), Andhra Pradesh, Odisha (Orissa) and Maharashtra.

The current rutile resources of India as of 2016 stand at 33.95 Mt of which 10.55 Mt is located in Andhra Pradesh, 8.74 Mt in Kerala, 7.85 Mt in Tamil Nadu, 6.58 Mt in Odisha and 0.23 Mt in West Bengal, Maharashtra, Gujarat and Jharkhand. Additionally, there are also very large resources of ilmenite including leucoxene (629.57 Mt), zircon (35.75 Mt), garnet (187.46 Mt), sillimanite (255.09 Mt) and monazite (12.47 Mt).

As of 2016 of a total 2436 km of India's 5921 km coastline had been explored for HM. 2272 km cannot be explored for various reasons leaving 1214 km of unexplored coast.

Until recently, there were four major producers of rutile or leucoxene in India mining at six different locations:

- IREL (India) Ltd. with its Chavara (Kerala), Manavalakurichi (Tamil Nadu) and OSCOM (Odisha) operations
- The Kerala Minerals and Metals Ltd. (Kerala)
- V.V. Mineral Pvt. Ltd. (Tamil Nadu)
- Trimex Sands Pvt. Ltd. (Andhra Pradesh).

Cochin Minerals and Rutile Ltd. (CMRL) has not mined HM recently but operates a synthetic rutile plant with a capacity of 50 ktpa (min. 96 % TiO_2) mainly for export. Cochin Minerals have always reported severe problems in sourcing ilmenite on the domestic market.

The Beach Minerals Company (BMC) India Ltd. used to produce various HM (especially garnet, ilmenite and zircon but also rutile) at Kuttam in Tamil Nadu. It had also applied for mining leases at Bangarammapeta village in Nakkapalii mandal of Visakhapatnam district in Andhra Pradesh. It also had plans for production of synthetic rutile from ilmenite. However, rumours are that BMC stopped all operations in 2016.

The Industrial Mineral Company (IMC) also mined HM in Tamil Nadu specializing in the production of garnet and more recently ilmenite. However, it also sold rutile, zircon, and sillimanite. Rumours are that IMC, similar to BMC, stopped all its operations in 2016.

Some 1847 t of rutile were exported by India in 2018/19 compared with 2038 t in 2017/18. By contrast, 20,825 t of rutile was imported by India in 2018/19 compared with 21,049 t in 2017/18.

Since August 2018 all mineral sands exports from India had to be canalized by the state-owned IREL (India) Ltd. In February 2019 all private companies were even banned from HM mining, leaving only the two state-owned HM mining companies, IREL (India) Ltd. and Kerala Minerals and Metals Ltd. (KMML).

The reasons for these decisions were findings in various reports by specialized governmental teams in recent years, stating that:

- Illegal beach sand mining is widespread in India and many companies do not have all necessary approvals.
- HM mining in Tamil Nadu has continued despite a ban effective since September 2013.
- Inventories of HM products in warehouses were much higher than officially declared by their owners.
- Exports of HM products were beyond permitted limits.
- The majority of the HM stocks ready for export contained monazite levels higher than allowed which is of special importance as monazite is a prescribed substance in India.
- Samples of finished products were impure containing 10–25 % of other minerals.

As a result of these findings, the Indian state took complete control of the national production of beach sands with Decree 26/2015-2020, New Delhi dated 21.8.2018: Standard Operating Procedure (SOP) towards export policy of Beach Sand Minerals (BSM) in terms of Notification No. 26/2015-2020, dated 21.8.2018, published by

Directorate General of Foreign Trade (DGFT), Ministry of Commerce, Govt. of India and published in the Gazette of India Extraordinary Part-II, Section-3, Sub-Section (ii) (Att. 1). This control also includes non-radioactive placer minerals like rutile, ilmenite, and garnet. Since August 2018 any export of placer deposit products must be inspected and approved by the state company IREL (India) Ltd. which on the other hand is under the administrative control of the Department of Atomic Energy (DAE).

IREL (India) Ltd.	
Address (Head office)	Plot No. 1207, Veer Savakar Marg Opp. Siddhivinayak Temple Prabhadevi Mumbai, 400 028 India
Phone	+91-22-24 382 042 / -24 220 843
Fax	+91-22-24 220 236
Website	www.irel.co.in
Contact person	Mr. Kishore Kumar Mohanty, Director Marketing
Phone	+91-22-24 220 843
Email	dir_mktg@irel.co.in

Under the Indian Companies Act 1913, Indian Rare Earths Limited (IREL), now IREL (India) Ltd., was incorporated on August 18, 1950 as a private company in a joint venture with the then Government of Travancore, Cochin. IREL was initially entrusted with acquiring the technology for the production of rare earths compounds from monazite. In 1952 production of rare earths and thorium commenced at its Rare Earths Division (RED) in Aluva, Kerala. In 1963 IREL became a full-fledged government undertaking under the Department of Atomic Energy (DAE).

Beach sand mineral operations were suspended between 1955 and 1960 due to market and management problems and, at the instance of the central government, IREL also took over beach sand mineral beneficiation operations. Accordingly, IREL took over the assets of the closed mineral operation companies at Chavara at Kollam, Kerala State and Manavalakurichi, Tamil Nadu State. The Manavalakurichi plant came into operation in 1968 and the Chavara plant in 1970. The Orissa Sand Complex (OSCOM) at Chatrapur, Orissa was set up in 1972, construction started in 1975 and mining operations commenced in 1984.

Today, IREL operates these three units and produces seven different heavy minerals: ilmenite, leucoxene, rutile, zircon, monazite, sillimanite and garnet, as well as various value added products. Its registered and corporate offices are in Mumbai, Maharashtra.

Chavara

The Chavara HM deposit in the Kollam (formerly Quilon) district of Kerala State is rated as one of the best of its kind in India due to its mineralogical assemblage, vast reserves and the chemical properties of ilmenite with 60 % TiO_2 on average. The deposit covers a coastal stretch of 22.54 km at a width of 225 m between the two tidal channels at Neendakara in the south and Kayamkulam in the north. The coastal strip from Neendakara to Kayamkulam was divided into 8 blocks for mining of which 4 were allotted to IREL. The remaining 4 were allotted to KMML (cf. below). The area has been mined intensively since 1933. Private parties carried out the mining operations of surficial storm deposits in this area even before the formation of Indian Rare Earths Ltd. The total area of the barrier beach licensed area further inland is 4.2 km^2 with an average THM content of 49.1 %. The deposit has an average thickness of 7.6 m and the grade gradually depletes with depth.

There has been intensive investigation of HM deposits extending south of Neendakara-Kayamkulam with mining progressing successively.

The Chavara Minerals Division of IREL was established at Chavara, 10 km north of Kollam, 85 km from Thiruvananthapuram, the capital of Kerala and 135 km by road from Kochi. Until 1988 mineral recovery operations were confined to surficial beach deposits with HM replenished by the annual monsoonal storms. The present annual production capacity of the Chavara unit active in dry as well as wet mining (in barrier beach areas) and mineral separation stands at 200 kt of ilmenite (Q Grade, min. 58 % TiO_2), 11.4 kt of rutile (Q Grade, min. 95.0 % TiO_2, cf. Appendix C), 17.5 kt of zircon (Q Grade), 7 kt of sillimanite (Q Grade) and small amounts of leucoxene (cf. Appendix C). All rutile produced is sold to domestic welding rod manufacturers. Although the head grade is relatively low, monazite has also been separated since 2014/2015. In addition, the plant has facilities for the production of ground zircon called Zirflour (–45 µm) at 6 ktpa and Microzir (1–3 µm) at 0.5 ktpa. TiO_2 pigment is also being produced and there are plans to produce synthetic rutile in future.

Manavalakurichi

The Manavalakurichi (MK) deposit stretches for 6 km from the mouth of the Valliyar River to Colachal in the Kannyakumari district of Tamil Nadu. It covers HM deposits between Rajakkamangalam and Pillaithoppu, including Ethamazhi and Manakudi. Inland deposits located within 200–300 m of the beach between Pithoir and Porivali at a grade of around 20 % HM are also mined with dredging operations. The IREL (MK) plant is situated 25 km north of Kanyakumari (Cape Comorin), the southernmost tip of the Indian sub-continent, in Tamil Nadu State. The major all-weather seaport Tuticorin and the nearest airport at Thiruvananthapuram are equidistant, about 65 km from the plant site. Nagercoil is about 18 km from the plant and is the closest major railway station. The MK plant has an annual production capacity of 90 kt of ilmenite (MK Grade, min. 55 % TiO_2), 3.5 kt of rutile (MK Grade, min. 94.0 % TiO_2, cf. Appendix C) and 10 kt of zircon (MK Grade) in addition to leucoxene (“brown ilmenite”), 8.8 kt of sillimanite, 6 kt of monazite and 10 kt of garnet based primarily on beach washings supplied by fishermen from the surrounding five villages. In addition to mining and minerals separation, the unit has a chemical plant to add value to zircon in the form of limited quantities of zircon flour, zircon frit and other zirconium-based chemicals.

DCW Ltd. procures ilmenite from Manavalakurichi and produces synthetic rutile (95 % TiO_2) at its plant in Sahupuram, Tamil Nadu. Plant capacity is 48 ktpa.

OSCOM

The Chatrapur HM deposit extends along the Ganjam district of the Odisha coast between the River Rushikulya and the Gopalpur lighthouse for about 18 km at a width of about 1.5 km (24.64 km²). It is the largest dunal HM deposit in India with a height of the mineralised dunes of 10 to 12 m. The average HM concentration is about 18 %. The highest HM concentration can be found close to the surface and then gradually decreases with depth. The land is barren and devoid of vegetation except for the occasional casuarinas trees which require less water to grow in the saline environment. The sand deposit in the frontal dune area closer to the sea is not compacted and is free from overburden, clay and rock debris. However, the deposit away from the sea towards the land sometimes contains clay lenses and compact sand below the water table.

In 1984 the Orissa Sand Complex (OSCOM) was commissioned by IREL at Chatrapur. It is about 150 km from Bhubaneswar the capital of Orissa and about 320 km from the all-weather seaport Vishakhapatanam. The OSCOM MSP has a current annual production capacity of 220 kt of ilmenite (OR Grade, min. 50.25 % TiO_2), 10 kt of rutile (OR grade, min. 94.25 % TiO_2, cf. Appendix C), 5 kt of zircon (OR grade), 30 kt of sillimanite (OR

Table 36: Production of rutile and leucoxene by Indian Rare Earths Ltd. in tonnes. Taken from Indian Minerals Yearbook and various statistical handbooks.

	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Chavara rutile	1224	1138	992	1010	2783	1515	1723
Chavara leucoxene	105	162	197	298	201	582	n.a.
Manavalakurichi rutile	1381	974	1260	1396	951	0	938
Chatrapur (OSCOM) rutile	7170	5766	7249	7382	7407	7860	8384

Grade), 4 kt of monazite and 20 kt of garnet (OR Grade). There is also thorium plant in operation since 1992 at OSCOM producing 240 tpa of mantle grade thorium nitrate. The OSCOM synthetic rutile plant (capacity 95 ktpa, min. 90.5 % TiO_2) has been out of operation since 1997.

The OSCOM plant capacity is undergoing a staged expansion, commencing with a new dredge and final nameplate capacities of 470 kt of ilmenite, 18.4 kt of rutile, 8 kt of zircon, 44 kt of sillimanite, 12 kt of monazite and 50 kt of garnet. The expansion is expected to increase production to 650 ktpa of ilmenite and co-products.

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Fax	+91-476-268 0101
Website	www.kmml.com
Email	kmml@md3.vsnl.net.in
Contact person	Mr. Arun B. Kumar, Assistant General Manager Marketing
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Email	agmmktg@kmml.com

The history of the beaches of Sankarmangalam and the nearby areas is inextricably intertwined with the history of monazite mining in India. In 1909 the German scientist Dr. Schomberg found traces of monazite in the sand grains among the imported coir from Sankaramangalam. By 1932 a visionary private entrepreneur established F. X. Perira and Sons (Travancore) Pvt. Ltd, the forerunner to The Kerala Minerals and Metals Ltd. (KMML). During the course of time, KMML changed hands three times: in 1956, it was taken over by the Kerala State Government and placed under the control of the industries department. The unit became The Kerala Minerals and Metals Ltd. in 1972.

KMML sources its feedstock from beaches where surficial sand (uppermost 25 cm) is collected manually and inland areas where mineralized sand is dredged by means of pumps or excavated.

In 1979 KMML started on the construction of a chloride TiO_2 pigment plant at Sankarmangalam which was commissioned five years later and was the first of its kind in India. In 2006 the foundation was laid for a titanium sponge plant (500 tpa capacity). The first batch of titanium sponge was poured in September 2011.

Plans to enhance the annual production capacity from 50 kt to 63 kt of ilmenite, from 3 kt to 4 kt of rutile, from 1.8 kt to 6.5 kt of zircon and to 3.6 kt of sillimanite by the treatment of tailings from the existing MSP have also been approved by the Kerala government.

KMML produces a vast array of minerals and mineral based products at its industrial complex in Sankarmangalam, including sulphate grade ilmenite (58 % TiO_2 min.), rutile (92 % TiO_2 min.,

Table 37: Production of rutile and leucoxene by Kerala Minerals & Metals Ltd. in tonnes. Taken from the Indian Minerals Yearbook and company information

	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Kerala	1850	2330	2638	2774	2405	2454	1548

Table 38: Production of titanium sponge by Kerala Minerals & Metals Ltd. in tonnes. Based on company information.

	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Kerala	88	132	138	140	137	161	246

cf. Appendix C), zircon, leucoxene (75 % TiO_2 min., currently no production), sillimanite (60 % Al_2O_3 min.), monazite, various rutile grades of TiO_2 pigment also of nano size, $TiCl_4$, $TiOCl_2$, titanium sponge and Fe-rich building bricks. In addition, a synthetic rutile plant with a capacity of 50 ktpa (92 – 93 % TiO_2) is in operation but only for captive use.

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Fax	+91-4637-272 802
Website	www.vvmineral.com
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Contact person	Mr. Ramesh Muthukumar, Marketing Executive

V.V. MINERAL

Vetri Vel (V.V.) Mineral Pvt. Ltd. is a privately owned company and was established in 1989. It was primarily a garnet producer until 2000 when it also started the production of ilmenite from its mining leases in Tamil Nadu. Zircon production followed in 2007/2008. The company was granted an export license in October 2000, the first ilmenite export license granted to a private company in India since the 1960s.

Transworld Garnet (India) Pvt. Ltd., which was acquired in 2008 from WGI Heavy Minerals Inc. and Heavy Industrial Minerals India, is another important member of the V.V. Mineral Group.

V.V. Mineral had been active in several seaside villages of the Thoothukudi, Tirunelveli, and Kanniyakumari districts of Tamil Nadu at the Gulf of Mannar. The beach sands here are continuously replenished with HM washed onshore. The villagers mined the HM-enriched beach sand by hand to ensure maximum local employment. The barren beach sand was returned to the mining area to be reclaimed after separation.

At each of the villages, the company owned a wet plant (total: 9) and a dry plant (total: 8) with state-of-the-art machinery. The total capacity of the plants was about 14 kt of garnet, 20 kt of ilmenite, 1 kt of zircon and 0.5 kt of rutile per month. Annual production capacity was reported by V.V. Mineral as 450 kt of ilmenite (55.5 % TiO_2 min.), 18 kt of zircon, 12 kt of zircon-sillimanite mix and 12 kt of rutile (94 % TiO_2 min.), or 654 kt HM in total. V.V. Minerals also published plans to extend its activities into monazite cracking and the production of titanium dioxide as well as various zirconium-based products.

V.V. Mineral owns three big warehouses situated 5 km from the loading berth of the seaport at Tuticorin seaport with a combined storage capacity of 300,000–450,000 tonnes of HM products.

V.V. Mineral produced one grade of rutile which was marketed as puRuTile™.

Table 39: Production of rutile by V.V. Mineral in tonnes. Taken from Indian Minerals Yearbook.

	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Tamil Nadu	7000	3580	2803	1505	1852	0	0

Trimex Sands Pvt. Ltd.	
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Email	sales@trimexsands.com

Founded in 1985 in Dubai, UAE, the Trimex Group was launched to fill the supply gap for quality industrial minerals to the oil drilling industry. Trimex Industries commenced operations in India in 1985 focussing mainly on the production and export of barite and bentonite. In 1999 the titanium business was identified as an interesting additional future opportunity. Trimex Sands Pvt. Ltd. was founded in 2004 to diversify into the extraction and beneficiation of HM.

In February 2004, an initial mining lease was granted to Trimex Sands covering 7.20 km^2 of the Srikurmam deposit in Vatsavalsa and Tonangi villages of Gara Mandal, Srikakulam District in Andhra Pradesh. Having initially met with stiff opposition from local farmers, the Srikurmam project commenced operations in June 2010 producing ilmenite (capacity 180 ktpa), garnet (39 ktpa), sillimanite (46 ktpa), rutile (6 ktpa, cf. Appendix C), and zircon (5 ktpa) from beach sands. In the light of the operational success and continuing demand for titanium feedstock, Trimex Sands had initiated capacity enhancement of the MSP from 180 ktpa of ilmenite to 300 ktpa of ilmenite, from 46 ktpa of sillimanite to 50 ktpa of sillmanite, and from 39 ktpa of garnet to 60 ktpa of garnet. Plans were to ultimately upgrade the ilmenite from Srikurmam to titanium dioxide pigment (60,000 tpa), Ti-slag (145,000 tpa) and Ti-metal (10,000 tpa).

However, on 17.09.2018 the Government of Andhra Pradesh issued a letter to Trimex Sands Pvt Ltd. and suspended the mining operations at its mining lease in Srikakulum district “for illegal mining in violation of lease deed conditions orders issued”.

Mining at Srikurmam was carried out by excavators and the ore sand was transported to a wet mill (pre-concentration plant) by tippers. Trimex had been given permission to mine 6 Mt of raw sand per annum. The ilmenite-rutile-zircon, garnet and sillimanite concentrates produced by wet gravity concentration processes were then transported to the dry mill by tippers. The five final HM concentrates were produced after drying and undergoing electrostatic and magnetic separation processes.

In March 2008 another prospecting license was granted to Trimex Sands for two HM deposits north of the Srikurmam deposit. In 2012 mining

Table 40: Production of rutile by TRIMEX Sands Private Ltd. in tonnes. Taken from TRIMEX Environmental Clearance Reports.

	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19[1)]
Srikurmam	5802	n. a.	6433	6325	6562	9140	4500

[1)] until September 2018, which operations suspended on 17.09.2018 licenses for the Kalingapatnam (15.39 km^2) and Bhavanapadu (17.88 km^2) deposits were also granted. The projected MSP at Bhavanpadu was to have a capacity of 300 ktpa of ilmenite, 50 ktpa of garnet, 50 ktpa of sillimanite, 8 ktpa of rutile and 7 ktpa of zircon.

In January 2011 Trimex Sands also signed a MoU with the Republic of Indonesia for the investment of US$ 800 – 850 million needed to build plants for titanium dioxide pigment, titanium slag and titanium metal in Indonesia within the next ten years.

INDONESIA

Deposits of titanomagnetite are widespread along the beaches of the Indonesian islands, but deposits of other HM are very limited. There are two known instances of rutile and leucoxene getting enriched in beneficiation processes:

The alluvial gold mining tailings on the island of Kalimantan are known to contain zircon although they only contain very limited amounts of ilmenite, rutile and leucoxene. Aral et al. (2008) reported rutile concentrations of 2.2 % and 5.5 % in "two 'as-supplied' artisan-produced zircon-rich concentrates". The ilmenite-rich conducting fraction of the processed zircon concentrates was made out of 71 % altered ilmenite (mostly pseudorutile), 10 % rutile, and 9 % primary ilmenite. The ilmenite contained 56.5 % TiO_2 and the rutile 94.9 % TiO_2 on average.

Pyx Resources Ltd. (2020) of Australia is owner of the Mandiri HM project (2032 ha) in central Kalimantan via its Indonesian subsidiary PT A.U.M. which commenced production in August 2015. Inferred mineral resources as of 2019 stand at 126.3 Mt of ore sand at 7.43 % HM of which 64 % is zircon, 9.5 % is ilmenite and 8.5 % is rutile (750 kt). The processed HM concentrate contains some 65.0 % zircon, 18.9 % ilmenite, 2.4 % rutile, 0.7 % monazite and 1.9 ppm gold as VHM. However, only zircon is being produced as a final product while the remainder is most probably being shipped to China for further processing.

As of 2019 there seems to be just one major producer of rutile in Indonesia. However, there may also be some Indonesian-Chinese joint ventures for which no data is available.

– PT. Irvan Prima Pratama was founded in 2008 and has its headquarters in Surabaya, East Java. Its mining and processing operations are located in Pangkalan Bun, Central Kalimantan. It produces zircon but also smaller amounts of ilmenite and rutile concentrates. All products are exported to China.

Another major zircon-producing company in Kalimantan is PT Karya Lisbeth, which kindly provided a rutile test sample from their operations for further analyses at BGR (cf. Appendix C).

Little information is available about the production of rutile from "amang" in Indonesia. While the potential may be high, it is not of interest to Indo-

Table 41: Imports of titanium mineral concentrates from Indonesia in tonnes. Taken from the Global Trade Atlas.

	2012	2013	2014	2015	2016	2017	2018
China	103,413	26,633	1485	20		457	1188
Germany							364
India			8252[1)]				
Japan	47						

[1)] Unprocessed ilmenite

Table 42: Exports of ilmenite concentrates by Indonesia in tonnes. Taken from the Global Trade Atlas.

	2012	2013	2014	2015	2016	2017	2018
China	6212	6482	500	22,238	n.a.	n.a.	n.a.
Japan	47						

nesian tin-mining companies (above all PT Timah, which is concentrating into unlocking the economic potential of its zircon, ilmenite and monazite/xenotime stockpiles).

In addition to its low availability, and similar to most other unprocessed ores in Indonesia, the export of rutile is banned.

KAZAKHSTAN

Detailed prospecting and exploration of the mineral resources of the former Kazakh Soviet Socialist Republic revealed a number of HM placer deposits. Information on the most important ones are given below:

Between 1999 and 2009 the Shokashsky deposit in north-eastern Kazakhstan was mined by OAO TNC "Kazchrome", a subsidiary of Eurasian Natural Resources Corporation plc based in London and Almaty. About 80 kt of ilmenite and 77 kt of zircon/rutile-mix were produced during the eleven years of operation.

VHM in the Shokashsky placer are ilmenite, rutile, and zircon with leucoxene and anatase occurring as minor Ti minerals. As of 1999 before mining began, the reserves of the Shokashsky deposit were said to be 46.7 Mt of ore sand at an average grade of 13 % HM while inferred resources of ore sand were calculated at 251 Mt. Current remaining reserves are said to be 10.3 Mt of ore sand with mining possibly to restart in 2021. The HM composition is about 70 % ilmenite of sulphate quality (52.5 % TiO_2), 12 % zircon, 4 % rutile (98.3 % TiO_2) and 1 % leucoxene.

Former company TOO "Altyn-Kulager" was planning to mine the Tobolskoye deposit in the Kostanay region of northern Kazakhstan. The Tobolskoye deposit was discovered in 1954 and has been explored in great detail ever since. The deposit contains 17 individual placers and a large number of ore sand occurrences which constitute three main groups: Shibyndovsk (central), Voroshilov and Livanovsk. In addition to these three groups placers are located in a strip 10–12 km wide and about 45 km long. Individual placer lengths vary from 200 to 7600 m in length with a width of between 100–1500 m. Identified VHM are ilmenite, rutile, leucoxene and zircon associated with monazite. Other minerals of potential interest are titanomagnetite, brookite, anatase, magnetite, chromite, platinum and gold. The HM grades vary greatly, but the average ratio of ilmenite : rutile : zircon is 80 : 10 : 9. Absolute grades of the most important deposits are 73.2–83.5 % ilmenite, 9.7–14.2 % rutile and 6.8–10.6 % zircon.

The ilmenite-rich Satpaevskaya (Bekhtimir) deposit in eastern Kazakhstan was discovered in 1989 and is currently being developed by Ust-Kamenogorsk Titanium Magnesium Plant JSC for the production of titanium sponge. The HM suite of this deposit is strongly dominated (90–97 %) by ilmenite (55 % TiO_2) and was calculated to contain about 1821 kt of this Ti-mineral (Kravchenko et al., 2016). Ilmenite from Satpaevskaya has apparently been exported to Russia since 2016.

The Obuhovskoye deposit is located some 40 km north of Kokshetau City in the Taiynsha district of northern Kazakhstan. It is a rather small deposit containing about 10.8 Mt of ore sand at a grade of 9.4 % VHM of which 43.8 % is ilmenite, 2.7 % is leucoxene, 10.8 % is rutile and 42.6 % is zircon. This zircon-rich deposit is owned by company TOO "TiOline" founded in 2004 by Russian steel-treating company TOO Prom Arsenal as majority owner and some Russian and Kazakh investors. A pilot plant produced about 2,400 t zircon, 2400 t ilmenite (55.5 % TiO_2) and 1200 t mixed zircon-rutile concentrate in 2011. A full-scale processing plant was scheduled to go into production in 2013 and to hit full capacity in 2014 producing rutile, ilmenite and zircon as separate products. However, production remains very limited with only mixed HMC being produced and sold to China.

Table 43: Import of zircon concentrates (heavy mineral concentrate) from Kazakhstan to China in tonnes. Taken from the Global Trade Atlas.

	2012	2013	2014	2015	2016	2017	2018
Zircon conc.	6423	7663	7050	5780	3300	2510	3494

KENYA

Production of HM, including rutile, started in Kenya at the end of 2013.

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The Kwale HM deposit is located about 48 km southwest of the Port of Mombasa in Kenya and is some 8 km inland. It consists of three fossil dunes (North, Central, and South) located within a 12 km northeast/southwest striking dune system.

In August 2010 Base Resources Ltd. acquired the Kwale project from Vaaldiam Mining Inc. (formerly Tiomin Resources Inc.) which had been trying to develop the project for 15 years at a cost of US$ 60 million. While continuing to develop the project, Tiomin struggled with local landowners who managed to halt all activity on the project in 2001 and between 2002 and 2005. Construction commenced but was halted again in 2007 as several farmers resisted expropriation by the Kenyan government. Tiomin negotiated a deal to sell 70 % of the project to its largest shareholder Jinchuan Group Ltd., but Jinchuan announced in October 2009 that it was stepping down from the project leaving Kwale undeveloped. Base Resources was able to resolve all previous issues and commence production in October 2013. Since then, Base Resources has become a major player in the world HM and especially rutile feedstock market.

Mining of the Central Dune by Base Titanium Ltd., the local subsidiary of Base Resources Ltd., started with dozers feeding a conventional dozer trap mining unit. In the meantime, three hydraulic mining units have replaced the dozers. The ore sand is fed to the wet mill with a slurry pipeline and the HMC processed in a conventional dry mill (MSP). The final products are ilmenite, rutile and zircon. Once the low-grade fringes of the Central Dune had been reached, mining shifted to the South Dune in mid-2019. Ilmenite and rutile products are transported in bulk by conventional road trucks and discharged in the 80,000-tonne-capacity storage shed at Likoni near Mombasa. Zircon and some rutile are containerized on site and exported through the container terminal at the Port of Mombasa.

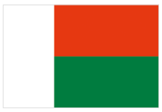
Total mineral resources at Kwale as of 30 June 2019 stand at 285 Mt of ore sand at a grade of 6.0 % HM of which 13 % is rutile. Total reserves as of 30 June 2019 stand at 62 Mt of ore sand at 3.8 % HM of which 13 % is rutile.

The current reserves of Base Titanium at Kwale will be depleted by the end of 2024 so exploration is an important topic. There are three possible extension projects north of Kwale at Vipingo, Kilifi (Sokoke) and Mambrui containing indicated and inferred resources of an additional 1,338,800 tonnes of ore sand at a grade of 3.80 % HM. Furthermore, recent coastal dunes at Sabaki contain more than 72 Mt of HM-enriched sand. In addition to its Special Mining Lease, Base Titanium holds two prospecting licenses covering the North Dune complex and a dunal complex north of the Tanzanian border between Vanga and Remsisi.

Base Titanium produces just one grade of rutile, which was kindly made available for analyses (cf. Appendix C).

Table 44: Production of rutile at Kwale by Base Titanium Ltd. in tonnes. Taken from Base Resources Quarterly Activities Reports.

	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Kwale	0	152	59,348	78,947	87,716	91,456	95,715	78,961



MADAGASCAR

There is currently one producer of heavy minerals in Madagascar:

- QIT Madagascar Minerals (QMM) S.A.

Another company plans to start production of heavy minerals in late 2021:

- Base Resources Ltd. (Toliara Sands project)

Base Resources Ltd. (cf. Kenya) acquired the Toliara project from the Toliara Sands Company in January 2018 and renamed the company Base Toliara SARL. The project had been under development by the Toliara Sands Company, a subsidiary of former World Titanium Resources Ltd. (formerly Madagascar Resources NL), for many years.

The Toliara Sands project lies some 40 km north of the regional town and port of Toliara in south-west Madagascar. The ore sands are bound up in a fully mineralized dune approximately 16 km long, 1–2 km wide and an average of 20–30 m in thickness. Total ore sand tonnage within the previous exploration permit areas at Ranobé, Ankililoaka, Basibasy and Morombe were suggested to be about 4.7 billion tonnes. As of 2019 the main Ranobé project area had a JORC resource of 1293 Mt of ore sand at an average grade of 5.1 % HM (66 Mt HM content) of which 72 % is ilmenite, 2.0 % is rutile and leucoxene and 5.7 % is zircon. The reserve is 586 Mt of ore sand at 6.5 % HM (38.1 Mt HM content) of which 74 % is ilmenite, 1.1 % is rutile, 0.9 % is leucoxene and 5.9 % is zircon.

According to the PFS released in March 2019, the proposed mine will have a life of 33 years, producing 25,736 kt of ilmenite, 1730 kt of zircon and 266 kt of rutile in total. The final products will include three grades of ilmenite (sulphate at 48.3 % TiO_2, slag at 50.5 % TiO_2, chloride at 57.0 % TiO_2), a rutile (chloride pigment-grade at 93.5–95 % TiO_2) and a zircon product. The start of production is currently planned for the end of 2022, delivering 2 kt of rutile in FY 2023, 8 kt of rutile in FY 2024, 7 kt of rutile in FY 2025 and 8 kt of rutile from FY 2026 onwards.

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QIT Madagascar Minerals (QMM) Ltd. is 80 % owned by QIT-Fer et Titane Inc., a wholly owned subsidiary of the Rio Tinto Group. The remaining 20 % is held by the Government of Madagascar. QMM is the license owner of the Fort Dauphin HM project at the very environmentally sensitive southeast tip of Madagascar.

Construction of the necessary buildings and infrastructure for this project started in January 2006 and the first shipment of ilmenite (including rutile) was sent via the newly completed Port of Ehoala southwest of Fort Dauphin in May 2009. Most of the ilmenite product (at 62.5 % TiO_2) is used for titanium slag production for chloride route pigment at Rio Tinto's Sorel smelter in Quebec, Canada. Smaller volumes have recently also been shipped to external customers. There are two commercial by-products: Zirsill which is a mixture of zircon and sillimanite, and more recently monazite or rather monazite-rich tailings.

There is current mining activity at the 2000 ha Madena site to the north of Fort Dauphin and some 14 km to the north of the Port of Ehoala. At the end of 2009, the initial resources of the Fort Dauphin project (Madena site only) were reported as 38.1 Mt of HM including reserves of 11.9 Mt of HM. At maximum capacity, this will sustain a mine lifetime at Madena of about 20 to 25 years. Later phases will be at the adjacent 4000 ha Sainte-Luce deposit (600 Mt of ore sand at 5.5 % HM) and the Petriky deposit (400 Mt of ore sand at 4.5 % HM).

The ore sand at Madena contains between 4.5–5.5 % HM with the HM suite strongly dominated by ilmenite (75-80 %) with zircon, rutile (about 1 %), sillimanite and monazite (1.5 %) being of minor importance. The ratio of rutile to ilmenite in the exported ilmenite product is about 1 to 50.

Table 45: Production of ilmenite and Zirsill by QMM, Madagascar in tonnes. Taken from the EITI Annual Reports.

	2012	2013	2014	2015	2016	2017	2018
Ilmenite	582,182	530,401	333,736	166,290	267,962	428,267*	306,354*
Zirsill	31,242	31,345	27,275	11,879	15,582	24,300*	25,000*

* Global imports after Global Trade Atlas.

MALAWI

Landlocked Malawi in southeastern Africa hosts noteworthy resources of rutile that have remained untapped mainly due to severe infrastructure problems. Elsner & Mylius (2012) summarized the information on these deposits and even more occurences have been found since then.

Chipoka is the name of a small harbour town on the western shores of Lake Malawi in the Salima District of central Malawi. The **Chipoka** HM deposit lies north of the lake port Chipoka with its facilities in good working order and with the port connected by (non-functioning) rail to the port of Nacala in Mozambique. This deposit has been explored since 1998 and prepared for mining since 2006. However, initial separation tests in a pilot plant by former junior exploration company Allied Procurement Agency of Zimbabwe did not achieve the desired results and meanwhile the project has now been abandoned.

Chipoka Bay stretches for about 6 km with a medium width of the sediments of about 1 km. A much smaller area has already been drilled with HM of consistent grade and composition from the bottom to the top of drill holes. Only one of more than a dozen drill holes reached the rock basement before drilling had to be stopped. The rest were still within ore sands at a depth of 50 m.

According to the Environmental Impact Report of the former Allied Procurement Agency the average HM grade is 7.4 %, which is obviously much too low. Also, internally the company used an average HM grade of 33 % while a beach sand sample analysed by BGR in 2006 even contained 75 % THM. The HM suite at Chipoka is dominated by ilmenite (46 %) followed by garnet (42 %) while zircon makes up 4.3 – 6.7 %, rutile 3.4 % and leucoxene 0.6 % of the composition. Inferred resources well exceed 400 Mt of ore sand with most probably much more than 30 Mt of HM content.

Ilmenite from Chipoka is of near stoichiometric chemical composition and does not warrant beneficiation and transport. Garnet from Chipoka was found to be suitable for industrial use by GMA Garnet, however, due to high freight charges only

Figure 20: View over Chipoka Bay with heavy mineral-rich sand clearly visible.

Figure 21: Small suction dredge and pilot wet mill behind for trial mining at Chipoka Bay in 2006.

rutile and zircon are currently of value. Zircon grains are uncoated but are rich in inclusions and therefore difficult to separate.

Opposite Chipoka on the eastern shores of Lake Malawi lies the **Makanjila** HM deposit. The Makanjila deposit is situated in a remote area close to the border of Mozambique and can only be reached by a strenuous trip by car from the south end of Lake Malawi or by boat. In contrast to the placer deposits on the western shores of Lake Malawi, the HM at this location are concentrated in a single large dune up to 100 m high, 4 km wide and about 20 km in length. Exploration commenced in 2003. Red, high-slime, semi-consolidated dune sands and yellow, low-slime, unconsolidated dune and beach sands could be delineated by auger drilling. The HM suite of the red sands was found to contain 7.1 % HM with 79 % ilmenite and 10 % zircon. The yellow sands contained 10.7 % HM with 38 % ilmenite and 5.2 % zircon. Ilmenite from Makanjila is said to be well below stoichiometric composition. The rutile content is below 0.1 %. Resources were estimated at 816 Mt of ore sand averaging about 6 % THM.

About 28 km north of the Chipoka deposit is the **Senga Bay** HM deposit, which has been drilled and contains indicated resources of about 70 Mt of ore sand. The average HM grade was given as around 17 % with 56 % ilmenite (at 46 % TiO_2), 1.4 % zircon and 1.6 % rutile. This is equivalent to indicated resources of 167 kt of zircon and 190 kt of rutile content. The garnet content is high but was not included in the assessment.

The **Nkhotakota** HM deposit about 1.5 km north of Nkhotakota town could possibly be of more interest. As no exploration data are yet available, the thickness of the deposit is unknown but could also be substantial. Bordering Lake Malawi, the youngest beach ridges are cut by waves revealing cliffs with an obvious layering of black heavy minerals. The surface of the beach is also covered with a HM layer. Representative beach sand samples taken and analysed by BGR in 2005 contained about 50 % HM each, with 36–39 % ilmenite, around 5 % zircon, 1.1–3.7 % rutile, 0.4–0.7 % leucoxene and 7–15 % garnet.

Figure 22: Nkhotakota beach is extremely rich in heavy minerals – but unexplored yet.

The Indian Avasya Resources Pvt Ltd. is currently prospecting Sierra Leone and Malawi for HM deposits. It owns an Exclusive Prospecting License (EPL) stretching 125 km along the western shores of Lake Malawi from Onini in Nkhotakota District in the north to Chikhu in Salima District to the south. In a 22.17 km^2 area within its EPL it estimates resources of ore sand at a grade of 6.2 % VHM. Total VHM resources are 5 Mt of ilmenite, 68 kt of rutile, 130 kt of zircon and 150 kt of garnet.

The occurrence of HM near **Tengani**, a small settlement in southernmost Malawi, was discovered almost a century ago. Tengani is 40 km north of the border to Mozambique on the Sena railway line between Malawi and Mozambique. Anorthositic gneisses containing both rutile and ilmenite in the form of stringers, bands, and pods have been found at the nearby Mulaka Hills. The Nkhande and Namyala Rivers begin in Mulaka Hills flowing east towards the Shire River. However, transport of minerals in these rivers is restricted to the rainy season. The riverbeds of the Nkhande and Namyala Rivers have changed course several times in the past and today HM are found in broadened channels several tens of metres wide. The colluvial and alluvial sediments are dominated by garnet and ilmenite and contain some rutile. A resource of 17 Mt of VHM was calculated based on proven average thickness of about 4 m and a concentration of > 20 % ilmenite, rutile and garnet. Rutile makes up 8 % of the HM composition in surface samples taken from the Nkhande's riverbed while the rutile grade in the Namyala's riverbed is only 2.8 %. Total drilled resources of colluvial heavy mineral sands at Tengani stand at 100 Mt averaging 0.34 % rutile (= 340 kt rutile).

Natural garnet from these samples also was checked by GMA Garnet and found suitable for the production of industrial grade garnet. However, the composition of Tengani ilmenite is also stoichiometric and the beneficiation and transport to the Port of Beira is therefore considered unviable, essentially making Tengani a rutile-garnet deposit. Due to the formational history of the Tengani deposit, which has resulted in a highly variable concentration of HM spread over a large area, the placer is not considered a feasible for mining. This appraisal may change when the Sena railway line linking Malawi and Mozambique to the Indian Ocean Port of Beira is fully reconstructed again.

HM in fine sediments of the lacustrine plain of **Lake Chilwa** were discovered by the BGR at the end of the 1980s. An extensive exploration campaign was initiated soon afterwards. The average HM grade is 4.3 % with ore sands of a proven minimum thickness of 4 m and an estimated 15 m. Using a cut-off grade of 2 % THM, indicated HM resources of about 15 Mt and measured resources of about 5 Mt distributed over an area of some 23 km^2 were calculated. The HM composition at Lake Chilwa is strongly dominated by ilmenite (51.5 % TiO_2) while leucoxene makes up 1.1 % and rutile 1.8 % of the HM composition. Due to low percentages of all other VHM besides ilmenite and the elevated clay content and poor infrastructure, the Lake Chilwa HM deposit does not seem to be worth mining.

In 2019 Perth-based Sovereign Metals Ltd. reported a broad and widespread rutile potential in soft, free-dig saprolite down to at least 12 m at Malingunde and Lifidzi in central Malawi. Exploration at this Kasiya prospect is proceeding with no resources having been established yet. However, a recoverable rutile grade of 1.16 % could be established and a bulk rutile concentrate was separated and analyzed (cf. Appendix C).

Table 46: Summary of resources of rutile and leucoxene in Malawi as of 2018.

Deposit	Ore sand [Mt]	HM grade [%]	THM [Mt]	Rutile [kt]	Leucoxene [kt]
Chipoka	> 400	~33	> 30	> 960	> 180
Makanjila	816	~6	49	< 48	
Senga Bay	70	17	17	190	
Nkhotakota		~50			
Onini-Chikhu		6.2 (VHM)	> 5	68	
Tengani	100	> 20 (VHM)	17	340	
Lake Chilwa	350	4.3	15	270	165

MALAYSIA

The only primary ilmenite mine in Malaysia was located in Terengganu State and closed in 2003 due to the depletion of its high-grade reserves.

The biggest remaining resources of Ti-minerals in Malaysia are found in the Kinta Valley area in the State of Perak, which was also dominated by former alluvial tin mining. Tin tailings, known as “amang”, are produced as a by-product of alluvial tin mining in SE-Asia, and very often contain ilmenite, leucoxene, cassiterite, monazite, zircon, xenotime, rutile, struverite and sometimes even wolframite as valuable HM. Tin mining companies have sometimes recovered these minerals from the amang themselves but more often it was sold to specialized processors.

Only small amounts of rutile/leucoxene are still being produced in Malaysia from tin mining operations in Perak and Selangor. Limited resources, due to drastically falling tin production, forced many of the mining and separation companies that existed between 1990 and 2010, to go out of business. Only a very limited amount of the rutile/leucoxene produced is consumed domestically while most is exported to China, India and to a limited extent Taiwan.

Seven amang processing plants in Malaysia were visited in December 2014 and their stocks reported by IAEA (2016), cf. Table 47.

Only four of the seven companies listed in 2014 were still active in 2019:

- Kilang Amang Onn Sdn. Bhd.
- Universal Minerals Trading Sdn. Bhd.
- Minex Corporation Sdn. Bhd. and
- Syarikat Pendorong Sdn. Bhd. was founded in 1974 in Kampar, Perak. It sources its feedstock in Vietnam but ceased rutile production some time ago.

Official production figures of HM recovered from amang are given in Table 48.

Table 47: Stocks of amang and HM produced from amang in Malaysia in tonnes as of December 2014 (IAEA 2016).

	Amang	Ilmenite	Rutile	Zircon	Monazite	Xenotime	Struverite
Universal Minerals Trading	50,000	200		10	25		
Beh Minerals	20,145	6442	97	14	322	64	65
Syarikat Pendorong	20,000	7000	100				
Kilang Amang Onn	7111	1187	28	42			
Yong Fong Jaya	3000				20		
Minex Corporation	1689	940	10	110	50	5	5
TOR Minerals	1000	1000	1200				

Table 48: Production of HM recovered from amang in Malaysia in tonnes, according to the Mineral and Geoscience Department Malaysia.

	2012	2013	2014	2015	2016	2017	2018
Rutile	20,008	5983	3069	198	3810	5266	5070
Ilmenite	22,275	16,043	8159	5814	4316	6363	14,158
Zircon	442	379	677	826	653	1595	509
RE minerals	178	357	455	565	1880	302	1654
Struverite	262	190	255	86	77	61	274

MAURITANIA

HM mining in Mauritania did not start before 2017 when Mauritania Titanium Resources SA began mining the HM-enriched beach sands south of Noukchott. Details of HM placers in this area were provided by LÄUFERTS in 1991.

Mauritania Titanium Resources SA is a subsidiary of Fujian Weiyuan Minerals Co., Ltd. of China, which processes the HMC exported from Mauritania. Seven big bags of HMC were sampled in Mauritania and analysed by the BGR in Germany. They revealed a quite uniform grade of 90 – 93 % HM and a similar VHM composition of 48 – 54 % ilmenite (at 58 % TiO_2, LÄUFERTS 1991), 24 – 38 % zircon and 1 – 4 % (on average 2 %) rutile.

According to Chinese import statistics, 204 t of titanium mineral concentrates from Mauritania were imported in 2017, 1122 t in 2018 and 1020 t in 2019.

Figure 23: Floating wet mills of Mauritania Titanium Resources SA in Mauritania with the Atlantic Ocean in the background. Photo: BGR.

Figure 24: Warehouse of Mauritania Titanium Resources Co., Ltd. with big bags of HMC destined for export to China. Photo: BGR.

MOZAMBIQUE

Due to its long coastline, Mozambique possesses huge potential for HM placers and many state organisations/companies have been active in prospecting for interesting deposits. Seven producers of HM have emerged so far:

- Kenmare Resources plc.
- Africa Great Wall Mining Development Company, Lda.
- Haiyu (Mozambique) Mining Co. Lda.
- Anhui Foreign Economic Construction (Group) Co., Ltd. (Dingsheng Minerais, S.A.)
- Tazetta Resources, Lda.
- Mozambique Heavysand Company, Lda.
- Mutamba Mineral Sands, S.A.

The arrival of potential producers in the near to medium future has been announced but this has so far to materialize reality may prove otherwise. The following gives the key data of two other important HM deposits in Mozambique:

- Corridor Sands between Chibuto and Xai-Xai
  About 180 km north of Maputo. Exploration history since 1997: Southern Mining Corp., WMC Resources Ltd., BHP Billiton, Rock Forage Titanium Lda., Delta Zambeze Consortium, Sofala Resources Pty Ltd. and others. Corridor North ("Corridor Sands 1") developed by Anhui Foreign Economic Construction (Group) Co., Ltd. since 2014 (cf. below). In early 2019 exploration licences covering Corridor Central and Corridor South taken over by MRG Metals Ltd./Australia. Fossil dunal sands with very high slime content; total resources of 16,593 Mt of ore sand with an average of 5.3 % HM in 10 deposits; the largest deposit contains 2672 Mt of ore sand at an average grade of 7.39 % HM (197.5 Mt HM content) and an average of 0.3 % rutile in the HMC. Projected total mine lifetime > 100 years

- Moebase (including Moebase M1+M2, Molocue, Lipobane L1+L2+L3, Decksand D1+D2) and Naburi.
  About 1,100 km northeast of Maputo and 210 km northeast of Quelimane. Exploration history since 1988: Edlow Resources Ltd., followed by Gencor and BHP Billiton; current licenses held since 2004 by Pathfinder Minerals plc. of UK but disputed since 2011. Active and fossil dunal sands with high slime content; 4.8 % THM in the coastal deposits on average, 3.1 % THM in the Decksand deposits and 2.7 % THM in the Naburi deposit. VHM: low-chrome ilmenite (44.5–49.7 %), high-chrome ilmenite (15.2–18.1 %), leucoxene (5.7–20.0 %), rutile (1.2–2.1 %) and zircon (4.7–5.6 %). U + Th in the ilmenite above accepted limits. Total resources of 2,021 Mt of ore sand at an average grade of 3.55 % HM (71.72 Mt HM content). Projected total mine lifetime 33 years. Projected annual production of 65 ktpa of zircon, 24 ktpa of rutile and 1245 ktpa of ilmenite

For details on many more HM deposits in Mozambique as well on the chemical composition of ilmenite and rutile of the most important deposits see Lächelt (2004).

Kenmare Resources plc.	
Address (Head office)	4th Floor, Styne House Hatch Street Upper Dublin 2 Ireland
Phone	+353-1-6710411
Fax	+353-1-6710810
Website	www.kenmarresources.com
Email	info@kenmareresouces.com
Contact person	Eamonn Keenan, Group General Manager, Sales and Marketing

Kenmare Resources plc. (via its local subsidiary Kenmare Moma Mining (Mauritius) Lda.) operates the Moma HM mine on the north-east coast of Mozambique. This coastal stretch of Mozambique was first explored by the Geological Survey of Yugoslavia, which identified several HM placer deposits between the towns of Moma to the south and Mogincual to the north. Kenmare acquired an interest in the project in 1987 with BHP as joint venture partner between 1993 and 1999. Kenmare acquired 100 % of the project after BHP withdrew.

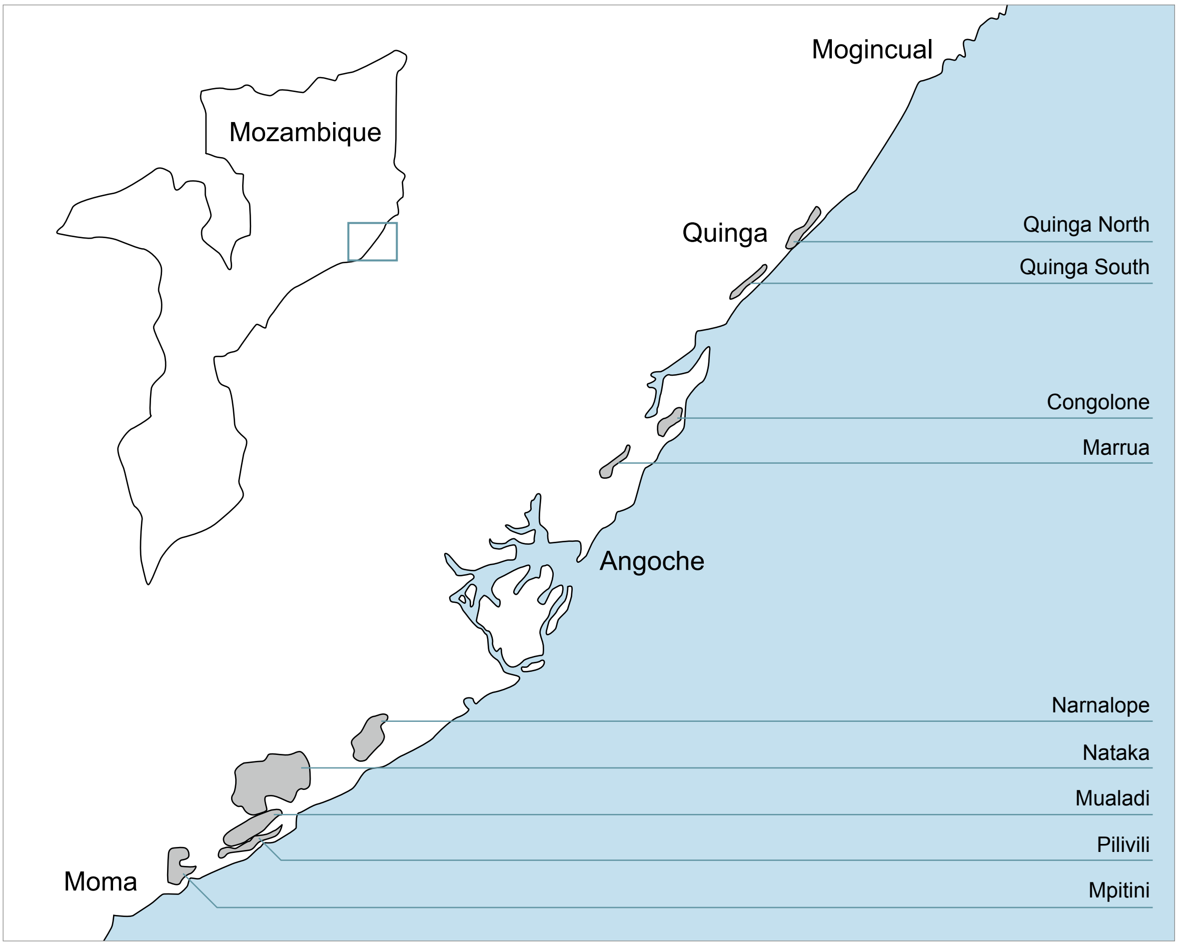


Figure 25: Map showing Kenmare HM licenses in northeastern Mozambique. Courtesy of Kenmare Resources plc.

Construction at Moma began in August 2004 and mining started in April 2007 followed by mineral separation five months later. Kenmare is currently still mining the Namalope deposit with mining carried out by three dredges feeding into two floating wet mills. Additionally and more recently, dozers are supplementing the wet mills with ore sand. Final products (ilmenite, zircon, rutile and HMC) are stored in a 145,000-tonne capacity warehouse with facilities for loading onto a 2.4-kilometre-long overland conveyor which leads to a 400-metre-long jetty. This overland conveyor transports the product to a ship loader at the end of the jetty which loads the product onto self-propelled product transhipment vessels. These vessels then transport the products to a deep-water transhipment point 10 km offshore where they self-discharge into customer's vessels.

Initial planned capacities at Moma were 800 ktpa of ilmenite, 50 ktpa of zircon and 14 ktpa of rutile from an operation with a lifetime of 20 years. In the first years of mining, production rates were much lower, but the rated capacity has now been reached and the first expansion implemented. The dry mill capacities of now are 1200 ktpa of ilmenite, 75 ktpa of zircon and 21 ktpa of rutile. The construction of a third wet mill was planned for 2019; the second wet mill was to be transferred to the Pilivili deposit in H2 2020; and in 2024+ the first wet mill is intended to be transferred to the Nataka deposit.

Three different ilmenite grades, one rutile grade (cf. Appendix C for analysis) and three zircon grades are currently being produced. A monazite-rich zircon-rutile mix has also been produced since 2018 but not yet sold.

At the end of 2019, the total reserves in the Namalope, Pilivili, and Nataka deposits under license to Kenmare were 1584 Mt ore sand at an average grade of 3.3 % THM (52.3 Mt HM content) of which 0.95 Mt was rutile. Additional resources at Namalope, Nataka, Congolone, Pilivili, Mualadi, Mpitini, Marrua, Quinga North and Quinga South deposits were 6371 Mt of ore sand at an average grade of 2.9 % THM (185 Mt HM content) of which 3.3 Mt were rutile. This means that, even at maximum expanded capacity, the mine lifetime at Moma will be well over a century!

Table 49: HM production by Kenmare Resources plc. in Mozambique in tonnes, according to company reports, EITI Mozambique reports and information provided by Ministério dos Recursos Minerais e Energia.

	2012	2013	2014	2015	2016	2017	2018	2019
Ilmenite	574,398	720,104	854,573	763,500	903,300	998,200	958,500	892,931
Rutile	5069	3915	6100	5981	7781	9100	8200	8274
Zircon	46,880	31,400	50,806	51,800	68,200	74,000	58,000	46,900
Concentrates							18,600[1)]	40,200

[1)] including 1900 t of monazite-rutile-zircon mix

Africa Great Wall Mining Development Co., Lda.	
Address (Head office)	Avenida 520 Maputo Mozambique
Phone	+258-1-87-2677 630
Website	www.africagreatwallmining.com
Email	info@africagreatwallmining.com
Contact person	Stuart Wang, Company Director

Africa Great Wall Mining Development Company, Lda. is a subsidiary of the Chinese Jinan Yuxiao Group Co., Ltd. founded in 1995. The company is active in the development, exploitation and export of coastal HM in Mozambique and has been operating in Zambézia Province since 2006.

In 2012 Africa Great Wall Mining in a Public Private Partnership between the Government of Mozambique, the Jinan Yuxiao Group and Guangxi Yinhe Tiancheng Industrial Co., Ltd., started to explore for HM near Deia at Micaune Village in the Chinde District of Zambézia Province. Extensive HM leases are also held by Africa Great Wall in the villages of Maquival and Mopeia-Sede, districts of Nicoadala and Inhassunge in Zambézia Province.

Since 2013 the ore sand from Deia has apparently mined by excavators which feed small floating wet mills for the production of HMC. Since 2017 this HMC is further split into a (magnetic?) ilmenite fraction and a (non-magnetic?) zircon-rutile fraction. The final products are then transported to the port at Quelimane some 10 km to the north for export.

Samples of all products, kindly provided by Africa Great Wall Mining Development Lda., were analysed by the BGR in Germany. The HMC contains around 94 % HM of which 64 % is ilmenite, 11 % is zircon, and 4.4 % is rutile. The ilmenite concentrate contains about 82 % HM of which 59 % is ilmenite, 9 % is zircon and 2 % is rutile. but 30 % are trash minerals (13 % magnetite, 6 % garnet). The zircon-rutile concentrate contains an average of 64 % HM of which 52 % is zircon, 12 % is rutile and 10.5 % is leucoxene/ilmenite.

Table 50: HM production by Africa Great Wall Mining Development Co., Lda. in Mozambique in tonnes, according to information provided by Ministério dos Recursos Minerais e Energia.

<table>
<tr><th></th><th>2013</th><th>2014</th><th>2015</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th></tr>
<tr><td>Ilmenite</td><td rowspan="2">n. a.</td><td rowspan="2">17,500</td><td rowspan="2">177,380</td><td rowspan="2">200,455</td><td>275,678</td><td>194,200</td><td>230,779</td></tr>
<tr><td>Zircon-rutile</td><td>46,430</td><td>45,280</td><td>29,206</td></tr>
</table>

Haiyu (Mozambique) Mining Co., Lda.	
Address (Head office)	n. a.
Phone	n. a.
Website	n. a.
Email	n. a.
Contact person	n. a.

Haiyu (Mozambique) Mining Co. Lda. was incorporated in Maputo in April 2011. The company is a joint venture between the two companies Africa Great Wall Mining Development Co. Lda., registered in Maputo, and Hainan Haiyu Mining Co., Ltd., based in Haikou, the capital of Hainan province.

Hainan Haiyu Mining Co., Ltd. is a joint-stock company registered in 2010 with two primary corporate shareholders: Hainan Non-Ferrous Metals, and Jinan Yuxiao Group.

Hainan Non-Ferrous Metals on the other hand is linked to the Hainan Bureau of Geological Exploration, a provincial Government agency, and to China Natural Resources Inc., a NASDAQ traded Chinese minerals exploration group with a head office in Hong Kong (Amnesty International 2018).

In 2011 Haiyu (Mozambique) Mining Co. Lda. started mining dunal HM sands 3 km north of the village of Nagonha in the Angoche District of Nampula Province, continuously moving southward. A second licence is held by Haiyu (Mozambique) Mining Co. Lda at Sangage some 13 km north of Nagonha (AI 2018).

In September 2013 a first shipment of HMC from Haiyu Mining operations in Mozambique arrived at the port of Haikou. In 2014 the company set up a dry mill to process HMC in Morrua just north of the town of Angoche. In February 2015 torrential rains destroyed the village of Nagonha due to the natural waterway being blocked by backfilled ore sand. Investigations by Amnesty International (2018) led to a temporary closure of the mine from May of that year to late 2018. Mining has now recommenced.

Samples of both products, kindly provided by Haiyu (Mozambique) Mining Co. Lda., were analysed by the BGR in Germany. The ilmenite concentrate contains 99.6 % HM on average of which 95.4 % is ilmenite and 0.5 % is zircon. The zircon-rutile concentrate contains 87.9 % HM on average of which 58 % is zircon, 15 % is rutile and 10 % is ilmenite.

Table 51: HM production by Haiyu (Mozambique) Mining Co., Lda. in Mozambique in tonnes, according to information provided by Ministério dos Recursos Minerais e Energia and EITI Mozambique Reports.

	2013	2014	2015	2016	2017	2018	2019
Ilmenite	67,713	72,188	44,768	67,800	28,091	63,866	66,962
Zircon-rutile		12,311	6450	20,550	5432	83,101	9480

Tazetta Resources, Lda.	
Address (Head office)	72 Le Thanh Ton Street District 1, Ho Chi Minh City Vietnam
Phone	+84-2838-270-181
Fax	+84-2828-270-185
Website	www.eastminerals.com
Email	info@eastminerals.com
Contact person	n. a.

The Pebane HM deposit, which includes the Idugo I, Idugo II, Gurai and Melai deposits, is located around 1000 km northeast of Maputo and 140 km northeast of Quelimane directly south of Pebane town. Pebane was the area of first commercial production of HM in Mozambique in 1959/1960. The historic HM concentrate contained 70 % ilmenite @ 53 % TiO_2, 10–13 % zircon and 3–5 % monazite. The concentrate was also high in Al-silicates, low in rutile and contained traces of chromite. Historic indicated resources stood at 81 Mt of ore sand at an average grade of 10 % HM. Inferred resources were 250 Mt of ore sand at 5 % HM.

Renewed exploration starting in 2011 by Tazetta Resources Lda, a subsidiary of Russian East Minerals Group, led to newly established resources of 200 Mt of ore sand at 5 % HM being found. New production of ilmenite and a mixed zircon-rutile-monazite concentrate was planned for December 2018.

HMC samples, kindly provided by Tazetta Resources Lda., were analysed by the BGR in Germany. They contain 89.3 % HM on average of which 60.1 % is ilmenite, 24.4 % is zircon and 5.7 % is rutile.

Table 52: HM production by Tazetta Resources, Lda. in Mozambique in tonnes, according to information provided by Ministério dos Recursos Minerais e Energia.

	2013	2014	2015	2016	2017	2018	2019
Ilmenite	0	0	0	0	0	n. a.	43,150
Zircon-rutile	0	0	0	0	0	n. a.	33,000[1)]

[1)] sales

Mozambique Heavysand Company, Lda.	
Address	n. a.
Phone	n. a.
Website	n. a.
Email	n. a.
Contact person	Mr. Feng Han

Not much is known about Mozambique Heavysand Co., Lda. which, similar to Africa Great Wall Mining Development Co., Lda. (cf. above) and exploration company Africa Yuxiao Mining Development Co., Lda, is a subsidiary of Chinese company Jinan Yuxiao Group Co., Ltd. Mozambique Heavysand mines a HM deposit adjoining Africa Great Wall Mining's deposit in the Chinde district of Zambézia Province.

HMC samples, kindly provided by Mozambique Heavysand Co., Lda., were analysed by the BGR in Germany. They contain 91.0 % HM on average of which 59.5 % is ilmenite, 14.0 % is zircon and 2.8 % is rutile.

Table 53: HM production by Mozambique Heavysand Co. Lda. in Mozambique in tonnes, according to information provided by Ministério dos Recursos Minerais e Energia.

	2013	2014	2015	2016	2017	2018	2019
Ilmenite	0	0	0	0	0	0	200,889
Zircon-rutile	0	0	0	0	0	0	8131

Mutamba Mineral Sands, S.A.	
Address (Head office)	Salisbury Road London Wall London United Kingdom EC2M 5PS
Phone	+44-207-117 2489
Website	www.savannahresources.com
Email	info@savannahresources.com
Contact person	David Archer, CEO

The enlarged combined Mutamba HM project (including the Jangamo, Dongane, and Ravene deposits, as well as the Chilubane deposit to 180 km to the southwest) lies 450 km northeast of Maputo. It covers some 399 km^2 in license areas. The project is based on a consortium agreement between Rio Tinto and Savannah Resources plc of the UK in October 2016. Savannah acts as the operator while Rio Tinto has an offtake agreement for 100 % of the production. As of 2017 the total resources of Mutamba's three northern deposits stood at 4,400 Mt of ore sand at an average grade of 3.9 % HM containing 172 Mt of HM of which about 1.3 % (2.2 Mt) was rutile.

A pilot plant was commissioned on site in December 2017. A PFS by TZMI was due in early 2019. While trial production has already started, the consortium is targeting first commercial production in 2020 with average annual production of 456 kt of ilmenite and 118 kt of non-magnetic concentrate over a mine life of > 30 years.

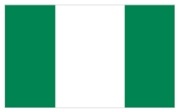
Anhui Foreign Economic Construction (Group) Co., Ltd.	
Address (Head office)	No. 28, Dongliu Road Hefei, Anhui, 230051 People's Republic of China
Phone	+86-551-53492558
Fax	+86-551-53492537
Website	www.afecc.com
Email	afecc@afecc.com
Contact person	n. a.

Anhui Foreign Economic Construction (Group) Co., Ltd. (AFECC) was established in 1992 and has successively undertaken nearly 100 large-medium infrastructure projects in around 30 countries worldwide. The group's construction projects include the Maputo International Airport, roads, hotels and Ministerial Office buildings in Mozambique. AFECC has also been active in overseas mineral resources development since 2009. Up to now, it has acquired prospecting licenses for diamond, gold, emerald, HM, copper and other commodities in Zimbabwe, Zambia, Mozambique and the Democratic Republic of Congo. It already mines diamonds in DRC and emeralds in Zambia.

In November 2014 Anhui Foreign Economic Construction (Group) Co., Ltd. and Yunnan XinLi Non-ferrous Metals Co. Ltd. signed a contract with the Mozambican government to develop the northern part of the Corridor Sands project. A new company, Dingsheng Minerais, SA, was founded for this purpose which is owned by AFECC (85 %) and EMEM (Empresa Moçambicana de Exploração Mineral) (15 %). Dingsheng Minerais' concession covers 10,544 ha and as of 2010 contained resources of 2673 Mt of ore sand at an average grade of 7.3 % HM of which 0.3 % (585 kt) is rutile.In order to develop this project, Anhui plans to build a new power plant, an air strip and a 70 km railway line from its mine site to Chókwè which is served by the Limpopo railway line. The mining company also plans to build a dedicated terminal for its HMC exports at the Maputo port.

As the railway line has yet to be completed, HMC from a pilot plant is currently transported by truck to Maputo port where it is shipped to China for further testing.

Dr. Elias Daudi, director of the Direccão Nacional de Geologia e Minas (DNGM), visited Dingsheng Minerais' operations in December 2018 and reported: "Current production is 1 t/d out of a small pilot plant which has been in operation since May 2018. The company plans to increase the capacity of this pilot plant for a production of 3 t/d by the end of 2019. After 2019 two production modules each with a capacity of 10 t/d are planned." (pers. communication with BGR staff).



NIGERIA

Most rutile from Nigeria is a by-product of alluvial cassiterite production, which has increased rapidly in recent years.

Funtua & Elegba (2008) provide a useful description of the origin of cassiterite from Nigeria:

"Alkaline rocks and granites which occur in central Nigeria are the source of commercial quantities of cassiterite, columbite, zircon, monazite, xenotime, thorite, molybdenite and pyrochlore. Cassiterite and columbite mining, mostly from alluvial deposits, and processing of the ores, have been taking place for over a hundred years, mostly centred on the Jos Plateau in central Nigeria. Associated with this activity are extensive mine tailings that have been generated over the years and these tailings are left either unsorted or separated into zircon, monazite and ilmenite. The wide dispersal of the alluvial deposits containing the ores favoured exploitation by a large number of operators, ranging from small scale miners to those that are large and highly mechanized. Dredging and gravel pump methods are applied in the mechanized mining of cassiterite and associated minerals in the Jos Plateau area of Nigeria. Dredging involves spreading the ore containing material on revolving or oscillating screens and disaggregating using high pressure water jets. The undersize portions, which contain the heavy minerals, are separated after passing through jigs. The concentrates are then taken to processing mills where the ores are separated from the tailings through the use of shaking tables, magnetic and electrostatic separators. A typical processing mill occupies an area of about 1000 m^2 with an office block and the mill shade housing separating tables, magnetic and electrostatic separators. With increasing depletion of the soft ore containing materials there was an increasing use of simple tools by the local population to dig out the ores in hand dug pits and use panning methods to recover the ores. The processing activities for the recovery of the concentrates take place in their households and backyards."

Rutile is not explicitly mentioned above and, in contrast to zircon and other HM, its output in Nigeria is rather limited.

As of 2019 the Nigerian Ministry of Mines and Steel Development granted three exploration licences (2 in Taraba State, 1 in Katsina State) and three small-scale mining leases for rutile (1 in Kaduna State, 1 in Bauchi State, 1 in Jigawa State). However, only the mining lease in Bauchi State is connected to cassiterite mining. Also as of 2019, the Ministry granted 30 exploration licences, 19 small-scale mining leases and 85 mining leases for cassiterite. Many of these leases cover a variety of potential by-products although rutile is not specifically mentioned.

Table 54: Imports of titanium mineral concentrates from Nigeria to China and Hong Kong in tonnes. Taken from the Global Trade Atlas.

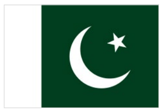
	2012	2013	2014	2015	2016	2017	2018	2019
China	1514	3230	196			15,594	9647	2915
Hong Kong						538		

NORWAY

There is no mining for rutile in Norway although there are plans for a hard-rock rutile project:

In 2006 Nordic Mining ASA acquired the rights to the Engebø rutile and garnet project located near Førde in Sogn og Fjordane District some 150 km north of Bergen. As of 2020 the Engebø deposit was reported to contain measured and indicated resources of 133.2 Mt of eclogite at a grade of 44.4 % garnet and 3.51 % TiO_2 (cut-off grade 2 % TiO_2) mostly in the form of rutile. Proven and probable ore reserves within the resources amount to 34.3 Mt (open-pit) plus 28.9 Mt (underground).

According to the DFS published in January 2020, open pit mining is planned to start in October 2022 with production following in 2024 due to continue for 15 years. Development of the underground mine will start in year 13 to enable underground production to take over from the open pit. The life of mine runs until 2057. Planned production is 1.5 Mtpa of ore yielding 278 kt of garnet and 34 kt of rutile (94.9 % TiO_2, medium grainsize 106 µm) on average per annum. TZMI considers Engebø rutile to be suitable feedstock for chloride pigment and titanium metal applications.



PAKISTAN

There is no reliable information on rutile production in Pakistan. However, at least one company states that it produces this commodity.

This company is Gulf Minerals fze (Pvt) Ltd. in Karachi. Gulf Minerals was established in February 2007 by a UAE businessman. Besides trading various mineral commodities like pyrite, fluorite, barite and especially chromite, it was granted an exploration license over 978 km^2 along Sonmiani Bay northwest of Karachi (cf. Choudri et al. 2010) in early 2006. This exploration licence was said to have been withdrawn in May 2007 although Gulf Minerals still mentions a mining licence on its website. Mined HM are upgraded (?) to final products ("HiTi" or rutile (?), zircon, and others) in a dry mill in Manghopir, Gadap Town, north of Karachi.

The Global Trade Atlas only gives data of zircon concentrates (apparently also containing rutile) imported from Pakistan mainly to China.

REPUBLIC OF SOUTH AFRICA

The Republic of South Africa (South Africa) hosts numerous HM deposits all of which were described a few years ago in detail by LIEDTKE & TONGU (2014). This study therefore only lists the current producers of rutile or leucoxene, and mentions major deposits with established HM resources.

There are currently three producers of rutile or rutile-rich mineral concentrates in South Africa mining four different deposits:

– Richards Bay Mining (Pty) Ltd.,
– Tronox Ltd. with two branches: Namakwa Sands in the Western Cape Province and KZN Sands in KwaZulu-Natal,
– Mineral Commodities Pty. Ltd.

There are also some noteworthy HM deposits which might be developed any time in the future:

Zirco Resources (SA) (Pty) Ltd., a private, South Africa based mineral sands exploration company, is developing the **Kamiesberg HM project** in the Northern Cape Province approx. 70 km north of Namakwa Sands HM mining operations (cf. below.). The project is made up of four license areas: Roode Heuvel in the south, Leeuvlei in the north, Langkuil in the west and Sabies in the east. Total resources as of 2020 stood at 2,715 Mt of ore sand at an average grade of 3.3 % HM (89.6 Mt HM content) of which 2.7 % is leucoxene and 1.5 % is rutile. Start of production could start in 2024 at the earliest with ilmenite (490 ktpa at 47 % TiO_2), a zircon-rutile mix (45 ktpa) and monazite (11 ktpa) to be sold as final projects. Major hurdles are the lack of infrastructure and the 530-kilometre distance to the port at Saldanha Bay for export. The adjacent Namakwa Sands Groen River Property was evaluated by Exxaro/Namakwa Sands

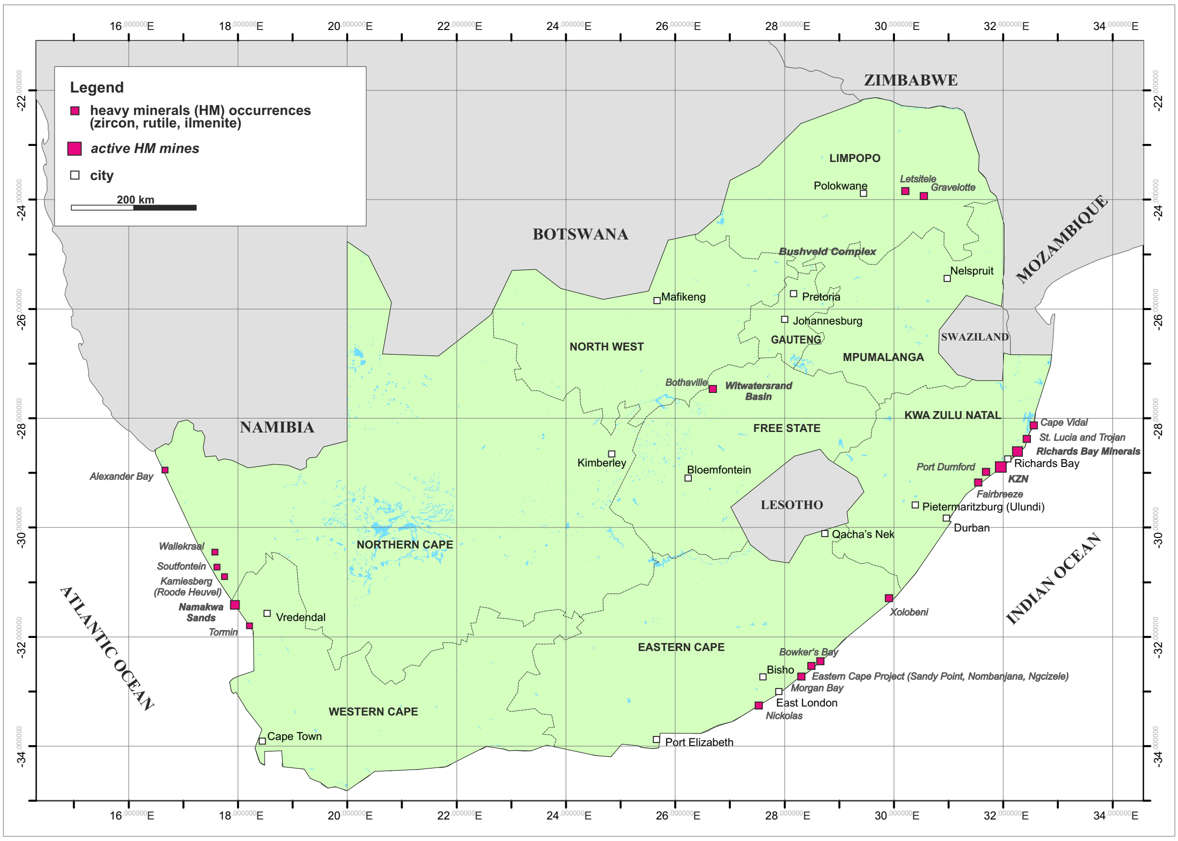


Figure 24: Map of HM deposits in South Africa. Taken from LIEDTKE & TONGU (2014).

and contains resources of 419.5 Mt of ore sand at 4.07 % HM of which 3.4 % is rutile and 7.9 % is leucoxene.

Australian based Mineral Commodities Ltd. (cf. below) has attempted to divest its shares in Transworld Energy and Minerals Resources (SA) (Pty) Ltd., which is the majority-owner of the **Xolobeni HM project**. The Xolobeni tenements are situated on the coast of the Eastern Cape south of Port Edward approx. 300 km north of East London and 200 km south of Durban. With its five distinct blocks Mpahlane, Mnyameni, Kwanyana, Sikombe and Mtentu, Xolobeni has an estimated resource of 346 Mt of ore sand at 5.0 % HM (17.3 Mt HM content) of which 9.3 Mt is ilmenite, about 570 kt is rutile, 450 kt is zircon and 450 kt is leucoxcene. Plans were to mine Xolobeni over a mine life of 22 years yielding 250 kt of ilmenite, 19 kt of rutile, 15 kt of zircon and 15 kt of leucoxene on average per annum. However, Xolobeni has faced strong environmental and local opposition from the very beginning and a government-imposed moratorium, which prevents any new or existing mining or prospecting applications being processed, remains in effect at Xolobeni with its future development open.

Tronox Ltd. held the prospecting rights on some remote HM deposits known as Sandy Point Recent, Sandy Point Old, Nombanjana (formerly Wavecrest) and Ngcizele (formerly Kobonqaba) in the Eastern Cape of South Africa. These deposits are situated about 80 km northeast of East London on the coast some 15 km northeast of the Kei River Mouth in the vicinity of Centane (Mnquma). As of 2012 the total resources of this **Eastern Cape HM project** stood at 255.9 Mt of ore sand at a grade of around 6.9 % HM of which some 65 % is ilmenite, 6 % is zircon and 3 % is rutile. The current license status of this project is unknown.

In the past, Tronox Ltd. also explored the **Port Durnford HM deposit** situated 25 to 35 km west-southwest of Richards Bay and extending over approx. 13 km between Tronox' former Hillendale Mine in the north and the town of Mtunzini in the south. Tronox' current Fairbreeze Mine (cf. below) is located South of Mtunzini. As of 2012 the total resources of the Port Durnford deposit stood at 948.6 Mt of ore sand of which 2.68 % is ilmenite. Port Durnford was thus evaluated as another source of ilmenite feed for the smelter operations at Tronox' central processing complex in Empangeni. The production rate at Port Durnford was planned to be 22 Mt run of mine per year with a life of mine of approx. 15 years. A PFS for the Port Durnford Project was completed in 2009. However, the current license status is unknown.

The **Bothaville HM occurrence** is located near Bothaville in the Free State some 200 km southeast of Johannesburg. The last known license owner was Southern Mining Corporation Ltd., however, which went into liquidation a few years ago. In contrast to most other HM deposits worldwide, the HM at Bothaville occur in consolidated sandstones with an average thickness of just 2.75 m. Additionally, the slime content is high and contaminants like goethite, silica and chromite are abundant. Inferred resources at Bothaville stand at 185 Mt of ore at a grade of around 30 % THM of which 30 Mt of VHM might be recoverable. The VHM composition is estimated to be 68 % ilmenite, 9 % zircon, 23 % other titaniferous minerals (anatase, rutile, leucoxene) and 1 % monazite.

Table 55: Global imports of rutile and leucoxene from South Africa as far as separately recorded or discernible (also contained in titanium mineral concentrates). Taken form the GLOBAL TRADE ATLAS [all data in tonnes].

	2012	2013	2014	2015	2016	2017	2018
Rutile to Mexico	2370	2564	2345	7543	3680	3933	3063
Micronized Rutile to Mexico	24		52	218	26		18
Rutile to South Korea	2040	702	1980	1920	2582	2160	4240
Rutile* to Singapore	2029						
Rutile to India	360	286	1886	2120	2880	4398	3094
Leucoxene to India	360	312	676	112		496	52
Rutile* to Indonesia	540	146	431	452	1400	1384	1728
Rutile* to Iran	100	234	400		504	476	532
Rutile* to Argentina	322	495	699	358	440	420	364
Rutile to Thailand	40			64	426	613	320
Leucoxene to Thailand	1940	360	100	298	200	160	280
Rutile* to Malaysia	341	206	400	520	636	48	527
Rutile* to Philippines			110	168		233	223
Rutile to Algeria			10			234	
Rutile* to Egypt		52	26				
Rutile* to Slovenia	125	212	123	150	74	98	149
Rutile* to Greece					144	80	106
Rutile* to Croatia	69	105	77	88	132	168	88
Rutile* to Romania				42			
Rutile* to France	52					20	20
Rutile* to Venezuela	205		178	110			
Rutile* to Peru	14	12	8	7	9	62	7
Rutile* to Paraguay	52						
Rutile* to Uruguay							10
Rutile* to Chile				6	5		
Rutile* to Mozambique					6	8	
Rutile* to Belarus	20						
Rutile* to Australia	24						
Rutile* to Sweden	72	75				50	
Rutile* to Russia	545	63	978				
Rutile* to Ukraine	80	62	4				
Rutile* to Kazakhstan						5	
Total	**11,724**	**5886**	**10,483**	**14,176**	**13,144**	**15,046**	**14,821**

* Rutile and possibly leucoxene

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Richards Bay Minerals (RBM) is a HM mining and processing operation established in 1976. 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 September 2012, RBM is owned by Rio Tinto Iron & Titanium Inc. (74 %), BBBEE Consortium Blue Horizon (24 %) and an employee's trust (2 %).

RBM has been mining elevated dunal sand deposits stretching from 10 to 50 km north of Richards Bay in KwaZulu-Natal since 1977. Mining is performed by six floating dredges at four mine sites (B, C, D and E) at various places within the dunes supported by dry mining in areas inaccessible to the dredges. The HM concentrates are trucked to a central processing plant where several grades of ilmenite, three grades of rutile (standard grade at min. 89 % TiO_2, welding grade at min. 92 % TiO_2, and prime grade at min. 95 % TiO_2, cf. Appendix C for analyses), and zircon (4 grades) are produced. The current capacity of this dry mill is estimated at up to 2 Mtpa of ilmenite, 250 ktpa of zircon, and 90 ktpa of rutile. Since a fourth furnace and mining plant were installed in 1992, the titanium slag capacity of RBM has been about 1 Mtpa and the pig iron production 555 ktpa.

Most of the Tisand lease just north of Richards Bay has already been mined and rehabilitated by RBM. Currently, the Zulti North mining lease (north of Lake Nhlabane) is being mined. Mining in this lease should last until 2036 with a reported 31 Mt of HM remaining as of the end of 2016. The Zulti North Extension, the St. Lucia, Tojan and the Cape Vidal deposits even further to the north will not be mined due to environmental restrictions. However, in March 2011 RBM announced that it intended to also mine its Zulti South mining lease area south of Richards Bay, extending mining operations to around 2044. The last year of full production will be 2032. Mining in the Zulti South area could start as early as 2022. Estimated resources for the latter lease are given as 26.4 Mt of THM or 22.3 Mt of VHM.

In March 2011 RBM commissioned a tailings treatment plant (TTP) with production beginning in April 2011. The operation had stockpiled 16 Mt of tailings from its MSP during the previous 30 years. In 2011 this TTP treated 415,034 tonnes of old tailings and 730,654 tonnes of new tailings from the MSP (RBM Abridged Sustainable Development Report 2011). The TTP is to treat 2.2 million tonnes of tailings on average annually yielding 60,000 tpa of zircon among others.

Information on the mineralogy of leucoxene from northern KwaZulu-Natal was provided by Dunlevey (1999) and Deysel (2007). Information on rutile from the same region can be found in Bramdeo & Dunlevey (1999).

Table 56: Rutile production by RBM [in tonnes], after company information. e = estimated

	2012	2013	2014	2015	2016	2017	2018	2019
Rutile	97,489	~60,000	~75,000	~70,000	~65,000	70,000e	60,000e	46,176

Figure 27: Mining lease areas of RBM (Source: Richards Bay Minerals).

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Tronox Ltd. owns two HM mining operations in South Africa: Namakwa Sands and KZN Sands. Namakwa Sands was formerly owned by Anglo American plc. while KZN Sands by South African steel giant ISCOR Ltd. and Ticor Ltd. of Australia (Ticor SA). From 2005 Namakwa Sands and KZN Sands were owned by Exxaro Resources Ltd. Before the mineral sands business of Exxaro Resources was taken over by Tronox Ltd. based in Stamford, CT, USA, in 2011.

The Namakwa (Namaqualand) Sands operations are located in the Western Cape province of South Africa. Mining by Anglo American started here in September 1994. Mining at two mine sites and pre-concentration at two primary and one secondary concentration plants is carried out at Brand se Baai around 385 km north of Cape Town. The MSP is located 52 km from the mine and 7 km west of Koekenaap. Shallow sand mining at Brand se Baai takes place at the East Mine (4–8 Mtpa run of mine) and deeper, more compacted sand is exploited at the West Mine (12–14 Mtpa run of mine). Most of the impure zircon and leucoxene, along with monazite, pyroxene and garnet, are returned to stockpiles from the MSP to be reclaimed in the future.

Namakwa Sands also operates two furnaces at Saldanha Bay where ilmenite is smelted to produce titanium slag and pig iron. Current capacity of Namakwa Sands is 125 ktpa of zircon, 190 ktpa of titanium slag (chloride and sulfate), 100 ktpa of pig iron and 31 ktpa of rutile/leucoxene. In addition, some garnet is separated during the ilmenite benefication process. The coarser garnet fraction is further refined by a local customer to produce sandblasting material.

Total reserves of Namakwa Sands at the end of 2019 stood at 748 Mt of ore sand at a grade of 6.1 % HM (45.6 Mt HM content) of which 10.2 % was rutile and leucoxene (4.6 Mt). A rutile (94 % TiO_2) and a leucoxene product (“Tiokwa” at 90 % TiO_2) (cf. Appendix C for analyses) were produced at Namakwa Sands until the end of 2017. From early 2018 these products started being combined into a single rutile stream that is typically 92–93 % TiO_2 and which is now only supplied in bulk to Tronox’s internal pigment plants, meaning there are now no more external titanium minerals sales.

Mineralogical details on the rutile from the Namakwa Sands HM deposit can be found in Rozendaal et al. (2009).

The KZN (KwaZulu-Natal) Sands project began in July 1994 when several HM projects in South Africa, including Hillendale and Fairbreeze, were sold by Shell South Africa and Rhombus Exploration Ltd. to ISCOR Ltd. Hydraulic mining of the silt-rich ore sands at Hillendale by Ticor SA commenced in 2001 and ended due to depletion of the Braeburn Extension deposit in December 2013.

Original plans to open the Fairbreeze deposit 25 km to the southwest soon afterwards were postponed in December 2009 but reactivated in March 2011. Mining finally commenced in April 2016. Reserves of the Fairbreeze deposit (A, B, C, C Extension and D Blocks) at the end of 2019 stood at 233 Mt of ore sand at an average grade of 5.7 % HM (13.3 Mt HM content) of which 7.2 % was rutile and leucoxene. Thus, rutile/leucoxene reserves at Fairbreeze were 950,000 tonnes. The expected minimum mine lifetime is 12 years.

Figure 28: The unconsolidated ore sands at Brand se Baai are mined with front-end loaders in a load-and-carry operation. The hardened layers are mined using hydraulic excavators in a backhoe configuration or by trackdozer. Photo: BGR.

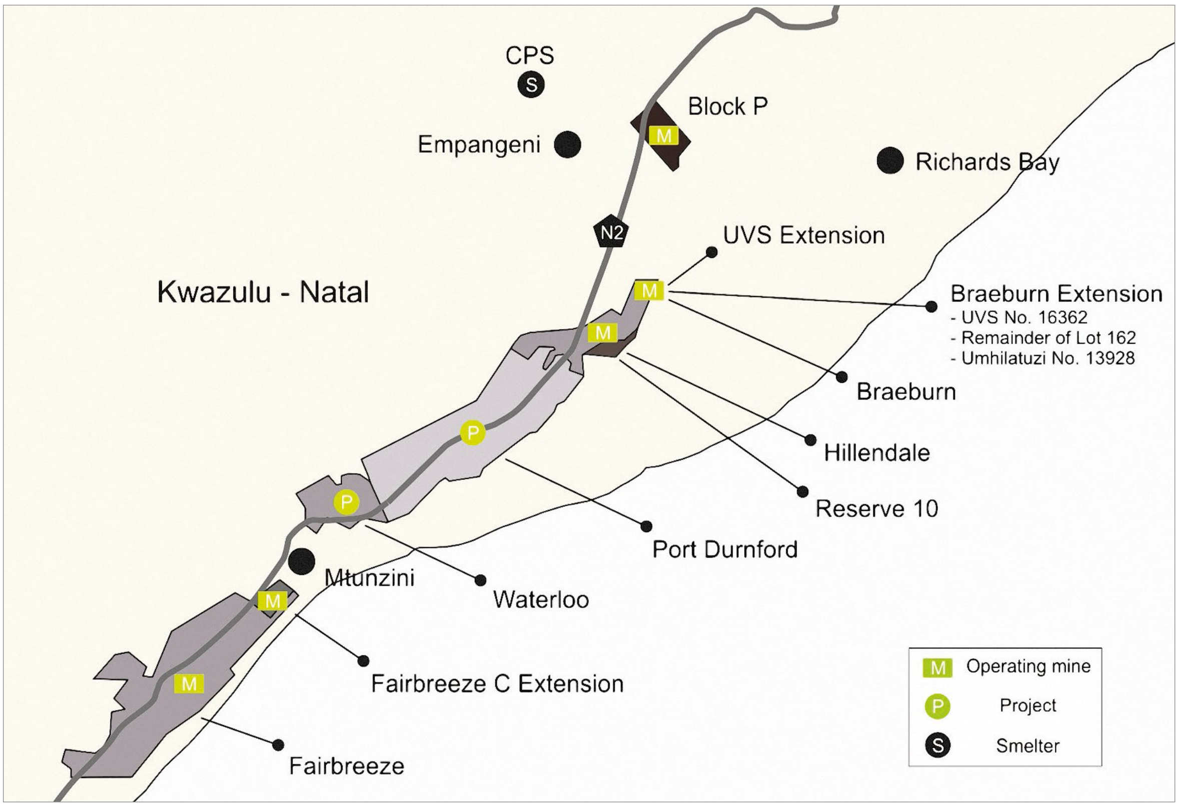

Figure 29: Mineral sand mines and projects in KwaZulu-Natal as of 2011. Taken from Liedtke & Tongu (2014).

KZN Sands used to produce ilmenite, zircon, rutile (two grades), leucoxene, titanium chloride slag, slag fines and low manganese pig iron. Once KZN switched from Hillendale to Fairbreeze, the two grades of rutile and one grade of leucoxene changed to just one grade of rutile (at 95 % TiO_2) and very small amounts of leucoxene (at 85 % TiO_2). Both of these products are now being blended to produce just one rutile stream used solely for internal pigment production.

The MSP and the furnaces for ilmenite smelting are located at a central processing complex at Empangeni 40 km from Fairbreeze and 18 km west of Richards Bay.

Table 57: Production of rutile and leucoxene by Tronox Ltd. in South Africa in tonnes. Taken from Tronox Ltd. company reports and company information (2012 data).

<table>
<tr><th></th><th>2012</th><th>2013</th><th>2014</th><th>2015</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th></tr>
<tr><td>Namakwa rutile</td><td>22,082</td><td rowspan="2">27,000</td><td rowspan="2">26,000</td><td rowspan="2">28,000</td><td rowspan="2">26,000</td><td rowspan="2">30,000</td><td rowspan="2">32,000</td><td rowspan="2">32,000</td></tr>
<tr><td>Namakwa leucoxene</td><td>3545</td></tr>
<tr><td>KZN rutile</td><td>9748</td><td rowspan="2">6000</td><td rowspan="2" colspan="2">no production</td><td rowspan="2">12,000</td><td rowspan="2">19,000</td><td rowspan="2">22,000</td><td rowspan="2">25,000</td></tr>
<tr><td>KZN leucoxene</td><td>0</td></tr>
</table>

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Mineral Commodities Ltd. of Western Australia has mined very rich HM sands at the Tormin site some 400 km north of Cape Town and south of the Namakwa Sands HM mine since October 2013. The Tormin HM mining rights are held by Mineral Sands Resources (Pty) Ltd., a 50 %-owned South African subsidiary of Mineral Commodities Ltd. The other 50 % was owned by the Black Economic Empowerment (BEE) partner Blue Bantry Investments (Pty) Ltd.

The HM deposits at Tormin have accumulated along the ~12-kilometre-long, 100-metre-wide beach to a maximum depth of 12 m, and are still being supplemented through erosion of a HM-enriched, 25 m thick paleo-beach terrace situated 35 m above current sea level. The predominant heavy mineral is garnet with ilmenite, pyroxene, zircon, rutile, and leucoxene in the HM assemblage. The HM placers overlie diamond bearing gravel beds. At the end of 2019, inferred resources stood at 2.40 Mt of ore sand at a grade of 8.68 % THM (cut-off grade 2 % THM) of which about 77 % was garnet, 12 % was ilmenite, 3 % was zircon and 1.2 % was rutile. While the Tormin deposit still is being replenished naturally every year, the volume and grade of replenished material is decreasing substantially and the remaining life of the mine in the currently mined stretch of beach is limited. In June 2019 a mining right

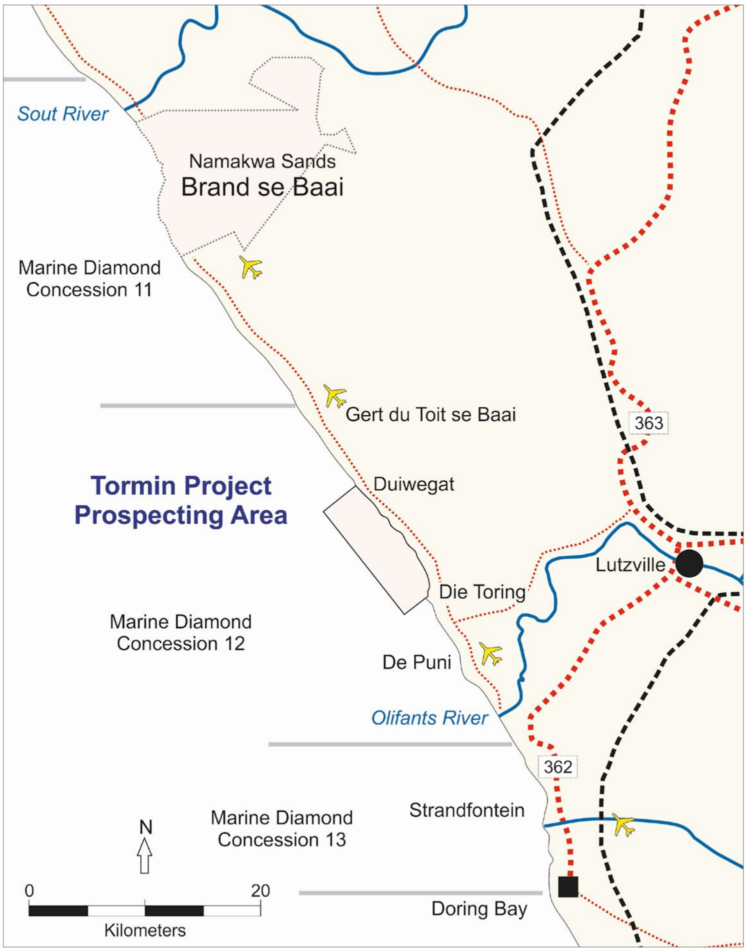

Figure 30:
Location of the Tormin Project prospecting (now mining) area south of the Namakwa Sands operations at Brand se Baai. Taken from Liedtke & Tongu (2014).

expansion application was granted which also covers the adjoining northern beach and some inland deposits.

In May 2020 an additional resource of 2.507 Mt of ore sand at a grade of 23.58 % HM (591,000 tonnes HM content) of which 49.27 % is garnet, 8.90 % is ilmenite, 3.77 % is zircon, 1.06 % is rutile, 0.55 % is magnetite and 0.16 % anatase could be published for parts of these northern beaches.

Additionally, in September 2020 resources for the Western Strandline Deposit were given as 22.8 Mt of sand at 20.92 % THM of which 0.88 % was rutile, meaning the deposit contains some 42,000 tonnes of rutile.

The primary concentrate is produced by two mobile primary beach concentrators (PBC, primary spiral-plant concentrators) followed by secondary concentration through a wet high-intensity magnetic separation circuit (WHIMS, located in a central position off the beach) and screens which separate magnetic ilmenite from zircon and rutile before bagging and shipment to destination markets.

In 2019 run of mine (ROM) production of 2.50 Mt (steadily increasing from 1.07 Mt since 2014) was achieved at Tormin at a grade of 11.15 % THM (steadily decreasing from 53.83 % THM since 2014) of which 67.5 % was garnet, 16.2 % was ilmenite, 10.6 % was leucoxene, 3.8 % was zircon and 1.9 % was rutile. Final products – also from retreatment of previously stockpiled concentates – include garnet, all sold to GMA Garnet, a bulk ilmenite, a bagged ilmenite and a non-magnetic zircon-rutile-mix. The latter concentrate contains close to 70 % % zircon and 9–18 % rutile and is sold globally in bulk or bagged to tertiary MSP processing facilities where it is electrostatically processed into final zircon and rutile products. Mineral Commodities has announced plans to construct ist own MSP for final separation.

Table 58: Production of Mineral Commodities Ltd. at Tormin in tonnes, according to Mineral Commodities Ltd. annual reports.

	2013	2014	2015	2016	2017	2018	2019
Garnet	–	254,816	284,990	270,802	211,393	278,205	179,057
Ilmenite	–	100,437	109,959	211,704	138,913	108,630	49,937
Zircon-Rutile Mix	1726	42,668	44,489	35,813	22,111	16,996	9939
– of which rutile	n. a.	3789	5979	4777	3914	2962	1527

RUSSIA

There is currently just one producer of mixed ilmenite-rutile-leucoxene concentrate in Russia:

– OAO Tuganskyi "GOK Ilmenite"

Only one other company is known to have investigated possibilities for starting ilmenite/rutile mining between 2011 and 2017:

– OOO "GPK Titan", a subsidiary of titanium metal producer VSMPO-AVISMA (Tsentralnoe ilmenite-rutile-zircon placer deposit in Tambov region with Russian reserves of 6396 Mt of TiO_2 in A+B+C1-categories). However, in 2017 the project was finally deemed to be unprofitable and abandoned.

Thus the largest known resources of titanium minerals in Russia are at the Yaregskoye oil field in the Komi Republic in Siberia. They stand at 66.83 Mt of TiO_2 in A+B+C1-categories plus 211,824 Mt of TiO_2 in category C2. This represents 46.4 % of the Russian titanium reserves. The reservoir at Yaregskoye has a thickness of 30–100 m and can be divided into two productive horizons. The upper one is composed of polymictic conglomerates and various-grains of quartz sandstone containing up to 30 % leucoxene (at 58.5–71.9 % TiO_2, cf. Appendix C for analysis). The deposit was formed as a result of erosion of the weathering crust of the underlying metamorphic schists and thus represents a residual to colluvial placer. Exploration of this buried placer began in 1959 with development starting in 1966. For some years after 2000 up to 1500 tpa of leucoxene concentrate was produced by the petrochemical company OJSC "Yaregskaya neftetitanovaya kompaniya". The leucoxene was supplied to the Klyuchevsky Ferroalloy Plant in Dvurechensk in the Ural Mountains. The current owner is LLC "Lukoil-Komi". The company hopes to be able to extract more leucoxene in the near future.

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JSC Tugansky "GOK Ilmenite" has mined the HM-enriched Tugansk quartz sand/gravel deposit (Kuskovsko-Shiryaevsk and Yuzhno-Aleksandrovsk) around 40 km from Tomsk in Tomsk province since 2005. The deposit is of marine origin and covers an area of around 19.6 km^2. The thickness of the ore sand/gravel layer varies from 7.5 to 8.4 m. It is covered by overburden of partly extreme thickness of up to 180 m. Besides ilmenite, rutile and leucoxene, the quartz sand is enriched with zircon. The average grade of TiO_2 in the deposit is given as 19.69 kg per m^3 of ore sand.

The northern extension of the Tugansk deposit is the Georgiyevsk deposit with its HM-rich ore body of up to 30 m thickness lying in a depth of 120–220 m. P1 resources were roughly estimated as 3300 Mt of ore sand containing 42 Mt of ilmenite and 13.4 Mt of zircon.

Original resources of the Tugansk deposit were given as 216 Mt of ore sand containing some 3.4 Mt of ilmenite and 1.38 Mt of zircon. As of 1 January 2019 JSC Tugansky "GOK Ilmenite" held 0.4 % of the Russian reserves of TiO_2, i.e. 2501 Mt of TiO_2 in A+B+C1 categories. Production figures of various minerals from the pilot plant (in operation between 2005 and 2016) are given below. Planned capacity once in operation is given as 62,700 tpa of ilmenite (at > 59.2 % TiO_2), 7000 tpa of rutile (> 89.9 % TiO_2), 24,100 tpa of zircon and more than 1 Mtpa of silica sands.

Table 59: Production of ilmenite-rutile-leucoxene and zircon concentrates from the Tugansk deposit in tonnes. Taken from the Ministry for Natural Resources and Environment of the Russian Federation (various years).

	2012	2013	2014	2015	2016	2017	2018
Zircon	n. a.	121	110	101	26	0	0
Ilmenite-rutile-leucoxene	n. a.	1005	449	383	91	0	0
TiO_2 content	n. a.	52.9 %	55.0 %	54.3 %	53.8 %	–	–

SENEGAL

There is currently one major HM mining company in Senegal, TiZir Ltd. – a subsidiary of ERAMET S.A., France.

Additionally, Astron Corporation Ltd. of Hong Kong holds an exploration licence stretching for 75 km along the Casamance coast of southwestern Senegal, i.e. south of The Gambia. Within this stretch lies the well-explored Niafarang deposit for which a Small Mining Licence was granted to Astron in June 2017. As of 2012 probable ore reserves in the Niafarang deposit stood at 4.65 Mt of ore sand at a grade of 10.91 % HM of which 2.27 % was rutile and 0.41 % was leucoxene (around 11,500 t of rutile and 2000 t of leucoxene). Plans are to dredge the deposit and ship the HMC for processing into ilmenite, zircon and rutile-leucoxene (“HiTi”) to China. Astron is hoping to commence activities very soon.

Project start-up is expected as soon as the locally appointed Government Resettlement Committee implements the resettlement plans with the local landowners.

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Phone	+44-20-3907 1155
Website	www.tizir.co.uk
Email	info@tizir.co.uk
Contact person	Francois Godin, CEO Grande Côte Operations

TiZir Ltd. is an integrated mineral sands company comprising two operating assets – the Grande Côte mineral sands operation (GCO) in Senegal in which the Government of Senegal holds a 10 % interest and the TiZir Titanium & Iron ilmenite upgrading facility (TTI) in Tyssedal, Norway.

TiZir was jointly owned and managed by ERAMET S.A., France and Mineral Deposits Ltd., Australia before ERAMET S.A. took over its joint-venture partner in 2018. Thus, since 2018 TiZir Ltd effectively represents the Mineral Sands business unit of ERAMET S.A., which takes a very restrictive approach towards giving out information.

The Grande Côte HM deposit is located on a mobile coastal dune system starting about 50 km northeast of Dakar and extending northward for more than 100 km. The mineralized dune system averages 4 km in width. The project area is 445.7 km² with the main HM deposits identified to date being Diogo, Mboro, Mboro Hotel, Fass Boye, Lompoul, Yodi and Noto.

As of 31 December 2017 total resources stood at 1847 Mt of ore sand at 1.4 % HM (26.2 Mt HM content) of which 3.2 % was leucoxene and 2.5 % was rutile. Proven and probable reserves included in the resources were 1765 Mt of ore sand at 1.4 % HM with the same mineral assemblage as the HM resources.

GCO commenced mining activities in March 2014 followed by processing operations in June 2014. It has a current mine life of about 35 years, i.e. to 2050. The majority of GCO's two ilmenite products (at 54 % TiO_2 and 58 % TiO_2) is shipped to TTI, where it is used for production of titanium slag as feedstock for TiO_2 production. Other importer countries of GCO low-grade ilmenite are China, the USA and Ukraine. High-grade ilmenite is exported to Mexico, Ukraine and the USA. GCO also produces three grades of zircon and small amounts of rutile (destined for South Korea) and leucoxene (for export to China, Dubai, Luxembourg and South Korea).

Table 60: Production of HM from the Grande Côte Project in tonnes. Taken from the TiZir Operations Review Reports and EITI Senegal reports.

<table>
<tr><th></th><th>2014</th><th>2015</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th></tr>
<tr><td>Ilmenite</td><td>100,590</td><td>427,690</td><td>416,349</td><td>492,441</td><td>506,937</td><td>491,602</td></tr>
<tr><td>Zircon</td><td>9,040</td><td>45,248</td><td>52,627</td><td>81,749</td><td>93,569</td><td>80,746</td></tr>
<tr><td>Rutile</td><td>262</td><td>2084</td><td>2892</td><td>2729</td><td>3961</td><td rowspan="2">10,130</td></tr>
<tr><td>Leucoxene</td><td>591</td><td>3227</td><td>6773</td><td>7245</td><td>5645</td></tr>
</table>

SIERRA LEONE

There is just one official producer of rutile in Sierra Leone, Sierra Rutile Ltd., the largest producer of rutile in the world.

Additionally to Sierra Rutile Ltd., exploration licences for potential rutile deposits offshore Sierra Leone are also held by Avasya Resources Pvt Ltd. of Hyderabad, India.

Figure 31: Photo of the Gangama processing plant in Sierra Leone. Source: Iluka Resources Ltd.

Sierra Rutile Ltd.	
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Fax	+232-22-234009
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Contact person	Bruce Kilpatrick, Product Manager – Titanium, Sales and Marketing
Email	Bruce.Kilpatrick@iluka.com

Sierra Rutile Limited

Mining for rutile in Sierra Leone began in 1967 and Sierra Rutile Ltd. (SRL) was founded in 1971. SRL had many different owners (Nord Resources Corp., Armco Steel Corp., Bethlehem Steel Corp., Consolidated Rutile Ltd., US Titanium Inc./Titanium Fields Resources Ltd., Titanium Resources Group, Pala Investments Holding, Government of Sierra Leone) before it was acquired by Iluka Resources Ltd., Australia at the end of 2016. Since then, Sierra Rutile Ltd. has acted as a subsidiary of Iluka Resources.

The Sierra Rutile mines are located in the Moyamba and Bonthe districts of southwest Sierra Leone near the Imperi Hills some 30 km from the Atlantic Ocean on low lying coastal plains about 135 km southeast of the capital Freetown. SRL holds mining leases for a land area of 742 km^2 in which 19 separate rutile deposits have been identified since 1962. Most deposits are located in two areas: Gbangbama (Gangama, Lanti, Gbeni, Pejebu, Bamba-Pelebu, Mogbwemo, Taninahun and Ndendemoia deposits) and Sembehun (Kibi, Dodo, Komende, Benduma, Gbap and Kamatipa deposits), but also the surrounding deposits of Mosavi, Gambia, Nyandehun, Jagbahun and Taninahun Boka. Other noteworthy rutile deposits are Rotifunk and Kambia in different areas.

At the end of 2005, the then current owner Titanium Resources Group announced that it had also acquired the Rotifunk mineral sands prospect covering the second largest single known rutile deposit (behind Sembehun-Benduma) in Sierra Leone. Rotifunk is located 65 km southeast of Freetown and lies approximately 40 km northwest of the Sierra Rutile mine. Inferred mineral resources of this deposit stand at 235 Mt of ore sand at 0.62 % rutile, 0.84 % ilmenite and 0.06 % zircon, i.e. the Rotifunk HM deposit may contain 1.5 Mt of rutile.

As of 31 December 2019, total resources of SRL in Sierra Leone (excluding Rotifunk) were 739 Mt of ore sand at a grade of 1.1 % rutile, 0.8 % ilmenite and 0.1 % zircon (8.2 Mt rutile content). Of these resources, the Kibi, Dodo, Komende, Benduma and Kamatipa deposits in the Sembehun area (cf. above) contained resources of 402 Mt of ore sand at a grade of 1.14 % rutile, 1.2 % ilmenite and 0.5 % zircon (4.60 Mt rutile content). Reserves included in the total resources given above were 272 Mt of ore sand at 1.3 % rutile (3.7 Mt rutile content).

Dredge mining in Sierra Leone began in February 1967 with a new dredge (D1) and a dedicated wet mill commissioned in March 1979. Between 1995 and 2005 the mine was closed due to the civil war. In January 2008 another dredge (D2) was commissioned but capsized in July 2008. Dry mining at Lanti started in 2013 and at the Gangama deposit in June 2016.

After decommissioning the old floating bucket line dredge (D1) in Q1 2019, SRL currently operates a conventional dry mine at Lanti and a dry mine at Gangama. Both the Lanti and Gangama dry mines shall be doubled in size in Q2–Q3 2019 and a new dry mine, including a new wet mill at Sembehun, will be openend in 2021. All dry mining operations feed dedicated concentrators (wet mills) which supply a stationary MSP. Conventional mineral processing methods are used to produce two

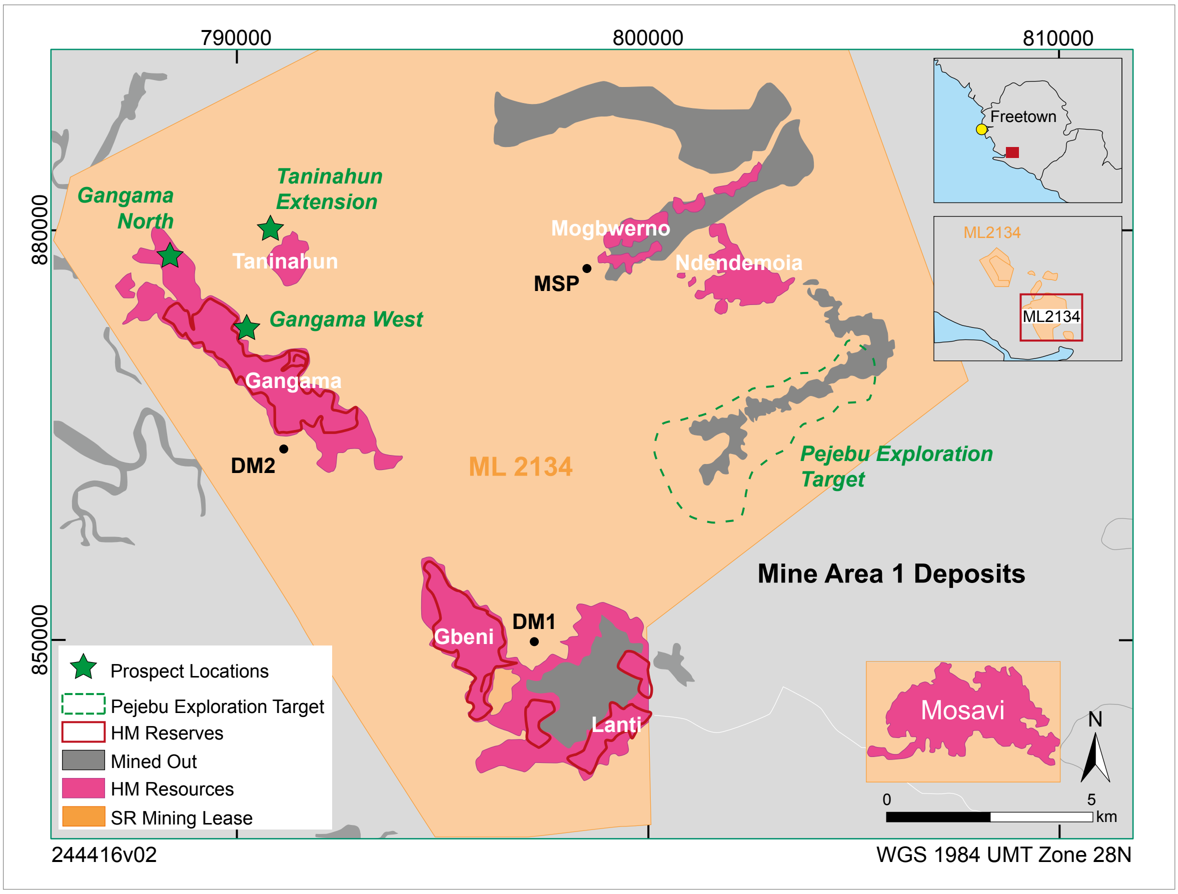

Figure 32: Map of relevant HM deposits in the Gbangbama area in southwest Sierra Leone. Source: Iluka Resources Ltd.

grades of rutile (85–90 vol.-% of premium coarse rutile at +95 % TiO_2 (Standard grade) and 10–15 vol.-% of fine rutile at 95.5–96 % TiO_2 (Industrial grade), cf. Appendix C for analyses, as well as ilmenite and small amounts of zircon concentrate which are exported via Niti Port. 75 % of the annual standard grade rutile output is bought by Kronos Worldwide Inc. for TiO_2 pigment production using the chloride process. Most of the remaining standard grade rutile is used for titanium sponge production in Japan while the industrial grade rutile is preferred by customers in the welding market.

The zircon-rich concentrate and all rutile tailings are sold to Chinese processing enterprises as they contain close to 20 % zircon and about 17 % rutile, respectively. In addition, there are some small-scale miners around Sierra Rutile's concession areas who also sell their impure zircon and rutile products to Chinese separation companies.

Table 61: Production of rutile, ilmenite and zircon-rich concentrates by SRL in tonnes, according to company reports.

	2012	2013	2014	2015	2016	2017	2018[1)]	2019
Rutile	94,493	120,349	114,163	126,021	148,541	167,600	121,500	137,200
Ilmenite	22,008	32,349	35,839	37,633	20,000	57,600	54,500	59,200
Zircon-rich concentrate	0	0	0	0	1200	3000	11,400	8500

[1)] reduced production due to a strike at the end of 2018

SRI LANKA

There is just one producer of HM in Sri Lanka, the state-owned Lanka Mineral Sands Ltd., which mines HM at Pulmoddai in the northeast of the island. However, there are many more known HM deposits in Sri Lanka, especially near Puttalam, Jaffna, and at Kudremalai Point to the south of Mannar.

In 2013 the Australian Iluka Resources Ltd. announced the acquisition of exploration licences near the city of Puttalam in northwest Sri Lanka covering an area of 146 km^2. As of December 2019 total resources in Iluka's tenements amounted to 673 Mt of ore sand at an average grade of 8.1 % HM (54.6 Mt HM content) of which 66.9 % was sulphate-grade ilmenite, 3.4 % was zircon, 3.6 % was rutile and 3.9 % was leucoxene of various qualities. Total rutile content was 2.0 Mt while total leucoxene content was 2.1 Mt. A limitation on foreign entities owning more than 40 % in a Sri Lankan mining company and the requirement of some form of downstream processing before a mining licence is granted present major hurdles before start of production.

Titanium Sands Ltd. also of Perth/Australia is exploring the HM potential of Mannar Island some 150 km north of Puttalam. Mannar Island is 26 km long, 6 km wide and 140 km^2 in area. Its beaches are rich in HM and in 2020 an updated inferred and indicated mineral resource of 264.93 Mt of ore sand, at 4.38 % HM could be declared of which about 44.5 % is ilmenite, 7.8 % is leucoxene, 2.0 % is rutile and 2.3 % is zircon.

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Lanka Mineral Sands Ltd. is a state-owned company and is the successor of the Ceylon Mineral Sands Corporation established in 1957 under the Industrial Corporation Act. In 1992 the Ceylon Mineral Sands Corporation became Lanka Mineral Sands Ltd., which is controlled by the Ministry of State Resources and Enterprise Development. At the beginning of 2019, it was announced that Lanka Mineral Sands Ltd. might be transferred into a Public Private Partnership with an as yet unknown Japanese company.

Ceylon Mineral Sands installed an ilmenite processing plant at Pulmoddai in north-eastern Sri Lanka in 1961 and commenced commercial production in 1963 at the same time as commercial HM mining. In 1968 rutile and zircon were separated from the Pulmoddai tailings for the first time at a processing plant at China Bay near Trincomalee. In 1978 an expanded plant was commissioned at Pulmoddai and the China Bay plant was closed. In 1985 the Tamil Tigers destroyed the water supply to the Pulmoddai plant, which did not reopen until 2004 and was then affected by the disruption caused by the tsunami of 26 December 2004. In the meantime, a makeshift plant was erected at Dambulla outside the war zone. Between 2004 and the end of the war in May 2009, just small volumes of beach sand were processed at the MSP at Pulmoddai to keep the plant in good working condition. Bulk shipments of ilmenite ended in September 1997 when the Tamil Tigers sank a bulk carrier anchored off Pulmoddai. By this time the company had already long stopped producing HM as its stockpiles were full and it had no further storage space. Noteworthy sales restarted in 2001 with previously stockpiled material slowly being replaced by fresh material since 2004.

Lanka Mineral Sands' head office of is located in Colombo while its MSP is located in Kanijapura in Pulmoddai 54 km north of Trincomalee. The beach sands south of Pulmoddai are very rich in HM reaching a grade of 50 – 60 % on average of which some 8 % is rutile. Total HM resources at Pulmoddai are estimated at about 12.5 Mt of which 3 Mt are accessible. The mineral sand deposit stretches 8 km from Asirimalai in the south to Kokilai in the north and has a maximum width of about 250 m and a maximum thickness of up to 3 m.

Apart from this high-grade deposit, more HM deposits are known in the same region in an area extending for 70 km from Nilaveli in the south to Mullaitivu in the north.

The seafloor at Pulmoddai has also been explored in detail but does not indicate any major offshore accumulation. Total offshore HM resources are estimated as 903 kt ilmenite, 9.5 kt rutile and 39 kt zircon (Ward & Towner 1985).

The beach sands are currently mined by old excavator draglines and new front-end wheel loaders at four locations near Pulmoddai Nayaru, Kokkilai, Poduwakattu and Periyakarachchi. Mining traditionally starts around February after the monsoon replenishes the beach placers mined in previous years. The raw sand at Yan Oya and Periyakarachchi is washed and screened to remove trash and shell fragments and put through a series of concentrators to separate the HM.

Sales are finalized by a Tender Board following the government tender procedures. Minerals are shipped from Trincomalee harbour in bulk or bags and through Colombo in bags on FOB or CFR terms.

The products and production capacity are reported by Lanka Mineral Sands as >90 ktpa of ilmenite (> 53 % TiO_2), >4 ktpa of high-titanium ilmenite (> 61 % TiO_2), 3200 tpa of rutile (> 95 % TiO_2, cf. Appendix C for analysies), 1125 tpa of zircon (> 65 % ZrO_2) and 100 tpa of monazite. However, monazite, together with garnet and magnetite, are currently only sold in the form of unprocessed HMC. Additionally, crude zircon, fine wet mill concentrate, wet mill tailings, oversize rutile and non-magnetic HMC are offered for sale. Most of those impure products are bought by Chinese processing enterprises, better able to separate all minerals thus producing HM concentrates with technically required specifications.

The technical equipment of Lanka Mineral Sands is not in good working order and has come in for harsh criticism from the Government of Sri Lanka (2016). The specifications of final products offered for tender support this assessment and still exhibit many impurities. For example, an ilmenite product (at 49 % TiO_2) offered for tender between October 2018 and January 2019 only contained 86.58 % ilmenite, but 3.19 % zircon, 2.91 % leucoxene, 1.85 % quartz, 1.54 % rutile, 0.83 % magnetite, 0.78 % garnet and 0.40 % monazite. A rutile product (at 96.27 % TiO_2) offered for tender in December 2018 contained 93.17 % rutile but 5.39 % magnetics and 1.44 % zircon. A high-titanium ilmenite product (at 57.71 % TiO_2) also offered for tender in December 2018 contained 89.26 % ilmenite and leucoxene but 4.74 % rutile, 0.91 % zircon, 0.96 % garnet and 4.13 % other magnetics.

Table 62: Rutile production by Lanka Mineral Sands Ltd. in tonnes. Taken from the Annual Reports of the Central Bank of Sri Lanka, BGS World Mineral Statistics and Department of Sri Lanka (2016).

	2012	2013	2014	2015	2016	2017	2018	2019
Pulmoddai	1590	1406	2111	1808	2237	2174	2319	1959

TANZANIA

Due to the world-class HM deposits of international importance in Mozambique, Kenya and even Malawi, HM rich sediments in Tanzania have also attracted the attention of geologists and mining companies since the 1960s. Because HM enrichments on beaches between Dar es Salaam and Bagamoyo to the north are visible to the naked eye, this area was the first to attract interest.

Trenches in recent berms were dug to a depth of 2 m and hundreds of samples were taken there and along the beach surface. The richest concentrations were found north of big river mouths. The overall composition was said to be fairly constant with grades varying locally and seasonally.

The initial reports on HM occurrences in Tanzania drew the attention of exploration companies resulting in not only the coastal stretch between Dar es Salaam and Bagamoyo but all of the Tanzanian beaches being explored for potential HM deposits and new samples being taken from several locations. Intense prospecting revealed that the information given in the older reports was wrong: the concentrations, at least at shallow surfaces, were actually much lower and VHM were hardly enriched. However, in 1973 a pilot plant was erected at the Silver Sands deposit (reserves of 11 kt of VHM) 15 km north of Dar es Salaam and small amounts of ilmenite, rutile and zircon concentrates were produced. Other prospective locations most frequently mentioned from north to south are: Tanga, Tongani, Pangani, Kimanga, Tajiri, Bagamoyo, and Fungoni, cf. below.

After all these new investigations, only one area in Tanzania was still said to be economically mineable. This was the Msimbati South deposit in the Mtwara Region. Here a high dune with a length of 2.4 km and a width of 450–650 m was said to contain reserves of some 33.5 Mt of ore sand with a concentration of about 2 % VHM. Absolute reserves were calculated to be some 470 kt of ilmenite, 70 kt of rutile and leucoxene and 60 kt of zircon.

In 2000 the Mnazi Bay-Ruvuma Estuary Marine Park was established around the Msimbati dune comprising some of the most beautiful and untouched beaches in Tanzania. For this reason, a final assessment was desirable and the potential deposit was therefore visited in 2005 by a joint field team of GST-Geological Survey of Tanzania, STAMICO-State Mining Company and BGR experts. A representative sample was taken revealing a HM grade of 8.5 %, however, of which only 8 % were VHM (ilmenite, leucoxene, rutile, zircon, and cassiterite) while 92 % were trash HM, mainly hornblende and epidote. The tonnage of VHM in the deposit is therefore only about 230 kt, which is only a third of the amount previously calculated and which shows that the Msimbati dune is not worth mining either (Elsner et al. 2008).

Since 2014 the Australian Strandline Resources Ltd. has held exploration licences for several HM ocurences in Tanzania. These are (from north to south): Vumbi, Tanga North, Tanga South, Bagamoyo, Fungoni, Mafia Island. Together with Rio Tinto Mining and Exploration Ltd., Strandline also holds licences for Miteja, Kiswere, Sudi, Madimba-Ziwani (Mtwara), and Mahuranga.

- As of 2019, the Tajiri (Vumbi, Tanga North, Tanga South) deposit stretching 30 km along the coastline had a total mineral resource of 268 Mt of slime-rich (33 %) ore sand at a grade of 3.3 % HM (8.8 Mt HM content) of which 59 % (5206 kt) was ilmenite, 17 % (1477 kt) was garnet, 7 % (580 kt) was rutile and 4 % (335 kt) was zircon.
- As of 2017 the much smaller Fungoni deposit was reported as having a total resource of 21.74 Mt of slime-enriched (22 %) ore sand at an average of 2.82 % HM (613 kt HM content) of which 40.7 % (250 kt) was ilmenite, 16.9 % (104 kt) was zircon, 4.3 % (26 kt) was rutile and 1.2 % (7 kt) was leucoxene. Reserves as of 2017 stood at 12.3 Mt of ore sand at 3.9 % HM (460 kt HM content) which would sustain a planned mine life of 6.2 years. All necessary licenses have been granted and Strandline Resources hopes to start dry mining and separation into final chloride-grade ilmenite, welding-grade rutile and mixed monazite-zircon concentrates within a short time. The zircon-monazite mix will be sold to the Chinese Hainan Wensheng High-Tech Materials Co.,

Ltd., the ilmenite will be exported to Maoming Ubridge Group Mineral Industry Co, Ltd., also from China, and the rutile will be distributed by Industrial Minerals and Metals Ltd. from Hong Kong.

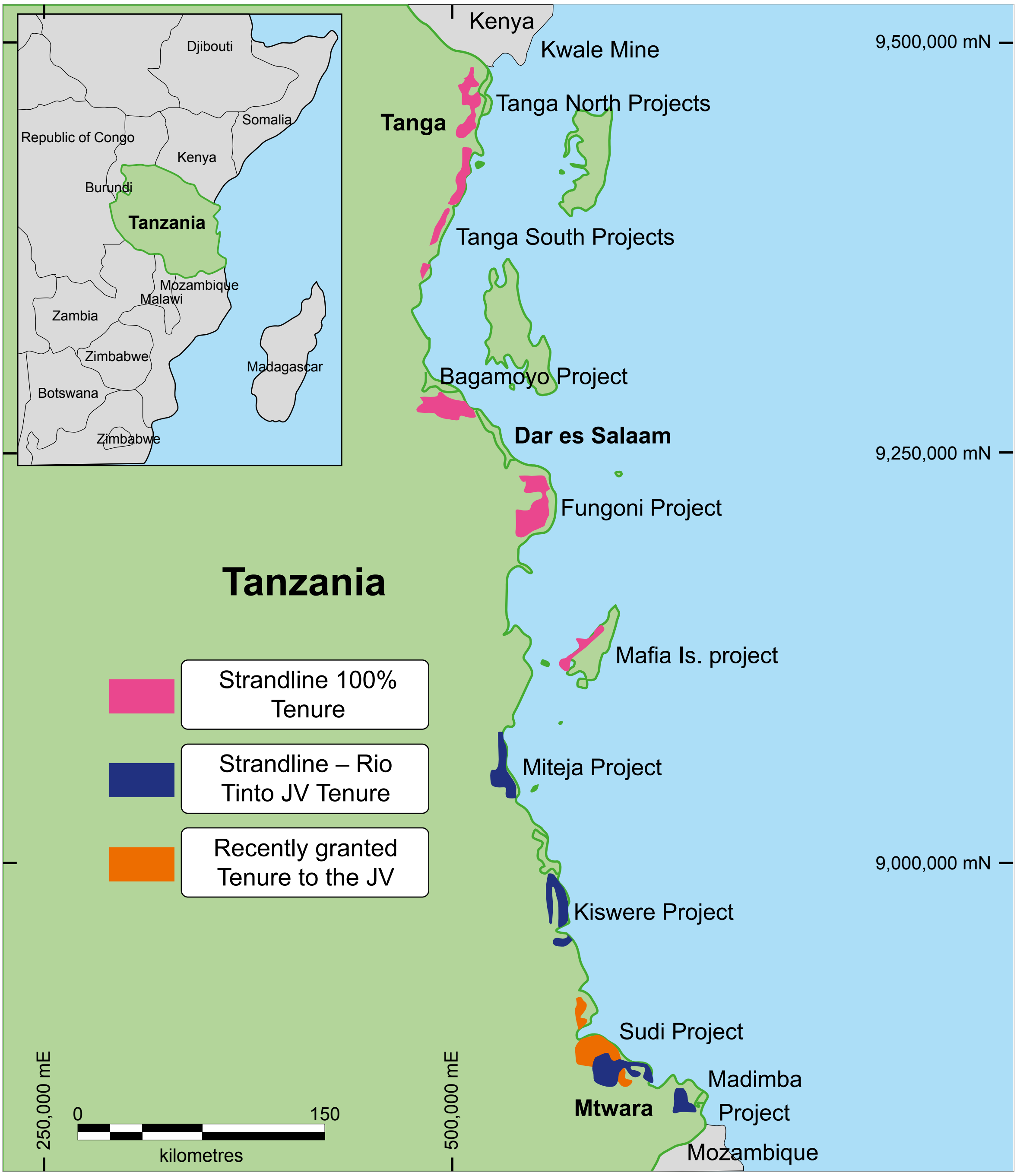

Figure 33: Map of HM exploration projects in Tanzania run by Strandline Resources Ltd./Rio Tinto. Source: Strandline Resources Ltd.

THAILAND

Very similar to Malaysia, all of the rutile and leucoxene in Thailand that is not imported comes from alluvial tin mining operations where it is produced from "amang" (cf. Malaysia).

Alluvial tin deposits have been mined in Thailand for over 1000 years. The most important areas have been in the Phang-nga and Phuket provinces in the southwest of the country. In the 1950s mining shifted to offshore areas as grades in onshore deposits declined. Since the 1990s tin production in all areas in Thailand has decreased substantially therefore providing only very little amang for further beneficiation. Additionally, only a very small proportion of the stockpiled amang in Thailand has traditionally been sent to amang treatment plants. Nowadays, amang is also imported from other countries for processing in Thailand.

Titanium minerals identified by Praditwan (1988) in tin deposits from Thailand are:

– Ilmenite (49.7 – 58.9 % TiO_2)
– Nb-Ta rutile (30.3 – 72.3 % TiO_2, 17.4 – 31.1 % Nb_2O_5/Ta_2O_5)
– Rutile (76.4 – 97.6 % TiO_2)
– Anatase (91.1 – 98.7 % TiO_2)
– Leucoxene (77.1 – 94.0 % TiO_2)

The ratio of ilmenite: Nb-Ta rutile : rutile : anatase : leucoxene is 82.7 : 7.5 : 2.3 : 1.5 : 6.0.

The last rutile production officially recorded in Thailand was in 1994 (49 t) while the last official leucoxene production was in 1995 (33 t). The last domestic HM mining operation also producing rutile was about 7 km north of Prachuabkhirikhan on the western side of the Gulf of Thailand. This present-day beach placer deposit was brought into production in 1969 but was closed by Sakorn Minerals Co. Ltd. due to depletion in 2000 when it last produced 50 t of zircon.

Amang processing is not recorded in Thailand as it is not classified as primary mineral production through mining. There are also no officially registered amang processing companies in Thailand.

Official HM production statistics of the Department of Primary Industries and Mines (DPIM) of Thailand differ markedly from official export statistics of DPIM, which are also different to export statistics from Thai Customs Department (available via IHS Markit - Global Trade Atlas®), cf. Table below. Members of the Thai mining community unofficially state that a relatively high percentage of Thai mining and mining services companies work in a legal grey area and secure financing via local and mid-level corruption networks. In regard to legal production and distribution, information is likely be concealed for tax and export duty reasons, but also due to environmental regulations and corruption issues amongst competitors. This secrecy extends to the tonnages of imported HM concentrates and mining waste products for final processing.

A local consultant identified several companies which are said to be active in the processing of tailings and the production of various titanium minerals. However, only two of them are currently active with company details given on the following pages.

Table 63: Production and export of HM products by amang processing in/from Thailand in tonnes. Taken from the Global Trade Atlas (GTA) and as far as reported by Department of Primary Industries and Mines (DPIM).

	2012	2013	2014	2015	2016	2017	2018	2019
Leucoxene								
Export (DPIM)	2397	1729	1447	2293	5985	3994	2133	1172
Export (GTA)	2787	3060	1385	2593	4569	3943	3832	1193
Rutile								
Export (DPIM)	617	410	194	432	226	965	364	0
Export (GTA)	2781	479	198	1284	0	425	0	29
Ilmenite								
Production (DPIM)	0	0	0	0	0	8	41	117
Export (DPIM)	1680	1273	147	320	276	0	8	20
Export (GTA)	1118	778	302	446	254	1	7037	219
Other Ti-minerals (Nb-Ta rutile, anatase)								
Export (GTA)	0	0	0	520	2326	1728	1072	4074
Zircon								
Production (DPIM)	0	0	0	0	0	0	0	0
Export (DPIM)	5122	8681	10,738	7857	9030	7439	4803	2104
Export (GTA)	6143	9226	14,002	12,794	10,104	8526	6736	2108
Garnet								
Export (DPIM)	23	162	216	0	0	6868	10,040	350
Export (GTA)	194	523	693	421	121	7631	4743	578
Columbite-Tantalite								
Export (DPIM)	0	0	50	0	0	0	0	n. a.
Export (GTA)	226	100	137	64	0	50	15	97
Struverite								
Export (DPIM)	410	147	87	64	100	298	178	0
Export (GTA)	0	1	0	0	100	85	44	830
Kyanite, sillimanite								
Export (GTA)	0	0	0	0	69	254	818	1080
Monazite								
Production (DPIM)	0	0	0	0	0	0	0	0
Export (DPIM)	200	210	3150	1260	2620	2150	1705	108
Export[1)] (GTA)	630	420	3570	1890	2667	1885	1285	3151
Xenotime								
Export (DPIM)	0	0	0	0	0	30	0	n. a.
Export[1)] (GTA)	0	0	0	0	0	675	420	0

[1)] recalculated from Chinese Th ore import statistics

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Email	skmmin@loxinfo.co.th
Contact person	Mr. Kriangsak Lawatanatrakul, Director

Sakorn Minerals Co. Ltd. is a privately owned company and was established in 1985. It has always been and is still the largest importer, producer and exporter of HM (zircon, rutile and leucoxene and to a lesser extent also ilmenite, monazite, xenotime, kyanite, tantalite, struverite, and cassiterite) in Thailand, which are separated from amang (Indonesia), gold tailings (Indonesia) and HM tailings from Australia, India, Indonesia, South Africa and to lesser extent from Vietnam. Sakorn Minerals can treat up to 180,000 t of tailings and produce up to 20,000 t of rutile per year at its processing plant in Prachuab Khirikhan where its own mining operations stopped in 2000. All final products are currently exported to China, specifically to the China Nonferrous Metal Mining Group with demand strongly surpassing supply, which is not limited by capacity but lack of raw materials.

Sakorn Minerals produces concentrates of rutile (min. 95 % TiO_2) and leucoxene (min. 89 % TiO_2) neither of which were available for analyses.

Figure 34: Product samples of Sakorn Minerals on display for marketing purposes.

Ratanarungsiwat Co. Ltd.	
Address (Head office)	29/21 Moo1 Mhoe Kapong Phang-Nga 82170 Thailand
Phone	+66-76-499-100
Fax	+66-76-499-349
Website	www.gmdu.net/corp-876003.html
Email	suphkarn_rtg@hotmail.com
Contact person	Mr. Parnuwat Aruntippaitoon (Trading Manager)

RATANA GROUP Ratanarungsiwat Co., Ltd. was established in 1988 and operates an award-winning (Ministry of Industry, 2009) processing plant in Amphur Kapong, Phang-nga province. With a capacity of 1200 t of raw material per month, it mainly processes amang from small-scale artisanal tin mining operations in south Thailand as well as from other domestic sources for the production of ilmenite and garnet but also monazite, xenotime, zircon and rutile (85–88 % TiO_2).

Production volumes and stock levels have been stable over the past few years. As exports to Japan and South Korea stopped some time ago, all products are now exclusively sold to China.

Average yearly production during recent years was about 5000–6000 t of ilmenite, 2000–3000 t of garnet, 200–300 t of zircon, 200 t of rutile (cf. Appendix C for analyses) and around 100 t of monazite and xenotime each.

UKRAINE

The main economic types of titanium deposits in Ukraine are ancient coastal-marine placers in the central part of Ukraine (Malyshevske deposit) and proximal continental deposits closely related to the weathering crust of the main titanium-bearing rocks in the northwest of the Ukrainian Shield (Mezhyrichne, Livoberezhne, Pravoberezhne and others that comprise the Irshanska group of deposits).

According to the State Register of Minerals Reserves of Ukraine, the country has 26 deposits of titanium ore of which 14 are developed, two are unique, twelve are categorized as large and ten as medium-sized. As of January 1 2017 total HM ore sand reserves (categories A+B+C1) were 199.3 Mm^3 of which 181.6 Mm^3 were designated to deposits in production. Some 4.2 Mm^3 of ore sand was mined in 2017 (www.minerals-ua.info). However, these reserve figures seem too low to be given much credibility.

There are currently five enterprises in the Ukraine which produce titanium minerals from HM deposits:

- United Mining and Chemical Company PJCS with its two branches: Irshansk Mining and Processing Combine, and Vilnohirsk (Volnogorsk) Mining and Metallurgical Combine
- Group DF with its two companies Valki Ilmenite LLC, and Mezhyrichensk Mining and Concentration Complex
- Demurinskyi GZK LLC
- Velta LLC
- Ukraine Minerals, cf. Volnogorsk Combine

Table 64: Exports of ilmenite and rutile concentrate to Russia and other countries from Ukraine in tonnes. Taken from the Global Trade Atlas.

	2012	2013	2014	2015	2016	2017	2018	2019
Ilmenite	n. a.	n. a.	259,094	236,557	404,210	530,368	559,087	568,781
to Russia	n. a.	n. a.	114,548	102,122	190,453	68,512	87,279	101,256
Rutile	n. a.	n. a.	69,413	58,467	59,231	53,403	40,506	52,125
to Russia	n. a.	n. a.	5883	5324	5275	5947	5902	5755

PJSC "United Mining and Chemical Company"	
Address (Head office)	N. Grinchenko St. 4 03035 Kiev Ukraine
Phone	+380-44-2371249, -67-5144030
Fax	+380-56-5350405
Website	www.en.umcc-titanium.com
Email	info@umcc-titanium.com
Contact person	Alexander V. Hldushko, Acting Chairman

The Public Joint-Stock Company (PJSC) United Mining and Chemical Company (UMCC), which is to be privatized in the near future, operates two branches: Irshansk Mining and Processing Combine (IGOK) in Zhytomyr region and Volnogorsk Mining and Metallurgical Combine (VGMK) in the Dnipropetrovsk region. IGOK and VGMK were leased to then state-owned Crimea TITAN CJSC and OstChem Germany, a subsidiary of OstChem Holdings, Austria between 2004 and 2009. Until 2014 when both combines had to be transferred to then State Enterprise (SE) United Mining and Chemical Company, they were part of Group DF (cf. below).

Production of HM from the giant Malyshevsky placer deposit on the banks of the Samotkan river near Volnogorsk started in 1961. The ore sand has a thickness of 10–35 m and extends for some 19 km. The deposit which contains 1.3–1.7 % HM is covered by thick overburden and is mined by excavators and draglines.

VGMK produces ilmenite (min. 63 % TiO_2), rutile (min. 94 % TiO_2, cf. Appendix C for analyses), zircon, staurolite and kyanite-sillimanite concentrates as well as silica sand for glass production and foundry sand. Nominal capacities are about 200 ktpa of ilmenite, 45 ktpa of rutile, 25 ktpa of zircon and 6 ktpa of kyanite-sillimanite. Numerous zircon-based products (zircon flour, zirconia, stabilised zirconia, various zirconium chemicals) together with a variety of noble metal chemicals are also distributed. Ilmenite concentrates from VGMK are further processed into titanium sponge by ZTMC – Zaporozhye Titanium & Magnesium Combine (Ukraine), UTMKP – Ust-Kamenogorsk Titanium Magnesium Plant JSC (Kazakhstan) and VSMPO-AVISMA Corporation (Russia). Minor amounts of ilmenite and most of the rutile concentrate are sold to various welding electrode plants.

UMIN-Ukraine Minerals also claims to produce limited amounts of ilmenite (min. 65.3 % TiO_2), rutile (min. 94 % TiO_2), zircon, kyanite-sillimanite, staurolite and silica sand from VGMK tailings through its subsidiary Color Metals Ltd..

In 1958 mining also started in Irshansk using a floating dredge before operations were transferred to dry mining in 1964. The ore sand of the various HM deposits in the Irshansk area are 5–10 m thick, extend for 10 km and have a width of up to 2.5 km (ancient buried valleys). IGOK currently mines

Table 65: Production of rutile and ilmenite by United Mining and Chemical Company and predecessors in tonnes, according to UMCC press releases and other sources. e = estimate by BGR

	2012	2013	2014	2015	2016	2017	2018	2019
VGMK-Rutile	67,600e	65,000e	62,000e	52,200e	55,200	54,620	47,936	48,500e
VGMK-Ilmenite	211,200	n. a.	n. a.	163,000	171,500	167,880	325,198	n. a.
IGOK-Ilmenite	373,100	n. a.	n. a.	n. a.	158,800	224,480		n. a.

the Lemnenske deposit and the areas Serednya, Emilivska, Yurska, Osynova and Bukinska of the Mizhrichne (Mezhdurechenskiy) deposit. In 2017 IGOK switched to processing tailings as resources in the middle section of the Mizhrichne deposit had been mined out. The company expected to produce 40 ktpa of saleable concentrates by 2020 from 2.5 Mm^3 of tailings accumulated from mining in the middle and Emilivska sections of the ore field. Production capacity of IGOK stands at 400 ktpa of sulphate-grade ilmenite (54 – 59 % TiO_2) which in the past was used for pigment production by Crimea TITAN and still is used for the same purpose by Sumykhimprom PJSC and to a lesser extent for the production of titanium sponge by UTMKP and VSMPO-AVISMA.

Group DF	
Address (Head office)	23rd Floor, Parus Business Centre Mechnykova St. 2A 01601 Kiev Ukraine
Phone	+380-44-3543333
Fax	+380-44-3931074
Website	www.groupdf.com
Email	info@groupdfi.com
Contact person	Boris Krasnyansky, CEO

In 2007 Group DF was established by the Ukrainian businessman Dmitry Firtash to provide efficient management of his assets in the energy and chemicals sectors as well as the real estate business. In the titanium sector, Group DF owns:

- Mezhyrichensk Mining and Concentration Complex in Zhytomyr region
- Valki Ilmenite LLC, in Zhytomyr region
- LLC “Motronivsky GOK” with a mine under construction in Dnipropetrovsk region since 2014. It will produce up to 120 ktpa of ilmenite, 27 ktpa of rutile, and 15 ktpa of zircon from the Motronivske-Annovske area of the Malyshevsky placer deposit. As of 2018 proven HM reserves include 2.0 Mt of rutile. Commissioning is planned for 2022.
- Ukrainian Chemical Products PrJSC (Crimea TITAN), a major TiO_2 producer in Armyansk, Crimean Peninsula
- 49 % of Zaporizhzhia Titanium and Magnesium Combine (ZTMC), which produces titanium slag, sponge and ingot

Mizhrichenskyi GZK LLC mines HM ore sand in the Mizhrichny deposit (Isakovsky and Pivdenna areas) and has the capacity to produce up to 250 ktpa of sulphate-grade ilmenite (42 % TiO_2) for TiO_2 production. Ilmenite concentrates are supplied on the domestic market to Ukrainian Chemical Products PrJSC and Sumykhimprom PJSC.

Valki Ilmenite LLC mines ilmenite-rich ore sand of the Valky-Gatskivske deposit. Current capacity is 65 ktpa of sulphate-grade ilmenite (42 % TiO_2) supplied primarily to Ukrainian Chemical Products PrJSC but also to Sumykhimprom PJSC.

The company also has a license to develop the giant hard-rock Stremigorodsky ilmenite-apatite deposit with initial plans to produce some 500 kt of ilmenite and about 150–200 kt of apatite concentrate per year. During the second stage, the complex will increase production to 1000 ktpa of ilmenite and to 500 ktpa of apatite concentrate.

Table 66: Production of titanium minerals by Group DF in tonnes, according to Group DF press releases and media reports.

<table>
<tr><th></th><th>2012</th><th>2013</th><th>2014</th><th>2015</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th></tr>
<tr><td>Mizhrichenskyi GZK ilmenite</td><td rowspan="2">109,000</td><td>73,600</td><td>145,000</td><td>158,900</td><td rowspan="2">170,200</td><td rowspan="2">102,400</td><td rowspan="2">140,000</td><td rowspan="2">150,000</td></tr>
<tr><td>Valki ilmenite</td><td>43,300</td><td>56,300</td><td>78,500</td></tr>
</table>

Demurinskyi GZK LLC	
Address (Head office)	Sichovyh Strilciv St. 3a -22 49044 Dnipropetrovsk Ukraine
Phone	+380-56-3701162, -7362424
Fax	+380-56-3701163
Website	www.demgok.com
Email	kislichenko@demgok.com
Contact person	Mikhail Voevodin, General Director

Demurinskyi GZK LLC, which was acquired by Russian titanium metal producer VSMPO-AVISMA Corporation in 2012 to reduce its critical dependence on ilmenite from Volnogorsk, has been mining the Volchansk placer deposit in the Dnipropetrovsk region since 2006. The Volchansk HM deposit is said to contain reserves of some 5 Mt of VHM. While production is still low, plans are to increase production gradually, i.e. on a yearly average to 22 ktpa of ilmenite (64 – 65 % TiO_2), 7 ktpa of rutile (94 – 96 % TiO_2), 1.5 kt of zircon, and 15 ktpa of kyanite-sillimanite and staurolite.

Table 67: Production by Demurinskyi GZK LLC in tonnes, according to company website and company information provided by an employee.

<table>
<tr><th></th><th>2012</th><th>2013</th><th>2014</th><th>2015</th><th>2016</th><th>2017</th><th>2018</th></tr>
<tr><td>Ilmenite</td><td colspan="5" rowspan="4">not available</td><td>9200</td><td>12,000</td></tr>
<tr><td>Rutile</td><td>2800</td><td>3000</td></tr>
<tr><td>Zircon</td><td>300</td><td>1000</td></tr>
<tr><td>Kyanite-sillimanite</td><td>2400</td><td>3000</td></tr>
</table>

Velta LLC	
Address (Head office)	Glinki St. 7 Business Centre "Prizma", 6th Floor 49070 Dnipropetrovsk Ukraine
Phone	+380-56-7320404, -3709393
Fax	+380-56-
Website	www.velta-ua.com
Email	office@velta-ua.com
Contact person	Olena Lesnyak, Sales and Marketing Director
Email	olena.lesnyak@velta-ua.com

Velta LLC was founded in 2000 and started production from its Birzulivske HM deposit at the end of 2011. The Birzulivske deposit is situated near Korobchino village in Kirovograd region approx. 200 km to the southeast from Kyiv and 250 km west from Dnipropetrovsk. All major Black Sea ports are situated within 300–350 km distance from the deposit by rail. Velta has its own transportation and storage facility which is situated in Novomyrhorod, 27 km from the existing processing plant.

The Birzulivske deposit contains resources of 148.9 Mm^3 of ore sand of which 9.45 Mt is ilmenite (54–57 % TiO_2). First stage production capacity was 185 ktpa of ilmenite with a second stage completed in November 2013 raising production capacity to 270 ktpa.

Virtually all ilmenite produced is currently sold on the international market for pigment production but plans are to build a TiO_2 pigment plant in Israel due to be commissioned in 2021.

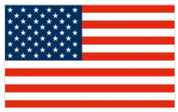
Velta also owns another titanium feedstock asset, the Likarivske ilmenite deposit, an extension of Birzulivske. The ilmenite resourse base of Likarivske is estimated at 3 Mt and in the spring of 2017 Velta signed a memorandum with CMC Cometals, Texas/USA for the development and construction of a MSP at this second deposit. The planned ilmenite capacity is 120 ktpa.

Prior to this in December 2011, Velta bought the Tarasovka placer deposit formerly owned by the Rutile-Ilmenite Company (RICO). Velta had plans to begin production at Tarasovka in 2014 and had commissioned TZMI of Australia to come up with a new JORC compliant resource of this deposit. The ore sand at Tarasovka (2.2–2.4 % VHM) has a thickness of 3 - 6 m while the thickness of the overburden reaches 33 m with a reported average thickness of 18.5 m.

The historical, non-JORC compliant resources of the Tarasovka placer deposit were given by RICO as 21.381 Mm^3 in category A, 79.975 Mm^3 in category C1 and 35.5 Mm^3 of ore sand in category C2. RICO had planned to produce 5 Mm^3 of ore sand containing 240 kt of HMC annually for a minimum of 20 years. Plans were to produce 55 kt of rutile, 22 kt of ilmenite, 80 kt of leucoxene, 32 kt of zircon, 10 kt of staurolite and 15 kt of kyanite-sillimanite annually.

Table 68: Production by Velta LLC in tonnes, according to media reports.

	2012	2013	2014	2015	2016	2017	2018
Ilmenite	n. a.	n. a.	100,000	n. a.	114,000	215,000	n. a.



USA

The USA has a long history of heavy mineral mining with rutile production in north-eastern Florida starting as early as 1925.

Currently there are two producers of rutile, leucoxene or HiTi products in the US:

- The Chemours Company TT, LLC
- Southern Ionics Minerals, LLC

In addition, Iluka Resources Ltd. still holds mining rights in Virginia (Brink and Old Hickory deposits) and North Carolina (Aurelian Springs deposit). As of 31 December 2019 total resources in this "Atlantic Seaboard region" amounted to 91 Mt of ore sand at 4.8 % HM (4.4 Mt HM content) of which the rutile grade was however very low.

The Chemours Company TT, LLC	
Address (Mine office)	P.O. Box 753 Starke, FL 32091 USA
Phone	+1-904-964-1200
Fax	+1-904-964-5075
Website	https://www.chemours.com/Florida_Mine/en_US/about.html
Email	Andrew.Romeo@chemours.com
Contact person	Andrew Romeo, Minerals Business Manager

The Chemours Company TT, LLC (Chemours), which split off from E.I. du Pont de Nemours & Company, Inc. in 2015, mines the aeolian Trail Ridge HM placer deposit in northeastern Florida. Mining and production began in the southernmost and highest-grade part (Trail Ridge plant, 3.5–5.5 % HM) in April 1949 with a second mine and plant (Highland plant, 2.5–4.0 % HM) opening 16 km to the north in April 1955. In June 1993 DuPont commenced mining at a third, northernmost site (Maxville, 2.4–3.5 % HM) separating the minerals at the Trail Ridge plant. The mined-out Highland site was abandoned and restored shortly afterwards. The Trail Ridge site is also no longer being mined.

Plans to develop a major fourth site immediately east of the Okefenokee Swamp in southernmost Georgia had to be abandoned in 1999 due to strong environmental opposition. In contrast, some years later, more land adjacent to the Maxville site could be acquired. In December 2017 Chemours applied for a mining permit at the North Maxville site (147 ha). The mine life at this last site will be 4–5 years with an anticipated end around August 2022.

A new mine site with a total size of 1074 ha at Jesup, Wayne County, GA (Amelia A & B HM deposits), was announced to be developed together with Southern Ionics Minerals (see below), which in August 2019 was taken over by Chemours. Mining was set to commence in mid-2020. This new deposit was already described by Pirkle et al. in 2013 and contains some 4 Mt of HM (incl. Amelia C) of which 45.7 % is ilmenite (> 65 % TiO_2), 13.0 % is leucoxene, 5.9 % is rutile and 13.6 % is zircon.

Original mineable reserves from the three combined Trail Ridge sites (excluding North Maxville) were some 49.1 Mt of HM including 26 Mt of titanium minerals of which about 18 Mt were ilmenite, 7 Mt were leucoxene and 1 Mt were rutile.

About 181,000 t of titanium minerals were produced from Trail Ridge in 1959, but this figure rose to more than 200,000 t in the early 1990s. Since 2004 production has fallen considerably due to the closure of mine sites and decreasing head grades. In 2013 titanium mineral production was about 127,000 t. For many decades titanium mineral products at DuPont/Chemours have comprised an ilmenite concentrate (64 % TiO_2) and a “Residue” (80 % TiO_2) (cf. Appendix C for analyses) which are blended into one titanium mineral product and shipped to Chemour’s TiO_2 pigment plant in Tennessee. Starting in 2019, Chemours planned to produce limited volumes of separated leucoxene (87–90 % TiO_2), HiTi (90–94 % TiO_2, cf. Appendix C for analyses), or rutile (+95 % TiO_2) concentrates for external sales.

Twin Pines Minerals, LLC of Birmingham, AL has been remining historic and modern tailings of the Trail Ridge deposit since 2016. The company uses a semi-mobile MSP primarily to produce a zircon concentrate, which is shipped to China for final processing. Other products include ilmenite, staurolite and AlZiPure™, a foundry-refractory sand composed primarily of kyanite, sillimanite, corundum and zircon.

Recently Twin Pines Minerals has applied for a mining concession immediately east of the Okefenokee Swamp in southernmost Georgia, once again facing stiff environmental opposition.

Southern Ionics Minerals, LLC	
Address (Head office)	2649 Zero Bay Road Patterson, GA 31557 USA
Phone	+1-912-647-0301
Website	www.southernionicsminerals.com
Email	info@simineralsllc.com
Contact person	Jason Geiger, Business Development & Sales Manager
Email	J.Geiger@simineralsllc.com

Southern Ionics Inc. of West Point, MS, USA began mining HM south of Nahunta, Charlton County in southernmost Georgia through its mineral business subsidiary Southern Ionics Minerals, LLC in 2014. In August 2019 Southern Ionics Minerals was taken over by Chemours (cf. above).

Southern Ionics' Mission mine is located 15 km south of Lulaton and 15 km north of Folkston both of which were HM mines in the past. On average, ilmenite makes up 39.5 % of the VHM produced at Mission, together with leucoxene and rutile (22.4 %), zircon (28.1 %), staurolite (5.3 %), kyanite/sillimanite (3.2 %) and monazite (0.86 %).

In May 2015 Southern Ionics Inc. also completed construction of its MSP near Offerman some 50 km further north. In February 2016 the company announced a curtailment of operations owing to a decreased demand for titanium concentrates. The mine resumed operations in 2017, conducting dry-mining to produce a HMC in a conventional floating wet mill located in a central water-filled canal running the length of the ore body. The

Figure 35: Dry mining at Southern Ionics Minerals' Mission South mine in August 2017. Photo: BGR.

HMC is then trucked some 65 km north to Offerman where high-purity individual concentrates of ilmenite (standard and premium grades), leucoxene, rutile (standard, premium and rutile 90) and zircon (standard and calcined premium) used to be produced. Southern Ionics reached a contractual agreement with Chemours some time ago and now sells virtually all of its titanium minerals to be blended into a single titanium mineral product for chloride pigment production. Monazite-enriched zircon tailings have been sold to China for further separation since 2018. Staurolite is also recovered for possible future sale.

As of 2013 total resources of Mission South and North stood at 57 Mt of ore sand at a grade of 2.3–2.8 % HM of which 49 % was ilmenite/leucoxene, 13 % was rutile and 10 % was zircon.

In 2016 production was 31,300 tonnes (t) of ilmenite, 4500 t of leucoxene, 4500 t of rutile and 11,970 t of zircon. Analyses of Southern Ionics' previous leucoxene and rutile products is given in Appendix C.

VIETNAM

HM placers are widespread along the coast of Vietnam, especially in the provinces of Bình Thuận and Ninh Thuận in the southeast, from Quảng Nam to Khánh Hòa in the south and from Thanh Hóa to Thừa Thiên-Huế in the north. On the positive side, the resources are big, mining costs are low and the infrastructure is excellent, however, the individual deposits are of low to medium quality. Official HM resources for Vietnam are 664 Mt of which 92 % (599 Mt) are bound to Bình Thuận province (InforMEA 2013). Of the 664 Mt, some 440 Mt distributed over 89 different deposits are deemed recoverable. The same source estimates domestic demand in Vietnam in 2015 at 1882 kt of ilmenite, 120 kt of titanium slag (Grade 1: >85 % TiO_2, Grade 2: 70–85 % TiO_2) and 20 kt of synthetic rutile (>83 % TiO_2) rising to 2081 kt of ilmenite, 312 kt of titanium slag and 30 kt of synthetic rutile by 2020 and 2103 kt of ilmenite, 390 kt of titanium slag and 60 kt of synthetic rutile by 2030.

The current seven major legal rutile mining companies in Vietnam are listed below. Numerous others have halted production.

- HaTinh Minerals and Trading Corporation (MITRACO), state-owned
- Binh Dinh Minerals Joint Stock Company (BIMICO), private and state-owned
- GPM Binh Thuan Joint Stock Company (GPM), private
- Biotan Mineral Joint Stock Company (BIOTAN), private
- Song Binh Minerals Joint Stock Company (Rang Dong Group), private
- Hung Thinh Titanium Slag Plant One Member Company, Ltd., private
- Sen Thuy Quang Binh Mineral Exploitation Factory (Quang Binh Imexco Group), private, with two operating HM mines in Tay Liem Bac Zones A & B, Ngu Thuy Nam Commune, Le Thuy District, Quang Binh Province.

The private Mountainous Rural Development and Construction Limited Liability Company (VCK Group) operates a licensed (hard-rock) titanium mine in Dong Dat and Phu Ly Commune, Phu Luong District, Thai Nguyen Province.

In addition, there are other smaller, often illegal or officially closed HM mining companies that have continued production. Until recently, over 40 companies were said to be active in 38 mines and 18 ore processing facilities existed with a throughput of about 2 Mt of ore sand per annum. Statistics of the Vietnam Titanium Association showed that by 2017, there were 47 valid titanium mining licenses with a titanium mineral content of over 1.26 Mt (cf. Table 67). Several of these 47 licenses have since expired while few have been added.

In the past, many of the HM placers along the coast of Vietnam, which are easy to reach and unguarded, were the target of illegal mining operations producing a mixed HMC which was sold to illegal separation companies or directly to Chinese customers. Legal mining companies also exported the bulk of their raw materials directly overseas and had only limited processing capacity.

In 2012 the Vietnamese government banned the export of raw materials forcing the local companies to invest in production capacity. However, the steady decline in the titanium price in combination with tighter environmental standards and stricter enforcement of those standards since 2014 have pushed many companies out of business or into illegal mining activities. According to Mr. Nguyen Thuong Dat, Deputy Chairman of the Vietnam Titanium Association, 90 % of the 70 titanium mining and processing plants with a combined output of nearly 1 Mtpa have stopped operations due to declining export prices (Hanoi Times, 19 August 2014). The remaining companies use mostly inefficient, environmentally unfriendly and outdated processing technologies.

Government document No. 7585/VPCP-CN of 9 August 2018 states the following regarding the general situation of Vietnam's titanium industry:

- Of the 13 exploration licenses issued since 2012, only 6 have been implemented
- Almost all licensed exploration projects have violated environmental regulations
- Processing technologies are outdated, have low recovery and consume lots of water

Table 69: List of licensed HM mines and exploration projcts in Vietnam up to 2015.

	Number	Ore sand content (kt)	HM content (kt)	Ilmenite content (kt)
Thai Nguyen Province		5603	505.3	219.6
licensed mines	3	2609	386.0	87.0
exploration projects	6	2994	179.3	132.6
Ha Tinh Province		3099	84.6	68.5
licensed mines	3	2886	64.6	48.5
exploration projects	1	213	20.0	20.0
Quang Binh Province		317	35.0	28.0
exploration projects	3	317	35.0	28.0
Quang Tri Province		788	62.0	53.1
licensed mines	4	480	34.0	27.1
exploration projects	3	308	28.0	26.0
Thua Thien Hue Province		894	61.6	40.1
licensed mines	1	568	31.6	17.6
exploration projects	1	326	30.0	22.5
Quang Nam Province		1700	103.0	82.0
licensed mines	1	440	43.0	34.0
exploration projects	1	1260	60.0	48.0
Quang Ngai Province		530	30.0	24.8
licensed mines	1	12	9.0	9.0
exploration projects	1	518	21.0	15.8
Binh Dinh Province		3203	304.4	257.5
licensed mines	6	1868	204.7	177.7
exploration projects	7	1335	99.7	79.8
Ninh Thuan Province		11,267	409.5	338.7
licensed mines	2	4182	229.5	194.7
exploration projects	2	7085	180.0	144,0
Binh Thuan Province		21,660	932.0	774.0
licensed mines	3	2537	277.0	228.0
exploration projects	16	19,123	654.8	515.6
Total Vietnam		49,061	2587.2	1861.9
licensed mines	24	15,582	1279.4	857.6
exploration projects	41	33,479	1307.8	1004.3

Table 70: List of newly licensed HM mines in Vietnam with probable commencement of operations between 2015 and 2025.

	Number	Ore sand content (kt)	HM content (kt)	Ilmenite content (kt)
Quang Nam Province	1	200	20.0	16.0
Ninh Thuan Province	2	2755	90.0	73.0
Binh Thuan Province	4	115,400[1)]	390.0	319.0
Total Vietnam	**7**	**118,355**	**500.0**	**408.0**

[1)] A single major project by VINACOMIN in three different districts of Binh Thuan Province.

Table 71: Number and capacities of titanium slag factories in Vietnam as of 2011 and expected growth in numbers and capacities up to 2030.

	Number of factories	Titanium slag capacity in kt			
		2011	to 2015	to 2020	to 2030
Thai Nguyen Province	3	10	100	100	100
Ha Tinh Province	1	0	30	30	30
Quang Binh Province	1	0	20	20	20
Quang Tri Province	2	0	40	40	40
Thua Thien Hu Province	1	10	10	30	30
Binh Dinh Province	4	42	180	204	216
Ninh Thuan Province	3	0	160	160	160
Binh Thuan Province	5	0	405	405	405
Total Vietnam	**20**	**62**	**945**	**989**	**1001**
Factories in production		4	20	20	20

Table 72: Number and capacities of synthetic rutile factories in Vietnam as of 2011 and expected growth in numbers and capacities up to 2030.

	Number of factories	Synthetic rutile capacity in kt			
		2011	to 2015	to 2020	to 2030
Quang Binh Province	1	0	10	20	20
Binh Thuan Province	1	0	50	100	100
Total Vietnam	**2**	**0**	**60**	**120**	**120**
Factories in production		0	2	2	2

Ninh Thuan province has temporarily (2018-2023) stopped all titanium exploitation projects (Government Resolution No. 115/NQ-CP of 31 August 2018) due to environmental concerns.

Binh Thuan Province, which is home to about 92 % of Vietnam's titanium reserves, has also postponed licensing due to environmental concerns in recent years. For example, the licensing of Hong Thang area 1, Hoa Thang Commune, Bac Dinh District for Quang Minh Investment Trading JSC was suspended in February 2017 due to environmental concerns. In 2019 Binh Thuan's Provincial People's Committee stated that at present there are 25 titanium extraction projects operating on 19,339 hectares of land. However, contribution to the provincial budget was only 1 %, which was only one tenth of the contribution of the tourism sector. The industry also used outdated technology and too much fuel and water. The government was therefore considering halting the titanium projects in Binh Thuan Province altogether due to their questionable economic efficiency and massive environmental impact.

A local consultant collated additional information on domestic rutile production from several but not all relevant mining companies for the present study. Care has to be taken when rounded and constant production figures are given as they may represent projected or even capacity figures which were never updated!

Table 73: Number and capacities of titanium sponge factories in Vietnam as of 2011 and expected growth in numbers and capacities up to 2030.

	Number of factories	Titanium sponge capacity in kt			
		2011	to 2015	to 2020	to 2030
Binh Thuan Province	2	0	0	40	50
Total Vietnam	**2**	**0**	**0**	**40**	**50**
Factories in production		0	0	2	2

Table 74: Global imports of titanium mineral and zircon concentrates and monazite from Vietnam in tonnes, according to IHS Markit – Global Trade Atlas®.

Global imports	2012	2013	2014	2015	2016	2017	2018	2019
Titanium minerals	1,164,152	606,719	222,607	194,303	402,769	344,535	310,531	304,776
Rutile to Japan	10,146	10,633	12,250	11,993	11,793	5340	9260	12,983
Rutile to South Korea	1857	555	6380	39,500	1	9	0	22
Rutile to India	150	50	125	0	0	0	0	0
Zircon	22,510	10,240	10,037	4229	9469	5447	10,741	6168
Monazite	369	178	n. a.	456	402	359	1539	2173

HaTinh Minerals and Trading Corporation (MITRACO)	
Address (Head office)	No.2 Vu Quang Street Hà Tĩnh City Hà Tĩnh Province Socialist Republic of Vietnam
Phone	+84-39-3855-603 / -3890-660
Fax	+84-39-3855-606 / -3855-604
Website	www.mitraco.com.vn
Email	contact@mitraco.com.vn
Contact person	Mr. Nguyen Anh Thang, Manager Economic Department
Phone	+84-913294327
Email	thangmitraco@gmail.com

HaTinh Minerals and Trading Corporation (MITRACO) is a state-owned enterprise directly under the control of Hà Tĩnh Province. It is active in production and business activities of various kinds from mining to road building and travel services.

The HM mining operation in the Hà Tĩnh Province of Vietnam was initially established in 1992 as a joint venture named "Austinh" between Westralian Sands Ltd., Meteco (the Hà Tĩnh provincial mining company) and Mideco (owned by the Vietnamese Ministry of Heavy Industry). Production started in May 1993 and ceased due to a dispute between the joint venture partners in June 1995. Westralian Sands withdrew from the joint venture in 1996 and the enterprise was disbanded. In 1999 following a period of unorganized mining by a large number of small companies, the Hà Tĩnh Province took over the operation through its wholly owned Minerals and Trading Company founded in 1991. The name changed to Minerals and Trading Corporation (MITRACO) in 2000.

MITRACO produces ilmenite, zircon and rutile (min. 83 % TiO_2, cf. Appendix C for analyses) concentrates from three HM sands licenses in Ky Anh District, Cam Xuyen District and the Nghi Xuan District of Hà Tĩnh Province which all will expire in October 2027. It owns wet concentration plants with a total capacity of between 200 and 250 ktpa of HMC. However, MITRACO has restricted mining and throughput to 100 ktpa due to limited reserves, hoping to extend operations until the end of the license period. Production in the past years is said to have been about 50,000 t of ilmenite, 2500 t of zircon, and 2000 t of rutile per annum and probably will remain the same until at least 2025.

Binh Dinh Minerals Joint Stock Company (BIMICO)	
Address (Head office)	11 Ha Huy Tap Street Quy Nhon City Bình Định Province Socialist Republic of Vietnam
Phone	+84-256-382-2073 / -3825857
Fax	+84-256-382-2497
Website	www.bimico.vn
Email	bimicovn@dng.vnn.vn
Contact person	Mr. Ho Trong Duc, Trading Manager
Phone	+84-90-5070757
Email	hotrongduc@bimico.vn

Binh Dinh Minerals Company (BIMICO) was established in 1985. In 2001 the People's Committee of Bình Định Province decided to convert the company into a joint stock company with a charter capital of 82.6 billion VND. The government ownership is now less than 30 %.

A joint venture between BIMICO and two Malaysian companies, Malaysia Mining Corp. and Pendorang (also known as Bimal Minerals Co. Ltd.) went into production at the end of 1996. BIMICO transferred all of its mining licenses to Bimal Minerals. The joint venture ceased production in early 2011 when its license expired.

BIMICO mines HM from its Degi II mine at Cát Thánh Village in the Phu Cat District of Bình Định Province. The production license currently covers an area of 150 ha and expires in 2021. HM placers have also been explored to the south of Cát Thánh and Cat Hai Villages in Phu My District since 2007 where a second mining license covering some 180.7 ha also was granted in 2011. The company owns one MSP with a capacity of 60,000 tpa of ilmenite, 2500 tpa of zircon, 1200 tpa of rutile, 400 tpa of monazite and 2000 tpa of magnetite, as well as a titanium slag factory with a capacity of 19,000 tonnes of titanium slag and 12,000 tonnes of pig iron per year.

The company's main product is ilmenite (min. 51 % TiO_2) and it also produces rutile (min. 85 % TiO_2, cf. Appendix C for analysies), zircon (most of which is milled to zircon flour), monazite and magnetite, while titanium slag (min. 85 % TiO_2) and pig iron currently are not being produced due to low prices. More than 95 % of the company's products are exported to Japan, Malaysia and China.

GPM Binh Thuan Minerals Joint Stock Company (GPM)	
Address (Head office)	Vincom Tower, 14th Floor 72 Le Thanh Ton Street District 1, Ho Chi Minh City Socialist Republic of Vietnam
Phone	+84-28-38270181 / +84-252-3730370 (Binh Thuan)
Website	www.gpm.asia
Email	info@gpm.asia
Contact person	Mr. Ngo Quang Anh
Phone	+84-91-4532696

GPM Binh Thuan Ltd., formerly Amigo Minerals JSC, is a subsidiary of GPM Asia which belongs to the Russian East Minerals Group.

GPM has operated a HM mining operation in Hong Chinh Village, near Phan Thiết in the Bắc Bình District of Bình Thuận Province since 2007. It produces two grades of ilmenite (min. 50 % TiO_2, and min. 54 % TiO_2), two grades of rutile (min. 83 % TiO_2, and min. 85 % TiO_2), two grades of zircon (standard and premium) incl. zircon flour and monazite as final products using modern mining and separation equipment from Australia, the US and Ukraine. Capacity some years ago was given as about 80,000 tpa of ilmenite, 15,000 tpa of zircon, 4000 tpa of rutile and 300 tpa of monazite, although titanium mineral capacity may currently be much higher.

A professional in-house geological team, modern exploration tools and drilling equipment also enable the company to provide drilling services and geological support across Vietnam, including the estimation of reserves under the international JORC standard.

Biotan Mineral Joint Stock Company (BIOTAN)	
Address (Head office)	422 Nguyen Thai Hoc Street Quy Nhon City Bình Định Province Socialist Republic of Vietnam
Phone	+84-256-2210915
Fax	+84-256-3646335
Website	www.biotan.com.vn
Email	info@biotan.com.vn
Contact person	Ms. Nguyen Thi Xuan Trang, Vice Business Director
Phone	+84-949556644
Email	Trangbiotan@yahoo.com

Biotan Mineral Joint Stock Company (BIOTAN) is a privately owned company and was established in 2006 with a chartered capital of 30 billion VND. In January 2008 the company was granted an exploration permit for HM in My Thanh Village in the Phú Mỹ District of Bình Định Province. In March 2009 this exploration permit was officially converted into a mining permit with a duration of 14 years and a maximum production capacity of 21,150 tonnes of HM per year. The mining area covers 180 ha.

BIOTAN produces ilmenite (min. 52 % TiO_2), monazite, rutile (min 87 % TiO_2, cf. Appendix C for analyses) and zircon. Annual capacities stand at 20,000 t of ilmenite, 3000 t of zircon, 2500 t of rutile and 2000 t of monazite. It also used to produce titanium slag with a capacity of 12,000 tpa and also holds a share in the titanium slag plant in My Thanh Village in the Phú Mỹ District of Bình Định Province (cf. Saigon – Quy Nhon Mining Corporation JSC).

Song Binh Minerals Joint Stock Company	
Address (Head office)	J45 Tôn Đức Thắng Phan Thiết City Bình Thuận Province Socialist Republic of Vietnam
Phone	+84-252-3822-301
Website	www.khoangsansongbinh.vn
Email	khoangsansongbinh@rangdonggroup.com
Contact person	Ms. Vo Thi My Hanh, Vice General Director
Phone	+84-90676048
Email	myhanh@rangdonggroup.com.vn

Song Binh Minerals Joint Stock Company is a subsidiary of the private Rang Dong Group which was established in early 1991 and is active in the fields of construction, infrastructure, tourist resort management, BOT projects, mining, production of building materials and forestry.

Song Binh Minerals Joint Stock Company was registered in April 2013, changing its original registration in June 2018. This mining subsidiary is active in HM mining and the processing of zircon and titanium minerals in Binh Thuan Province. The company is currently implementing two major projects in Lang Xeo Village in the Bac Binh District of Binh Thuan Province.

The first project is a HM processing and ultra-fine zircon grinding plant, which is already in full operation and has a capacity of 35,000 tpa. This factory produces several grades of zircon and zircon flour, ilmenite and three grades of rutile (at min. 83 % TiO_2, min. 85 % TiO_2 and min. 87 % TiO_2, cf. Appendix C for analyses). Products are sold both on the domestic and international markets.

The second project is a TiO_2 pigment plant which is under construction and will have a capacity of 80,000 tpa. Byproducts will include plaster, construction materials and fertilizer.

There are also plans for titanium slag production which might start in 2022-23.

Production of mineral concentrates at Lang Xeo Village started in 2013 and range from 20,000–35,000 tpa of ilmenite, 3000–4000 tpa of zircon and rutile and negligible amounts of monazite.

The Song Binh titanium processing plant has been in operation since 2013 and primarily produces zircon, ilmenite, rutile and monazite. The current annual capacity is about 35,000 tonnes of ilmenite, 3,500 tonnes of zircon, 3,000 tonnes of rutile and a negligible fraction of monazite. The company expects to take a titanium slag plant into production in 2022-23. Rang Dong believes its mine reserves are large enough to maintain the same output until 2025.

Hung Thinh Titanium Slag One Member Company, Ltd. Titanium Trading Company, Ltd.	
Address (Head office)	169-171 Ton Duc Thang Street Phu Thuy Ward Phan Thiet City Binh Thuan Province Socialist Republic of Vietnam
Phone	+84-262-6267979
Fax	+84-262-6257979
Website	www.hungthinhminerals.com, www.vtitanium.vn
Email	contact@vtitanium.vn
Contact person	Mr. Vo Trung Ta, CEO
Phone	+84-929292977
Email	vota@vtitanium.vn

The titanium activities of the private Hung Thinh Group via Hung Thinh Minerals Investment Co., Ltd. consist of two companies. Hung Thinh Titanium Slag Plant One Member Co., Ltd. is the mining and processing business of the group and the Titanium Trading Co., Ltd. with its brand name VTitanium is the trading business of the group. The company formerly traded as Hung Thinh Phat Trading and Minerals Joint Stock Company. The company has been in the field of minerals for many years and specializes in titanium minerals from the Binh Thuan province.

Hung Thinh Group owns a HM license covering 316 ha in Zone 6 of the Thien Ai of Bac Binh District, Binh Than Province. It has processed the mined HM in Hong Thang Village in the same district since 2014 and produces ilmenite (at 52 % TiO_2), rutile (min. 80 %/83 %/85 % TiO_2, cf. Appendix C for analyses), leucoxene, zircon and monazite concentrates. While the ilmenite is upgraded to titanium slag (at up to 93 % TiO_2), the other products are sold to domestic and international customers.

The company claims annual production during past years to be about 60,000 – 100,000 t of ilmenite, 7000 t of rutile, and 2000 - 5000 t of other HM products although annual production is currently closer to about 40,000 t of ilmenite, 3600 t of rutile, 1200 t of zircon and 800 t of monazite.

Dat Quang Chu Lai Minerals Joint Stock Company (DQCL)	
Address (Head office)	4th Floor, Saigon Centre Building 65 Le Loi, District 1 Ho Chi Minh City Socialist Republic of Vietnam
Phone	+84-28-38219580
Fax	+84-28-38219181
Website	www.dqcl.com.vn
Email	contact@dqcl.com.vn
Contact person	Mr. Tran Linh Thang, CEO
Phone	+84-968617777
Email	linhthang1976@gmail.com

Dat Quang Chu Lai Minerals (DQCL) was established in 2006. It was renamed Dat Quang Chu Lai Minerals Joint Stock Company in March 2009.

DQCL has held a 468 ha mining license in the Chu Lai Airport Zone of Tam Nghia Village in the Nui Than District of Quảng Nam Province since 2011 and also prospects for HM in the surrounding areas. In addition, a second mining license covering some 592 ha was expected for a HM deposit in the Binh Hai and Binh Nam Districts of Quảng Nam Province. DQCL also is active in the tourism, entertainment and real estate sectors.

After having erected a first HM separation plant with a capacity of 50 ktpa in Bac Chu Lai Industry Park, Quảng Nam Province, DQCL published plans for several upstream plants, namely TiO_2 pigment plants in the Hà Tĩnh and Binh Thuan Provinces, titanium slag plants in the Quảng Nam and Binh Thuan Provinces and titanium sponge plants in Quảng Nam and in Ninh Thuan Provinces.

DQCL's plant is currently out of operation but used to produce ilmenite (min. 52 % TiO_2), two grades of rutile (cf. Appendix C for analyses), zircon, zircon flour, monazite and titanium slag. Final products were exported to Japan, China, Malaysia and other Southeast Asian countries.

Thua Thien Hue Minerals Single-Member Limited Liability Corporation (HUMEXCO)	
Address (Head office)	53 Nguyen Gia Thieu Street Hue City Thừa Thiên-Huế Province Socialist Republic of Vietnam
Phone	+84-54-354-1044 / -54-352-3965
Fax	+84-54-352-7926
Website	www.humexco.com.vn
Email	sales@humexco.com.vn
Contact person	Mr. Le Phạm Nguyen Truong, Chief of Business Department
Phone	+84-91-4078687
Email	truongctks@gmail.com

Thua Thien Hue Minerals Single-Member Ltd. Corporation (HUMEXCO) was established in 1983. It is controlled by Thừa Thiên-Huế Province.

The company's main products were sulphate-grade ilmenite (min. 52 % TiO_2), rutile (min. 85 % TiO_2), monazite, two grades of zircon, zircon flour, titanium slag (min. 92 % TiO_2), pig iron and TiO_2 pigment. Official titanium slag and pig iron production started in January 2011. In 2011 HUMEXCO also invested in two zircon grinding lines with a total capacity of 4500 tpa. The HM products of HUMEXCO were exported to several countries in SE Asia including Japan, China and Malaysia. Production stopped due to inefficient operations at the end of 2016.

The company still owns a HM mining license in the Ke Sinh and Vinh Xuan zones of Thừa Thiên-Huế Province where it also has an exploration project in the Quảng Ngan, Quảng Cong, and Quảng Dien villages.

Table 75: Production statistics of HUMEXCO in Thừa Thiên-Huế Province in tonnes, according to company information.

HUMEXCO	2012	2013	2014	2015	2016	2017	2018
Zircon	n. a.	n. a.	4600	3620	602	–	–
Ilmenite	n. a.	n. a.			1880	–	–
Rutile	n. a.	n. a.	6476	3197	265	–	–
Monazite	n. a.	n. a.	295	528	25	–	–
Zircon flour	n. a.	n. a.	6175	2954	221	–	–
Titanium slag	n. a.	n. a.	3690	4306	330	–	–

Saigon – Quy Nhon Mining Corporation Joint Stock Company (SQC)	
Address (Head office)	Building 6, Street 5 Nhon Hoi Industrial Park Quy Nhon City Bình Định Province Socialist Republic of Vietnam
Phone	+84-256-365-9181 / -83-822-8289
Fax	+84-256-365-9187 / -83-822-8291
Website	www.sqcmining.com
Email	info_sqc@saigoninvest.com
Contact person	Mr. Ngo Huu Linh, Business Manager
Phone	+84-914070215

Saigon – Quy Nhon Mining Corporation JSC (SQC) is a member of the Saigon Invest Group (SIG) which specializes in mining activities. SQC was founded in December 2006 with an initial chartered capital of 10 billion VND. Three years later in December 2009, it was listed on the Hanoi Stock Exchange. The stock was suspended from trading on 15 April 2015 after being placed under supervision.

Until 2017 SQC operated a HM mine in Cát Khánh Village in the Phù Cát District of Bình Định Province. Its main mineral was ilmenite (min. 52 % TiO_2, capacity 100,000 tpa) most of which was used for titanium slag production. In May 2009 a titanium slag plant with two furnaces, in which SQC has a share of 30 %, went into production in My Thanh Village in the Phú Mỹ District of Bình Định Province. The plant, which has a capacity of 24,000 tpa of titanium slag (min. 93 % TiO_2) and 30,000 tpa of pig iron, became fully operational in July 2009. SQC has also produced zircon (capacity 3000 tpa), rutile (min. 83 % TiO_2, capacity 3000 tpa, cf. Appendix C for analyses), and monazite (capacity 1800 tpa) since late 2009.

Appendix B

Comparative statistics of commercial leucoxene, rutile, and HiTi concentrates

Comparative statistics of commercial leucoxene, rutile and HiTi concentrates

1. Colour
2. TiO_2 content
3. $Zr(Hf)O_2$ content
4. Fe_2O_3 content
5. Al_2O_3 content
6. Cr_2O_3 content
7. V_2O_5 content
8. P_2O_5 content
9. Radioactivity (U+Th)
10. Purity (rutile-anatase-leucoxene content)
11. Quartz content
12. Grain size (mean)

1. Colour

Dark black	SQC Rutile
	Xiamen King Far East Rutile 95
	RZM Rutile
	Universal Rutile
	Trimex Rutile Standard Grade
	SRL Rutile Standard Grade
	Green Cove Springs Leucoxene
Dark greyish-black	Chemours Residue
	Ratana Rutile
	SRL Rutile Industrial Grade
	Southern Ionics Rutile Premium Grade
Greyish black	Green Cove Springs Rutile
	Southern Ionics Rutile
	PT Karya Lisbeth Rutile 90
Dark grey	OMC Rutile
Dark reddish-black	RBM Rutile Prime Grade
White mottled black	Jesup HiTi
	Tronox Australia Leucoxene Standard Grade
	Southern Ionics Leucoxene
Red mottled black	Moma Rutile
	Kwale Rutile
	Suixi Jindi Mineral Rutile 95
	Lanka Rutile
	IREL Rutile “OR” Grade
	DQCL Rutile 92
Orange mottled black	Cataby Rutile Premium Grade
	CRUZOR Rutile
	Eneabba Rutile Premium Grade
	Tronox Australia Rutile Premium Grade
	Tronox Murray Basin Rutile
	Tronox Brasil Rutilo
	Vilnohirsk Rutile Standard Grade
	Southern Ionics Rutile 90
	Jacksonville Rutile
	BIOTAN Rutile
	BIMICO Rutile
	DQCL Rutile 95
	IREL Rutile “MK” Grade
	IREL Rutile “Q” Grade

Orange mottled black	KMML Rutile
	RBM Rutile Welding Grade Hainan Wensheng Rutile 95
	Naicher Advanced Material Rutile 90
	Naicher Advanced Material Rutile 92
	Naicher Advanced Material Rutile 95
	Suixi Jindi Mineral Rutile 90
	Suixi Ruifeng Mining Rutile 90
	Suixi Ruifeng Mining Rutile 95
	Wanning Yiyuanfeng Mining Rutile 90
	Senegal Rutile
	Senegal Leucoxene
	Keysbrook Leucoxene L70
	Keysbrook Leucoxene L88
Dark orange black	Hainan Wensheng Rutile 85
	Suixi Ruifeng Mining Rutile 85 (Senegal)
	IREL Leucoxene “Q” Grade
	Eucla HiTi 90
	Doral Leucoxene
Dark orange	Folkston Rutile
	Suixi Ruifeng Mining Rutile 85 (Russia)
Light orange grey	Guangxi Liufeng Mining Rutile 90
	Hainan Wensheng Rutile 90
	Hainan Xiongxiu Mining Rutile 91
	Wanning Yiyuanfeng Mining Rutile 80
	Hung Thinh Rutile 85
	Song Binh Rutile 87
	Namakwa Sands Rutile
	Namakwa Sands Leucoxene
Greyish brown	Mitraco Rutile
	Hainan Xiongxiu Mining Rutile 85
	Hainan Xiongxiu Mining Rutile 89
Brownish	Sheffield HiTi Naicher Advanced Material Rutile 85
	Suixi Jindi Mineral Rutile 85
	Siberia Leucoxene
	Folkston Leucoxene
Brownish black	Tronox Wonnerup Leucoxene
Light greenish brown	Jesup Rutile
	CODEMIG Anatase

2. TiO_2 content

Name	TiO_2 (wt.-%)
Southern Ionics Rutile Premium Grade	96.76
IREL Rutile „OR“ Grade	96.52
RZM Rutile	96.38
Malawi Rutile	(96.27)
Southern Ionics Rutile	96.13
SRL Rutile Industrial Grade	95.97
Cataby Rutile Premium Grade	95.91
Trimex Rutile Standard Grade	95.83
Kwale Rutile	95.82
Lanka Rutile	95.62
Vilnohirsk Rutile Standard Grade	95.61 – 93.72
SRL Rutile Standard Grade	95.54
Suixi Jindi Mineral Rutile 95	95.38
Eneabba Rutile Premium Grade	95.31 – 95.22
VV Mineral Rutile	(95.23)
Cameroon Rutile	(95.2)
Folkston Rutile	95.09
Tronox Murray Basin Rutile	94.99
CRUZOR Rutile	94.95
Hainan Wensheng Rutile 95	94.95
Nordic Rutile	(94.90)
Suixi Ruifeng Mining Rutile 95	94.88
KMML Rutile	94.87
RBM Rutile Prime Grade	94.82
IREL Rutile “MK” Grade	94.81
Naicher Advanced Material Rutile 95	94.77
Jacksonville Rutile	94.65
Jesup Rutile	94.52
Xiamen King Far East Rutile 95	94.23
Senegal Rutile	94.22
Suixi Ruifeng Mining Rutile 90	94.17
IREL Rutile “Q” Grade	94.10
Namakwa Sands Rutile	93.91
Tronox Australia Rutile Premium Grade	93.69
RBM Rutile Welding Grade	93.54
Tronox Australia Leucoxene Standard Grade	93.22 – 86.26
Green Cove Springs Rutile	92.85
BIMICO Rutile	92.72
Kalbar Rutile	(92.7)
BIOTAN Rutile	92.56
DQCL Rutile 92	92.42
Naicher Advanced Material Rutile 92	92.18
Jesup HiTi	91.77

Name	TiO_2 (wt.-%)
Namakwa Sands Leucoxene	91.75
Eucla HiTi 90	91.69 – 90.17
Moma Rutile	91.36
Southern Ionics Rutile 90	91.27
SQC Rutile	91.17
Hainan Wensheng Rutile 90	91.09
Tronox Brasil Rutilo	91.00
Hainan Xiongxiu Mining Rutile 91	90.94
Guangxi Liufeng Mining Rutile 90	90.11
Wanning Yiyuanfeng Mining Rutile 90	89.95
Suixi Ruifeng Mining Rutile 85 (Russia)	89.57
Capel Leucoxene	89.40
OMC Rutile	89.32
Hainan Xiongxiu Mining Rutile 89	89.23
Senegal Leucoxene	88.94
Song Binh Rutile 87	88.90
Universal Rutile	88.87
Suixi Ruifeng Mining Rutile 85 (Senegal)	88.30
Tronox Wonnerup Leucoxene	88.22
Naicher Advanced Material Rutile 90	88.13
DQCL Rutile 95	88.13
Doral Leucoxene	87.92
Suixi Jindi Mineral Rutile 90	87.75
Hainan Xiongxiu Mining Rutile 85	87.56
Sheffield HiTi	86.94
Hainan Wensheng Rutile 85	86.42
Ratana Rutile	85.42
Keysbrook Leucoxene L88	85.15
Hung Thinh Rutile 85	84.52
Mitraco Rutile	83.64
Naicher Advanced Material Rutile 85	82.54
Suixi Jindi Mineral Rutile 85	81.96
Chemours Residue	81.54
Wanning Yiyuanfeng Mining Rutile 80	81.34
Folkston Leucoxene	81.23
IREL Leucoxene “Q” Grade	81.21
KMML Leucoxene	(79.65)
Southern Ionics Leucoxene	72.51
Keysbrook Leucoxene L70	66.91
Green Cove Springs Leucoxene	65.16
PT Karya Lisbeth Rutile 90	60.36
CODEMIG Anatase	58.09
Siberia Leucoxene	50.84

3. $Zr(Hf)O_2$ content

Name	$Zr(Hf)O_2$ (wt.-%)
Cameroon Rutile	(0.03)
Nordic Rutile	(0.06)
Folkston Leucoxene	0.07
Green Cove Springs Leucoxene	0.07
Green Cove Springs Rutile	0.11
SQC Rutile	0.13
Southern Ionics Rutile 90	0.19
Chemours Residue	0.21
Jesup Rutile	0.29
Universal Rutile	0.29
Tronox Australia Leucoxene Standard Grade	0.31 – 0.50
Mitraco Rutile	0.35
Jacksonville Rutile	0.37
Southern Ionics Rutile	0.38
Southern Ionics Rutile Premium Grade	0.39
CODEMIG Anatase	0.42
Keysbrook Leucoxene L70	0.42
Namakwa Sands Leucoxene	0.42
Suixi Ruifeng Mining Rutile 95	0.42
Hainan Wensheng Rutile 95	0.44
BIMICO Rutile	0.44
IREL Rutile “MK” Grade	0.44
Tronox Murray Basin Rutile	0.47
KMML Rutile	0.49
Siberia Leucoxene	0.50
Malawi Rutile	(0.52)
Hainan Xiongxiu Mining Rutile 89	0.55
RBM Rutile Prime Grade	0.57
Xiamen King Far East Rutile 95	0.58
Guangxi Liufeng Mining Rutile 90	0.60
IREL Rutile „OR“ Grade	0.65
KMML Leucoxene	(0.65)
Kwale Rutile	0.66
Song Binh Rutile 87	0.67
Jesup HiTi	0.68
Folkston Rutile	0.73
Senegal Rutile	0.74
Cataby Rutile Premium Grade	0.75
IREL Rutile “Q” Grade	0.75
Namakwa Sands Rutile	0.77
Vilnohirsk Rutile Standard Grade	0.78 – 1.19
SRL Rutile Industrial Grade	0.83
Tronox Australia Rutile Premium Grade	0.85

Name	$Zr(Hf)O_2$ (wt.-%)
CRUZOR Rutile	0.85
Lanka Rutile	0.86
SRL Rutile Standard Grade	0.87
Eneabba Rutile Premium Grade	0.88
Naicher Advanced Material Rutile 95	0.88
RZM Rutile	0.89
OMC Rutile	0.91
IREL Leucoxene “Q” Grade	0.96
Hainan Wensheng Rutile 90	0.96
Suixi Ruifeng Mining Rutile 90	0.96
Trimex Rutile Standard Grade	0.99
BIOTAN Rutile	1.03
Hainan Xiongxiu Mining Rutile 85	1.06
Capel Leucoxene	1.07
Kalbar Rutile	(1.1)
Suixi Jindi Mineral Rutile 95	1.17
Tronox Wonnerup Leucoxene	1.25
Hainan Wensheng Rutile 85	1.27
VV Mineral Rutile	(1.42)
Hainan Xiongxiu Mining Rutile 91	1.43
RBM Rutile Welding Grade	1.50
Naicher Advanced Material Rutile 92	1.72
Doral Leucoxene	1.82
Ratana Rutile	1.98
Senegal Leucoxene	1.99
Southern Ionics Leucoxene	2.03
Keysbrook Leucoxene L88	2.04
DQCL Rutile 92	2.07
Eucla HiTi 90	2.07 – 2.53
Wanning Yiyuanfeng Mining Rutile 90	2.13
DQCL Rutile 95	2.16
Hung Thinh Rutile 85	2.21
Suixi Ruifeng Mining Rutile 85 (Senegal)	2.40
Tronox Brasil Rutilo	2.78
Suixi Jindi Mineral Rutile 85	2.89
Sheffield HiTi	3.17
Moma Rutile	3.63
Suixi Ruifeng Mining Rutile 85 (Russia)	3.88
Suixi Jindi Mineral Rutile 90	4.22
Naicher Advanced Material Rutile 85	4.50
Naicher Advanced Material Rutile 90	5.20
PT Karya Lisbeth Rutile 90	6.35
Wanning Yiyuanfeng Mining Rutile 80	6.54

4. Fe_2O_3 content

Name	Fe_2O_3 (wt.-%)
Cameroon Rutile	(0.23)
RZM Rutile	0.33
VV Mineral Rutile	(0.38)
Trimex Rutile Standard Grade	0.42
Southern Ionics Rutile Premium Grade	0.45
Kalbar Rutile	(0.5)
Suixi Jindi Mineral Rutile 95	0.51
Namakwa Sands Rutile	0.52
IREL Rutile „OR“ Grade	0.54
SRL Rutile Industrial Grade	0.59
Malawi Rutile	(0.59)
Moma Rutile	0.60
CRUZOR Rutile	0.63
Naicher Advanced Material Rutile 92	0.63
IREL Rutile “MK” Grade	0.67
RBM Rutile Welding Grade	0.67
Tronox Murray Basin Rutile	0.68
Suixi Ruifeng Mining Rutile 95	0.69
Naicher Advanced Material Rutile 95	0.70
Cataby Rutile Premium Grade	0.72
Senegal Rutile	0.73
DQCL Rutile 92	0.74
Naicher Advanced Material Rutile 90	0.77
Vilnohirsk Rutile Standard Grade	0.81 – 1.32
RBM Rutile Prime Grade	0.82
Eneabba Rutile Premium Grade	0.82 – 0.95
Southern Ionics Rutile	0.86
SRL Rutile Standard Grade	0.90
Suixi Ruifeng Mining Rutile 90	0.94
Suixi Ruifeng Mining Rutile 85 (Russia)	0.94
Hung Thinh Rutile 85	0.95
Suixi Jindi Mineral Rutile 90	0.97
BIOTAN Rutile	0.99
Lanka Rutile	0.99
Kwale Rutile	1.03
Hainan Xiongxiu Mining Rutile 91	1.03
IREL Rutile “Q” Grade	1.05
Folkston Rutile	1.06
Naicher Advanced Material Rutile 85	1.06
Song Binh Rutile 87	1.11
Wanning Yiyuanfeng Mining Rutile 80	1.14
KMML Rutile	1.15
Suixi Jindi Mineral Rutile 85	1.15

Name	Fe_2O_3 (wt.-%)
BIMICO Rutile	1.16
Tronox Brasil Rutilo	1.22
Suixi Ruifeng Mining Rutile 85 (Senegal)	1.23
Ratana Rutile	1.25
DQCL Rutile 95	1.27
Namakwa Sands Leucoxene	1.30
Hainan Wensheng Rutile 95	1.35
Tronox Australia Rutile Premium Grade	1.38
Guangxi Liufeng Mining Rutile 90	1.42
OMC Rutile	1.43
Hainan Xiongxiu Mining Rutile 89	1.47
Hainan Xiongxiu Mining Rutile 85	1.50
Tronox Australia Leucoxene Standard Grade	1.53–6.29
Hainan Wensheng Rutile 90	1.58
Nordic Rutile	(1.63)
Eucla HiTi 90	1.64–2.19
Universal Rutile	1.75
Wanning Yiyuanfeng Mining Rutile 90	1.91
Jacksonville Rutile	1.95
Senegal Leucoxene	1.99
Hainan Wensheng Rutile 85	2.09
Xiamen King Far East Rutile 95	2.14
Jesup Rutile	2.15
Sheffield HiTi	2.82
Siberia Leucoxene	3.05
Jesup HiTi	3.06
Mitraco Rutile	3.09
Green Cove Springs Rutile	3.28
Tronox Wonnerup Leucoxene	3.48
Doral Leucoxene	3.79
Capel Leucoxene	4.01
Keysbrook Leucoxene L88	4.01
Southern Ionics Rutile 90	4.12
IREL Leucoxene “Q” Grade	4.83
SQC Rutile	4.87
KMML Leucoxene	(7.5)
CODEMIG Anatase	8.74
Folkston Leucoxene	9.18
Southern Ionics Leucoxene	12.57
PT Karya Lisbeth Rutile 90	12.62
Chemours Residue	13.09
Keysbrook Leucoxene L70	22.53
Green Cove Springs Leucoxene	27.57

5. Al_2O_3 content

Name	Al_2O_3 (wt.-%)
VV Mineral Rutile	(0.21)
RZM Rutile	0.22
Xiamen King Far East Rutile 95	0.22
IREL Rutile „OR“ Grade	0.25
SRL Rutile Industrial Grade	0.25
Vilnohirsk Rutile Standard Grade	0.26 – 0.65
Trimex Rutile Standard Grade	0.28
SRL Rutile Standard Grade	0.31
Nordic Rutile	(0.31)
Malawi Rutile	(0.33)
Kwale Rutile	0.34
Lanka Rutile	0.34
Tronox Murray Basin Rutile	0.34
Suixi Jindi Mineral Rutile 95	0.35
Southern Ionics Rutile Premium Grade	0.35
Cataby Rutile Premium Grade	0.37
Hainan Wensheng Rutile 95	0.38
Eneabba Rutile Premium Grade	0.38 – 0.50
Moma Rutile	0.40
Jacksonville Rutile	0.43
Cameroon Rutile	(0.44)
Eucla HiTi 90	0.47 – 0.49
Naicher Advanced Material Rutile 95	0.48
Southern Ionics Rutile	0.48
CRUZOR Rutile	0.52
RBM Rutile Welding Grade	0.53
KMML Rutile	0.54
Suixi Ruifeng Mining Rutile 85 (Russia)	0.54
RBM Rutile Prime Grade	0.54
Kalbar Rutile	(0.6)
Namakwa Sands Rutile	0.61
Universal Rutile	0.61
Ratana Rutile	0.62
Green Cove Springs Rutile	0.62
Sheffield HiTi	0.63
DQCL Rutile 92	0.66
Tronox Brasil Rutilo	0.67
Suixi Ruifeng Mining Rutile 90	0.68
IREL Rutile “MK” Grade	0.71
IREL Rutile “Q” Grade	0.72
Suixi Ruifeng Mining Rutile 95	0.78
Naicher Advanced Material Rutile 92	0.79
Folkston Rutile	0.81

Name	Al_2O_3 (wt.-%)
Tronox Australia Rutile Premium Grade	0.83
Naicher Advanced Material Rutile 85	0.86
Senegal Rutile	0.87
Jesup Rutile	0.90
Namakwa Sands Leucoxene	0.90
Chemours Residue	0.96
Naicher Advanced Material Rutile 90	0.97
Tronox Australia Leucoxene Standard Grade	0.98 – 1.53
Jesup HiTi	1.00
BIOTAN Rutile	1.06
Hainan Xiongxiu Mining Rutile 91	1.08
Wanning Yiyuanfeng Mining Rutile 90	1.09
Hainan Wensheng Rutile 90	1.12
Southern Ionics Rutile 90	1.17
Suixi Jindi Mineral Rutile 90	1.18
BIMICO Rutile	1.20
Green Cove Springs Leucoxene	1.22
DQCL Rutile 95	1.27
Wanning Yiyuanfeng Mining Rutile 80	1.36
Guangxi Liufeng Mining Rutile 90	1.40
Senegal Leucoxene	1.48
OMC Rutile	1.51
Doral Leucoxene	1.62
SQC Rutile	1.62
Suixi Ruifeng Mining Rutile 85 (Senegal)	1.64
Capel Leucoxene	1.64
Hung Thinh Rutile 85	1.68
Song Binh Rutile 87	1.75
Hainan Xiongxiu Mining Rutile 85	1.89
Hainan Xiongxiu Mining Rutile 89	1.94
Mitraco Rutile	1.99
Tronox Wonnerup Leucoxene	2.15
Hainan Wensheng Rutile 85	2.35
Suixi Jindi Mineral Rutile 85	2.36
Folkston Leucoxene	2.42
Keysbrook Leucoxene L88	2.50
CODEMIG Anatase	2.94
Siberia Leucoxene	3.30
KMML Leucoxene	(3.31)
Southern Ionics Leucoxene	3.60
IREL Leucoxene “Q” Grade	3.65
PT Karya Lisbeth Rutile 90	3.69
Keysbrook Leucoxene L70	4.02

6. Cr_2O_3 content

Name	Cr_2O_3 (wt.-%)
Siberia Leucoxene	< 0.01
Nordic Rutile	(0.01)
Cameroon Rutile	(0.02)
CODEMIG Anatase	< 0.03
Universal Rutile	0.03
Ratana Rutile	0.03
OMC Rutile	0.05
KMML Leucoxene	(0.06)
Sheffield HiTi	0.07
SQC Rutile	0.07
Hainan Xiongxiu Mining Rutile 85	0.07
Hainan Xiongxiu Mining Rutile 89	0.07
Hainan Xiongxiu Mining Rutile 91	0.08
Suixi Ruifeng Mining Rutile 85 (Russia)	0.08
BIMICO Rutile	0.08
Hung Thinh Rutile 85	0.08
Suixi Jindi Mineral Rutile 85	0.08
Southern Ionics Rutile Premium Grade	0.08
DQCL Rutile 95	0.09
Mitraco Rutile	0.09
Song Binh Rutile 87	0.09
Southern Ionics Rutile	0.09
Guangxi Liufeng Mining Rutile 90	0.09
Naicher Advanced Material Rutile 85	0.09
Naicher Advanced Material Rutile 90	0.09
BIOTAN Rutile	0.10
Folkston Rutile	0.10
Green Cove Springs Rutile	0.10
Chemours Residue	0.10
Jacksonville Rutile	0.10
Jesup HiTi	0.10
Namakwa Sands Rutile	0.10
Wanning Yiyuanfeng Mining Rutile 80	0.10
Kalbar Rutile	(0.1)
Southern Ionics Leucoxene	0.11
Hainan Wensheng Rutile 85	0.11
Jesup Rutile	0.11
DQCL Rutile 92	0.11
Naicher Advanced Material Rutile 92	0.11
Green Cove Springs Leucoxene	0.11
IREL Rutile „OR“ Grade	0.12
RBM Rutile Welding Grade	0.12
Southern Ionics Rutile 90	0.12

Name	Cr_2O_3 (wt.-%)
Tronox Brasil Rutilo	0.12
Moma Rutile	0.12
RBM Rutile Prime Grade	0.12
Namakwa Sands Leucoxene	0.12
Trimex Rutile Standard Grade	0.12
Vilnohirsk Rutile Standard Grade	0.12
Hainan Wensheng Rutile 95	0.12
Malawi Rutile	(0.012)
Eucla HiTi 90	0.12–0.13
Tronox Murray Basin Rutile	0.13
Folkston Leucoxene	0.13
Suixi Jindi Mineral Rutile 90	0.13
Keysbrook Leucoxene L70	0.14
Eneabba Rutile Premium Grade	0.14–0.16
Naicher Advanced Material Rutile 95	0.15
Hainan Wensheng Rutile 90	0.15
Capel Leucoxene	0.16
Cataby Rutile Premium Grade	0.16
Doral Leucoxene	0.16
Kwale Rutile	0.17
Suixi Jindi Mineral Rutile 95	0.17
RZM Rutile	0.17
Suixi Ruifeng Mining Rutile 95	0.17
Lanka Rutile	0.18
Tronox Australia Rutile Premium Grade	0.18
IREL Rutile “MK” Grade	0.19
Tronox Australia Leucoxene Standard Grade	0.19–0.28
Tronox Wonnerup Leucoxene	0.20
Suixi Ruifeng Mining Rutile 90	0.20
KMML Rutile	0.21
Senegal Rutile	0.21
Xiamen King Far East Rutile 95	0.21
IREL Rutile “Q” Grade	0.22
CRUZOR Rutile	0.22
SRL Rutile Standard Grade	0.22
SRL Rutile Industrial Grade	0.23
Keysbrook Leucoxene L88	0.27
IREL Leucoxene “Q” Grade	0.27
Wanning Yiyuanfeng Mining Rutile 90	0.29
Suixi Ruifeng Mining Rutile 85 (Senegal)	0.42
Senegal Leucoxene	0.53
PT Karya Lisbeth Rutile 90	7.23

7. V_2O_5 content

Name	V_2O_5 (wt.-%)
Siberia Leucoxene	< 0.01
CODEMIG Anatase	0.05
Cameroon Rutile	(0.06)
Universal Rutile	0.07
Mitraco Rutile	0.08
Green Cove Springs Leucoxene	0.09
Southern Ionics Leucoxene	0.09
Chemours Residue	0.11
Jesup Rutile	0.11
Jesup HiTi	0.11
OMC Rutile	0.11
Ratana Rutile	0.11
Suixi Jindi Mineral Rutile 85	0.12
Keysbrook Leucoxene L70	0.13
Keysbrook Leucoxene L88	0.13
Southern Ionics Rutile 90	0.13
Tronox Wonnerup Leucoxene	0.14
IREL Leucoxene “Q” Grade	0.14
Song Binh Rutile 87	0.16
SQC Rutile	0.16
Hainan Xiongxiu Mining Rutile 91	0.16
Hainan Xiongxiu Mining Rutile 89	0.16
Hainan Xiongxiu Mining Rutile 85	0.16
Naicher Advanced Material Rutile 90	0.17
Folkston Leucoxene	0.18
Sheffield HiTi	0.18
Southern Ionics Rutile	0.18
Doral Leucoxene	0.19
Capel Leucoxene	0.19
Suixi Ruifeng Mining Rutile 85 (Senegal)	0.19
DQCL Rutile 95	0.20
Suixi Ruifeng Mining Rutile 85 (Russia)	0.20
Hainan Wensheng Rutile 85	0.20
Senegal Leucoxene	0.21
Green Cove Springs Rutile	0.22
Southern Ionics Rutile Premium Grade	0.22
Guangxi Liufeng Mining Rutile 90	0.22
Namakwa Sands Leucoxene	0.23
Senegal Rutile	0.23
Tronox Brasil Rutilo	0.23
Eucla HiTi 90	0.23–0.26
Wanning Yiyuanfeng Mining Rutile 90	0.24
Wanning Yiyuanfeng Mining Rutile 80	0.24

Name	V_2O_5 (wt.-%)
Hung Thinh Rutile 85	0.24
PT Karya Lisbeth Rutile 90	0.24
BIMICO Rutile	0.25
Jacksonville Rutile	0.27
BIOTAN Rutile	0.27
Hainan Wensheng Rutile 90	0.27
Folkston Rutile	0.27
Suixi Jindi Mineral Rutile 90	0.28
KMML Leucoxene	(0.28)
Naicher Advanced Material Rutile 85	0.29
Suixi Ruifeng Mining Rutile 95	0.29
Namakwa Sands Rutile	0.30
Kalbar Rutile	(0.3)
RBM Rutile Welding Grade	0.32
Suixi Ruifeng Mining Rutile 90	0.32
Tronox Australia Leucoxene Standard Grade	0.32 – 0.36
Vilnohirsk Rutile Standard Grade	0.32 – 0.37
Naicher Advanced Material Rutile 92	0.33
Hainan Wensheng Rutile 95	0.33
DQCL Rutile 92	0.35
Tronox Australia Rutile Premium Grade	0.41
Moma Rutile	0.41
Nordic Rutile	(0.41)
RBM Rutile Prime Grade	0.42
IREL Rutile "Q" Grade	0.45
KMML Rutile	0.45
Eneabba Rutile Premium Grade	0.47 – 0.52
Naicher Advanced Material Rutile 95	0.48
VV Mineral Rutile	(0.48)
Cataby Rutile Premium Grade	0.49
Suixi Jindi Mineral Rutile 95	0.50
IREL Rutile "MK" Grade	0.51
Trimex Rutile Standard Grade	0.52
IREL Rutile „OR" Grade	0.55
Tronox Murray Basin Rutile	0.55
Kwale Rutile	0.55
Lanka Rutile	0.55
CRUZOR Rutile	0.56
RZM Rutile	0.57
SRL Rutile Industrial Grade	0.59
Xiamen King Far East Rutile 95	0.60
SRL Rutile Standard Grade	0.62
Malawi Rutile	(0.66)

8. P_2O_5 content

Name	P_2O_5 (wt.-%)
SQC Rutile	0.002
RZM Rutile	0.008
Nordic Rutile	(0.01)
Malawi Rutile	(0.01)
VV Mineral Rutile	(0.012)
Kwale Rutile	0.015
Naicher Advanced Material Rutile 95	0.015
SRL Rutile Standard Grade	0.016
Lanka Rutile	0.017
Eneabba Rutile Premium Grade	0.018–0.026
SRL Rutile Industrial Grade	0.019
Cameroon Rutile	(<0.02)
Suixi Jindi Mineral Rutile 95	0.021
Xiamen King Far East Rutile 95	0.024
CRUZOR Rutile	0.024
RBM Rutile Welding Grade	0.024
RBM Rutile Prime Grade	0.025
IREL Rutile “MK” Grade	0.026
Vilnohirsk Rutile Standard Grade	0.027–0.043
DQCL Rutile 92	0.034
IREL Rutile „OR“ Grade	0.036
Moma Rutile	0.036
Eucla HiTi 90	0.038–0.053
Southern Ionics Rutile Premium Grade	0.039
Tronox Murray Basin Rutile	0.039
Universal Rutile	0.039
KMML Rutile	0.041
Hainan Wensheng Rutile 95	0.043
BIOTAN Rutile	0.043
Trimex Rutile Standard Grade	0.043
Cataby Rutile Premium Grade	0.045
Suixi Ruifeng Mining Rutile 95	0.045
Suixi Ruifeng Mining Rutile 90	0.046
Naicher Advanced Material Rutile 92	0.047
BIMICO Rutile	0.049
Keysbrook Leucoxene L70	0.052
Song Binh Rutile 87	0.053
Tronox Brasil Rutilo	0.054
IREL Rutile “Q” Grade	0.055
Suixi Jindi Mineral Rutile 90	0.055
OMC Rutile	0.055
Senegal Rutile	0.057
DQCL Rutile 95	0.068

Name	P_2O_5 (wt.-%)
Tronox Wonnerup Leucoxene	0.068
Hung Thinh Rutile 85	0.072
Ratana Rutile	0.073
Guangxi Liufeng Mining Rutile 90	0.077
Suixi Ruifeng Mining Rutile 85 (Russia)	0.077
Tronox Australia Rutile Premium Grade	0.079
Jacksonville Rutile	0.08
Doral Leucoxene	0.081
Namakwa Sands Rutile	0.082
Capel Leucoxene	0.083
Southern Ionics Rutile	0.083
Hainan Xiongxiu Mining Rutile 89	0.088
Hainan Wensheng Rutile 90	0.091
Wanning Yiyuanfeng Mining Rutile 90	0.096
Hainan Xiongxiu Mining Rutile 91	0.098
Folkston Rutile	0.10
Mitraco Rutile	0.119
Hainan Wensheng Rutile 85	0.119
Hainan Xiongxiu Mining Rutile 85	0.124
Naicher Advanced Material Rutile 90	0.131
Tronox Australia Leucoxene Standard Grade	0.136 – 0.196
Suixi Jindi Mineral Rutile 85	0.139
Suixi Ruifeng Mining Rutile 85 (Senegal)	0.140
Senegal Leucoxene	0.141
Namakwa Sands Leucoxene	0.149
Siberia Leucoxene	0.150
Green Cove Springs Rutile	0.16
Jesup HiTi	0.165
Sheffield HiTi	0.167
PT Karya Lisbeth Rutile 90	0.169
Naicher Advanced Material Rutile 85	0.185
Southern Ionics Rutile 90	0.191
Jesup Rutile	0.220
Chemours Residue	0.230
Wanning Yiyuanfeng Mining Rutile 80	0.231
Green Cove Springs Leucoxene	0.244
Keysbrook Leucoxene L88	0.285
KMML Leucoxene	(0.35)
IREL Leucoxene “Q” Grade	0.484
Southern Ionics Leucoxene	0.592
Folkston Leucoxene	1.12
CODEMIG Anatase	6.789

9. Radioactivity (U+Th)

Name	U+Th (ppm)
Jacksonville Rutile	19
Nordic Rutile	(< 20)
Green Cove Springs Rutile	30
Malawi Rutile	(30)
Jesup Rutile	32
Southern Ionics Rutile Premium Grade	32
Southern Ionics Rutile	41
Chemours Residue	45
Jesup HiTi	51
RZM Rutile	55
Vilnohirsk Rutile Standard Grade	57 – 61
SRL Rutile Standard Grade	58
Southern Ionics Rutile 90	59
SRL Rutile Industrial Grade	59
Kwale Rutile	63
Tronox Murray Basin Rutile	68
Cataby Rutile Premium Grade	76
CRUZOR Rutile	77
Hainan Wensheng Rutile 95	79
RBM Rutile Prime Grade	83
Naicher Advanced Material Rutile 95	86
Lanka Rutile	92
Eneabba Rutile Premium Grade	93 – 130
Xiamen King Far East Rutile 95	94
RBM Rutile Welding Grade	98
Eucla HiTi 90	101 – 145
Folkston Rutile	107
KMML Rutile	110
Siberia Leucoxene	115
IREL Rutile “MK” Grade	116
Kalbar Rutile	(116)
Namakwa Sands Rutile	118
Suixi Ruifeng Mining Rutile 95	118
SQC Rutile	121
IREL Rutile “Q” Grade	124
Green Cove Springs Leucoxene	129
Universal Rutile	131
Tronox Australia Rutile Premium Grade	133
Senegal Rutile	133
Naicher Advanced Material Rutile 90	139
Suixi Jindi Mineral Rutile 95	154
Suixi Ruifeng Mining Rutile 90	168
Capel Leucoxene	169

Name	U+Th (ppm)
OMC Rutile	181
Namakwa Sands Leucoxene	186
Suixi Jindi Mineral Rutile 90	190
IREL Rutile „OR“ Grade	194
Tronox Australia Leucoxene Standard Grade	194 – 349
Keysbrook Leucoxene L70	207
Mitraco Rutile	209
VV Mineral Rutile	(214)
Song Binh Rutile 87	224
Hainan Wensheng Rutile 90	229
Suixi Ruifeng Mining Rutile 85 (Russia)	232
Suixi Ruifeng Mining Rutile 85 (Senegal)	243
Tronox Wonnerup Leucoxene	251
Hainan Wensheng Rutile 85	261
Suixi Jindi Mineral Rutile 85	288
Moma Rutile	289
Naicher Advanced Material Rutile 92	290
PT Karya Lisbeth Rutile 90	293
Trimex Rutile Standard Grade	293
Naicher Advanced Material Rutile 85	319
Hainan Xiongxiu Mining Rutile 89	320
Wanning Yiyuanfeng Mining Rutile 90	323
Senegal Leucoxene	345
Tronox Brasil Rutilo	351
Doral Leucoxene	376
DQCL Rutile 95	386
Sheffield HiTi	394
Guangxi Liufeng Mining Rutile 90	403
CODEMIG Anatase	425
Ratana Rutile	491
Keysbrook Leucoxene L88	496
Wanning Yiyuanfeng Mining Rutile 80	523
Hainan Xiongxiu Mining Rutile 85	564
BIMICO Rutile	590
Southern Ionics Leucoxene	667
DQCL Rutile 92	711
BIOTAN Rutile	731
IREL Leucoxene “Q” Grade	801
Hung Thinh Rutile 85	899
Hainan Xiongxiu Mining Rutile 91	1028
Folkston Leucoxene	1538

10. Purity (rutile-anatase-leucoxene content)

Name	Rutile + Leucoxene (%)
Capel Leucoxene	99.0
Jesup Rutile	98.7
Southern Ionics Rutile Premium Grade	98.6
Cataby Rutile Premium Grade	98.5
RZM Rutile	98.5
Eneabba Rutile Premium Grade	98.4
Southern Ionics Rutile	98.4
Tronox Wonnerup Leucoxene	98.0
IREL Rutile „OR“ Grade	97.4
Trimex Rutile Standard Grade	97.4
Kwale Rutile	97.3
Suixi Jindi Mineral Rutile 95	97.3
Jesup HiTi	97.1
Tronox Australia Rutile Premium Grade	97.0
Hainan Wensheng Rutile 95	97.0
Vilnohirsk Rutile Standard Grade	97.0–94.8
Tronox Murray Basin Rutile	96.9
SRL Rutile Industrial Grade	96.8
Tronox Australia Leucoxene Standard Grade	96.8–95.4
Naicher Advanced Material Rutile 95	96.7
Suixi Ruifeng Mining Rutile 95	96.6
Lanka Rutile	96.6
CRUZOR Rutile	96.4
Southern Ionics Rutile 90	96.4
Suixi Ruifeng Mining Rutile 90	96.2
RBM Rutile Prime Grade	96.1
Jacksonville Rutile	96.0
Keysbrook Leucoxene L88	96.0
SQC Rutile	95.9
KMML Rutile	95.8
SRL Rutile Standard Grade	95.8
Senegal Rutile	95.8
Doral Leucoxene	95.4
IREL Rutile “Q” Grade	95.1
IREL Rutile “MK” Grade	95.0
Namakwa Sands Rutile	94.9
Eucla HiTi 90	94.9–94.4
RBM Rutile Welding Grade	94.8
Xiamen King Far East Rutile 95	94.6
DQCL Rutile 92	94.2
BIMICO Rutile	94.2
Tronox Brasil Rutilo	93.6
BIOTAN Rutile	93.5

Name	Rutile + Leucoxene (%)
Green Cove Springs Rutile	93.3
Namakwa Sands Leucoxene	93.1
Senegal Leucoxene	92.4
Naicher Advanced Material Rutile 92	92.0
Moma Rutile	92.0
Naicher Advanced Material Rutile 90	91.7
Hainan Wensheng Rutile 90	91.5
Universal Rutile	91.0
Suixi Ruifeng Mining Rutile 85 (Russia)	91.0
Wanning Yiyuanfeng Mining Rutile 90	90.8
Hainan Xiongxiu Mining Rutile 91	90.4
Suixi Jindi Mineral Rutile 90	90.4
Ratana Rutile	90.3
Suixi Ruifeng Mining Rutile 85 (Senegal)	90.1
OMC Rutile	89.4
Hainan Wensheng Rutile 85	88.8
Hainan Xiongxiu Mining Rutile 89	88.5
Sheffield HiTi	88.3
Guangxi Liufeng Mining Rutile 90	87.7
DQCL Rutile 95	86.9
Hainan Xiongxiu Mining Rutile 85	86.9
Song Binh Rutile 87	86.3
Naicher Advanced Material Rutile 85	83.2
IREL Leucoxene “Q” Grade	83.0
Wanning Yiyuanfeng Mining Rutile 80	82.5
Folkston Rutile	78.9
Suixi Jindi Mineral Rutile 85	78.0
Mitraco Rutile	77.6
Chemours Residue	74.8
Southern Ionics Leucoxene	70.4
CODEMIG Anatase	70.0
Keysbrook Leucoxene L70	60.8
PT Lisbeth Rutile 90	57.6
Siberia Leucoxene	33.4
Green Cove Springs Leucoxene	31.9
Folkston Leucoxene	17.7

11. Quartz content

Name	Quartz (%)
Eneabba Rutile Premium Grade	0.0
Chemours Residue	0.0
CODEMIG Anatase	0.0
Folkston Rutile	0.0
Green Cove Springs Leucoxene	0.0
Green Cove Springs Rutile	0.0
KMML Rutile	0.0
Jacksonville Rutile	0.0
Xiamen King Far East Supply Rutile 95	0.0
Folkston Leucoxene	traces
Capel Leucoxene	traces
IREL Rutile “Q” Grade	0.1
IREL Rutile “MK” Grade	0.1
IREL Rutile „OR“ Grade	0.1
Trimex Rutile Standard Grade	0.1
Jesup Rutile	0.1
RBM Rutile Prime Grade	0.1
Moma Rutile	0.1
Kwale Rutile	0.1
Suixi Jindi Mineral Rutile 95	0.1
Keysbrook Leucoxene L88	0.1
Tronox Wonnerup Leucoxene	0.1
Naicher Advanced Material Rutile 90	0.1
Cataby Rutile Premium Grade	0.2
Suixi Ruifeng Mining Rutile 90	0.2
Lanka Rutile	0.2
Senegal Rutile	0.2
Southern Ionics Rutile	0.2
Southern Ionics Rutile 90	0.2
Tronox Brasil Rutilo	0.2
RZM Rutile	0.2
Tronox Australia Leucoxene Standard Grade	0.2–0.7
Suixi Ruifeng Mining Rutile 95	0.3
IREL Leucoxene “Q” Grade	0.3
Wanning Yiyuanfeng Mining Rutile 90	0.3
Southern Ionics Rutile Premium Grade	0.3
Keysbrook Leucoxene L70	0.3
Tronox Australia Rutile Premium Grade	0.3
Eucla HiTi 90	0.3–0.4
Suixi Ruifeng Mining Rutile 85 (Russia)	0.4
Universal Rutile	0.4
Doral Leucoxene	0.4
Senegal Leucoxene	0.4

Name	Quartz (%)
SQC Rutile	0.5
DQCL Rutile 92	0.5
CRUZOR Rutile	0.6
SRL Rutile Standard Grade	0.6
Vilnohirsk Rutile Standard Grade	0.6
PT Lisbeth Rutile 90	0.7
Suixi Ruifeng Mining Rutile 85 (Senegal)	0.7
Hainan Wensheng Rutile 95	0.7
Jesup HiTi	0.8
RBM Rutile Welding Grade	0.8
SRL Rutile Industrial Grade	0.8
BIOTAN Rutile	0.9
Namakwa Sands Leucoxene	0.9
Ratana Rutile	0.9
Namakwa Sands Rutile	0.9
Sheffield HiTi	0.9
OMC Rutile	1.0
Tronox Murray Basin Rutile	1.0
Hainan Xiongxiu Mining Rutile 91	1.0
Naicher Advanced Material Rutile 95	1.0
Naicher Advanced Material Rutile 92	1.0
Suixi Jindi Mineral Rutile 90	1.0
BIMICO Rutile	1.1
Wanning Yiyuanfeng Mining Rutile 80	1.1
DQCL Rutile 95	1.1
Hainan Xiongxiu Mining Rutile 89	1.2
Hainan Wensheng Rutile 90	1.5
Song Binh Rutile 87	1.6
Southern Ionics Leucoxene	1.6
Hainan Wensheng Rutile 85	1.6
Guangxi Liufeng Mining Rutile 90	1.8
Hainan Xiongxiu Mining Rutile 85	2.0
Naicher Advanced Material Rutile 85	3.3
Mitraco Rutile	3.8
Suixi Jindi Mineral Rutile 85	3.9
Siberia Leucoxene	39.1

12. Grain size (mean)

Name	Grain size (mean) (µm)
CODEMIG Anatase	541.8
Ratana Rutile	293.7
OMC Rutile	261.9
DQCL Rutile 92	250.5
IREL Leucoxene “Q” Grade	249.1
Siberia Leucoxene	221.9
SRL Rutile Standard Grade	212.8
BIOTAN Rutile	204.3
BIMICO Rutile	197.3
Tronox Australia Leucoxene Standard Grade	195.2–264.2
Universal Rutile	193.1
Cataby Rutile Premium Grade	189.8
Moma Rutile	185.8
Xiamen King Far East Supply Rutile 95	185.2
Tronox Australia Rutile Premium Grade	181.3
IREL Rutile „OR“ Grade	180.9
IREL Rutile “MK” Grade	178.8
Suixi Ruifeng Mining Rutile 90	171.2
Trimex Rutile Standard Grade	169.9
KMML Rutile	169.2
IREL Rutile “Q” Grade	168.7
RZM Rutile	167.3
Eneabba Rutile Premium Grade	165.3
Jesup HiTi	155.5
Chemours Residue	152.6
Jesup Rutile	152.2
Suixi Jindi Mineral Rutile 90	151.9
Tronox Brasil Rutilo	151.1
Tronox Wonnerup Leucoxene	148.5
Naicher Advanced Material Rutile 95	148.3
SQC Rutile	148.1
Doral Leucoxene	146.3
Mitraco Rutile	145.0
Guangxi Liufeng Mining Rutile 90	143.4
Keysbrook Leucoxene L70	142.5
Tronox Murray Basin Rutile	140.9
Lanka Rutile	138.4
PT Lisbeth Rutile 90	137.6
Suixi Jindi Mineral Rutile 95	136.0
Keysbrook Leucoxene L88	134.6
Hainan Wensheng Rutile 90	133.6
Song Binh Rutile 87	130.9
Suixi Jindi Mineral Rutile 85	130.7

Name	Grain size (mean) (μm)
DQCL Rutile 95	129.6
Vilnohirsk Rutile Standard Grade	128.1 – 131.0
Hainan Wensheng Rutile 95	126.8
Naicher Advanced Material Rutile 92	126.3
RBM Rutile Welding Grade	125.6
Naicher Advanced Material Rutile 90	125.5
RBM Rutile Prime Grade	124.7
Hainan Wensheng Rutile 85	123.3
Kwale Rutile	122.0
Senegal Leucoxene	120.0
Green Cove Springs Leucoxene	119.8
Naicher Advanced Material Rutile 85	118.7
CRUZOR Rutile	116.7
Namakwa Sands Rutile	113.1
Suixi Ruifeng Mining Rutile 95	110.2
Southern Ionics Rutile Premium Grade	109.5
Wanning Yiyuanfeng Mining Rutile 80	109.0
Jacksonville Rutile	108.2
Wanning Yiyuanfeng Mining Rutile 80	108.0
Senegal Rutile	107.0
Suixi Ruifeng Mining Rutile 85 (Senegal)	106.9
Namakwa Sands Leucoxene	106.6
Hung Thinh Rutile 85	106.5
Green Cove Springs Rutile	106.1
Southern Ionics Rutile	105.1
Eucla HiTi 90	102.4 – 103.6
Southern Ionics Leucoxene	101.0
Southern Ionics Rutile 90	100.9
Hainan Xiongxiu Mining Rutile 89	100.7
Hainan Xiongxiu Mining Rutile 85	99.8
Hainan Xiongxiu Mining Rutile 91	97.1
Folkston Rutile	95.5
SRL Rutile Industrial Grade	88.4
Folkston Leucoxene	87.1
Sheffield HiTi	80.5
Suixi Ruifeng Mining Rutile 85 (Russia)	71.0

Appendix C

Specifications of commercial leucoxene, rutile, and HiTi concentrates

Methodology

Incoming HM concentrate samples were were split for chemical, mineralogical and grain size analyses.

Chemical analysis

Sample preparation of fused beads:

- A 1000 mg finely ground sample was used to determine the loss on ignition by heating to a final temperature of 1000 °C using a temperature-controlled muffle furnace.
- A 200 mg separate sub-sample was mixed with 2500 mg Lithiummetaborate and 2415 mg Lithiumtetraborate, and then fused to a glass bead using PtAu-95/5 lab ware.
- Prior to pouring the liquid melt into a 32 mm diameter cast dish, a small amount (~5 mg) of Iodinepentoxide was added as a releasing agent.
- The spectrometric analysis was performed using a PANalytical AXIOS wavelength-dispersive X-ray-spectrometer equipped with an Rh-end-window X-ray tube operated at 2.7 kW power using a classical, standard based, calibration.
- A set of artificial standard compositions made of SARM-62 (zircon, certified reference material) and SpS (glass-sand, certified reference material) were used for calibration.
- Cr, Th, U and other minor element values were determined by ICP-QMS. The determinations were made on a Perkin Elmer Sciex ELAN 5000 A with an autosampler. Data capture was performed by Sciex software loaded onto a PC connected to the QMS system.

Mineralogical analysis

The heavy mineral concentrates were fixed with the colourless two-component epoxy resin Araldite® 2020 (XW 396/XW 397, density 1.1 kg/m³, dynamic viscosity 150 mPa·s). The section surfaces were cut and polished. The embedded samples were inspected using an Environmental Scanning Electron Microscope (ESEM) of the type FEI Quanta 650F equipped with two EDX-detectors (XFlash Detector 5030, Silicon Drift Detector; Bruker Nano) for semi-quantitative element analysis without standardization.

Using the Mineral Liberation Analyzer (MLA) software developed by JKMRC/FEI, backscattered electron (BSE) images were combined with EDX spectra. A series of BSE images, including an X-ray spectrum for each mineral particle, was collected. The offline processing routine compares the measured mineral spectra with known mineral standards to determine the mineral identity for each grain. It should be noted that this technique quantifies the content of a mineral by using the area it occupies in the image, and not its mass percentage.

Grain size analysis

The grain size analysis of the dried concentrate samples was performed using an optically based instrument (CAMSIZER®, Retsch). The instrument employs two digital cameras (CCD) to record falling particles (dynamic image analysis) in the grain size of 0.03–30.0 mm. The instrument images a falling curtain of sediment and determines the grain size of each particle in the image using two different cameras. Typically images of a few million grains were processed for each sample.

Grain size frequency weights in defined classes were recorded and granulometric statistical data, including mean and median, were computed automatically.

Name: **BIMICO Rutile 87 %**
Deposit: Degi Mine, Cát Khánh Village, Phu Cat District, Bình Định Province, Vietnam
Producer: Binh Dinh Minerals Company (BIMICO)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			BIMICO Analysis	BGR Analysis
TiO_2	> 87			92.72
$Zr(Hf)O_2$				0.44
ZrO_2				0.43
SiO_2				2.17
Al_2O_3				1.20
Fe_2O_3				1.16
Cr_2O_3				0.08
V_2O_5				0.25
Nb_2O_5				0.61
P_2O_5				0.049
S				0.01
CaO				0.079
MgO				0.04
MnO				0.025
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.68
U				87 ppm
Th				503 ppm

Sample (BGR Analysis): 10 ppm As, 28 ppm Pb, 229 ppm Sn, 435 ppm Ta, 695 ppm W, 94 ppm Y, 21 ppm Zn

Mineralogical composition (BGR Analysis): 87.6 % rutile, 6.6 % leucoxene, 1.3 % garnet/tourmaline/aluminosilicates, 1.1 % quartz, 0.7 % zircon, 0.4 % ilmenite, 0.1 % monazite, 2.2 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			BIMICO Analysis	BGR Analysis
> 500				0.0
420				0.3
355				1.0
300				3.8
250				11.8
212				19.3
180				21.8
150				20.2
125				12.6
106				5.7
90				2.4
75				0.8
63				0.2
53				0.1
45				0.0
< 45				0.0
Mean (µm)				197.3
D50 (µm)				181.9

Name: **BIOTAN Rutile 87 %**
Deposit: My Thanh Village, Phú Mỹ District, Bình Định Province, Vietnam
Producer: Biotan Mineral Joint Stock Company (BIOTAN)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			BIOTAN Analysis	BGR Analysis
TiO_2	> 87			92.56
$Zr(Hf)O_2$				1.03
ZrO_2				1.00
SiO_2				2.15
Al_2O_3				1.06
Fe_2O_3				0.99
Cr_2O_3				0.10
V_2O_5				0.27
Nb_2O_5				0.63
P_2O_5				0.043
S				< 0.01
CaO				0.076
MgO				0.02
MnO				0.023
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.56
U				114 ppm
Th				617 ppm

Sample (BGR Analysis): 26 ppm Pb, 226 ppm Sn, 437 ppm Ta, 695 ppm W, 107 ppm Y, 19 ppm Zn

Mineralogical composition (BGR Analysis): 89.0 % rutile, 4.5 % leucoxene, 1.2 % garnet/tourmaline/aluminosilicates, 1.0 % zircon, 0.9 % quartz, 0.5 % ilmenite, 0.1 % monazite, 2.8 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			BIOTAN Analysis	BGR Analysis
> 500				0.0
420				0.3
355				1.2
300				4.5
250				12.9
212				21.2
180				23.2
150				19.9
125				10.5
106				4.2
90				1.5
75				0.5
63				0.1
53				0.0
45				0.0
< 45				0.0
Mean (µm)				204.3
D50 (µm)				188.3

Name: **BMC Rutile**
Deposit: Kuttam, Tamil Nadu, India
Producer: Beach Minerals Company India Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			BMC Analysis	BGR Analysis
TiO_2		98.37		
$Zr(Hf)O_2$				
ZrO_2				
SiO_2		0.03		
Al_2O_3		0.03		
Fe_2O_3				
Cr_2O_3		0.08		
V_2O_5		0.45		
Nb_2O_5				
P				
S				
CaO		0.02		
MgO		0.07		
MnO		0.03		
Moisture (@ 105 °C)				
LOI (@ 950 °C)				
U				
Th				

Typical: 0.06 % FeO, 0.09 % ZnO, 0.07 % BaO

Grain size distribution µm	Guaranteed	Typical	Sample	
			BMC Analysis	BGR Analysis
> 500				
420				
355				
300				
250				
212				
180				
150				
125				
106				
90				
75				
63				
53				
45				
< 45				
Mean (µm)				
D50 (µm)				

Name: **Cameroon Rutile**
Deposit: Akonolinga, Cameroon
Producer: Cameroon Rutile Ltd. / BRGM

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			BRGM Analysis	BGR Analysis
TiO_2			95.2	
$Zr(Hf)O_2$				
ZrO_2			0.03	
SiO_2			2.13	
Al_2O_3			0.44	
Fe_2O_3			0.23	
Cr_2O_3			0.02	
V_2O_5			0.06	
Nb_2O_5			0.02	
P_2O_5			< 0.02	
S			0.03	
CaO			0.03	
MgO			0.026	
MnO			< 0.05	
Moisture (@ 105 °C)				
LOI (@ 950 °C)			0.48	
U				
Th				

Sample: 0.30 % C_{total}, < 20 ppm As, < 10 ppm Sn

Grain size distribution µm	Guaranteed	Typical	Sample	
			BRGM Analysis	BGR Analysis
> 500				
420				
355				
300				
250				
212				
180				
150				
125				
106				
90				
75				
63				
53				
45				
< 45				
Mean (µm)				
D50 (µm)				

Name: **Capel HyTi 70 (Historic data)**
Deposit: Yoganup, Western Australia, Australia
Producer: Westralian Sands Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Westralian Analysis	BGR Analysis
TiO_2	> 70.0	70.0–72.0		
$Zr(Hf)O_2$				
ZrO_2		0.6–0.8		
SiO_2		1.0–2.0		
Al_2O_3		2.0–3.0		
Fe_2O_3		18.0–19.0		
Cr_2O_3		0.10–0.14		
V_2O_5		0.19–0.21		
Nb_2O_5		0.25–0.30		
P		0.07–0.10		
S		0.03–0.05		
CaO		0.03–0.05		
MgO				
MnO		0.30–0.40		
Moisture (@ 105 °C)				
LOI (@ 950 °C)		0.60–0.80		
U				
Th				

Typical: 0.7–1.0 % FeO, 0.01–0.03 % Y_2O_3

<table>
<tr><th rowspan="2">Grain size distribution µm</th><th rowspan="2">Guaranteed</th><th rowspan="2">Typical</th><th colspan="2">Sample</th></tr>
<tr><th>Westralian Analysis</th><th>BGR Analysis</th></tr>
<tr><td>> 500</td><td></td><td rowspan="5">0.5</td><td></td><td></td></tr>
<tr><td>420</td><td></td><td></td><td></td></tr>
<tr><td>355</td><td></td><td></td><td></td></tr>
<tr><td>300</td><td></td><td></td><td></td></tr>
<tr><td>250</td><td></td><td></td><td></td></tr>
<tr><td>212</td><td></td><td>1.5</td><td></td><td></td></tr>
<tr><td>180</td><td></td><td rowspan="2">39.3</td><td></td><td></td></tr>
<tr><td>150</td><td></td><td></td><td></td></tr>
<tr><td>125</td><td></td><td>26.3</td><td></td><td></td></tr>
<tr><td>106</td><td></td><td>20.3</td><td></td><td></td></tr>
<tr><td>90</td><td></td><td rowspan="2">11.3</td><td></td><td></td></tr>
<tr><td>75</td><td></td><td></td><td></td></tr>
<tr><td>63</td><td></td><td rowspan="4">0.8</td><td></td><td></td></tr>
<tr><td>53</td><td></td><td></td><td></td></tr>
<tr><td>45</td><td></td><td></td><td></td></tr>
<tr><td>< 45</td><td></td><td></td><td></td></tr>
<tr><td>Mean (µm)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>D50 (µm)</td><td></td><td></td><td></td><td></td></tr>
</table>

Name: **Capel HyTi 72 (Historic data)**
Deposit: Yoganup, Western Australia, Australia
Producer: Westralian Sands Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Westralian Analysis	BGR Analysis
TiO_2	> 72.0	73.0–75.0		
$Zr(Hf)O_2$				
ZrO_2		0.3–0.8		
SiO_2		1.0–2.0		
Al_2O_3		1.5–2.5		
Fe_2O_3		17.0–20.0		
Cr_2O_3		0.10–0.14		
V_2O_5		0.19–0.21		
Nb_2O_5		0.25–0.30		
P		0.07–0.10		
S		0.03–0.05		
CaO		0.03–0.05		
MgO				
MnO		0.30–0.40		
Moisture (@ 105 °C)				
LOI (@ 950 °C)		0.6–1.0		
U				
Th				

Typical: 1.0–2.0 % FeO, 0.01–0.03 % Y_2O_3

Grain size distribution µm	Guaranteed	Typical	Sample	
			Westralian Analysis	BGR Analysis
> 500		0.1		
420				
355				
300				
250				
212		0.6		
180		4.2		
150		24.7		
125		21.2		
106		28.7		
90		18.7		
75				
63		1.8		
53				
45				
< 45				
Mean (µm)				
D50 (µm)				

Name: **Capel HyTi 91 (Historic data)**
Deposit: Yoganup, Western Australia, Australia
Producer: Westralian Sands Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Westralian Analysis	BGR Analysis
TiO_2	> 91.0	91.0–92.0		
$Zr(Hf)O_2$				
ZrO_2		1.0–1.8		
SiO_2		1.1–1.5		
Al_2O_3		0.6–1.1		
Fe_2O_3		2.0–3.5		
Cr_2O_3		0.11–0.13		
V_2O_5		0.30–0.35		
Nb_2O_5		0.35–0.40		
P		0.04–0.05		
S		0.02–0.03		
CaO		0.02–0.03		
MgO				
MnO		0.09–0.12		
Moisture (@ 105 °C)				
LOI (@ 950 °C)		0.2–0.3		
U				
Th				

Typical: 1.0–2.0 % FeO, < 0.01–0.02 % Y_2O_3

Grain size distribution µm	Guaranteed	Typical	Sample	
			Westralian Analysis	BGR Analysis
> 500		2.3		
420				
355				
300				
250				
212		6.1		
180		14.9		
150		34.7		
125		19.1		
106		14.7		
90		7.7		
75				
63		0.5		
53				
45				
< 45				
Mean (µm)				
D50 (µm)				

Name: **Capel Leucoxene (Historic sample)**
Deposit: Capel, Western Australia, Australia
Producer: Renison Goldfields Consolidated (RGC)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			RGC Analysis	BGR Analysis
TiO_2				89.40
$Zr(Hf)O_2$				1.07
ZrO_2				1.05
SiO_2				0.96
Al_2O_3				1.64
Fe_2O_3				4.01
Cr_2O_3				0.16
V_2O_5				0.19
Nb_2O_5				0.35
P_2O_5				0.083
S				0.01
CaO				0.113
MgO				0.03
MnO				0.045
Moisture (@ 105 °C)				
LOI (@ 950 °C)				1.62
U				29 ppm
Th				140 ppm

Sample (BGR Analysis): 62 ppm As, 30 ppm Cu, 122 ppm Mo, 134 ppm Pb, 188 ppm Sn, 172 ppm Ta, 164 ppm W, 17 ppm Zn

Mineralogical composition (BGR Analysis): 70.4 % leucoxene, 28.6 % rutile, 1.0 % zircon, traces of quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			RGC Analysis	BGR Analysis
> 500				
420				
355				
300				
250				
212				
180				
150				
125				
106				
90				
75				
63				
53				
45				
< 45				
Mean (µm)				
D50 (µm)				

Name: **Cataby Rutile Premium Grade**
Deposit: Cataby, Western Australia, Australia
Producer: Iluka Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Iluka Analysis	BGR Analysis
TiO_2			96.0	95.91
$Zr(Hf)O_2$				0.75
ZrO_2			0.73	0.73
SiO_2			0.58	0.57
Al_2O_3			0.31	0.37
Fe_2O_3			0.75	0.72
Cr_2O_3			0.16	0.16
V_2O_5			0.53	0.49
Nb_2O_5			0.33	0.32
P_2O_5			0.06	0.045
S			< 0.01	0.01
CaO			0.01	0.058
MgO			< 0.01	< 0.01
MnO				0.005
Moisture (@ 105 °C)			0.05	
LOI (@ 950 °C)				0.42
U			36 ppm	34 ppm
Th			33 ppm	42 ppm

Sample (Iluka Analysis): 177 ppm Sn

Sample (BGR Analysis): 28 ppm As, 16 ppm Cu, 81 ppm Mo, 147 ppm Pb, 111 ppm Sn, 170 ppm Ta, 224 ppm W, 11 ppm Zn
Mineralogical composition (BGR Analysis): 94.8 % rutile, 3.7 % leucoxene, 0.4 % zircon, 0.2 % quartz, 0.1 % garnet/tourmaline/aluminosilicates, 0.8 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Iluka Analysis	BGR Analysis
> 500			1.2	0.0
420				0.0
355				0.5
300				2.2
250			6.5	8.6
212			17.8	17.2
180			21.3	24.6
150			37.2	25.9
125			11.0	14.0
106			4.0	4.8
90			0.7	1.5
75			0.2	0.5
63			0.0	0.1
53				0.0
45				0.0
< 45				0.0
Mean (µm)				189.8
D50 (µm)			177	175.1

Name: **Chemours Residue**
Deposit: Maxville/Trail Ridge, Florida, USA
Producer: The Chemours Company FC, LLC

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Chemours Analysis	BGR Analysis
TiO_2			82.08	81.54
$Zr(Hf)O_2$				0.21
ZrO_2			0.23	0.21
SiO_2			0.31	0.27
Al_2O_3			0.87	0.96
Fe_2O_3			12.98	13.09
Cr_2O_3			0.10	0.10
V_2O_5			0.11	0.11
Nb_2O_5			0.27	0.26
P_2O_5			0.23	0.230
S			0.086	0.02
CaO			0.03	0.079
MgO			0.08	0.08
MnO			0.42	0.448
Moisture (@ 105 °C)			0.51	
LOI (@ 950 °C)				2.34
U			19 ppm	< 11 ppm
Th			10 ppm	34 ppm

Sample (Chemours Analysis): 27 ppm As, 44 ppm Ce, 51 ppm Co, 25 ppm Cu, 70 ppm La, 92 ppm Mo, 18 ppm Nd, 241 ppm Pb, 69 ppm Zn
Sample (BGR Analysis): 23 ppm As, 23 ppm Cu, 78 ppm Mo, 214 ppm Pb, 231 ppm Sn, 173 ppm Ta, 125 ppm W, 77 ppm Zn

Typical mineralogical composition: 30–50 % leucoxene, 20–30 % rutile, 0.1–1 % quartz Mineralogical composition (BGR Analysis): 47.3 % rutile, 27.5 % leucoxene, 24.6 % ilmenite, 0.2 % zircon, 0.4 % others/ unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Chemours Analysis	BGR Analysis
> 500			0.04	0.0
420				0.1
355			0.38	0.0
300				0.6
250			10.49	3.0
212				7.6
180			40.94	14.2
150				22.4
125			36.30	22.1
106				15.1
90			11.06	8.6
75				4.2
63			0.79	1.4
53				0.5
45			0.00	0.1
< 45			0.00	0.1
Mean (µm)				152.6
D50 (µm)			152	142.8

Name: **CODEMIG Anatase**
Deposit: Minais Gerais, Brazil
Producer: Companhia de Desenvolvimento Econômico de Minas Gerais

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			CODEMIG Analysis	BGR Analysis
TiO_2				58.09
$Zr(Hf)O_2$				0.42
ZrO_2				0.41
SiO_2				9.17
Al_2O_3				2.94
Fe_2O_3				8.74
Cr_2O_3				< 0.03
V_2O_5				0.05
Nb_2O_5				0.66
P_2O_5				6.789
S				0.01
CaO				4.864
MgO				0.11
MnO				0.361
Moisture (@ 105 °C)				
LOI (@ 950 °C)				4.84
U				117 ppm
Th				308 ppm

Sample (BGR Analysis): 5 ppm Ag, 17 ppm As, 1776 ppm Ba, 8450 ppm Ce, 51 ppm Co, 42 ppm Cu, 4244 ppm La, 19 ppm Mo, 2884 ppm Nd, 28 ppm Ni, 17 ppm Pb, 934 ppm Pr, 629 ppm Sm, 7 ppm Sn, 2240 ppm Sr, 260 ppm Ta, 26 ppm W, 409 ppm Y, 70 ppm Zn

Mineralogical composition (BGR Analysis): 65.2 % leucoxene, 7.6 % quartz, 6.1 % apatite, 4.8 % anatase, 4.2 % Fe-oxy-hydroxides, 3.9 % garnet/tourmaline/aluminosilicates, 2.4 % ilmenite, 0.2 % monazite, 0.1 % sphene, 5.5 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			CODEMIG Analysis	DERA Analysis
> 500				53.1
420				11.0
355				9.2
300				7.2
250				5.2
212				3.5
180				2.7
150				2.4
125				2.0
106				1.4
90				1.1
75				0.7
63				0.3
53				0.1
45				0.1
< 45				0.0
Mean (µm)				541.8
D50 (µm)				480.1

Name: **CRUZOR Rutile**
Deposit: Ibis Ore Body, North Stradbroke Island, Queensland, Australia
Producer: Sibelco Australia and New Zealand

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Sibelco Analysis	BGR Analysis*
TiO_2		95.5		94.95
$Zr(Hf)O_2$				0.85
ZrO_2		0.90		0.83
SiO_2		1.10		1.24
Al_2O_3		0.40		0.52
Fe_2O_3		0.70		0.63
Cr_2O_3		0.25		0.22
V_2O_5		0.60		0.56
Nb_2O_5		0.40		0.35
P_2O_5				0.024
S				0.01
CaO				0.057
MgO				0.04
MnO				0.014
Moisture (@ 105 °C)				
LOI (@ 950 °C)		~0.20		0.32
U		~50 ppm		49 ppm
Th		~20 ppm		28 ppm

* Historic Sample (BGR Analysis): 8 ppm As, 36 ppm Cu, 39 ppm Mo, 187 ppm Sn, 188 ppm Ta, 285 ppm W

Typical mineralogical composition: 82 % rutile, 17 % leucoxene, 1 % zircon
Mineralogical composition (BGR Analysis): 93.2 % rutile, 3.2 % leucoxene, 0.9 % zircon, 0.6 % quartz, 0.3 % ilmenite, 0.1 % garnet/tourmaline/aluminosilicates, 1.7 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Sibelco Analysis	BGR Analysis
> 420				0.0
355				
300				
250				0.1
212				0.3
180				2.1
150				9.8
125				24.4
106				29.6
90				21.3
75				9.6
63				2.2
53				0.5
45				0.1
< 45				0.0
Mean (µm)				116.7
D50 (µm)				113.3

Name: **DEMGOK Rutile**
Deposit: Volchansk, Dniepropetrovsk region, Ukraine
Producer: Demurinskyi GZK LLC

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			DEMGOK Analysis	BGR Analysis
TiO_2		94–96		
$Zr(Hf)O_2$				
ZrO_2		0.5–0.6		
SiO_2		0.9–1.28		
Al_2O_3		0.37–0.5		
Fe_2O_3		1.11–1.9		
Cr_2O_3				
V_2O_5				
Nb_2O_5				
P_2O_5	< 0.07			
S	< 0.02			
CaO				
MgO				
MnO				
Moisture (@ 105 °C)	< 0.1			
LOI (@ 950 °C)				
U				
Th				

Grain size distribution µm	Guaranteed	Typical	Sample	
			DEMGOK Analysis	BGR Analysis
> 420				
355		0		
300				
250		0		
212				
180		0.6		
150		45.9		
125				
106				
90		53.2		
75				
63				
53				
45		0.1		
< 45				
Mean (µm)				
D50 (µm)				

Name: **Doral Leucoxene**
Deposit: Yoongarillup, Western Australia, Australia
Producer: Doral Mineral Sands Pty Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Doral Analysis	BGR Analysis
TiO_2				87.92
$Zr(Hf)O_2$				1.82
ZrO_2				1.79
SiO_2				1.95
Al_2O_3				1.62
Fe_2O_3				3.79
Cr_2O_3				0.16
V_2O_5				0.19
Nb_2O_5				0.30
P_2O_5				0.081
S				0.01
CaO				0.098
MgO				0.02
MnO				0.027
Moisture (@ 105 °C)				
LOI (@ 950 °C)				1.58
U		50 ppm		37 ppm
Th		360 ppm		339 ppm

Sample (BGR Analysis): 58 ppm As, 282 ppm Ce, 77 ppm Mo, 170 ppm Pb, 459 ppm Sn, 163 ppm Ta, 138 ppm W, 14 ppm Zn

Typical mineralogical composition: 95 % rutile/leucoxene, 3 % zircon, 0 % ilmenite, < 0.1 % quartz
Mineralogical composition (BGR Analysis): 48.2 % leucoxene, 47.2 % rutile, 2.3 % zircon, 0.5 % ilmenite, 0.5 % quartz, 0.3 % garnet/tourmaline/aluminosilicates, 0.2 % staurolite, 0.8 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Doral Analysis	BGR Analysis
> 420				0.0
355				0.1
300				0.6
250				2.2
212				5.8
180				12.1
150				21.7
125				23.7
106				16.1
90				9.4
75				5.1
63				2.0
53				0.8
45				0.3
< 45				0.1
Mean (µm)				146.3
D50 (µm)				137.5

Name: **DQCL Rutile 92 %**
Deposit: Chu Lai Airport Zone, Tam Nghia Village, Nui Than District, Quảng Nam Province, Vietnam
Producer: Dat Quang Chu Lai Minerals Joint Stock Company (DQCL)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			DQCL Analysis	BGR Analysis
TiO_2				92.42
$Zr(Hf)O_2$				2.07
ZrO_2				2.02
SiO_2				1.93
Al_2O_3				0.66
Fe_2O_3				0.74
Cr_2O_3				0.11
V_2O_5				0.35
Nb_2O_5				0.88
P_2O_5				0.034
S				0.01
CaO				0.067
MgO				< 0.01
MnO				0.014
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.44
U				191 ppm
Th				520 ppm

Sample (BGR Analysis): 10 ppm As, 25 ppm Mo, 193 ppm Sn, 477 ppm Ta, 803 ppm W, 127 ppm Y

Mineralogical composition (BGR Analysis): 90.2 % rutile, 4.0 % leucoxene, 2.5 % zircon, 0.6 % garnet/tourmaline/aluminosilicates, 0.5 % quartz, 0.2 % ilmenite, 0.1 % xenotime, 1.9 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			DQCL Analysis	BGR Analysis
> 500				0.2
420				1.5
355				5.2
300				12.7
250				24.4
212				25.5
180				18.0
150				9.1
125				2.7
106				0.6
90				0.1
75				0.0
63				0.0
53				0.0
45				0.0
< 45				0.0
Mean (µm)				250.5
D50 (µm)				227.7

Name: **DQCL Rutile 95 %**
Deposit: Chu Lai Airport Zone, Tam Nghia Village, Nui Than District, Quảng Nam Province, Vietnam
Producer: Dat Quang Chu Lai Minerals Joint Stock Company (DQCL)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			DQCL Analysis	BGR Analysis
TiO_2				88.13
$Zr(Hf)O_2$				2.16
ZrO_2				2.12
SiO_2				3.30
Al_2O_3				1.27
Fe_2O_3				1.27
Cr_2O_3				0.09
V_2O_5				0.20
Nb_2O_5				0.58
P_2O_5				0.068
S				0.01
CaO				0.079
MgO				0.03
MnO				0.047
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.70
U				99 ppm
Th				287 ppm

Sample (BGR Analysis): 24 ppm As, 171 ppm Ce, 84 ppm Pb, 25 ppm Mo, 10322 ppm Sn (1.31 % SnO_2), 506 ppm Ta, 845 ppm W, 153 ppm Y, 22 ppm Zn

Mineralogical composition (BGR Analysis): 77.4 % rutile, 9.5 % leucoxene, 4.5 % zircon, 2.0 % cassiterite, 1.1 % quartz, 1.0 % garnet/tourmaline/aluminosilicates, 0.5 % ilmenite, 0.1 % monazite, 3.9 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			DQCL Analysis	BGR Analysis
> 500				
420				
355				0.0
300				0.1
250				0.5
212				2.0
180				6.7
150				17.1
125				25.9
106				22.6
90				14.7
75				7.4
63				2.2
53				0.6
45				0.2
< 45				0.0
Mean (µm)				129.6
D50 (µm)				123.5

Name: **Eneabba Rutile Premium Grade**
Deposit: Eneabba, Western Australia, Australia
Producer: Iluka Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Samples I (II)	
			Iluka Analysis I	BGR Analysis I (II)
TiO_2	> 95.0	95–96	95.6	95.31 (95.22)
$Zr(Hf)O_2$				0.88 (0.88)
ZrO_2	< 1.0	0.7–1.0	0.90	0.86 (0.86)
SiO_2		0.5–1.0	0.73	0.74 (0.77)
Al_2O_3		0.2–0.5	0.41	0.50 (0.38)
Fe_2O_3	< 1.0	0.5–1.0	0.82	0.82 (0.95)
Cr_2O_3		0.1–0.2	0.16	0.16 (0.14)
V_2O_5		0.5–0.6	0.56	0.52 (0.47)
Nb_2O_5		0.3–0.4	0.35	0.35 (0.37)
P_2O_5		0.02–0.04	0.03	0.026 (0.018)
S			< 0.01	< 0.01 (< 0.01)
CaO			0.03	0.058 (< 0.005)
MgO			0.05	< 0.01 (< 0.01)
MnO			0.01	0.007 (0.01)
Moisture (@ 105 °C)			0.08	
LOI (@ 950 °C)				0.44 (0.34)
U		40–60 ppm	49 ppm	49 ppm (47 ppm)
Th		40–90 ppm	70 ppm	81 ppm (46 ppm)

Sample I (II) (BGR Analysis): 11 (< 2) ppm As, 62 (68) ppm Mo, 46 (69) ppm Pb, 138 (138) ppm Sn, 173 (185) ppm Ta, 232 (240) ppm W

Typical mineralogical composition: 82–97 % rutile, 1–17 % leucoxene, < 1 % ilmenite, approx. 1 % zircon, 0.5 % kyanite, < 0.1 % monazite, < 0.1 % quartz
Mineralogical composition of sample I (BGR Analysis): 90.5 % rutile, 7.9 % leucoxene, 0.6 % zircon, 0.2 % garnet/tourmaline/aluminosilicates, 0.8 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample I	
			Iluka Analysis	BGR Analysis
> 420				0.0
355			0.3	0.2
300				0.7
250			1.2	3.4
212			4.4	9.3
180			16.5	19.4
150			34.0	28.2
125			26.4	21.7
106			11.1	10.4
90			4.5	4.4
75			1.2	1.6
63				0.5
53				0.1
45			0.4	0.1
< 45				0.1
Mean (µm)				165.3
D50 (µm)			156	155.2

Name: **Eucla HYTI 90**
Deposit: Jacinth-Ambrosia, Eucla Basin, Victoria, Australia
Producer: Iluka Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Samples I (II)	
			Iluka Analysis	BGR Analysis
TiO_2			90.4	90.17 (91.69)
$Zr(Hf)O_2$				2.53 (2.07)
ZrO_2			2.79	2.49 (2.03)
SiO_2			2.42	2.58 (2.23)
Al_2O_3			0.35	0.49 (0.47)
Fe_2O_3			2.36	2.19 (1.64)
Cr_2O_3			0.13	0.12 (0.13)
V_2O_5			0.20	0.23 (0.26)
Nb_2O_5			0.38	0.40 (0.37)
P_2O_5			0.06	0.053 (0.038)
S			0.02	0.01 (0.01)
CaO			0.02	0.072 (0.071)
MgO			0.01	< 0.01 (< 0.01)
MnO			0.01	0.017 (0.017)
Moisture (@ 105 °C)			0.14	
LOI (@ 950 °C)				0.80 (0.70)
U			40 ppm	46 ppm (34 ppm)
Th			68 ppm	99 ppm (67 ppm)

Sample I (Iluka Analysis): 654 ppm Sn
Samples (BGR Analysis): 61 (55) ppm As, 61 (58) ppm Mo, 79 (60) ppm Pb, 287 (450) ppm Sn, 275 (238) ppm Ta, 454 (428) ppm W

Mineralogical composition (BGR Analysis): 77.4 (78.9) % rutile, 17.0 (16.0) % leucoxene, 3.7 (2.8) % zircon, 0.3 (0.5) % ilmenite, 0.3 (0.4) % quartz, 0.3 (0.5) % garnet/tourmaline/aluminosilicates, 1.0 (0.9) % others/unknown

Grain size distribution µm	Guaranteed	Typical	Samples I (II)	
			Iluka Analysis	BGR Analysis
> 355			0.0	
300				
250			0.0	
212			0.0	
180			0.0	0.1 (0.3)
150			0.3	2.4 (2.8)
125			3.3	13.1 (13.9)
106			29.1	28.7 (29.1)
90			46.0	31.7 (31.6)
75			19.0	18.2 (17.4)
63			2.3	4.9 (4.3)
53				0.8 (0.6)
45				0.1 (0.1)
< 45				0.0 (0.0)
Mean (µm)				102.4 (103.6)
D50 (µm)			100	101.1 (101.8)

Name: **Folkston Leucoxene (Historic data)**
Deposit: Folkston, Georgia, USA
Producer: Humphreys Mining Company

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			HMC Analysis	Elsner (1992)
TiO_2				81.23
$Zr(Hf)O_2$				1.33
ZrO_2				1.30
SiO_2				1.00
Al_2O_3				2.42
Fe_2O_3				9.18
Cr_2O_3				0.13
V_2O_5				0.18
Nb_2O_5				0.19
P_2O_5				1.12
S				< 0.03
CaO				0.21
MgO				0.20
MnO				0.05
LOI (@ 950 °C)				1.08
U				193 ppm
Th				1345 ppm

Sample (Elsner 1992): 28 ppm As, 158 ppm Cu, 30 ppm Mo, 47 ppm Ni, 257 ppm Pb, 74 ppm Sn, 107 ppm Ta, 132 ppm W, 1077 ppm Y, 182 ppm Zn

Mineralogical composition (Elsner 1992): 78.8 % ilmenite, 15.3 % rutile, 2.2 % leucoxene, 1.8 % zircon, 1.2 % monazite/xenotime, 0.2 % anatase, 0.2 % tourmaline, 0.2 % epidote, traces of kyanite, sphene, and quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			HMC Analysis	Elsner (1992)
> 500				0.002
420				0.003
355				0.006
300				0.010
250				0.013
212				0.007
180				0.010
150				0.032
125				1.500
106				11.262
90				32.679
75				38.082
63				14.577
53				1.303
45				0.436
< 45				0.070
Mean (µm)				87.1
D50 (µm)				

Name: **Folkston Rutile (Historic data)**
Deposit: Folkston, Georgia, USA
Producer: Humphreys Mining Company

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			HMC Analysis	Elsner (1992)
TiO_2				95.09
$Zr(Hf)O_2$				0.73
ZrO_2				0.72
SiO_2				0.31
Al_2O_3				0.81
Fe_2O_3				1.06
Cr_2O_3				0.10
V_2O_5				0.27
Nb_2O_5				0.42
P_2O_5				0.10
S				< 0.03
CaO				0.10
MgO				0.15
MnO				0.05
LOI (@ 950 °C)				0.36
U				31 ppm
Th				76 ppm

Sample (Elsner 1992): 22 ppm As, 37 ppm Mo, 81 ppm Pb, 179 ppm Sn, 267 ppm Ta, 258 ppm W, 119 ppm Y, 14 ppm Zn

Mineralogical composition (Elsner 1992): 74.9 % rutile, 20.1 % ilmenite, 3.1 % anatase, 0.9 % zircon, 0.7 % leucoxene, 0.2 % brookite, 0.1 % sphene

Grain size distribution µm	Guaranteed	Typical	Sample	
			HMC Analysis	Elsner (1992)
> 500				0.002
420				0.003
355				0.004
300				0.008
250				0.025
212				0.263
180				0.903
150				2.005
125				5.047
106				21.236
90				33.653
75				26.655
63				9.254
53				0.671
45				0.020
< 45				0.060
Mean (µm)				95.5
D50 (µm)				

Name: **GPM Rutile**
Deposit: Phan Thiết, Bắc Bình District, Bình Thuận Province, Vietnam
Producer: GPM Binh Thuan Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			GPM Analysis	BGR Analysis
TiO_2	> 83/> 85			
$Zr(Hf)O_2$				
ZrO_2	< 2.5			
SiO_2	6.5–9.5			
Al_2O_3				
Fe_2O_3				
Cr_2O_3				
V_2O_5				
Nb_2O_5				
P_2O_5	< 0.7			
S	< 0.03			
CaO				
MgO				
MnO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				
U				
Th				

Grain size distribution µm	Guaranteed	Typical	Sample	
			GPM Analysis	BGR Analysis
> 500				
420				
355				
300				
250				
212				
180				
150				
125				
106				
90				
75				
63				
53				
45				
< 45				
Mean (µm)				
D50 (µm)				

Name: **Green Cove Springs Leucoxene (Historic sample)**
Deposit: Green Cove Springs, Florida, USA
Producer: Iluka Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Iluka Analysis	BGR Analysis
TiO_2				65.16
$Zr(Hf)O_2$				0.07
ZrO_2				0.06
SiO_2				0.62
Al_2O_3				1.22
Fe_2O_3				27.57
Cr_2O_3				0.11
V_2O_5				0.09
Nb_2O_5				0.11
P_2O_5				0.244
S				< 0.01
CaO				0.235
MgO				0.18
MnO				1.223
Moisture (@ 105 °C)				
LOI (@ 950 °C)				2.76
U				20 ppm
Th				109 ppm

Sample (BGR Analysis): 16 ppm As, 33 ppm Co, 362 ppm Cu, 141 ppm Ga, 193 ppm La, 21 ppm Mo, 167 ppm Nd, 177 ppm Pb, 47 ppm Sn, 84 ppm Ta, 276 ppm Zn

Typical mineralogical composition: 93–96 % ilmenite/rutile/leucoxene, 0.1–1.5 % zircon, < 1 % staurolite, 0.2–0.3 % monazite, < 0.5 % quartz

Mineralogical composition (BGR Analysis): 66.2 % ilmenite, 31.3 % leucoxene, 0.9 % garnet/tourmaline/aluminosilicates, 0.6 % rutile, 0.6 % staurolite, 0.1 % zircon, 0.1 % monazite, 0.2 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Iluka Analysis	BGR Analysis
> 300				0.1
250				0.1
212				0.4
180				2.0
150				10.2
125				27.1
106				30.6
90				19.6
75				7.8
63				1.6
53				0.3
45				0.1
< 45				0.0
Mean (µm)				119.8
D50 (µm)				115.7

Name: **Green Cove Springs Rutile (Historic data)**
Deposit: Green Cove Springs, Florida, USA
Producer: Iluka Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Iluka Analysis	Elsner (1992)
TiO_2				92.85
$Zr(Hf)O_2$				0.11
ZrO_2				0.10
SiO_2				0.09
Al_2O_3				0.62
Fe_2O_3				3.28
Cr_2O_3				0.10
V_2O_5				0.22
Nb_2O_5				0.38
P_2O_5				0.16
S				< 0.03
CaO				0.19
MgO				0.14
MnO				0.15
LOI (@ 950 °C)				1.39
U				< 5 ppm
Th				26 ppm

Sample (Elsner 1992): 30 ppm As, 57 ppm Mo, 144 ppm Pb, 166 ppm Sn, 258 ppm Ta, 225 ppm W, 198 ppm Zn

Typical mineralogical composition: 82–97 % rutile, 1–17 % leucoxene, < 1 % ilmenite, approx. 1 % zircon, 0.5 % kyanite, < 0.1 % monazite, < 0.1 % quartz
Mineralogical composition (Elsner 1992): 46.7 % rutile, 46.6 % leucoxene, 6.5 % ilmenite, 0.2 % monazite

Grain size distribution µm	Guaranteed	Typical	Sample	
			Iluka Analysis	Elsner (1992)
> 420				0.005
355				0.001
300				0.001
250				0.013
212				0.124
180				0.668
150				2.769
125				13.705
106				33.204
90				35.336
75				12.277
63				1.586
53				0.076
45				0.107
< 45				0.120
Mean (µm)				106.1
D50 (µm)				

Name: **Guangxi Liufeng Mining Rutile 90**
Deposit: from Vietnamese Leone HM concentrates
Producer: Guangxi Liufeng Mining Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Guangxi Liufeng Analysis	BGR Analysis
TiO_2				90.11
$Zr(Hf)O_2$				0.60
ZrO_2				0.58
SiO_2				4.12
Al_2O_3				1.40
Fe_2O_3				1.42
Cr_2O_3				0.09
V_2O_5				0.22
Nb_2O_5				0.44
P_2O_5				0.077
S				< 0.01
CaO				0.05
MgO				0.04
MnO				0.05
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.74
U				87
Th				316

Chemical analysis (BGR): 412 ppm Sn, 281 ppm Ta, 603 ppm W

Mineralogical composition of sample (BGR Analysis): 71.7 % rutile, 16.0 % leucoxene, 1.8 % quartz, 1.1 % zircon, 1.1 % garnet/tourmaline/aluminosilicates, 0.8 % ilmenite, 7.3 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Guangxi Liufeng Analysis	BGR Analysis
> 500				0.0
420				0.1
355				0.6
300				1.6
250				3.9
212				5.0
180				7.5
150				15.3
125				23.1
106				20.0
90				12.8
75				6.7
63				2.3
53				0.8
45				0.2
< 45				0.1
Mean (µm)				143.4
D50 (µm)				111.2

Name: **Hainan Wensheng Rutile 85**
Deposit: from Australian HM concentrates
Producer: Hainan Wensheng High-Tech Materials Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Hainan Wensheng Analysis	BGR Analysis
TiO_2			87.02	86.42
$Zr(Hf)O_2$			1.77	1.27
ZrO_2				1.25
SiO_2			3.62	5.35
Al_2O_3			1.71	2.35
Fe_2O_3				2.09
Cr_2O_3			0.21	0.11
V_2O_5			0.30	0.20
Nb_2O_5			0.29	0.36
P_2O_5			0.14	0.119
S				< 0.01
CaO			0.21	0.17
MgO			0.16	0.08
MnO			0.10	0.04
LOI (@ 950 °C)			0.31	0.82
U				75 ppm
Th				186 ppm

Chemical analysis (Hainan Wensheng): Fe_{total}: 2.96 %, SnO_2: 0.16 %
Sample (BGR Analysis): 30 ppm As, 299 ppm Ce, 120 ppm La, 129 ppm Nd, 111 ppm Pb, 525 ppm Sn, 219 ppm Ta, 417 ppm W, 198 ppm Y

Mineralogical composition of sample (BGR Analysis): 59.4 % rutile, 29.4 % leucoxene, 2.0 % zircon, 1.6 % quartz, 1.3 % garnet/tourmaline/aluminosilicates, 0.5 % ilmenite, 0.2 % sphene, 0.1 % cassiterite, 5.5 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Hainan Wensheng Analysis	BGR Analysis
> 355				0.0
> 300				
250				0.4
212				1.4
180				4.5
150				14.0
125				24.9
106				24.5
90				17.1
75				9.0
63				3.0
53				0.9
45				0.2
< 45				0.1
Mean (µm)				123.3
D50 (µm)				103.6

Name: **Hainan Wensheng Rutile 90**
Deposit: from Australian HM concentrates
Producer: Hainan Wensheng High-Tech Materials Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Hainan Wensheng Analysis	BGR Analysis
TiO_2			90.35	91.09
$Zr(Hf)O_2$			0.78	0.96
ZrO_2				0.94
SiO_2			3.12	3.22
Al_2O_3			1.41	1.12
Fe_2O_3			2.38	1.58
Cr_2O_3			0.10	0.15
V_2O_5			0.30	0.27
Nb_2O_5			0.35	0.37
P_2O_5			0.14	0.091
S			< 0.01	< 0.01
CaO			0.20	0.10
MgO			0.20	0.05
MnO			0.04	0.03
LOI (@ 950 °C)			0.35	0.38
U				50
Th				179

Chemical analysis (Hainan Wensheng): SnO_2: 0.13 %
Sample (BGR Analysis): 197 ppm Ce, 105 ppm Pb, 0.15 % Sn, 233 ppm Ta, 309 ppm W, 142 ppm Y

Mineralogical composition of sample (BGR Analysis): 65.7 % rutile, 25.8 % leucoxene, 1.5 % quartz, 0.9 % zircon, 0.9 % garnet/tourmaline/aluminosilicates, 0.6 % ilmenite, 0.1 % sphene, 0.1 % cassiterite, 4.4 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Hainan Wensheng Analysis	BGR Analysis
> 420				0.2
355				0.3
300				0.5
250				1.4
212				3.3
180				7.1
150				15.5
125				23.7
106				21.9
90				14.7
75				7.7
63				2.6
53				0.8
45				0.2
< 45				0.1
Mean (µm)				133.6
D50 (µm)				107.9

Name: **Hainan Wensheng Rutile 95**
Deposit: from Australian HM concentrates
Producer: Hainan Wensheng High-Tech Materials Co., Ltd.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Hainan Wensheng Analysis	**BGR Analysis**
TiO_2				94.95
$Zr(Hf)O_2$				0.44
ZrO_2				0.43
SiO_2				1.25
Al_2O_3				0.38
Fe_2O_3				1.35
Cr_2O_3				0.12
V_2O_5				0.33
Nb_2O_5				0.37
P_2O_5				0.043
S				< 0.01
CaO				0.04
MgO				0.01
MnO				0.04
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.38
U				31
Th				48

Chemical analysis (BGR): 45 ppm Pb, 310 ppm Sn, 182 ppm Ta, 168 ppm W

Mineralogical composition of sample (BGR Analysis): 89.6 % rutile, 7.4 % leucoxene, 1.0 % ilmenite, 0.7 % quartz, 0.4 % zircon, 0.2 % garnet/tourmaline/aluminosilicates, 0.6 % others/unknown

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			Hainan Wensheng Analysis	**BGR Analysis**
> 500				0.0
420				
355				
300				
250				0.1
212				0.9
180				4.6
150				15.9
125				29.6
106				26.7
90				15.0
75				5.6
63				1.2
53				0.3
45				0.1
< 45				0.0
Mean (µm)				126.8
D50 (µm)				107.1

Name: **Hainan Xiongxiu Mining Rutile 85**
Deposit: Hainan Island, China
Producer: Hainan Xiongxiu Mining Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Hainan Xiongxiu Analysis	BGR Analysis
TiO_2				87.56
$Zr(Hf)O_2$				1.06
ZrO_2				1.03
SiO_2				5.06
Al_2O_3				1.89
Fe_2O_3				1.50
Cr_2O_3				0.07
V_2O_5				0.16
Nb_2O_5				0.36
P_2O_5				0.124
S				< 0.01
CaO				0.11
MgO				0.08
MnO				0.04
Moisture (@ 105 °C)				
LOI (@ 950 °C)				1.24
U				128
Th				436

Chemical analysis (BGR): 348 ppm Ce, 149 ppm Pb, 314 ppm Sn, 234 ppm Ta, 533 ppm W, 320 ppm Y

Mineralogical composition of sample (BGR Analysis): 64.8 % rutile, 22.1 % leucoxene, 2.0 % quartz, 1.4 % zircon, 0.9 % garnet/tourmaline/aluminosilicates, 0.2 % ilmenite, 8.5 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Hainan Xiongxiu Analysis	BGR Analysis
> 500				0.0
420				
355				
300				
250				
212				0.1
180				0.7
150				4.2
125				12.0
106				21.0
90				25.8
75				21.8
63				10.0
53				3.2
45				0.9
< 45				0.3
Mean (µm)				99.8
D50 (µm)				86.3

Name: **Hainan Xiongxiu Mining Rutile 89**
Deposit: Hainan Island, China
Producer: Hainan Xiongxiu Mining Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Hainan Xiongxiu Analysis	BGR Analysis
TiO_2				89.23
$Zr(Hf)O_2$				0.55
ZrO_2				0.54
SiO_2				3.91
Al_2O_3				1.94
Fe_2O_3				1.47
Cr_2O_3				0.07
V_2O_5				0.16
Nb_2O_5				0.41
P_2O_5				0.088
S				< 0.01
CaO				0.06
MgO				0.06
MnO				0.04
Moisture (@ 105 °C)				
LOI (@ 950 °C)				1.28
U				76
Th				244

Chemical analysis (BGR): 158 ppm Pb, 769 ppm Sn, 297 ppm Ta, 596 ppm W, 237 ppm Y

Mineralogical composition of sample (BGR Analysis): 63.7 % rutile, 24.8 % leucoxene, 1.2 % quartz, 0.8 % zircon, 0.8 % garnet/tourmaline/aluminosilicates, 0.2 % ilmenite, 0.1 % monazite, 0.1 % cassiterite, 8.3 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Hainan Xiongxiu Analysis	BGR Analysis
> 420				0.0
355				
300				
250				
212				0.1
180				0.5
150				3.2
125				14.4
106				24.5
90				26.3
75				19.5
63				8.5
53				2.9
45				0.8
< 45				0.3
Mean (µm)				100.7
D50 (µm)				88.2

Name: **Hainan Xiongxiu Mining Rutile 91**
Deposit: Hainan Island, China
Producer: Hainan Xiongxiu Mining Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Hainan Xiongxiu Analysis	BGR Analysis
TiO_2				90.94
$Zr(Hf)O_2$				1.43
ZrO_2				1.39
SiO_2				2.99
Al_2O_3				1.08
Fe_2O_3				1.03
Cr_2O_3				0.08
V_2O_5				0.16
Nb_2O_5				0.41
P_2O_5				0.098
S				< 0.01
CaO				0.06
MgO				0.04
MnO				0.02
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.84
U				186
Th				842

Chemical analysis (BGR): 455 ppm Ce, 91 ppm Pb, 0.13 % SnO_2, 305 ppm Ta, 638 ppm W, 342 ppm Y

Mineralogical composition of sample (BGR Analysis): 75.9 % rutile, 14.5 % leucoxene, 2.7 % zircon, 1.0 % quartz, 0.6 % garnet/tourmaline/aluminosilicates, 0.2 % ilmenite, 0.1 % monazite, 0.1 % cassiterite, 4.9 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Hainan Xiongxiu Analysis	BGR Analysis
> 420				0.0 (> 212)
355				
300				
250				
212				
180				0.4
150				2.8
125				10.4
106				20.5
90				26.8
75				23.5
63				10.9
53				3.5
45				1.0
< 45				0.2
Mean (µm)				97.1
D50 (µm)				

Name: **Hung Thinh Rutile 85 %**
Deposit: Thien Ai, Bac Binh District, Binh Than Province, Vietnam
Producer: Hung Thinh Titanium Slag Plant One Member Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Hung Thinh Analysis	BGR Analysis
TiO_2	> 85			84.52
$Zr(Hf)O_2$	< 1			2.21
ZrO_2				2.14
SiO_2	< 1			4.89
Al_2O_3				1.68
Fe_2O_3	< 1			0.95
Cr_2O_3				0.08
V_2O_5				0.24
Nb_2O_5				0.52
P_2O_5				0.072
S				0.01
CaO				0.090
MgO				0.02
MnO				0.027
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.96
U	< 400 ppm			211 ppm
Th				688 ppm

Sample (BGR Analysis): 91 ppm Pb, 17377 ppm Sn (2.21 % SnO_2), 349 ppm Ta, 863 ppm W, 432 ppm Y, 20 ppm Zn

Mineralogical composition (BGR Analysis): 72.8 % rutile, 10.6 % leucoxene, 3.9 % zircon, 2.2 % cassiterite, 1.1 % quartz, 1.1 % garnet/tourmaline/aluminosilicates, 8.3 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Hung Thinh Analysis	BGR Analysis
> 500				0.0
420				0.0
355				0.0
300				0.0
250				0.0
212				0.2
180				0.9
150				4.8
125				16.3
106				28.3
90				27.6
75				15.8
63				4.7
53				1.1
45				0.2
< 45				0.1
Mean (µm)				106.5
D50 (µm)				104.0

Name: **IREL Rutile "MK" Grade**
Deposit: Manavalakurichi, Tamil Nadu, India
Producer: IREL (India) Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			IREL Analysis	BGR Analysis
TiO_2		94.4	94.37	94.81
$Zr(Hf)O_2$				0.44
ZrO_2		1.8		0.42
SiO_2		1.8		0.79
Al_2O_3		0.06		0.71
Fe_2O_3		1.9		0.67
Cr_2O_3		0.09		0.19
V_2O_5		0.05		0.51
Nb_2O_5		0.97		1.01
P_2O_5		0.04		0.026
S		–		0.01
CaO				0.12
MgO				< 0.01
MnO				0.002
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.46
U		160 ppm		75 ppm
Th				41 ppm

Sample (BGR Analysis): 61 ppm Mo, 23 ppm Pb, 45 ppm Sn, 498 ppm Ta, 448 ppm W, 17 ppm Zn

Typical mineralogical composition (IREL Analysis): ~90 % rutile, ~8 % leucoxene, ~1.4 % zircon, 0.2 % monazite, 0.2 % ilmenite, 0.2 % quartz, traces of sillimanite + kyanite
Mineralogical composition (IREL Analysis): 87.48 % rutile, 11.26 % leucoxene, 0.85 % zircon, 0.15 % monazite, 0.09 % shells, 0.07 % sillimanite, 0.06 % quartz, 0.04 % ilmenite, 0.0 % garnet
Mineralogical composition (BGR Analysis): 89.4 % rutile, 5.6 % leucoxene, 0.2 % zircon, 0.2 % calcite, 0.1 % ilmenite, 0.1 % aluminosilicates, 0.1 % tourmaline, 0.1 % quartz, 4.2 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			IREL Analysis	BGR Analysis
> 500				
420				0.0
355				0.4
300				1.9
250				6.7
212				13.1
180				20.6
150				26.6
125				19.1
106				8.0
90				2.7
75				0.7
63				0.2
> 53				0.0
Mean (µm)				178.8
D50 (µm)				171

Name: **IREL Rutile "OR" Grade**
Deposit: Chatrapur, Orissa, India
Producer: IREL (India) Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			IREL Analysis	BGR Analysis
TiO_2		94.5		96.52
$Zr(Hf)O_2$				0.65
ZrO_2		0.90		0.63
SiO_2		0.90		0.51
Al_2O_3				0.25
Fe_2O_3		1.1		0.54
Cr_2O_3				0.12
V_2O_5				0.55
Nb_2O_5				0.40
P_2O_5		0.06		0.036
S				0.01
CaO				0.064
MgO				< 0.01
MnO				0.008
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.18
U				32 ppm
Th				162 ppm

Sample (BGR Analysis): 170 ppm Ce, 20 ppm Cu, 82 ppm La, 27 ppm Mo, 69 ppm Nd, 15 ppm Ni, 83 ppm Sn, 178 ppm Ta, 102 ppm W, 21 ppm Zn

Typical mineralogical composition (IREL Analysis): 97.3 % rutile, 1.45 % zircon, 0.7 % ilmenite, 0.16 % monazite, 0.13 % sillimanite, 0.05 % garnet, 0.07 % quartz, 0.14 % others
Mineralogical composition (BGR Analysis): 96.2 % rutile, 1.2 % leucoxene, 1.3 % zircon, 0.3 % ilmenite, 0.2 % monazite, 0.1 % tourmaline, 0.1 % quartz, 0.8 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			IREL Analysis	BGR Analysis
> 500				0.1
420				0.1
355				0.5
300				2.1
250				6.8
212				13.8
180				21.1
150				25.5
125				18.3
106				7.8
90				2.9
75				0.8
63				0.2
< 53				0.0
Mean (µm)				180.9
D50 (µm)				173

Name: **IREL Leucoxene "Q" Grade**
Deposit: Chavara, Kerala, India
Producer: IREL (India) Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			IREL Analysis	BGR Analysis
TiO_2				81.21
$Zr(Hf)O_2$				0.96
ZrO_2				0.94
SiO_2				3.56
Al_2O_3				3.65
Fe_2O_3				4.83
Cr_2O_3				0.27
V_2O_5				0.14
Nb_2O_5				0.67
P_2O_5				0.484
S				0.01
CaO				0.286
MgO				0.52
MnO				0.021
Moisture (@ 105 °C)				
LOI (@ 950 °C)				2.36
U				52 ppm
Th				749 ppm

Sample (BGR Analysis): 59 ppm As, 138 ppm Ba, 1335 ppm Ce, 28 ppm Cu, 631 ppm La, 37 ppm Mo, 544 ppm Nd, 15 ppm Ni, 242 ppm Pb, 185 ppm Pr, 126 ppm Sm, 31 ppm Sn, 194 ppm Sr, 387 ppm Ta, 286 ppm W, 53 ppm Y, 180 ppm Zn

Mineralogical composition (BGR Analysis): 58.0 % leucoxene, 25.0 % rutile, 1.8 % ilmenite, 0.6 % zircon, 0.4 % monazite, 0.3 % tourmaline, 0.3 % quartz, 0.1 % aluminosilicates, 13.0 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			IREL Analysis	BGR Analysis
> 500				0.8
420				2.0
355				4.7
300				11.8
250				22.9
212				24.8
180				18.0
150				9.8
125				3.7
106				1.1
90				0.3
75				0.1
63				0.0
53				
45				
< 45				
Mean (µm)				249.1
D50 (µm)				238

Name: **IREL Rutile "Q" Grade**
Deposit: Chavara, Kerala, India
Producer: IREL (India) Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			IREL Analysis	BGR Analysis
TiO_2	> 95.00	95.5		94.10
$Zr(Hf)O_2$				0.75
ZrO_2		1.40		0.73
SiO_2		1.00		0.86
Al_2O_3				0.72
Fe_2O_3		0.70		1.05
Cr_2O_3				0.22
V_2O_5				0.45
Nb_2O_5				0.94
P_2O_5		0.04		0.055
S		trace		0.01
CaO				0.086
MgO				< 0.01
MnO				0.006
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.48
U				74 ppm
Th				50 ppm

Sample (BGR Analysis): 9 ppm As, 53 ppm Mo, 34 ppm Pb, 53 ppm Sn, 500 ppm Ta, 424 ppm W, 28 ppm Zn

Typical mineralogical composition (IREL Analysis): 91.705 % rutile, 6.30 % leucoxene, 1.80 % zircon, 0.10 % sillimanite, trace of ilmenite
Mineralogical composition (BGR Analysis): 83.1 % rutile, 12.0 % leucoxene, 0.7 % zircon, 0.3 % ilmenite, 0.2 % aluminosilicates, 0.1 % K-feldspar, 0.1 % quartz, 3.3 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			IREL Analysis	BGR Analysis
> 420				0.0
355				0.3
300				1.6
250				5.4
212				10.8
180				17.5
150				24.5
125				21.2
106				11.2
90				4.9
75				1.8
63				0.6
53				0.1
45				0.1
< 45				0.0
Mean (µm)				168.7
D50 (µm)				162

Name: **Jacksonville Rutile (Historic data)**
Deposit: Jacksonville, Florida, USA
Producer: Humphreys Gold Corporation

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			HGC Analysis	Elsner (1992)
TiO_2				94.65
$Zr(Hf)O_2$				0.37
ZrO_2				0.36
SiO_2				0.11
Al_2O_3				0.43
Fe_2O_3				1.95
Cr_2O_3				0.10
V_2O_5				0.27
Nb_2O_5				0.55
P_2O_5				0.08
S				< 0.03
CaO				0.06
MgO				0.14
MnO				0.09
LOI (@ 950 °C)				0.81
U				< 5 ppm
Th				15 ppm

Sample (Elsner 1992): 16 ppm As, 10 ppm Mo, 205 ppm Sn, 350 ppm Ta, 338 ppm W, 78 ppm Zn

Mineralogical composition (Elsner 1992): 77.2 % rutile, 16.0 % leucoxene, 3.4 % ilmenite, 2.8 % anatase, 0.4 % zircon, 0.2 % garnet

Grain size distribution µm	Guaranteed	Typical	Sample	
			HGC Analysis	Elsner (1992)
> 500				0.007
420				0.004
355				0.004
300				0.013
250				0.098
212				0.623
180				1.749
150				3.606
125				14.225
106				32.858
90				32.750
75				12.088
63				1.809
53				0.069
45				0.036
< 45				0.050
Mean (µm)				108.2
D50 (µm)				

Name: **Jesup HiTi**
Deposit: Amelia, Georgia, USA
Producer: The Chemours Company FC, LLC

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Chemours Analysis	BGR Analysis
TiO_2				91.77
$Zr(Hf)O_2$				0.68
ZrO_2				0.67
SiO_2				1.17
Al_2O_3				1.00
Fe_2O_3				3.06
Cr_2O_3				0.10
V_2O_5				0.11
Nb_2O_5				0.43
P_2O_5				0.165
S				0.04
CaO				0.283
MgO				0.02
MnO				0.062
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.80
U				18 ppm
Th				33 ppm

Sample (BGR Analysis): 27 ppm As, 125 ppm Ga, 67 ppm Mo, 176 ppm Pb, 46 ppm Sc, 174 ppm Sn, 287 ppm Ta, 233 ppm W, 48 ppm Zn

Mineralogical composition (BGR Analysis): 77.0 % rutile, 20.1 % leucoxene, 1.0 % ilmenite, 0.8 % quartz, 0.5 % zircon, 0.1 % aluminosilicates, 0.1 % staurolite, 0.4 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Chemours Analysis	BGR Analysis
> 500				
420				0.0
355				0.1
300				1.2
250				4.4
212				8.6
180				13.9
150				20.9
125				20.9
106				14.2
90				8.5
75				4.5
63				1.7
53				0.7
45				0.3
< 45				0.1
Mean (µm)				155.5
D50 (µm)				149

Name: **Jesup Rutile**
Deposit: Amelia, Georgia, USA
Producer: The Chemours Company FC, LLC

Chemical composition wt.-%	Guaranteed	Typical	Samples	
			Chemours Analysis	BGR Analysis
TiO_2				94.52
$Zr(Hf)O_2$				0.29
ZrO_2				0.28
SiO_2				0.32
Al_2O_3				0.90
Fe_2O_3				2.15
Cr_2O_3				0.11
V_2O_5				0.11
Nb_2O_5				0.35
P_2O_5				0.220
S				0.01
CaO				0.113
MgO				0.01
MnO				0.032
LOI (@ 950 °C)				0.64
U				< 11 ppm
Th				21 ppm

Sample (BGR Analysis): 36 ppm As, 25 ppm Cu, 120 ppm Ga, 99 ppm Mo, 220 ppm Pb, 46 ppm Sc, 202 ppm Sn, 230 ppm Ta, 193 ppm W, 32 ppm Zn

Typical mineralogical composition: 90–100 % rutile, 10–20 % leucoxene, 1–5 % zircon, 1–5 % kyanite, 1–5 % quartz
Mineralogical composition (BGR Analysis): 82.5 % rutile, 16.2 % leucoxene, 0.5 % ilmenite, 0.4 % zircon, 0.1 % aluminosilicates, 0.1 % staurolite, 0.1 % quartz, 0.1 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Chemours Analysis	BGR Analysis
> 420				0.0
355				0.1
300				0.8
250				3.6
212				8.0
180				13.6
150				20.9
125				21.4
106				14.8
90				8.9
75				4.9
63				1.9
53				0.7
45				0.2
< 45				0.2
Mean (µm)				152.2
D50 (µm)				149

Name: **Kalbar Rutile 92**
Deposit: Fingerboards, Victoria, Australia
Producer: Kalbar Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Kalbar Analysis	BGR Analysis
TiO_2		92.7		
$Zr(Hf)O_2$				
ZrO_2		1.1		
SiO_2		3.7		
Al_2O_3		0.6		
Fe_2O_3		0.5		
Cr_2O_3		0.1		
V_2O_5		0.3		
Nb_2O_5		0.3		
P_2O_5		0		
S		–		
CaO		0		
MgO		0.1		
MnO		0		
Moisture (@ 105 °C)				
LOI (@ 950 °C)				
U		41 ppm		
Th		75 ppm		

Typical: 0.1 % K_2O, 0 % CeO_2, 0.05 % SnO_2

Grain size distribution µm	Guaranteed	Typical	Sample	
			Kalbar Analysis	BGR Analysis
> 500				
420				
355				
300				
250				
212				
180				
150		0.0		
125		7.9		
106				
90		16.4		
75		30.5		
63		32.9		
53		11.8		
45				
< 45		0.7		
Mean (µm)				
D50 (µm)				

Name: **PT Karya Lisbeth Rutile 90**
Deposit: Kalimantan, Indonesia
Producer: PT Karya Lisbeth

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Karya Lisbeth Analysis	BGR Analysis
TiO_2				60.36
$Zr(Hf)O_2$				6.35
ZrO_2				6.23
SiO_2				4.56
Al_2O_3				3.69
Fe_2O_3				12.62
Cr_2O_3				7.23
V_2O_5				0.24
Nb_2O_5				0.17
P_2O_5				0.169
S				< 0.01
CaO				0.03
MgO				1.62
MnO				0.44
LOI (@ 950 °C)				1.06
U				74
Th				219

Chemical analysis (BGR): 616 ppm Ce, 82 ppm Co, 30 ppm Cu, 349 ppm La, 270 ppm Nd. 126 ppm Ni, 179 ppm Pb, 6925 ppm Sn, 412 ppm Y, 488 ppm Zn

Mineralogical composition (BGR Analysis): 40.0 % rutile/anatase, 17.6 % leucoxene, 16.0 % ilmenite, approx. 10 % magnesio-chromite, 7.9 % zircon, 0.7 % quartz, 0.5 % staurolite, 0.4 % cassiterite, 0.3 % garnet/tourmaline/aluminosilicates, 0.3 % monazite, 0.1 % xenotime, 6.0 % others (pyrochroite, hematite, TiO_2-quartz-albite mix)

Grain size distribution µm	Guaranteed	Typical	Sample	
			Karya Lisbeth Analysis	BGR Analysis
> 420				0.0
355				0.1
300				0.3
250				1.6
212				4.8
180				10.2
150				18.0
125				22.1
106				18.3
90				12.5
75				7.4
63				3.0
53				1.1
45				0.4
< 45				0.2
Mean (µm)				137.6
D50 (µm)				111.5

Name: **Leucoxene L70**
Deposit: Keysbrook, Western Australia, Australia
Producer: MZI Resources Ltd. (Doral Minerals Sands Pty Ltd.)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			MZI Analysis	BGR Analysis
TiO_2				66.91
$Zr(Hf)O_2$				0.42
ZrO_2				0.42
SiO_2				1.97
Al_2O_3				4.02
Fe_2O_3				22.53
Cr_2O_3				0.14
V_2O_5				0.13
Nb_2O_5				0.15
P_2O_5				0.052
S				0.02
CaO				0.079
MgO				0.29
MnO				0.740
Moisture (@ 105 °C)				
LOI (@ 950 °C)				2.22
U				17 ppm
Th				190 ppm

Sample (BGR Analysis): 30 ppm As, 14 ppm Cu, 26 ppm Mo, 349 ppm Pb, 36 ppm Sn, 93 ppm Ta, 49 ppm W, 224 ppm Zn

Mineralogical composition (BGR Analysis): 56.4 % leucoxene, 33.3 % ilmenite, 4.4 % rutile, 2.2 % staurolite, 2.0 % garnet/tourmaline/aluminosilicates, 0.4 % zircon, 0.3 % quartz, 0.1 % Fe-oxy-hydroxides, 0.9 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			MZI Analysis	BGR Analysis
> 500				0.0
420				0.1
355				0.3
300				1.3
250				4.1
212				6.5
180				8.7
150				14.7
125				20.1
106				17.9
90				12.8
75				7.8
63				3.4
53				1.3
45				0.6
< 45				0.4
Mean (µm)				142.5
D50 (µm)				127.9

Name: **Leucoxene L88**
Deposit: Keysbrook, Western Australia, Australia
Producer: MZI Resources Ltd. (Doral Minerals Sands Pty Ltd.)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			MZI Analysis	BGR Analysis
TiO_2				85.15
$Zr(Hf)O_2$				2.04
ZrO_2				2.00
SiO_2				1.92
Al_2O_3				2.50
Fe_2O_3				4.01
Cr_2O_3				0.27
V_2O_5				0.13
Nb_2O_5				0.23
P2O5				0.285
S				0.02
CaO				0.097
MgO				0.10
MnO				0.031
Moisture (@ 105 °C)				
LOI (@ 950 °C)				2.52
U				90 ppm
Th				406 ppm

Sample (BGR Analysis): 46 ppm As, 535 ppm Ce, 205 ppm La, 55 ppm Mo, 292 ppm Nd, 330 ppm Pb, 102 ppm Pr, 110 ppm Sm, 74 ppm Sn, 213 ppm Ta, 304 ppm W, 1919 ppm Y, 26 ppm Zn

Mineralogical composition (BGR Analysis): 71.6 % leucoxene, 24.4 % rutile, 2.4 % zircon, 0.4 % garnet/tourmaline/aluminosilicates, 0.2 % ilmenite, 0.2 % staurolite, 0.1 % quartz, 0.7 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			MZI Analysis	BGR Analysis
> 420				0.0
355				0.0
300				0.1
250				0.5
212				3.2
180				9.1
150				19.3
125				25.2
106				20.2
90				12.7
75				6.6
63				2.2
53				0.7
45				0.1
< 45				0.1
Mean (µm)				134.6
D50 (µm)				128.3

Name: **KMML Leucoxene**
Deposit: Sankarmangalam, Kerala, India
Producer: The Kerala Minerals & Metals Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			KMML Analysis	BGR Analysis
TiO_2	> 75.0	79.65		
$Zr(Hf)O_2$				
ZrO_2		0.65		
SiO_2		4.18		
Al_2O_3		3.31		
Fe_2O_3		7.5		
Cr_2O_3		0.06		
V_2O_5		0.28		
Nb_2O_5				
P_2O_5		0.35		
S				
CaO		0		
MgO		1.1		
MnO		traces		
Moisture (@ 105 °C)				
LOI (@ 950 °C)		2.38		
U				
Th				

Typical: 0.47 % FeO

Grain size distribution µm	Guaranteed	Typical	Sample	
			KMML Analysis	BGR Analysis
> 500				
420				
355				
300				
250				
212				
180				
150				
125				
106				
90				
75				
63				
53				
45				
< 45				
Mean (µm)				
D50 (µm)				

Name: **KMML Rutile**
Deposit: Sankarmangalam, Kerala, India
Producer: The Kerala Minerals & Metals Ltd.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			KMML Analysis	**BGR Analysis**
TiO_2	> 92.00	93.02		94.87
$Zr(Hf)O_2$				0.49
ZrO_2		0.69		0.48
SiO_2		0.62		0.54
Al_2O_3		0.71		0.54
Fe_2O_3		3.46		1.15
Cr_2O_3				0.21
V_2O_5		0.36		0.45
Nb_2O_5				0.95
P_2O_5				0.041
S				0.01
CaO				0.083
MgO				< 0.01
MnO				0.007
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.44
U				69 ppm
Th				41 ppm

Sample (BGR Analysis): 55 ppm Mo, 24 ppm Pb, 48 ppm Sn, 488 ppm Ta, 415 ppm W, 23 ppm Zn

Mineralogical composition (BGR Analysis): 86.1 % rutile, 9.7 % leucoxene, 1.0 % ilmenite, 0.5 % zircon, 0.1 % aluminosilicates, 0.1 % tourmaline, 2.5 % others/unknown

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			KMML Analysis	**BGR Analysis**
> 500		0		
420				0.0
355		12.5		0.2
300				1.6
250				5.3
212		10.0		11.2
180				18.2
150		39.2		24.7
125		15.9		20.5
106		17.2		10.6
90		2.6		4.7
75		2.6		2.0
63				0.7
53				0.2
45				0.1
< 45				0.0
Mean (µm)				169.2
D50 (µm)				163

Name: **Kwale Rutile**
Deposit: Kwale, Kenya
Producer: Base Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Base Analysis	BGR Analysis
TiO_2				95.82
$Zr(Hf)O_2$				0.66
ZrO_2				0.65
SiO_2				0.61
Al_2O_3				0.34
Fe_2O_3				1.03
Cr_2O_3				0.17
V_2O_5				0.55
Nb_2O_5				0.25
P_2O_5				0.015
S				< 0.01
CaO				0.059
MgO				< 0.01
MnO				0.028
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.32
U				34 ppm
Th				29 ppm

Sample (BGR Analysis): 32 ppm Mo, 81 ppm Sn, 121 ppm Ta, 159 ppm W, 28 ppm Zn

Mineralogical composition (BGR Analysis): 96.0 % rutile, 1.3 % leucoxene, 1.0 % ilmenite, 1.0 % zircon, 0.2 % garnet/tourmaline/aluminosilicates, 0.1 % quartz, 0.1 % Fe-oxy-hydroxides, 0.3 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Base Analysis	BGR Analysis
> 500				0.0
420				0.0
355				0.0
300				0.1
250				0.2
212				1.2
180				4.6
150				13.9
125				24.1
106				23.4
90				17.3
75				10.0
63				3.6
53				1.2
45				0.3
< 45				0.1
Mean (µm)				122.0
D50 (µm)				116.9

Name: **Lanka Rutile**
Deposit: Pulmoddai, Sri Lanka
Producer: Lanka Mineral Sands Ltd.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Lanka Analysis	**BGR Analysis**
TiO_2		95.0	95.06	95.62
$Zr(Hf)O_2$				0.86
ZrO_2				0.84
SiO_2				0.56
Al_2O_3				0.34
Fe_2O_3				0.99
Cr_2O_3				0.18
V_2O_5				0.55
Nb_2O_5				0.33
P_2O_5				0.017
S				0.01
CaO				0.09
MgO				0.04
MnO				0.014
Moisture (@ 105 °C)	< 2.0		< 0.50	
LOI (@ 950 °C)				0.24
U				63 ppm
Th				29 ppm

Sample (BGR Analysis): 55 ppm Mo, 105 ppm Sn, 149 ppm Ta, 245 ppm W, 14 ppm Zn

Mineralogical composition (Lanka Analysis): 92.45 % rutile, 3.38 % altered ilmenite, 1.22 % zircon, 1.01 % ilmenite, 0.03 % garnet, 1.91 % other magnetics
Mineralogical composition (BGR Analysis): 92.9 % rutile, 3.7 % leucoxene, 1.7 % ilmenite, 0.6 % zircon, 0.2 % quartz, 0.1 % aluminosilicates, 0.1 % hornblende, 0.1 % calcite, 0.8 % others/unknown

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			Lanka Analysis	**BGR Analysis**
> 420			1.18	0.0
355				0.1
300				0.4
250				2.2
212			28.52	5.3
180				9.9
150				16.9
125			43.50	21.4
106				18.6
90			16.44	13.3
75			7.78	7.7
63			2.14	2.9
53			0.04	1.0
45				0.2
< 45				0.1
Mean (µm)				138.4
D50 (µm)				132

Name: **Malawi Rutile**
Deposit: Kasiya, Malawi
Producer: Sovereign Metals Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Sovereign Analysis	BGR Analysis
TiO_2			96.27	
$Zr(Hf)O_2$			0.52	
ZrO_2				
SiO_2			0.62	
Al_2O_3			0.33	
Fe_2O_3			0.59	
Cr_2O_3			0.12	
V_2O_5			0.66	
Nb_2O_5			0.39	
P_2O_5			0.01	
S			0.01	
CaO			0.01	
MgO			0.02	
MnO			0.01	
Moisture (@ 105 °C)				
LOI (@ 950 °C)				
U			26 ppm	
Th				

Sample (Sovereign Analysis): 50 ppm Sn

Grain size distribution µm	Guaranteed	Typical	Sample	
			Sovereign Analysis	BGR Analysis
> 500				
420				
355				
300				
250				
212				
180				
150				
125				
106				
90				
75				
63				
53				
45				
< 45				
Mean (µm)				
D50 (µm)			145	

Name: **MITRACO Rutile 85 %**
Deposit: Hà Tĩnh Province, Vietnam
Producer: HaTinh Minerals and Trading Corporation (MITRACO)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			MITRACO Analysis	BGR Analysis
TiO_2				83.64
$Zr(Hf)O_2$				0.35
ZrO_2				0.35
SiO_2				7.92
Al_2O_3				1.99
Fe_2O_3				3.09
Cr_2O_3				0.09
V_2O_5				0.08
Nb_2O_5				0.28
P_2O_5				0.119
S				0.01
CaO				0.104
MgO				0.08
MnO				0.156
Moisture (@ 105 °C)				
LOI (@ 950 °C)				1.38
U				56
Th				153

Sample (BGR Analysis): 30 ppm As, 254 ppm Ce, 16 ppm Cu, 126 ppm La, 107 ppm Nd, 170 ppm Pb, 758 ppm Sn, 156 ppm Ta, 454 ppm W, 208 ppm Y, 61 ppm Zn

Mineralogical composition (BGR Analysis): 50.4 % rutile, 27.2 % leucoxene, 3.8 % quartz, 3.2 % ilmenite, 1.4 % garnet/tourmaline/aluminosilicates, 0.4 % zircon, 0.1 % monazite, 13.5 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			MITRACO Analysis	BGR Analysis
> 500				0.0
420				0.0
355				0.0
300				0.1
250				1.1
212				4.2
180				11.6
150				24.6
125				27.9
106				17.2
90				8.5
75				3.5
63				1.0
53				0.2
45				0.1
< 45				0.0
Mean (µm)				145.0
D50 (µm)				137.5

Name: **Moma Rutile**
Deposit: Namalope/Moma, Mozambique
Producer: Kenmare Resources plc.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Kenmare Analysis	BGR Analysis
TiO_2				91.36
$Zr(Hf)O_2$				3.63
ZrO_2				3.54
SiO_2				2.23
Al_2O_3				0.40
Fe_2O_3				0.60
Cr_2O_3				0.12
V_2O_5				0.41
Nb_2O_5				0.42
P_2O_5				0.036
S				0.01
CaO				0.060
MgO				< 0.01
MnO				0.010
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.38
U				148 ppm
Th				141 ppm

Sample (BGR Analysis): 8 ppm As, 22 ppm Cu, 51 ppm Mo, 872 ppm Sn, 247 ppm Ta, 343 ppm W, 230 ppm Y, 12 ppm Zn

Mineralogical composition (BGR Analysis): 90.8 % rutile, 6.4 % zircon, 1.2 % leucoxene, 0.4 % garnet/tourmaline/aluminosilicates, 0.3 % ilmenite, 0.1 % cassiterite, 0.1 % quartz, 0.7 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Kenmare Analysis	BGR Analysis
> 500				0.0
420				0.2
355				0.6
300				2.2
250				8.1
212				15.4
180				22.4
150				24.9
125				16.3
106				6.8
90				2.3
75				0.7
63				0.1
53				0.0
45				0.0
< 45				0.0
Mean (µm)				185.8
D50 (µm)				170.9

Name: **Naicher Advanced Material Rutile 85**
Deposit: from Pakistan HM concentrates
Producer: Naicher Advanced Material (Yingkou) Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Naicher Analysis	BGR Analysis
TiO_2		85		82.54
$Zr(Hf)O_2$				4.50
ZrO_2				4.40
SiO_2				8.65
Al_2O_3				0.86
Fe_2O_3				1.06
Cr_2O_3				0.09
V_2O_5				0.29
Nb_2O_5				0.24
P_2O_5		0.18		0.185
S		0.08		< 0.01
CaO				0.11
MgO				0.03
MnO				0.02
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.86
U				132
Th				187

Chemical analysis (BGR): 506 ppm Ce, 187 ppm Sn, 122 ppm Ta, 305 ppm W, 830 ppm Y

Mineralogical composition of sample (BGR Analysis): 69.1 % rutile, 14.1 % leucoxene, 7.8 % zircon, 3.3 % quartz, 0.3 % garnet/tourmaline/aluminosilicates, 0.1 % ilmenite, 5.2 % others/unknown

<table>
<tr><th rowspan="2">Grain size distribution µm</th><th rowspan="2">Guaranteed</th><th rowspan="2">Typical</th><th colspan="2">Sample</th></tr>
<tr><th>Naicher Analysis</th><th>BGR Analysis</th></tr>
<tr><td>> 500</td><td></td><td></td><td></td><td rowspan="4">0.0</td></tr>
<tr><td>420</td><td></td><td></td><td></td></tr>
<tr><td>355</td><td></td><td></td><td></td></tr>
<tr><td>300</td><td></td><td></td><td></td></tr>
<tr><td>250</td><td></td><td></td><td></td><td>0.1</td></tr>
<tr><td>212</td><td></td><td></td><td></td><td>0.5</td></tr>
<tr><td>180</td><td></td><td></td><td></td><td>2.9</td></tr>
<tr><td>150</td><td></td><td></td><td></td><td>11.9</td></tr>
<tr><td>125</td><td></td><td></td><td></td><td>25.1</td></tr>
<tr><td>106</td><td></td><td></td><td></td><td>26.6</td></tr>
<tr><td>90</td><td></td><td></td><td></td><td>19.0</td></tr>
<tr><td>75</td><td></td><td></td><td></td><td>9.8</td></tr>
<tr><td>63</td><td></td><td></td><td></td><td>3.0</td></tr>
<tr><td>53</td><td></td><td></td><td></td><td>0.9</td></tr>
<tr><td>45</td><td></td><td></td><td></td><td>0.1</td></tr>
<tr><td>< 45</td><td></td><td></td><td></td><td>0.1</td></tr>
<tr><td>Mean (µm)</td><td></td><td></td><td></td><td>118.7</td></tr>
<tr><td>D50 (µm)</td><td></td><td></td><td></td><td>101.1</td></tr>
</table>

Name: **Naicher Advanced Material Rutile 90**
Deposit: from Australian HM concentrates
Producer: Naicher Advanced Material (Yingkou) Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Naicher Analysis	BGR Analysis
TiO_2		90		88.13
$Zr(Hf)O_2$				5.20
ZrO_2				5.10
SiO_2				3.14
Al_2O_3				0.97
Fe_2O_3				0.77
Cr_2O_3				0.09
V_2O_5				0.17
Nb_2O_5				0.45
P_2O_5		0.11		0.131
S		0.05		< 0.01
CaO				0.06
MgO				< 0.01
MnO				0.01
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.54
U				72
Th				67

Chemical analysis (BGR): 506 ppm Ce, 135 ppm Sn, 270 ppm Ta, 297 ppm W, 830 ppm Y

Mineralogical composition of sample (BGR Analysis): 85.1 % rutile, 6.6 % leucoxene, 7.0 % zircon, 0.8 % garnet/tourmaline/aluminosilicates, 0.2 % ilmenite, 0.1 % quartz, 0.3 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Naicher Analysis	BGR Analysis
> 500				0.0
420				
355				
300				0.2
250				0.4
212				1.6
180				5.6
150				15.1
125				24.2
106				23.3
90				16.6
75				9.1
63				2.9
53				0.8
45				0.1
< 45				0.1
Mean (µm)				125.5
D50 (µm)				104.7

Name: **Naicher Advanced Material Rutile 92**
Deposit: from US American HM concentrates
Producer: Naicher Advanced Material (Yingkou) Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Naicher Analysis	BGR Analysis
TiO_2			92.05	92.18
$Zr(Hf)O_2$				1.72
ZrO_2			0.08	1.68
SiO_2			1.50	2.81
Al_2O_3				0.79
Fe_2O_3			0.07	0.63
Cr_2O_3				0.11
V_2O_5				0.33
Nb_2O_5				0.36
P_2O_5			0.09	0.047
S			0.04	< 0.01
CaO				0.04
MgO				0.03
MnO				0.01
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.50
U				62
Th				228

Chemical analysis (BGR): 614 ppm Sn, 197 ppm Ta, 307 ppm W

Mineralogical composition of sample (BGR Analysis): 83.8 % rutile, 8.2 % leucoxene, 2.4 % zircon, 1.0 % quartz, 0.9 % garnet/tourmaline/aluminosilicates, 0.1 % ilmenite, 0.1 % cassiterite, 3.5 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Naicher Analysis	BGR Analysis
> 500				0.0
420				
355				
300				
250				0.5
212				2.2
180				6.0
150				15.2
125				24.0
106				22.7
90				16.2
75				9.0
63				3.0
53				0.9
45				0.2
< 45				0.1
Mean (µm)				126.3
D50 (µm)				105.0

Name: **Naicher Advanced Material Rutile 95**
Deposit: from Australian HM concentrates
Producer: Naicher Advanced Material (Yingkou) Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Naicher Analysis	BGR Analysis
TiO_2			95.15	94.77
$Zr(Hf)O_2$				0.88
ZrO_2			0.08	0.86
SiO_2			1.00	1.50
Al_2O_3				0.48
Fe_2O_3			0.05	0.70
Cr_2O_3				0.15
V_2O_5				0.48
Nb_2O_5				0.37
P_2O_5			0.05	0.015
S			0.02	< 0.01
CaO				0.01
MgO				< 0.01
MnO				< 0.01
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.34
U				43
Th				43

Chemical analysis (BGR): 276 ppm Sn, 212 ppm Ta, 490 ppm W

Mineralogical composition of sample (BGR Analysis): 91.4 % rutile, 5.3 % leucoxene, 1.1 % zircon, 1.0 % quartz, 0.4 % garnet/tourmaline/aluminosilicates, 0.1 % ilmenite, 1.2 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Naicher Analysis	BGR Analysis
> 500				0.0
420				
355				0.1
300				0.2
250				1.3
212				5.1
180				13.4
150				25.1
125				25.9
106				16.2
90				8.2
75				3.4
63				0.8
53				0.2
45				0.1
< 45				0.0
Mean (µm)				148.3
D50 (µm)				119.8

Name: **Namakwa Sands Leucoxene (Tiokwa)**
Deposit: Brand se Baai, Western Cape, Republic of South Africa
Producer: Tronox Ltd., Namakwa Sands

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Tronox Analysis	BGR Analysis
TiO_2				91.75
$Zr(Hf)O_2$				0.42
ZrO_2				0.41
SiO_2				3.06
Al_2O_3				0.90
Fe_2O_3				1.30
Cr_2O_3				0.12
V_2O_5				0.23
Nb_2O_5				0.54
P_2O_5				0.149
S				0.01
CaO				0.230
MgO				< 0.01
MnO				0.029
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.74
U				55 ppm
Th				131 ppm

Sample (BGR Analysis): 12 ppm As, 20 ppm Cu, 23 ppm Mo, 53 ppm Pb, 433 ppm Sn, 326 ppm Ta, 525 ppm W, 140 ppm Y, 18 ppm Zn

Mineralogical composition (BGR Analysis): 75.4 % rutile, 17.7 % leucoxene, 0.9 % quartz, 0.5 % zircon, 0.4 % garnet/tourmaline/aluminosilicates, 0.3 % ilmenite, 0.1 % cassiterite, 0.1 % sphene, 4.6 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Tronox Analysis	BGR Analysis
> 500				
420				
355				
300				
250				0.0
212				0.1
180				0.6
150				4.5
125				16.8
106				28.8
90				28.7
75				15.7
63				4.1
53				0.6
45				0.1
< 45				0.0
Mean (µm)				106.6
D50 (µm)				104.3

Name: **Namakwa Sands Rutile**
Deposit: Brand se Baai, Western Cape, Republic of South Africa
Producer: Tronox Ltd., Namakwa Sands

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Tronox Analysis	**BGR Analysis**
TiO_2	> 94.0	94.5		93.91
$Zr(Hf)O_2$				0.77
ZrO_2	< 1.2	1.1		0.75
SiO_2		2.0		2.30
Al_2O_3		0.60		0.61
Fe_2O_3	< 1.0	0.80		0.52
Cr_2O_3		0.14		0.10
V_2O_5		0.33		0.30
Nb_2O_5		0.04		0.36
P_2O_5		0.02		0.082
S		0.0235		0.01
CaO		0.04		0.128
MgO		< 0.01		< 0.01
MnO		0.40		0.009
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.50
U		40 ppm		40 ppm
Th		65 ppm		78 ppm

Typical: 0.01 % Na_2O, < 0.2 % Sn
Sample (BGR Analysis): 9 ppm As, 17 ppm Cu, 21 ppm Mo, 18 ppm Pb, 642 ppm Sn, 191 ppm Ta, 325 ppm W, 140 ppm Y, 18 ppm Zn

Mineralogical composition (BGR Analysis): 84.3 % rutile, 10.6 % leucoxene, 0.9 % quartz, 0.6 % zircon, 0.4 % garnet/tourmaline/aluminosilicates, 0.1 % ilmenite, 0.1 % staurolite, 0.1 % sphene, 4.6 % others/unknown

<table>
<tr><th rowspan="2">Grain size distribution µm</th><th rowspan="2">Guaranteed</th><th rowspan="2">Typical</th><th colspan="2">Sample</th></tr>
<tr><th>Tronox Analysis</th><th>BGR Analysis</th></tr>
<tr><td>> 355</td><td></td><td rowspan="6">14</td><td></td><td></td></tr>
<tr><td>300</td><td></td><td></td><td>0.0</td></tr>
<tr><td>250</td><td></td><td></td><td>0.1</td></tr>
<tr><td>212</td><td></td><td></td><td>0.2</td></tr>
<tr><td>180</td><td></td><td></td><td>1.6</td></tr>
<tr><td>150</td><td></td><td></td><td>8.5</td></tr>
<tr><td>125</td><td></td><td>47</td><td></td><td>21.6</td></tr>
<tr><td>106</td><td></td><td>23</td><td></td><td>27.9</td></tr>
<tr><td>90</td><td></td><td>9</td><td></td><td>23.6</td></tr>
<tr><td>75</td><td></td><td>6</td><td></td><td>12.5</td></tr>
<tr><td>63</td><td></td><td rowspan="4">1</td><td></td><td>3.3</td></tr>
<tr><td>53</td><td></td><td></td><td>0.6</td></tr>
<tr><td>45</td><td></td><td></td><td>0.1</td></tr>
<tr><td>< 45</td><td></td><td></td><td>0.0</td></tr>
<tr><td>Mean (µm)</td><td></td><td></td><td></td><td>113.1</td></tr>
<tr><td>D50 (µm)</td><td></td><td></td><td></td><td>109.5</td></tr>
</table>

Name: **Nordic Rutile**
Deposit: Engebø, Sogn og Fjordane District, Norway
Producer: Nordic Mining ASA

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Nordic Analysis	BGR Analysis
TiO_2	> 94.0		94.90	
$Zr(Hf)O_2$				
ZrO_2	< 1.0		0.06	
SiO_2	< 2.5		1.53	
Al_2O_3	< 1.5		0.31	
Fe_2O_3	< 1.0		1.63	
Cr_2O_3			0.01	
V_2O_5	< 0.65		0.41	
Nb_2O_5	< 0.25–0.5		n.d.	
P_2O_5	< 0.015		0.01	
S			0.17	
CaO	< 0.8		0.35	
MgO	< 1.0		0.03	
MnO	< 1.0		0.02	
Moisture (@ 105 °C)				
LOI (@ 950 °C)				
U			< 10 ppm	
Th			< 10 ppm	

Sample (Nordic Analysis): 0.01 % K_2O, 0.30 % FeS_2, < 0.02 % SnO_2

Grain size distribution µm	Guaranteed	Typical	Sample	
			Nordic Analysis	BGR Analysis
> 500				
420				
355				
300				
250				
212				
180				
150				
125				
106				
90				
75				
63				
53				
45				
< 45				
Mean (µm)				
D50 (µm)				

Name: **OMC Rutile**
Deposit: from Amang, Malaysia
Producer: Kilang Amang Onn Sdn. Bhd. Onn Mineral Company (OMC)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			OMC Analysis	BGR Analysis
TiO_2				89.32
$Zr(Hf)O_2$				0.91
ZrO_2				0.89
SiO_2				2.42
Al_2O_3				1.51
Fe_2O_3				1.43
Cr_2O_3				0.05
V_2O_5				0.11
Nb_2O_5				0.94
P_2O_5				0.055
S				0.01
CaO				0.087
MgO				0.06
MnO				0.058
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.62
U				87 ppm
Th				94 ppm

Sample (BGR Analysis): 39 ppm As, 144 ppm Ce, 129 ppm Pb, 9730 ppm Sn (1.24 % SnO_2), 1765 ppm Ta (0.22 % Ta_2O_5), 3458 ppm W, 178 ppm Y, 36 ppm Zn

Mineralogical composition (BGR Analysis): 81.2 % rutile, 8.2 % leucoxene, 4.1 % zircon, 2.0 % garnet/tourmaline/aluminosilicates, 1.0 % quartz, 0.8 % cassiterite, 0.3 % ilmenite, 2.4 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			OMC Analysis	BGR Analysis
> 500				0.0
420				1.1
355				7.3
300				18.7
250				27.4
212				21.5
180				13.2
150				7.2
125				2.6
106				0.7
90				0.2
75				0.1
63				0.0
53				0.0
45				0.0
< 45				0.0
Mean (µm)				261.9
D50 (µm)				242.3

Name: **Ratana Rutile**
Deposit: from Amang from Thailand
Producer: RATANA GROUP Ratanarungsiwat Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Ratana Analysis	BGR Analysis
TiO_2				85.42
$Zr(Hf)O_2$				1.98
ZrO_2				1.93
SiO_2				2.23
Al_2O_3				0.62
Fe_2O_3				1.25
Cr_2O_3				0.03
V_2O_5				0.11
Nb_2O_5				1.27
P_2O_5				0.073
S				0.02
CaO				0.088
MgO				< 0.01
MnO				0.040
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.46
U				114
Th				377

Sample (BGR Analysis): 11 ppm As, 274 ppm Ce, 121 ppm La, 108 ppm Nd, 131 ppm Pb, 33016 ppm Sn (4.19 % SnO_2), 2765 ppm Ta (0.34 % Ta_2O_5), 2361 ppm W, 200 ppm Y, 18 ppm Zn

Mineralogical composition (BGR Analysis): 80.4 % rutile, 9.7 % leucoxene, 3.4 % cassiterite, 0.9 % quartz, 0.8 % garnet/tourmaline/aluminosilicates, 0.4 % zircon, 0.2 % monazite, 0.1 % ilmenite, 0.1 % columbite-group minerals, 0.1 % pyrochlor-group minerals, 3.2 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Ratana Analysis	BGR Analysis
> 500				3.9
420				7.3
355				13.0
300				17.5
250				20.6
212				15.3
180				10.4
150				6.8
125				3.1
106				1.2
90				0.5
75				0.2
63				0.1
53				0.0
45				0.1
< 45				0.0
Mean (µm)				293.7
D50 (µm)				262.3

Name: **Richards Bay Rutile Prime Grade**
Deposit: Richards Bay, KwaZulu-Natal, Republic of South Africa
Producer: Richards Bay Minerals

Chemical composition wt.-%	Guaranteed	Typical	Sample RBM Analysis	Sample BGR Analysis
TiO_2				94.82
$Zr(Hf)O_2$				0.57
ZrO_2				0.56
SiO_2				1.51
Al_2O_3				0.54
Fe_2O_3				0.82
Cr_2O_3				0.12
V_2O_5				0.42
Nb_2O_5				0.31
P_2O_5				0.025
S				0.01
CaO				0.153
MgO				< 0.01
MnO				0.014
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.46
U				36 ppm
Th				47 ppm

Sample (BGR Analysis): 26 ppm Mo, 100 ppm Sn, 159 ppm Ta, 230 ppm W, 12 ppm Zn

Mineralogical composition (BGR Analysis): 91.3 % rutile, 4.8 % leucoxene, 0.6 % quartz, 0.5 % zircon, 0.5 % garnet/tourmaline/aluminosilicates, 0.3 % ilmenite, 0.1 % sphene, 1.9 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample RBM Analysis	Sample BGR Analysis
> 500				0.0
420				
355				
300				
250				0.1
212				0.5
180				3.6
150				14.8
125				29.8
106				28.0
90				15.8
75				5.8
63				1.2
53				0.3
45				0.1
< 45				0.0
Mean (µm)				124.7
D50 (µm)				121.0

Name: **Richards Bay Rutile Welding Grade**
Deposit: Richards Bay, KwaZulu-Natal, Republic of South Africa
Producer: Richards Bay Minerals

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			RBM Analysis	BGR Analysis
TiO_2	> 92.00	93.50		93.54
$Zr(Hf)O_2$				1.50
ZrO_2	< 2.30	1.80		1.47
SiO_2		0.50		0.53
Al_2O_3		2.00		2.05
Fe_2O_3	< 1.00	0.80		0.67
Cr_2O_3		0.12		0.12
V_2O_5		0.45		0.32
Nb_2O_5		0.30		0.30
P_2O_5		0.04		0.024
S		0.005		0.01
CaO		0.15		0.112
MgO		0.03		< 0.01
MnO		0.02		0.011
Moisture (@ 105 °C)		0.10		
LOI (@ 950 °C)		0.35		0.48
U				44 ppm
Th				54 ppm

Sample (BGR Analysis): 30 ppm Mo, 107 ppm Sn, 156 ppm Ta, 227 ppm W

Mineralogical composition (BGR Analysis): 89.9 % rutile, 4.9 % leucoxene, 2.1 % zircon, 0.8 % quartz, 0.4 % garnet/tourmaline/aluminosilicates, 0.2 % ilmenite, 0.1 % sphene, 1.6 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			RBM Analysis	BGR Analysis
> 500		0.5		0.0
420				0.0
355				0.1
300				0.0
250				0.1
212		0.6		1.0
180		2.3		4.3
150		12.1		14.7
125		26.6		28.4
106		31.9		27.4
90		21.1		16.1
75		4.1		6.2
63		0.8		1.3
53				0.3
45				0.1
< 45				0.0
Mean (µm)				125.6
D50 (µm)				120.6

Name: **RZM Rutile (Historic sample)**
Deposit: Tomago Sandbeds, New South Wales, Australia
Producer: RZM Pty Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			RZM Analysis	BGR Analysis
TiO_2				96.38
$Zr(Hf)O_2$				0.89
ZrO_2				0.87
SiO_2				0.62
Al_2O_3				0.22
Fe_2O_3				0.33
Cr_2O_3				0.17
V_2O_5				0.57
Nb_2O_5				0.35
P_2O_5				0.008
S				0.01
CaO				0.054
MgO				< 0.01
MnO				0.015
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.18
U				46 ppm
Th				< 10 ppm

Sample (BGR Analysis): 44 ppm Mo, 137 ppm Sn, 188 ppm Ta, 262 ppm W

Mineralogical composition (BGR Analysis): 97.3 % rutile, 1.2 % leucoxene, 0.5 % zircon, 0.2 % ilmenite, 0.2 % quartz, 0.6 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			RZM Analysis	BGR Analysis
> 500				0.0
420				0.0
355				0.0
300				0.3
250				2.2
212				8.7
180				21.6
150				33.5
125				22.9
106				7.9
90				2.2
75				0.6
63				0.1
53				0.0
45				0.0
< 45				0.0
Mean (µm)				167.3
D50 (µm)				157.3

Name: **Sakorn Rutile**
Deposit: Mixed sources
Producer: Sakorn Minerals Co. Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Sakorn Analysis	BGR Analysis
TiO_2	> 95.0			
$Zr(Hf)O_2$				
ZrO_2	< 1.0			
SiO_2	< 1.0			
Al_2O_3				
Fe_2O_3				
Cr_2O_3				
V_2O_5				
Nb_2O_5				
P_2O_5				
S				
CaO				
MgO				
MnO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				
U				
Th				

Grain size distribution µm	Guaranteed	Typical	Sample	
			Sakorn Analysis	BGR Analysis
> 500		0.00		
420		0.01		
355				
300				
250				
212		2.17		
180				
150				
125		72.92		
106		14.81		
90		9.93		
75				
63				
53		0.15		
45				
< 45		0.00		
Mean (µm)				
D50 (µm)				

Name: **Senegal Leucoxene**
Deposit: Grande Côte, Senegal
Producer: TiZir Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			TiZir Analysis	BGR Analysis
TiO_2		82–92	89.73	88.94
$Zr(Hf)O_2$				1.99
ZrO_2		0.4–5.1	2.12	1.95
SiO_2		1.5–4.5	2.55	2.59
Al_2O_3		1–2	1.42	1.48
Fe_2O_3		0.9–2.9	2.00	1.99
Cr_2O_3		0.2–1	0.41	0.53
V_2O_5			0.33	0.21
Nb_2O_5			0.44	0.43
P_2O_5		0.07–0.16	0.16	0.141
S		0.01–0.07	0.01	0.01
CaO			0.08	0.114
MgO			0.00	0.02
MnO			0.03	0.032
Moisture (@ 105 °C)				
LOI (@ 950 °C)				1.10
U		30–150 ppm	92 ppm	64 ppm
Th		120–270 ppm	245 ppm	281 ppm

Sample (TiZir Analysis): 0.03 % SnO_2
Sample (BGR Analysis): 23 ppm As, 29 ppm Cu, 27 ppm Mo, 105 ppm Pb, 198 ppm Sn, 251 ppm Ta, 283 ppm W

Mineralogical composition (BGR Analysis): 65.2 % rutile, 27.2 % leucoxene, 2.6 % zircon, 0.4 % quartz, 0.4 % garnet/tourmaline/aluminosilicates, 0.2 % ilmenite, 4.0 % others/unknown

<table>
<tr><th rowspan="2">Grain size distribution µm</th><th rowspan="2">Guaranteed</th><th rowspan="2">Typical</th><th colspan="2">Sample</th></tr>
<tr><th>TiZir Analysis</th><th>BGR Analysis</th></tr>
<tr><td>> 500</td><td></td><td></td><td rowspan="7">1.7</td><td rowspan="4"></td></tr>
<tr><td>420</td><td></td><td></td></tr>
<tr><td>355</td><td></td><td></td></tr>
<tr><td>300</td><td></td><td></td></tr>
<tr><td>250</td><td></td><td></td><td>0.0</td></tr>
<tr><td>212</td><td></td><td></td><td>1.0</td></tr>
<tr><td>180</td><td></td><td></td><td>3.4</td></tr>
<tr><td>150</td><td></td><td></td><td>7.6</td><td>10.7</td></tr>
<tr><td>125</td><td></td><td></td><td>18.6</td><td>22.9</td></tr>
<tr><td>106</td><td></td><td></td><td>32.2</td><td>27.3</td></tr>
<tr><td>90</td><td></td><td></td><td>28.1</td><td>20.7</td></tr>
<tr><td>75</td><td></td><td></td><td>9.1</td><td>10.3</td></tr>
<tr><td>63</td><td></td><td></td><td rowspan="2">2.7</td><td>2.7</td></tr>
<tr><td>53</td><td></td><td></td><td>0.6</td></tr>
<tr><td>45</td><td></td><td></td><td rowspan="2">0.1</td><td>0.2</td></tr>
<tr><td>< 45</td><td></td><td></td><td>0.0</td></tr>
<tr><td>Mean (µm)</td><td></td><td></td><td></td><td>120.0</td></tr>
<tr><td>D50 (µm)</td><td></td><td></td><td>112</td><td>113.7</td></tr>
</table>

Name: **Senegal Rutile**
Deposit: Grande Côte, Senegal
Producer: TiZir Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			TiZir Analysis	BGR Analysis
TiO_2			95.32	94.22
$Zr(Hf)O_2$				0.74
ZrO_2			0.75	0.73
SiO_2			1.20	1.49
Al_2O_3			0.77	0.87
Fe_2O_3			0.73	0.73
Cr_2O_3			0.19	0.21
V_2O_5			0.01	0.23
Nb_2O_5			0.39	0.38
P_2O_5			0.02	0.057
S			0.01	0.01
CaO			0.00	0.079
MgO			0.00	0.01
MnO			0.01	0.006
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.68
U			30 ppm	33 ppm
Th			57 ppm	100 ppm

Sample (TiZir Analysis): 0.07 % SnO_2
Sample (BGR Analysis): 22 ppm Mo, 45 ppm Pb, 313 ppm Sn, 184 ppm Ta, 289 ppm W

Mineralogical composition (BGR Analysis): 85.1 % rutile, 10.7 % leucoxene, 1.1 % zircon, 0.3 % garnet/tourmaline/aluminosilicates, 0.2 % quartz, 2.6 % others/unknown

<table>
<tr><th rowspan="2">Grain size distribution µm</th><th rowspan="2">Guaranteed</th><th rowspan="2">Typical</th><th colspan="2">Sample</th></tr>
<tr><th>TiZir Analysis</th><th>BGR Analysis</th></tr>
<tr><td>> 500</td><td></td><td></td><td rowspan="7">0.1</td><td rowspan="4">0.0</td></tr>
<tr><td>420</td><td></td><td></td></tr>
<tr><td>355</td><td></td><td></td></tr>
<tr><td>300</td><td></td><td></td></tr>
<tr><td>250</td><td></td><td></td><td>0.0</td></tr>
<tr><td>212</td><td></td><td></td><td>0.1</td></tr>
<tr><td>180</td><td></td><td></td><td>0.8</td></tr>
<tr><td>150</td><td></td><td></td><td>2.3</td><td>5.2</td></tr>
<tr><td>125</td><td></td><td></td><td>12.0</td><td>16.8</td></tr>
<tr><td>106</td><td></td><td></td><td>28.3</td><td>28.2</td></tr>
<tr><td>90</td><td></td><td></td><td>35.6</td><td>27.8</td></tr>
<tr><td>75</td><td></td><td></td><td>17.3</td><td>15.8</td></tr>
<tr><td>63</td><td></td><td></td><td rowspan="2">4.3</td><td>4.3</td></tr>
<tr><td>53</td><td></td><td></td><td>0.8</td></tr>
<tr><td>45</td><td></td><td></td><td rowspan="2">0.1</td><td>0.2</td></tr>
<tr><td>< 45</td><td></td><td></td><td>0.0</td></tr>
<tr><td>Mean (µm)</td><td></td><td></td><td></td><td>107.0</td></tr>
<tr><td>D50 (µm)</td><td></td><td></td><td>101</td><td>104.3</td></tr>
</table>

Name: **Sheffield HiTi (Leucoxene 88%)**
Deposit: Thunderbird, Western Australia, Australia
Producer: Sheffield Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Sheffield Analysis	BGR Analysis
TiO_2		87.8		86.94
$Zr(Hf)O_2$		3.2		3.17
ZrO_2				3.11
SiO_2		3.4		3.67
Al_2O_3		0.5		0.63
Fe_2O_3		2.9		2.82
Cr_2O_3		0.07		0.07
V_2O_5		0.24		0.18
Nb_2O_5		0.43		0.43
P_2O_5		0.16		0.167
S		0.02		0.02
CaO		0.04		0.093
MgO		0.04		< 0.01
MnO		0.09		0.088
Moisture (@ 105 °C)				
LOI (@ 950 °C)				1.10
U		96 ppm		89 ppm
Th		308 ppm		305 ppm

Typical: 0.02 % K_2O, 0.05 % CeO_2, 0.11 % SnO_2, 100 ppm As
Sample (BGR Analysis): 29 ppm As, 318 ppm Ce, 77 ppm Cu, 78 ppm Mo, 73 ppm Pb, 222 pm Sc, 1004 ppm Sn, 306 ppm Ta, 468 ppm W, 63 ppm Zn

Typical mineralogical composition: > 85 % rutile/leucoxene, < 5.0 % ilmenite, < 5.0 % zircon, < 0.5 % monazite, < 0.1 % quartz Mineralogical composition (BGR Analysis): 70.6 % rutile, 17.7 % leucoxene, 1.3 % zircon, 1.7 % ilmenite, 0.9 % quartz, 0.6 % garnet/tourmaline/aluminosilicates, 0.2 % Fe-oxy-hydroxides, 0.1 % cassiterite, 3.2 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Sheffield Analysis	BGR Analysis
> 300				0.0
250				0.1
212				0.0
180				0.1
150				0.6
125				1.9
106				6.4
90				17.0
75				31.7
63				25.9
53				12.1
45				3.2
< 45				1.0
Mean (µm)				80.5
D50 (µm)				77.5

Name: **Siberian Leucoxene**
Deposit: Yaregskoye Oil Field, Komi Republic, Russian Federation
Producer: E.I. du Pont de Nemours & Company, Inc.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			DuPont Analysis	BGR Analysis
TiO_2		66.14		50.84
$Zr(Hf)O_2$				0.50
ZrO_2				0.49
SiO_2		28.81		39.90
Al_2O_3		2.64		3.30
Fe_2O_3		1.74		3.05
Cr_2O_3				< 3 ppm
V_2O_5				< 5 ppm
Nb_2O_5		0.08		0.07
P_2O_5				0.150
S				< 0.01
CaO				0.06
MgO		0.13		0.20
MnO				0.01
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.68
U				25 ppm
Th				90 ppm

Sample (BGR Analysis): 58 ppm As, 1017 ppm Ce, 31 ppm Co, 93 ppm Cu, 485 pm La, 454 ppm Nd, 48 ppm Ni, 37 ppm Pb, 89 ppm Pr, 111 ppm Sm, 14 ppm Sn, 41 ppm Ta, 56 ppm W, 229 ppm Y, 127 ppm Zn

Mineralogical composition (BGR Analysis): 39.1 % quartz, 17.3 % rutile, 16.1 % leucoxene, 6.3 % garnet/tourmaline/aluminosilicates, 0.6 % Fe-oxy-hydroxides, 0.5 % zircon, 0.2 % ilmenite, 0.2 % monazite, 19.7 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			DuPont Analysis	BGR Analysis
> 500				3.6
420				2.7
355				4.8
300				7.4
250				11.1
212				12.6
180				13.3
150				13.7
125				10.7
106				7.1
90				5.0
75				3.5
63				2.1
53				1.2
45				0.6
< 45				0.6
Mean (µm)				221.9
D50 (µm)				183.2

Name: **Song Binh Rutile 83 %**
Deposit: Lang Xeo Village, Bac Binh District, Binh Thuan Province, Vietnam
Producer: Song Binh Minerals Joint Stock Company

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Song Binh Analysis	BGR Analysis
TiO_2		> 83.0		
$Zr(Hf)O_2$				
ZrO_2		< 2.0		
SiO_2		6.5–9.5		
Al_2O_3		1–2		
Fe_2O_3		< 2.0		
Cr_2O_3				
V_2O_5				
Nb_2O_5				
P_2O_5				
S				
CaO		< 0.2		
MgO		< 0.04		
MnO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				
U		< 700		
Th				

Grain size distribution µm	Guaranteed	Typical	Sample	
			Song Binh Analysis	BGR Analysis
> 500		0		
420		0.003		
355				
300				
250				
212		46.06		
180				
150				
125				
106		53.77		
90				
75				
63				
53		0.17		
45				
< 45		0		
Mean (µm)				
D50 (µm)				

Name: **Song Binh Rutile 85 %**
Deposit: Lang Xeo Village, Bac Binh District, Binh Thuan Province, Vietnam
Producer: Song Binh Minerals Joint Stock Company

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Song Binh Analysis	BGR Analysis
TiO_2		> 85.0		
$Zr(Hf)O_2$				
ZrO_2		< 1.5		
SiO_2		6.5–9.5		
Al_2O_3		1–2		
Fe_2O_3		< 1.5		
Cr_2O_3				
V_2O_5				
Nb_2O_5				
P_2O_5				
S				
CaO		< 0.2		
MgO		< 0.04		
MnO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				
U		< 700		
Th				

Grain size distribution µm	Guaranteed	Typical	Sample	
			Song Binh Analysis	BGR Analysis
> 500		0		
420		0.003		
355				
300				
250				
212		46.06		
180				
150				
125				
106		53.77		
90				
75				
63				
53		0.17		
45				
< 45		0		
Mean (µm)				
D50 (µm)				

Name: **Song Binh Rutile 87 %**
Deposit: Lang Xeo Village, Bac Binh District, Binh Thuan Province, Vietnam
Producer: Song Binh Minerals Joint Stock Company

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Song Binh Analysis	BGR Analysis
TiO_2		> 87.0		88.90
$Zr(Hf)O_2$				0.67
ZrO_2		< 1.5		0.65
SiO_2		4.5–6.5		4.45
Al_2O_3		1–2		1.75
Fe_2O_3		< 1.25		1.11
Cr_2O_3				0.09
V_2O_5				0.16
Nb_2O_5				0.50
P_2O_5				0.053
S				0.01
CaO		< 0.2		0.091
MgO		< 0.04		0.04
MnO				0.048
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.96
U		< 700		55 ppm
Th				169 ppm

Sample (BGR Analysis): 10 ppm As, 15 ppm Cu, 88 ppm Pb, 4030 ppm Sn (0.51 % SnO_2), 328 ppm Ta, 738 ppm W, 169 ppm Y, 25 ppm Zn

Mineralogical composition (BGR Analysis): 70.1 % rutile, 16.2 % leucoxene, 1.6 % quartz, 0.9 % zircon, 0.8 % garnet/tourmaline/aluminosilicates, 0.7 % cassiterite, 0.1 % ilmenite, 9.6 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Song Binh Analysis	BGR Analysis
> 500		0		
420		0.003		
355				
300				
250				
212		46.06		0.5
180				4.3
150				18.1
125				31.6
106		53.77		25.3
90				13.4
75				5.0
63				1.2
53		0.17		0.2
45				0.1
< 45		0		0.0
Mean (µm)				130.9
D50 (µm)				124.8

Name: **Southern Ionics Mission Leucoxene**
Deposit: Mission, Georgia, USA
Producer: Southern Ionics Inc. (The Chemours Company FC, LLC)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			S. Ionics Analysis	BGR Analysis
TiO_2				72.51
$Zr(Hf)O_2$				2.03
ZrO_2				1.99
SiO_2				3.93
Al_2O_3				3.60
Fe_2O_3				12.57
Cr_2O_3				0.11
V_2O_5				0.09
Nb_2O_5				0.21
P_2O_5				0.592
S				0.01
CaO				0.455
MgO				0.12
MnO				0.531
Moisture (@ 105 °C)				
LOI (@ 950 °C)				2.14
U				81 ppm
Th				586 ppm

Sample (BGR Analysis): 30 ppm As, 2318 ppm Ce, 155 ppm Ga, 1128 ppm La, 55 ppm Mo, 1027 ppm Nd, 270 ppm Pb, 364 ppm Pr, 262 ppm Sm, 89 ppm Sn, 134 ppm Ta, 104 ppm W, 290 ppm Y, 248 ppm Zn

Mineralogical composition (BGR Analysis): 48.4 % leucoxene, 22.0 % rutile, 18.8 % ilmenite, 3.3 % staurolite, 2.7 % garnet/tourmaline/aluminosilicates, 1.8 % zircon, 1.6 % quartz, 0.8 % monazite, 0.6 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			S. Ionics Analysis	BGR Analysis
> 500				0.0
420				0.0
355				0.0
300				0.0
250				0.1
212				0.3
180				0.9
150				3.2
125				11.1
106				23.2
90				29.2
75				21.6
63				7.9
53				1.9
45				0.5
< 45				0.1
Mean (µm)				101.0
D50 (µm)				98.0

Name: **Southern Ionics Mission Rutile Premium Grade**
Deposit: Mission, Georgia, USA
Producer: Southern Ionics Inc. (The Chemours Company FC, LLC)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			S. Ionics Analysis	BGR Analysis
TiO_2				96.76
$Zr(Hf)O_2$				0.39
ZrO_2				0.38
SiO_2				0.65
Al_2O_3				0.35
Fe_2O_3				0.45
Cr_2O_3				0.08
V_2O_5				0.22
Nb_2O_5				0.48
P_2O_5				0.039
S				0.01
CaO				0.063
MgO				< 0.01
MnO				0.003
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.34
U				15 ppm
Th				17 ppm

Sample (BGR Analysis): 23 ppm As, 25 ppm Mo, 17 ppm Pb, 211 ppm Sn, 232 ppm Ta, 307 ppm W

Mineralogical composition (BGR Analysis): 95.9 % rutile, 2.7 % leucoxene, 0.3 % quartz, 0.3 % zircon, 0.1 % garnet/tourmaline/aluminosilicates, 0.7 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			S. Ionics Analysis	BGR Analysis
> 500				0.0
420				0.0
355				0.0
300				0.0
250				0.3
212				0.8
180				2.3
150				6.8
125				16.0
106				24.0
90				25.2
75				17.1
63				5.8
53				1.4
45				0.2
< 45				0.1
Mean (µm)				109.5
D50 (µm)				104.0

Name: **Southern Ionics Mission Rutile 90**
Deposit: Mission, Georgia, USA
Producer: Southern Ionics Inc. (The Chemours Company FC, LLC)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			S. Ionics Analysis	BGR Analysis
TiO_2				91.27
$Zr(Hf)O_2$				0.19
ZrO_2				0.19
SiO_2				0.50
Al_2O_3				1.17
Fe_2O_3				4.12
Cr_2O_3				0.12
V_2O_5				0.13
Nb_2O_5				0.51
P_2O_5				0.191
S				0.01
CaO				0.084
MgO				0.02
MnO				0.116
Moisture (@ 105 °C)				
LOI (@ 950 °C)				1.42
U				16 ppm
Th				43 ppm

Sample (BGR Analysis): 23 ppm As, 25 ppm Cu, 104 ppm Ga, 55 ppm Mo, 173 ppm Pb, 234 ppm Sn, 245 ppm Ta, 240 ppm W, 34 ppm Zn

Mineralogical composition (BGR Analysis): 63.9 % rutile, 32.5 % leucoxene, 2.3 % ilmenite, 0.2 % quartz, 0.2 % zircon, 0.2 % staurolite, 0.7 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			S. Ionics Analysis	BGR Analysis
> 500				0.0
420				0.0
355				0.0
300				0.0
250				0.0
212				0.2
180				0.8
150				3.3
125				11.4
106				23.5
90				29.1
75				21.5
63				7.8
53				1.9
45				0.4
< 45				0.1
Mean (µm)				100.9
D50 (µm)				98.0

Name: **Southern Ionics Mission Rutile**
Deposit: Mission, Georgia, USA
Producer: Southern Ionics Inc. (The Chemours Company FC, LLC)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			S. Ionics Analysis	BGR Analysis
TiO_2				96.13
$Zr(Hf)O_2$				0.38
ZrO_2				0.37
SiO_2				0.53
Al_2O_3				0.48
Fe_2O_3				0.86
Cr_2O_3				0.09
V_2O_5				0.18
Nb_2O_5				0.48
P_2O_5				0.083
S				0.01
CaO				0.072
MgO				< 0.01
MnO				0.015
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.46
U				17 ppm
Th				24 ppm

Sample (BGR Analysis): 8 ppm As, 37 ppm Mo, 43 ppm Pb, 287 ppm Sn, 253 ppm Ta, 307 ppm W

Mineralogical composition (BGR Analysis): 88.7 % rutile, 9.7 % leucoxene, 0.6 % zircon, 0.2 % garnet/tourmaline/aluminosilicates, 0.2 % quartz, 0.6 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			S. Ionics Analysis	BGR Analysis
> 500				0.0
420				0.0
355				0.0
300				0.0
250				0.1
212				0.5
180				1.4
150				5.0
125				14.0
106				24.0
90				27.0
75				19.2
63				6.8
53				1.6
45				0.3
< 45				0.1
Mean (µm)				105.1
D50 (µm)				100.8

Name: **SQC Rutile 87 %**
Deposit: Cát Khánh Village, Phù Cát District, Bình Định Province, Vietnam
Producer: Saigon – Quy Nhon Mining Corporation (SQC)

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			SQC Analysis	**BGR Analysis**
TiO_2				91.17
$Zr(Hf)O_2$				0.13
ZrO_2				0.13
SiO_2				2.01
Al_2O_3				1.62
Fe_2O_3				4.87
Cr_2O_3				0.07
V_2O_5				0.16
Nb_2O_5				0.10
P_2O_5				0.002
S				0.02
CaO				0.310
MgO				0.25
MnO				2.687
Moisture (@ 105 °C)				
LOI (@ 950 °C)				–3.62
U				19 ppm
Th				102 ppm

Sample (BGR Analysis): 216 ppm Ce, 35 ppm Sn, 94 ppm Ta, 24 ppm W, 206 ppm Y, 12 ppm Zn

Mineralogical composition (BGR Analysis): 56.2 % rutile, 39.7 % leucoxene, 1.2 % garnet/tourmaline/aluminosilicates, 0.5 % quartz, 0.3 % ilmenite, 0.2 % sphene, 0.1 % Fe-oxy-hydroxides, 1.8 % others/unknown

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			SQC Analysis	**BGR Analysis**
> 500				0.1
420				0.2
355				1.2
300				4.4
250				7.2
212				7.6
180				8.4
150				10.6
125				11.8
106				11.0
90				10.5
75				9.9
63				7.1
53				4.5
45				2.6
< 45				2.9
Mean (µm)				148.1
D50 (µm)				124.4

Name: **SRL Industrial Grade Rutile**
Deposit: Lanti/Gangama, Gbangbama District, Sierra Leone
Producer: Iluka Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Iluka Analysis	BGR Analysis
TiO_2			96.3	95.97
Zr(Hf)O_2				0.83
ZrO_2			0.83	0.83
SiO_2			0.84	0.89
Al_2O_3			0.16	0.25
Fe_2O_3			0.6	0.59
Cr_2O_3			0.234	0.23
V_2O_5			0.62	0.59
Nb_2O_5			0.15	0.15
P_2O_5			< 0.01	0.019
S			0.010	0.01
CaO			0.01	0.049
MgO			< 0.02	< 0.01
MnO			0.01	0.007
Moisture (@ 105 °C)			0.02	
LOI (@ 950 °C)				0.32
U			24 ppm	23 ppm
Th			32 ppm	36 ppm

Sample (Iluka Analysis): < 0.01 % CeO_2, < 10 ppm As, < 10 ppm Cu, 128 ppm Ni, < 20 ppm Pb, 25 ppm Sn, < 20 pm Zn
Sample (BGR Analysis): 29 ppm Mo, 27 ppm Sn, 52 ppm Ta, 23 ppm W, 19 ppm Zn

Mineralogical composition (BGR Analysis): 95.5 % rutile, 1.3 % leucoxene, 1.4 % zircon, 0.7 % ilmenite, 0.6 % quartz, 0.3 % garnet/tourmaline/aluminosilicates, 0.2 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Iluka Analysis	BGR Analysis
> 500			0.1	0.0
420				0.0
355				0.0
300				0.0
250			0.0	0.0
212			0.1	0.0
180			0.1	0.2
150			0.4	1.3
125			2.9	6.4
106			19.5	14.6
90			25.2	21.5
75			19.5	24.4
63			32.2	17.1
53				8.8
45				3.8
< 45				1.8
Mean (µm)				88.4
D50 (µm)				85.1

Name: **SRL Standard Grade Rutile**
Deposit: Lanti/Gangama, Gbangbama District, Sierra Leone
Producer: Iluka Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Iluka Analysis	BGR Analysis
TiO_2			96.4	95.54
$Zr(Hf)O_2$				0.87
ZrO_2			0.97	0.86
SiO_2			0.79	0.81
Al_2O_3			0.34	0.31
Fe_2O_3			1.1	0.90
Cr_2O_3			0.231	0.22
V_2O_5			0.67	0.62
Nb_2O_5			0.16	0.14
P_2O_5			0.04	0.016
S			0.164	0.01
CaO			0.01	0.051
MgO			0.04	< 0.01
MnO			0.01	0.007
Moisture (@ 105 °C)			0.03	
LOI (@ 950 °C)				0.38
U			29 ppm	18 ppm
Th			44 ppm	40 ppm

Sample (Iluka Analysis): 0.05 % CeO_2, < 10 ppm As, < 20 ppm Cu, 27 ppm Ni, < 20 ppm Pb, < 25 ppm Sn, < 20 pm Zn
Sample (BGR Analysis): 27 ppm Mo, 83 ppm Sn, 57 ppm Ta, 27 ppm W, 10 ppm Zn

Mineralogical composition (BGR Analysis): 94.6 % rutile, 1.2 % leucoxene, 1.2 % zircon, 1.0 % ilmenite, 0.6 % quartz, 0.5 % garnet/tourmaline/aluminosilicates, 0.9 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Iluka Analysis	BGR Analysis
> 500			16.3	5.0
420				3.1
355				4.0
300				5.4
250			8.0	8.1
212			10.2	9.7
180			7.8	11.6
150			19.3	14.2
125			12.8	13.2
106			10.7	9.9
90			7.0	7.1
75			4.0	4.7
63			4.0	2.3
53				1.0
45				0.4
< 45				0.3
Mean (µm)				212.8
D50 (µm)				165.7

Name: **Suixi Jindi Mineral Rutile 85**
Deposit: from Vietnamese HM concentrates
Producer: Suixi Jindi Mineral Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Suixi Jindi Analysis	BGR Analysis
TiO_2			85	81.96
$Zr(Hf)O_2$				2.89
ZrO_2				2.83
SiO_2				9.08
Al_2O_3				2.36
Fe_2O_3				1.15
Cr_2O_3				0.08
V_2O_5				0.12
Nb_2O_5				0.29
P_2O_5			0.10	0.139
S			0.025	< 0.01
CaO				0.12
MgO				0.07
MnO				0.03
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.94
U				103
Th				185

Chemical analysis (BGR): 477 ppm Ce, 146 ppm La, 112 ppm Pb, 302 ppm Sn, 164 ppm Ta, 480 ppm W, 280 ppm Y

Mineralogical composition of sample (BGR Analysis): 59.2 % rutile, 18.8 % leucoxene, 4.5 % zircon, 3.9 % quartz, 2.6 % garnet/tourmaline/aluminosilicates, 0.2 % ilmenite, 10.8 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Suixi Jindi Analysis	BGR Analysis
> 500				0.0
420				
355				
300				
250				0.2
212				1.4
180				5.9
150				18.9
125				29.9
106				23.4
90				12.9
75				5.4
63				1.4
53				0.4
45				0.1
< 45				0.1
Mean (µm)				130.7
D50 (µm)				109.7

Name: **Suixi Jindi Mineral Rutile 90**
Deposit: from US American HM concentrates
Producer: Suixi Jindi Mineral Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Suixi Jindi Analysis	BGR Analysis
TiO_2			90.2	87.75
$Zr(Hf)O_2$				4.22
ZrO_2				4.15
SiO_2				3.78
Al_2O_3				1.18
Fe_2O_3				0.97
Cr_2O_3				0.13
V_2O_5				0.28
Nb_2O_5				0.29
P_2O_5			0.05	0.055
S			0.018	< 0.01
CaO				0.07
MgO				0.03
MnO				0.01
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.76
U				49
Th				141

Chemical analysis (BGR): 349 ppm Ce, 98 ppm Pb, 0.13 % SnO_2, 161 ppm Ta,167 ppm W

Mineralogical composition of sample (BGR Analysis): 70.3 % rutile, 20.1 % leucoxene, 4.9 % zircon, 1.5 % garnet/tourmaline/aluminosilicates, 1.0 % quartz, 2.1 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Suixi Jindi Analysis	BGR Analysis
> 500				0.0
420				
355				0.1
300				0.9
250				3.7
212				8.7
180				14.8
150				20.7
125				18.5
106				12.1
90				8.3
75				6.1
63				3.4
53				1.7
45				0.6
< 45				0.4
Mean (µm)				151.9
D50 (µm)				122.1

Name: **Suixi Jindi Mineral Rutile 95**
Deposit: from Indonesian HM concentrates
Producer: Suixi Jindi Mineral Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Suixi Jindi Analysis	BGR Analysis
TiO_2			95.1	95.38
$Zr(Hf)O_2$				1.17
ZrO_2				1.14
SiO_2				0.91
Al_2O_3				0.35
Fe_2O_3				0.51
Cr_2O_3				0.17
V_2O_5				0.50
Nb_2O_5				0.42
P_2O_5			0.05	0.021
S			0.018	< 0.01
CaO				0.02
MgO				< 0.01
MnO				0.01
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.22
U				56
Th				98

Chemical analysis (BGR): 451 ppm Sn, 213 ppm Ta, 333 ppm W

Mineralogical composition of sample (BGR Analysis): 95.2 % rutile, 2.1 % leucoxene, 1.7 % zircon, 0.2 % garnet/tourmaline/aluminosilicates, 0.1 % ilmenite, 0.1 % quartz, 0.6 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Suixi Jindi Analysis	BGR Analysis
> 500				0.0
420				
355				
300				0.4
250				2.1
212				6.0
180				11.7
150				16.8
125				15.7
106				14.3
90				13.7
75				10.8
63				5.3
53				2.1
45				0.8
< 45				0.3
Mean (µm)				136.0
D50 (µm)				109.1

Name: **Suixi Ruifeng Mining Rutile 85**
Deposit: from Russian HM concentrates
Producer: Suixi Ruifeng Mining Co., Ltd.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Suixi Ruifeng Analysis	**BGR Analysis**
TiO_2				89.57
$Zr(Hf)O_2$				3.88
ZrO_2				3.81
SiO_2				3.30
Al_2O_3				0.54
Fe_2O_3				0.94
Cr_2O_3				0.08
V_2O_5				0.20
Nb_2O_5				0.32
P_2O_5				0.077
S				
CaO				0.07
MgO				0.01
MnO				0.02
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.56
U				87
Th				145

Chemical analysis (BGR): 306 ppm Ce, 205 ppm Sn, 181 ppm Ta, 400 ppm W, 322 ppm Y

Mineralogical composition of sample (BGR Analysis): 82.5 % rutile, 8.5 % leucoxene, 6.3 % zircon, 0.4 % quartz, 0.2 % garnet/tourmaline/aluminosilicates, 0.1 % ilmenite, 2.0 % others/unknown

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			Suixi Ruifeng Analysis	**BGR Analysis**
> 500				0.0
420				
355				
300				0.1
250				0.0
212				0.1
180				0.2
150				0.3
125				0.7
106				1.3
90				4.4
75				22.4
63				38.2
53				25.9
45				4.8
< 45				1.6
Mean (µm)				71.0
D50 (µm)				64.0

Name: **Suixi Ruifeng Mining Rutile 85**
Deposit: from Senegalese HM concentrates
Producer: Suixi Ruifeng Mining Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Suixi Ruifeng Analysis	BGR Analysis
TiO_2				88.30
$Zr(Hf)O_2$				2.40
ZrO_2				2.35
SiO_2				3.76
Al_2O_3				1.64
Fe_2O_3				1.23
Cr_2O_3				0.42
V_2O_5				0.19
Nb_2O_5				0.31
P_2O_5				0.140
S				< 0.01
CaO				0.08
MgO				0.04
MnO				0.02
Moisture (@ 105 °C)				
LOI (@ 950 °C)				1.04
U				87
Th				256

Chemical analysis (BGR): 339 ppm Ce, 86 ppm Pb, 155 ppm Sn, 143 ppm Ta, 245 ppm W, 322 ppm Y

Mineralogical composition of sample (BGR Analysis): 65.5 % rutile, 24.6 % leucoxene, 3.3 % zircon, 0.7 % quartz, 0.6 % garnet/tourmaline/aluminosilicates, 0.1 % ilmenite, 5.2 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Suixi Ruifeng Analysis	BGR Analysis
> 500				0.0
420				
355				
300				
250				
212				
180				0.4
150				4.1
125				19.2
106				31.2
90				25.7
75				13.1
63				4.3
53				1.4
45				0.5
< 45				0.1
Mean (µm)				106.9
D50 (µm)				94.4

Name: **Suixi Ruifeng Mining Rutile 90**
Deposit: from Australian HM concentrates
Producer: Suixi Ruifeng Mining Co., Ltd.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Suixi Ruifeng Analysis	**BGR Analysis**
TiO_2				94.17
$Zr(Hf)O_2$				0.96
ZrO_2				0.94
SiO_2				1.35
Al_2O_3				0.68
Fe_2O_3				0.94
Cr_2O_3				0.20
V_2O_5				0.32
Nb_2O_5				0.49
P_2O_5				0.046
S				< 0.01
CaO				0.03
MgO				0.04
MnO				0.01
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.44
U				40
Th				128

Chemical analysis (BGR): 128 ppm Sn, 243 ppm Ta, 285 ppm W, 322 ppm Y

Mineralogical composition of sample (BGR Analysis): 85.7 % rutile, 10.5 % leucoxene, 1.2 % zircon, 0.2 % quartz, 0.2 % ilmenite, 0.3 % garnet/tourmaline/aluminosilicates, 1.9 % others/unknown

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			Suixi Ruifeng Analysis	**BGR Analysis**
> 500				0.0
420				
355				0.1
300				0.0
250				1.8
212				11.6
180				28.3
150				30.8
125				15.1
106				6.6
90				3.4
75				1.5
63				0.5
53				0.2
45				0.1
< 45				0.0
Mean (µm)				171.2
D50 (µm)				136.9

Name: **Suixi Ruifeng Mining Rutile 95**
Deposit: from Australian HM concentrates
Producer: Suixi Ruifeng Mining Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Suixi Ruifeng Analysis	BGR Analysis
TiO_2				94.88
$Zr(Hf)O_2$				0.42
ZrO_2				0.41
SiO_2				1.44
Al_2O_3				0.78
Fe_2O_3				0.69
Cr_2O_3				0.17
V_2O_5				0.29
Nb_2O_5				0.39
P_2O_5				0.045
S				< 0.01
CaO				0.04
MgO				0.02
MnO				< 0.01
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.48
U				33
Th				85

Chemical analysis (BGR): 334 ppm Sn, 195 ppm Ta, 285 ppm W

Mineralogical composition of sample (BGR Analysis): 86.0 % rutile, 10.6 % leucoxene, 0.4 % zircon, 0.4 % garnet/tourmaline/aluminosilicates, 0.3 % quartz, 0.1 % ilmenite, 2.2 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Suixi Ruifeng Analysis	BGR Analysis
> 500				0.0
420				
355				
300				
250				
212				0.2
180				1.4
150				7.3
125				19.2
106				27.6
90				24.7
75				14.0
63				4.3
53				1.0
45				0.2
< 45				0.1
Mean (µm)				110.2
D50 (µm)				95.2

Name: **Rutile Standard Grade**
Deposit: Srikurmam, Andhra Pradesh, India
Producer: Trimex Sands Pvt. Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Trimex Analysis	BGR Analysis
TiO_2	> 94.00	94.50		95.83
$Zr(Hf)O_2$				0.99
ZrO_2	< 2.0	1.50		0.97
SiO_2	< 2.0	1.50		0.79
Al_2O_3	< 0.5	0.50		0.28
Fe_2O_3	< 1.0	0.70		0.42
Cr_2O_3		0.07		0.12
V_2O_5				0.52
Nb_2O_5				0.37
P_2O_5	< 0.07	0.04		0.043
S	< 0.002			0.01
CaO		0.03		0.082
MgO		0.30		< 0.01
MnO				0.004
Moisture (@ 105 °C)		0.40		
LOI (@ 950 °C)				0.32
U		32 ppm		36 ppm
Th				257 ppm

Sample (BGR Analysis): 25 ppm Mo, 182 ppm Sn, 154 ppm Ta, 81 ppm W, 27 ppm Zn

Mineralogical composition (BGR Analysis): 96.5 % rutile, 1.4 % zircon, 0.9 % leucoxene, 0.2 % ilmenite, 0.2 % garnet/tourmaline/aluminosilicates, 0.2 % monazite, 0.1 % cassiterite, 0.1 % quartz, 0.4 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Trimex Analysis	BGR Analysis
> 500		traces		0.0
420				0.0
355		< 1.0		0.2
300				1.3
250		1.0–4.0		5.7
212		5.0–15.0		12.1
180		18.0–30.0		18.8
150		20.0–35.0		23.9
125		15.0–25.0		19.2
106		5.0–15.0		10.6
90		2.0–6.0		5.1
75		< 2.5		2.3
63		traces		0.6
53				0.1
45				0.1
< 45				0.0
Mean (µm)				169.9
D50 (µm)				157.9

Name: **Rutile Premium Grade**
Deposit: Cooljarloo, Western Australia, Australia
Producer: Tronox Australia Pty Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Tronox Analysis	BGR Analysis
TiO_2	> 95.00	95.22–96.01		93.69
$Zr(Hf)O_2$				0.85
ZrO_2	< 1.00	0.67–1.00		0.83
SiO_2		0.61–0.85		1.17
Al_2O_3		0.25–0.41		0.83
Fe_2O_3	< 1.00	0.71–1.00		1.38
Cr_2O_3		0.15–0.17		0.18
V_2O_5		0.48–0.53		0.41
Nb_2O_5				0.32
P_2O_5		0.02–0.07		0.079
S		0.005–0.010		0.01
CaO		0.01–0.02		0.071
MgO		0.01–0.03		< 0.01
MnO		< 0.01		0.018
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.72
U		15–45 ppm		55 ppm
Th		5–55 ppm		78 ppm

Sample (BGR Analysis): 34 ppm As, 72 ppm Mo, 198 ppm Pb, 98 ppm Sn, 170 ppm Ta, 185 ppm W

Mineralogical composition (BGR Analysis): 84.6 % rutile, 12.4 % leucoxene, 1.7 % zircon, 0.3 % quartz, 0.1 % ilmenite, 0.1 % garnet/tourmaline/aluminosilicates, 0.8 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Tronox Analysis	BGR Analysis
> 500				0.0
420				0.2
355		2.1		0.8
300				2.6
250		5.4		7.7
212		12.3		14.4
180		22.6		20.5
150		29.7		22.5
125		25.4		15.9
106				8.4
90				4.3
75				1.9
63				0.6
53		2.5		0.2
45				0.0
< 45				0.0
Mean (µm)				181.3
D50 (µm)				166.9

Name: **Leucoxene Standard Grade**
Deposit: Cooljarloo, Western Australia, Australia
Producer: Tronox Australia Pty Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Samples I (II)	
			Tronox Analysis	BGR Analysis
TiO_2	> 92.00	92.00–93.60		86.26 (93.22)
$Zr(Hf)O_2$				0.50 (0.31)
ZrO_2		0.31–0.69		0.49 (0.30)
SiO_2		0.69–0.98		1.29 (1.36)
Al_2O_3		0.60–0.95		1.53 (0.98)
Fe_2O_3		2.20–3.64		6.29 (1.53)
Cr_2O_3		0.18–0.22		0.28 (0.19)
V_2O_5		0.25–0.35		0.36 (0.32)
Nb_2O_5				0.31 (0.32)
P_2O_5		0.14–0.21		0.196 (0.136)
S		0.010–0.030		0.02 (0.01)
CaO		0.02–0.05		0.098 (0.089)
MgO		0.03–0.09		0.03 (0.01)
MnO		0.01–0.03		0.107 (0.016)
Moisture (@ 105 °C)				
LOI (@ 950 °C)				2.26 (1.20)
U		30–80 ppm		81 ppm (45 ppm)
Th		60–140 ppm		268 ppm (149 ppm)

Typical: 0.02–0.04 % PbO_2,
Samples I (II) (BGR Analysis): 86 (55) ppm As, 22 (< 13) ppm Cu, 75 (83) ppm Mo, 779 (181) ppm Pb, 145 (94) ppm Sn, 186 (175) ppm Ta, 174 (186) ppm W, 78 (< 11) ppm Zn

Mineralogical composition (BGR Analysis): 62.0 (24.7) % leucoxene, 33.4 (72.1) % rutile, 1.2 (0.1) % ilmenite, 0.6 (0.3) % zircon, 0.3 (0.0) % staurolite, 0.2 (0.7) % quartz, 0.2 (0.4) % garnet/tourmaline/aluminosilicates, 2.1 (1.7) % others/unknown

Grain size distribution µm	Guaranteed	Typical	Samples I (II)	
			Tronox Analysis	BGR Analysis
> 500		4.6		0.0 (0.1)
420				0.2 (1.9)
355				0.8 (8.2)
300				4.1 (20.5)
250		14.1		12.4 (27.4)
212		24.4		18.4 (16.7)
180		23.5		20.7 (10.6)
150		18.8		19.4 (7.9)
125		10.6		12.5 (4.1)
106				6.5 (1.7)
90		4.1		3.2 (0.6)
75				1.3 (0.2)
63				0.4 (0.1)
53				0.1 (0.0)
< 53				0.0 (0.0)
Mean (µm)				195.2 (264.2)
D50 (µm)				180.7 (249.1)

Name: **Tronox Brasil Rutilo (01)**
Deposit: Mataraca, Paraiba, Brazil
Producer: Tronox Pigmentos do Brasil S.A.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Tronox Analysis	BGR Analysis
TiO_2	> 94.0	94.5		91.00
$Zr(Hf)O_2$				2.78
ZrO_2		1.50		2.71
SiO_2		1.00		1.98
Al_2O_3		0.70		0.67
Fe_2O_3	< 1.0	0.85		1.22
Cr_2O_3				0.12
V_2O_5				0.23
Nb_2O_5		< 0.60		0.71
P_2O_5		0.05		0.054
S				0.01
CaO		< 0.10		0.066
MgO		< 0.50		< 0.01
MnO		< 0.05		0.030
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.60
U				110 ppm
Th				241 ppm

Sample (BGR Analysis): 8 ppm As, 33 ppm Mo, 31 ppm Pb, 1314 ppm Sn, 391 ppm Ta, 472 ppm W, 61 ppm Zn

Mineralogical composition (BGR Analysis): 90.1 % rutile, 4.4 % zircon, 3.5 % leucoxene, 0.5 % ilmenite, 0.5 % garnet/tourmaline/aluminosilicates, 0.2 % quartz, 0.2 % cassiterite, 0.6 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Tronox Analysis	BGR Analysis
> 500		13.2		1.1
420				0.8
355				0.7
300				0.8
250				1.6
212		48.9		3.8
180				9.6
150		25.0		20.5
125		10.7		25.3
106				18.2
90		2.1		10.4
75				4.9
63		0.1		1.6
53				0.5
45				0.1
< 45				0.1
Mean (µm)				151.1
D50 (µm)				134.2

Name: **Tronox Murray Basin Rutile**
Deposit: Gingko-Snapper, New South Wales, Australia
Producer: Tronox Australia Pty Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Tronox Analysis	BGR Analysis
TiO_2			95.2	94.99
$Zr(Hf)O_2$				0.47
ZrO_2			0.48	0.46
SiO_2			1.65	1.72
Al_2O_3			0.27	0.34
Fe_2O_3			0.67	0.68
Cr_2O_3			0.14	0.13
V_2O_5			0.60	0.55
Nb_2O_5			0.33	0.32
P_2O_5			0.04	0.039
S			< 0.005	0.01
CaO			0.02	0.068
MgO			< 0.03	< 0.01
MnO			< 0.01	0.009
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.46
U			45 ppm	43 ppm
Th			< 15 ppm	25 ppm

Sample (Tronox Analysis): < 10 ppm As, 24 ppm Pb, < 20 ppm Zn, 347 ppm Sn, 0.01 % CeO_2
Sample (BGR Analysis): 39 ppm Mo, 14 ppm Pb, 268 ppm Sn, 166 ppm Ta, 272 ppm W

Mineralogical composition (BGR Analysis): 90.9 % rutile, 6.0 % leucoxene, 1.0 % quartz, 0.3 % zircon, 0.1 % ilmenite, 0.1 % garnet/tourmaline/aluminosilicates, 1.6 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Tronox Analysis	BGR Analysis
> 500				0.0
420				0.0
355				0.0
300				0.2
250				1.5
212				4.5
180				10.2
150				20.4
125				25.7
106				19.2
90				11.1
75				5.1
63				1.5
53				0.4
45				0.2
< 45				0.0
Mean (µm)				140.9
D50 (µm)				132.4

Name: **Tronox Wonnerup Leucoxene 88 %**
Deposit: Wonnerup, Western Australia, Australia
Producer: Tronox Australia Pty Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Tronox Analysis	BGR Analysis
TiO_2			88.4	88.22
$Zr(Hf)O_2$				1.25
ZrO_2			1.15	1.24
SiO_2			1.10	1.15
Al_2O_3			2.04	2.15
Fe_2O_3			3.53	3.48
Cr_2O_3			0.20	0.20
V_2O_5			0.19	0.14
Nb_2O_5			0.36	0.35
P_2O_5			0.06	0.068
S			0.021	0.01
CaO			0.06	0.109
MgO			0.05	0.04
MnO			0.03	0.030
Moisture (@ 105 °C)				
LOI (@ 950 °C)				2.52
U			23 ppm	22 ppm
Th			226 ppm	229 ppm

Sample (Tronox Analysis): 44 ppm As, 296 ppm Pb, < 20 ppm Zn, 107 ppm Sn, 0.05 % CeO_2
Sample (BGR Analysis): 47 ppm As, 231 ppm Ce, 85 ppm Mo, 230 ppm Pb, 94 ppm Sn, 169 ppm Ta, 85 ppm W, 14 ppm Zn

Mineralogical composition (BGR Analysis): , 69.0 % leucoxene, 29.0 % rutile, 1.0 % zircon, 0.2 % ilmenite, 0.2 % garnet/tourmaline/aluminosilicates, 0.1 % staurolite, 0.1 % quartz, 0.4 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Tronox Analysis	BGR Analysis
> 420				0.0
355				0.1
300				0.7
250				2.4
212				5.9
180				12.5
150				22.2
125				24.0
106				16.6
90				9.2
75				4.4
63				1.4
53				0.4
45				0.1
< 45				0.1
Mean (µm)				148.5
D50 (µm)				138.5

Name: **Universal Rutile**
Deposit: from Amang, Malaysia
Producer: Universal Minerals Trading Sdn. Bhd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Universal Analysis	BGR Analysis
TiO_2				88.87
$Zr(Hf)O_2$				0.29
ZrO_2				0.28
SiO_2				1.04
Al_2O_3				0.61
Fe_2O_3				1.75
Cr_2O_3				0.03
V_2O_5				0.07
Nb_2O_5				1.48
P_2O_5				0.039
S				0.01
CaO				0.078
MgO				< 0.01
MnO				0.052
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.48
U				47 ppm
Th				84 ppm

Sample (BGR Analysis): 233 ppm As, 138 ppm Ce, 168 ppm Pb, 26204 ppm Sn (3.33 % SnO_2), 3735 ppm Ta (0.46 % Ta_2O_5), 5180 ppm W, 129 ppm Y, 12 ppm Zn

Mineralogical composition (BGR Analysis): 76.6 % rutile, 14.4 % leucoxene, 2.4 % cassiterite, 0.8 % garnet/tourmaline/aluminosilicates, 0.4 % zircon, 0.4 % quartz, 0.1 % ilmenite, 0.1 % columbite-group minerals, 0.1 % pyrochlo-group minerals, 4.7 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Universal Analysis	BGR Analysis
> 500				0.0
420				0.2
355				0.7
300				3.7
250				11.2
212				17.9
180				21.2
150				21.2
125				13.3
106				5.9
90				2.7
75				1.2
63				0.5
53				0.2
45				0.0
< 45				0.1
Mean (µm)				193.1
D50 (µm)				178.2

Name: **Vilnohirsk Rutile Standard Grade**
Deposit: Malyshev, Dniepropetrovsk region, Ukraine
Producer: United Mining and Chemical Company PJCS

Chemical composition wt.-%	Guaranteed	Typical	Samples I (II)	
			UMCC Analysis	BGR Analysis
TiO_2	> 94.00	94.75		95.61 (93.72)
$Zr(Hf)O_2$				0.78 (1.19)
ZrO_2	< 1.00	0.80		0.76 (1.17)
SiO_2	< 1.50	1.30		1.06 (1.60)
Al_2O_3	< 0.60	0.40		0.26 (0.65)
Fe_2O_3	< 1.50	1.30		0.81 (1.32)
Cr_2O_3				0.12 (0.12)
V_2O_5				0.37 (0.32)
Nb_2O_5				0.37 (0.37)
P_2O_5	< 0.07	0.06		0.027 (0.043)
S	< 0.03	0.02		0.01 (0.01)
CaO				0.077 (0.083)
MgO				< 0.01 (< 0.01)
MnO				0.019 (0.044)
Moisture (@ 105 °C)	< 0.5	0.3		
LOI (@ 950 °C)				0.36 (0.36)
U		30 ppm		31 ppm (26 ppm)
Th				26 ppm (35 ppm)

Samples I (II) (BGR Analysis): 6 (10) ppm As, (< 12) 15 ppm Cu, 35 (40) ppm Mo, 21 (20) ppm Pb, 76 (75) ppm Sn, 171 (174) ppm Ta, 167 (160 ppm) W, 10 (14) ppm Zn

Mineralogical composition (BGR Analysis): 92.8 (88.6) % rutile, 4.2 (6.2) % leucoxene, 1.0 (1.7) % zircon, 0.6 (0.6) % quartz, 0.4 (1.3) % ilmenite, 0.2 (0.8) % garnet/tourmaline/aluminosilicates, 0.8 (0.8) % others/ unknown

Grain size distribution µm	Guaranteed	Typical	Samples I (II)	
			UMCC Analysis	BGR Analysis
> 420		1.00		0.0
355				0.0 (0.1)
300				0.0 (0.0)
250				0.1 (0.1)
212				0.9 (0.8)
180		4.00		4.4 (4.0)
150				18.3 (15.9)
125		40.00		33.0 (30.8)
106				26.0 (27.4)
90		54.00		12.5 (14.7)
75				3.9 (5.0)
63		1.00		0.7 (0.9)
53				0.1 (0.1)
45				0.0 (0.1)
< 45				0.0 (0.0)
Mean (µm)				131.0 (128.1)
D50 (µm)				126.1 (122.7)

Name: **V.V. Mineral Rutile**
Deposit: Kanyakumari District, Tamil Nadu, India
Producer: V.V. Mineral Pvt. Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			V.V. Analysis	BGR Analysis
TiO_2	> 94.00	95.23		
$Zr(Hf)O_2$	< 2.00	1.42		
ZrO_2				
SiO_2	< 1.50	0.94		
Al_2O_3	< 0.40	0.21		
Fe_2O_3	< 0.70	0.38		
Cr_2O_3				
V_2O_5	< 0.60	0.48		
Nb_2O_5				
P_2O_5	< 0.03	0.012		
S				
CaO				
MgO				
MnO				
Moisture (@ 105 °C)	< 0.5	0.3		
LOI (@ 950 °C)				
U	< 150 ppm	94 ppm		
Th	< 200 ppm	120 ppm		

Grain size distribution µm	Guaranteed	Typical	Sample	
			V.V. Analysis	BGR Analysis
> 500	< 1	0.0		
420				
355	0–3	0.16		
300				
250	0–4	2.10		
212	3–15	7.80		
180	10–25	15.70		
150	25–40	31.44		
125	20–35	27.80		
106	5–20	10.16		
90	0–10	3.26		
75	0–5	1.42		
63	0–3	0.16		
53				
45				
< 45				
Mean (µm)				
D50 (µm)				

Name: **Wanning Yiyuanfeng Mining Rutile 80**
Deposit: from Mozambique HM concentrates
Producer: Wanning Yiyuanfeng Mining Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Wanning Yiyuanfeng Analysis	BGR Analysis
TiO_2				81.34
$Zr(Hf)O_2$				6.54
ZrO_2				6.40
SiO_2				6.56
Al_2O_3				1.36
Fe_2O_3				1.14
Cr_2O_3				0.10
V_2O_5				0.24
Nb_2O_5				0.44
P_2O_5				0.231
S				< 0.01
CaO				0.23
MgO				0.11
MnO				0.02
LOI (@ 950 °C)				0.88
U				164
Th				359

Chemical analysis (BGR): 861 ppm Ce, 309 ppm La, 240 ppm Nd, 59 ppm Pb, 616 ppm Sn, 283 ppm Ta, 437 ppm W, 497 ppm Y

Mineralogical composition of sample (BGR Analysis): 66.6 % rutile, 15.9 % leucoxene, 9.9 % zircon, 1.7 % garnet/tourmaline/aluminosilicates, 1.1 % quartz, 0.2 % sphene, 0.1 % ilmenite, 0.1 % cassiterite, 4.3 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Wanning Yiyuanfeng Analysis	BGR Analysis
> 500				0.0
420				
355				0.1
300				0.2
250				0.2
212				0.6
180				1.4
150				4.9
125				15.8
106				28.4
90				28.1
75				15.4
63				4.0
53				0.7
45				0.2
< 45				0.0
Mean (µm)				109.0
D50 (µm)				93.1

Name: **Wanning Yiyuanfeng Mining Rutile 90**
Deposit: from Mozambique HM concentrates
Producer: Wanning Yiyuanfeng Mining Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Wanning Yiyuanfeng Analysis	BGR Analysis
TiO_2				89.95
$Zr(Hf)O_2$				2.13
ZrO_2				2.09
SiO_2				2.30
Al_2O_3				1.09
Fe_2O_3				1.91
Cr_2O_3				0.29
V_2O_5				0.24
Nb_2O_5				0.53
P_2O_5				0.096
S				< 0.01
CaO				0.05
MgO				0.05
MnO				0.03
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.76
U				81
Th				242

Chemical analysis (BGR): 84 ppm Pb, 0.13 % SnO_2, 531 ppm Ta, 339 ppm W, 497 ppm Y

Mineralogical composition of sample (BGR Analysis): 69.6 % rutile, 21.2 % leucoxene, 4.3 % zircon, 0.8 % ilmenite, 0.3 % garnet/tourmaline/aluminosilicates, 0.3 % quartz, 3.5 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Wanning Yiyuanfeng Analysis	BGR Analysis
> 500				0.0
420				
355				
300				
250				
212				0.2
180				0.9
150				4.9
125				17.8
106				30.0
90				27.1
75				14.3
63				3.9
53				0.7
45				0.2
< 45				0.0
Mean (µm)				108.0
D50 (µm)				93.9

Name: **Xiamen King Far East Rutile 95**
Deposit: from Sierra Leone HM concentrates
Producer: Xiamen King Far East Supply Chain Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Xiamen King Analysis	BGR Analysis
TiO_2				94.23
$Zr(Hf)O_2$				0.58
ZrO_2				0.57
SiO_2				0.38
Al_2O_3				0.22
Fe_2O_3				2.14
Cr_2O_3				0.21
V_2O_5				0.60
Nb_2O_5				0.18
P_2O_5				0.024
S				< 0.01
CaO				0.01
MgO				< 0.01
MnO				0.02
Moisture (@ 105 °C)				
LOI (@ 950 °C)				1.22
U				21
Th				73

Chemical analysis (BGR): 104 ppm W

Mineralogical composition of sample (BGR Analysis): 91.7 % rutile, 2.9 % leucoxene, 1.1 % zircon, 0.8 % ilmenite, 0.1 % garnet/tourmaline/aluminosilicates, 3.5 % others/unknown

Grain size distribution µm	Guaranteed	Typical	Sample	
			Xiamen King Analysis	BGR Analysis
> 500				0.7
420				1.6
355				3.1
300				5.2
250				8.3
212				10.5
180				13.0
150				16.0
125				15.2
106				11.2
90				7.6
75				4.5
63				2.0
53				0.7
45				0.3
< 45				0.1
Mean (µm)				185.2
D50 (µm)				132.9

Deutsche
Rohstoffagentur
Bundesanstalt für Geowissenschaften und Rohstoffe

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