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14 DERA Rohstoffinformationen

Zircon – insufficient supply in the future?

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Contents

Executive Summary

Figure 1: Zircon sand. Photo courtesy of Iluka Resources Ltd.

Mineralogical and chemical characteristics of zircon are given. Emphasis is placed on the radioactivity associated with zircon concentrates.

Approximately 54 % of the zircon is used in finely ground form in the ceramics industry. 14 % goes into the foundry industry, and 11 – 14 % into refractory applications. A growing portion of the zircon mined worldwide is used for the extraction of the metals zirconium and hafnium or their further processing to produce zirconium chemicals.

Demand data for zircon are available from TZMI, Roskill and Iluka Resources. Although there are significant differences in the figures for historic demand, the future demand estimates are similar until 2015. Only Iluka Resources and most recently TZMI have estimated zircon demand for the time interval between 2015 and 2020. Most demand estimates were calculated before the increase in zircon prices in 2011/12 which led to strong substitution in many applications.

For many decades, Australia has been the leading producer of zircon, followed by South Africa. The third country in the zircon production ranking is the USA, in some years outperformed by Indonesia. Fifth place is held by India, followed by Mozambique, China, Ukraine, Vietnam, and Brazil. Baddeleyite is only produced in Russia.

There will be no important changes in zircon production in South Africa, India, China, Vietnam and many other smaller producing countries in 2012ff. Possibly at the end of this decade, more zircon might be produced in Africa than in Australia.

In the next years, probable zircon production will rise to 1.85 million tonnes before declining very slowly till 2019. A rate of substitution of only 1.5 % in future would convert all supply-demand balances for probable production into the positive, i.e. into a surplus. As substitution in 2011/12 was apparently much higher than 1.5 %, a strong surplus in the worldwide zircon supply-demand balance can be forecast for all years until 2019.

Assuming a continued substitution rate of 10 – 15 %, which seems very realistic, the surplus will not turn into a deficit before 2020 at probable production and base case demand rates. Similarly, at maximum production and even at high demand there will be a strong surplus of the supply-demand balance until 2019.

Information on all zircon producing companies in all countries is given in Appendix A. Appendix B gives comparative statistics of almost all commercially available zircon concentrates, while raw analytical data can be found in Appendix C.

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1 Introduction

Figure 2: Loading of zircon from Iluka's stockpile in Geraldton, Western Australia. Photo courtesy of Iluka Resources Ltd.

In October 2010, the German Mineral Resources Agency (DERA) was founded within the Federal Institute of Geosciences and Natural Resources (BGR, German Geological Survey), which is a government agency of the German Ministry of Economics and Technology (BMWi).

Two of the functions of DERA are to provide information and analysis about mineral markets and to advice German companies on all aspects of securing mineral resources supply.

In mid 2011, DERA was approached by German companies concerning price increases for zircon and titanium minerals. Their questions were: how long would these price increases last and how best to react?

Based on an initial evaluation of market studies by TZMI and Roskill, DERA decided to concentrate on zircon and obtain more information on the projected future supply and demand of this mineral.

TZ Minerals International Pty Ltd. (TZMI) is a global, renowned, independent consulting and publishing company based in Australia which specializes in all aspects of the mineral sands, titanium dioxide and coatings industries. According to studies by TZMI (2011a, b), although titanium prices were going to decrease again within the next few years due to increases in supply, zircon was going to be in strong demand with high prices to stay for many years.

A competitor to TZMI as an independent and renowned consulting company is Roskill Information Services Ltd. (Roskill), based in the UK. Coincidentally, Roskill also published the 13th edition of its zirconium study in 2011 (Roskill 2011). According to this study, zircon demand was going to exceed supply for just two more years, after which time, new projects coming online would solve the "zircon problem".

Due to contradictions in the evaluations of the zircon availability by TZMI and Roskill, DERA decided to go into details and to come up with its own evaluation. DERA concentrated on the supply side of zircon, putting a strong emphasis on obtaining as precise as possible data on past, present and probable future worldwide production. As some German companies need very special zircon qualities, as many as possible different commercial zircon concentrates were also obtained for in-house analysis.

This study comes in two versions:

- A preliminary version with a chapter on the zircon supply and demand in Germany only available to companies in Germany and distributed among participants of a DERA workshop on zircon in December 2012 in Berlin.
- A final version without the chapter on Germany available for free download from the DERA homepage.

2 Mineralogy and chemistry of zircon

Pure zircon has the following characteristics:

Formula	$ZrSiO_4$
Chemistry	67.22 % by mass ZrO_2, 32.78 % by mass SiO_2
Density	4.68 g/cm^3
Mohs hardness	7 ½
Color	colorless, yellowish, pink, reddish, brownish, rarely green, blue, black
Magnetic property	non-magnetic
Electrostatic property	non-conducting

In addition to the element zirconium, Zr, the chemically very similar element hafnium, Hf, is always built into the crystal lattice of the mineral zircon. The content of HfO_2 in zircon averages 0.5 – 2.0 (4.0) % by mass. Zircons with increased contents of up to 24 % Hf are called alvites in mineralogical terms. Naegite, however, is a zircon with increased Y, Nb and Ta contents. In addition to hafnium, zircon can also contain larger quantities of uranium and thorium. This renders zircon one of the main sources of radioactivity in granitic rocks. This radioactivity can lead to the destruction of the lattice and therefore to "metamictization" of the mineral. U contents > 1 % result in complete destruction of the lattice structure. The metamictization results from the α decay of ^{238}U, ^{235}U and ^{232}Th and their daughter isotopes. It is accompanied by hydration, a reduction in density, a reduction in hardness, a reduction in the refractive index, an increase in opacity, and a color change (cf. Table 1).

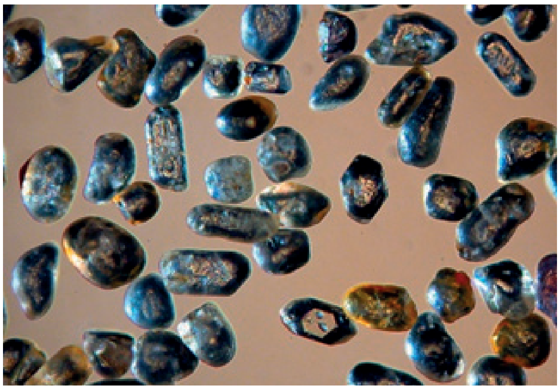


Figure 3: Zircon grains from fossil strandlines in Oregon. Photo courtesy of Oregon Resources Corp.

The effects of metamictization, particularly the color change, can be temporarily reversed by heating to more than 1,000 °C for 30 min (calcination). Calcination is a common processing step in the industry. It is used for dehydrating and burning organic coatings before zircon is used as casting sand (cf. below). If the zircons are covered by coatings containing iron, these will take on a reddish-yellow color during calcination. Coatings containing iron are therefore removed in acid baths before calcination.

Table 1: Selected properties of zircon with varying degrees of metamictization, supplemented according to Garnar (1994)

	Common zircon	Modified zircon (hyacinth)	Highly modified zircon (malacon)
Density (g/cm^3)	4.6 – 4.7	4.2 – 4.6	3.6 – 4.2
Mohs hardness	7 ½	7	6 – 7
Color	white	violet	dark
Refractive index	1.92 – 1.96	1.90 – 1.92	1.76 – 1.90
LOI (% by mass)	0.1	0.5 – 1	10
Radioactivity	low	medium	high

According to Rozendaal & Philander (2000):

- clear zircons contain:
  low levels of Fe, U and Th
- pink zircons:
  increased levels of rare earths (RE), U and Th
- yellow zircons:
  highly increased levels of RE, U, Th and increased levels of Fe, Al, P and Ca
- metamictic zircons: very highly increased levels of RE, U (up to the % range), Fe and Y

Microcrystalline cracks are a result of metamictization (from the inside) or impacts (from the outside).

Very often, zircon contains inclusions of liquids and/or other minerals (rutile, spinel, feldspar, mica, silica, xenotime, monazite, Al silicates, cassiterite, magnetite and especially apatite).

Other zirconium minerals of commercial interest are *baddeleyite* (ZrO_2), (cf. Appendix A – Russia), and *caldasite* (cf. Appendix A – Brazil).

2.1 Radioactivity

Radioactivity in zircon concentrates can be caused by U and Th and/or their decay products contained in the crystal lattice, in mineral or fluid inclusions, in cracks and fissures in the zircon grains or in other radioactive minerals (above all monazite, xenotime, allanite, tantalite, betafite, thorianite, thorite) contained in the zircon concentrate.

As a natural bearer of U and Th, all zircon is slightly radioactive and therefore carcinogenic. In general, a global limit of 500 ppm U + Th or U + (0.4 xTh) < 100 ppm applies to all zircon concentrates. Different countries, however, have adopted differing or no limits.

Compliance with the above U and Th limits in zircon concentrates has been one of the most important assessment criteria for its suitability for some years. The lower the level of U and Th, the higher its marketing potential. Moreover, according to current legislation in most countries, zircons with U and Th levels exceeding the legal limits do not constitute valuable heavy minerals, but radioactive waste material! In almost all mineral separation plants (MSP), radioactive zircons (which are often weakly magnetic) are therefore separated out during processing. As this, however, leads to production losses and to storage capacity for radioactive materials, radioactive or otherwise undesirable zircon ("zircon rejects") are often sold to specialized companies in China for further processing.

The radioactivity of zircon and its potential impact has been investigated and discussed in numerous studies and independent assessments.

These reveal that there is no real hazard potential for persons coming into contact with the material.

A comparison list of U and Th grades of almost all commercial zircon concentrates traded worldwide is given in Appendix B.

3 Applications and specifications

3.1 Applications of zircon, zirconia, and zirconium and hafnium products

The main application (approx. 54 % of the worldwide share in 2011) of zircon is in finely ground form in the **ceramics** industry. The very high refractive index of zircon enables the opacification of melts and the white coloring of ceramic bodies. Typical areas of application are therefore the manufacture of porcelain melts for glazes, sanitary ware, wall and floor tiles, china, tableware, special and technical porcelains, earthenware, glazed tiles and industrial tiles. The largest markets for zircon by far are for ceramic floor and wall tiles, then followed to a much smaller amount by sanitary ware, with consumption dominated by China.

The proportion of zircon flour (d_{99} 45 µm) in enamel coats is approx. 7 – 12 %. The proportion of micronized zircon (d_{95} 5 µm) in raw glazes that are directly applied to the goods varies between 6 – 15 %. A typical glaze based on zircon requires grinding the zircon in a very narrow particle size band depending on the required opacifying effect. The commercially available products for ceramics applications include:

- zircon flour (opacifying enamels)
- 9 µm opacifier (ceramic glazes)
- 6 µm opacifier (glazes, substitute for 5 µm opacifier in sanitary ceramics and densely fired unglazed tiles)
- 5 µm opacifier (limit value for sanitary ceramics and densely fired unglazed tiles)
- 3 – 1 µm opacifier (sanitary ceramics and special applications)

The good dielectric properties of zircon are used in the production of special ceramics. Zirconium dioxide, ZrO_2, called zirconia, is produced by the dissociation of zircon at high temperatures in a plasma arc furnace (“fused zirconia”) or by calcination of zirconium oxychloride (ZOC) or zirconium basic sulfate (ZBS) via zirconium hydroxide (ZOH) (cf. below) (“chemical zirconia”).

On average, standard fused zirconia assays at around 98.8 % ZrO_2, while chemical zirconia is much purer at 99.9 % ZrO_2.

Zirconia has gained increasing significance over the last years, due to its:

- high chemical purity, great hardness and high apparent density,
- high melting point,
- high bending fracture and tensile strength,
- high fracture resistance,
- high wear resistance, and corrosion resistance,
- low thermal conductivity,
- thermal expansion similar to cast iron,
- Young's modulus similar to steel,
- onset of electrical conductivity at temperatures > 600 °C,
- oxygen ion conductivity,
- very good tribological properties, i.e. good properties in relation to friction, wear and lubrication.

Depending on the temperature, ZrO_2 occurs in monoclinic (< 1,170 °C), tetragonal (1,170 – 2,370 °C) and cubic (2,370 – 2,680 °C (melting point)) crystal types. In order to stabilize the cubic crystal type, stabilizers in the form of MgO, CaO or Y_2O_3 must be added to the ZrO_2. Occasionally, CeO_2, Sc_2O_3 or Yb_2O_3 are also used as stabilizers.

The very fine, tetragonal crystal phase exhibits a unique phenomenon in high-performance ceramics: the tetragonal crystallites are converted into the monoclinic crystal type under high mechanical stresses, undergoing a volume expansion – they can therefore react in a “pseudoelastic” manner, but at the same time this can also in part generate very fine micro fractures in their surrounding matrices. Cracks that start to run through the material under high tensile stress are stopped, slowed or branched by the volume expansion working against them or by the creation of micro fractures during this crystal conversion from the tetragonal to the monoclinic types.

This leads to extremely high component strengths in zirconia ceramics which can be utilized up to an application temperature of approx. 600 °C.

Because of the properties above, zirconia is used for the manufacture of:

- Advanced ceramics for mechanically highly stressed components (such as in pumps or for implants), and in ceramic catalyst supports and ceramic filters for the control of emissions from cars and industrial applications,
- Electronic ceramics, e.g. oxygen sensors in petrol engines, due to the oxygen ion conductivity of the ZrO_2 and therefore ability to measure oxygen partial pressures,
- Stabilized zirconia refractories with low thermal conductivity and consequently very low heat loss,
- Grinding media (alumina-zirconia and alumina-titania-zirconia), bonded and coated abrasives on paper, cloth or plastic films and special products that must be abrasion-proof and corrosion-resistant (coatings, textiles, printing inks, ceramics and others), since the yttrium stabilized ZrO_2 (YSZ) is ultra hard, tough and dense,
- Special glasses, because levels of up to 30 % ZrO_2 give rise to high refractive indices and long lifetimes,
- Color pigments in connection with Si, Fe, V, Pr, Cd, S, Se because these exhibit the high temperature resistance required for glazes and enamels,
- Ammunition and explosives, in airbags and in professional flash technology because ZrO_2 powder is highly flammable,
- Synthetic zirconia gemstones (cubic zirconia) that can easily be colored using other oxides.

The main markets for zirconia are refractories (mainly fused zirconia) (cf. below) and catalysts (mainly chemical zirconia), followed by abrasives, advanced ceramics and electronic materials.

An additional future major market may be in the manufacture of solid oxide fuel cells (SOFCs) where YSZ is the material of choice for both the anode and the electrolyte.

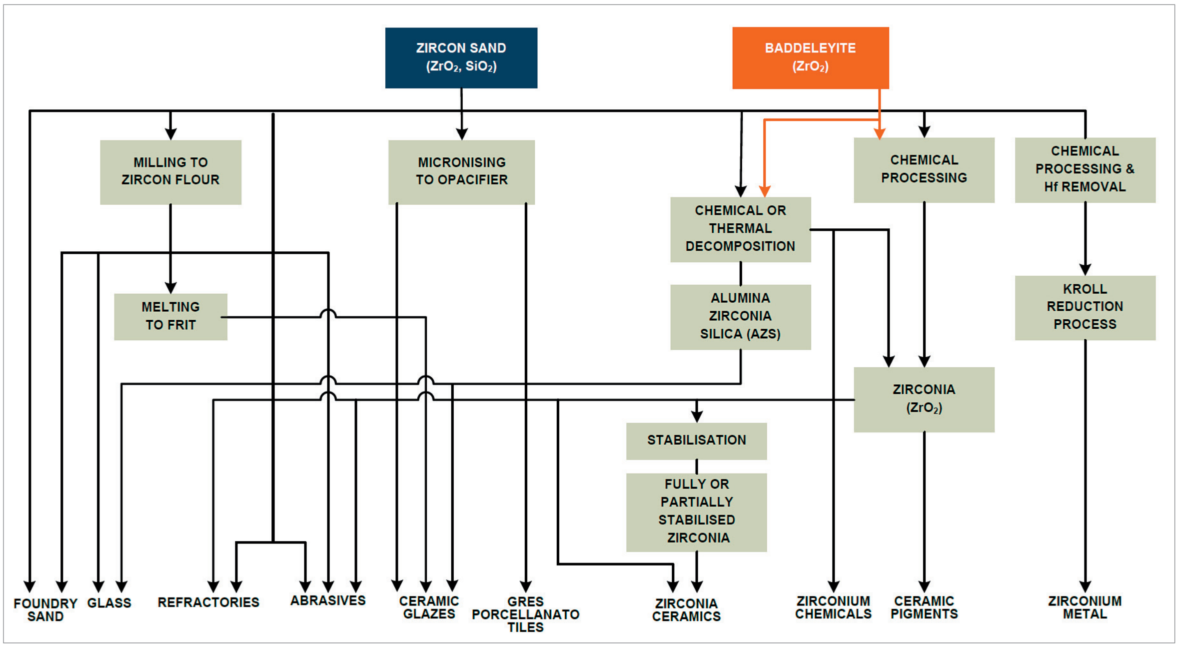


Figure 4: Schematic structure of the zircon industry, from TZMI (2011b).

Zircon has several properties that particularly distinguish it as a refractory material. These are:

- high melting point: > 2,430 °C. The fire resistance of zircon sands corresponds to pyrometric cone 39/40, i.e. at temperatures around 1,885 °C.
- very low and regular thermal expansion,
- poor wettability by molten metal,
- moderate to high thermal conductivity,
- good thermal shock resistance, due to its low, uniform thermal expansion,
- chemical stability.

Depending on the zircon content, quantity and type of the other aggregates, and the application temperature, zircon's properties result in potential uses in widely varying **refractory** applications (approx. 11 – 14 % global share in 2011, cf. Tables 3 and 4).

These are refractory mortar, refractory bricks or refractory linings for furnaces, kilns, incinerators, reactors and crucibles for different glass and metal melts. The iron and steel industry is by far the main consumer of refractories, but other markets include glass, cement, ceramics, non-ferrous metals and chemicals.

The low solubility of zirconium in molten silica or silicates makes zircon refractories particularly suitable for use in the most exposed (hottest) areas of glass furnaces. Refractories incorporating zirconium can be used at continuous temperatures up to 1,700 °C, and approaching 2,000 °C for short periods.

Zirconium is used in refractories mainly in the form of zircon, zirconia and fused cast aluminium-zirconia-silica (AZS), the latter containing 33 – 35 % ZrO_2. Super high zirconia AZS refractories may contain up to 94 % ZrO_2, and have an increasing share, particularly in the manufacture of speciality glasses (borosilicate glass, opal fluoride glass, lead crystal and CRT glasses).

Due to their high prices, all zirconia refractories tend to be used in high temperature applications, such as continuous casting nozzles and gates, crucibles, furnace liners, setter plates and kiln installations.

The above refractory properties together with the characteristics:

- neutral to slightly acid pH,
- clean and round grains, which can be bonded at little cost and with little material,
- binding ability with all organic and inorganic molding sand binders,
- superior spatial and thermal stability at increased temperatures,
- good recycling options,

allow zircon to be used as a moulding base material in the **foundry** industry (approx. 14 % global share in 2011) in the form of zircon sand (steel) or zircon flour (casting paints, casing castings, super alloy and titanium castings). Here, the fineness of the zircon flour improves the subsequent casting surface and reduces "burning".

The three basic methods used for casting metals are sand casting, die-casting and investment casting.
In sand casting, zircon sand and flour are both used as a replacement for silica sand in moulds and cores. Zircon flour is also used to coat mould components to reduce the permeability of the mould and to improve the surface finish. Increasing recycling and recovery have contributed to the decline in the consumption of zircon in this sector.
In die-casting, zircon, alumina, or silica is used on the moulding surface to improve surface quality and extend the life of the mould.
Zircon is ideal for investment casting when a high level of precision is required in the final metal casting. Here, zircon distinguishes itself because of its high refractory properties (which prevent the minerals from sticking to the cast metal), low coefficient of thermal expansion, and chemical inertness.

The world market for foundry sands is strongly dominated by silica sand. However, olivine sand and chromite sand are the main competitors to zircon sand in the remaining small market share. Due to its high costs, the use of zircon sand is restricted to specialised applications, such as facings for heavy iron and steel castings poured at high temperatures, mould paint or washes to improve surface quality, high definition cores, as well as shell and investment casting.

Zircon flour can be incorporated into refractory paints and washes that improve the resistance of foundry sands to metal penetration. These paints can contain 60 – 70 % zircon flour and can be used regardless of the type of moulding sand employed.

In recent months, the foundry sector has been seriously affected by the high prices for zircon. Many customers, especially from the automobile industry, have changed to chromite sand as a substitute (cf. Chapter 4.5). On the other hand, the wind turbine blade sector is expected to become increasingly important in terms of demand for zircon in the castings industry.

A growing portion of the zircon mined worldwide (cf. Figure 5) is used for the extraction of the metals zirconium and hafnium or their further processing to produce **zirconium chemicals**. Zirconium and hafnium are highly reactive elements that form stable bonds with oxygen, sulphur, nitrogen and carbon. These again serve as base materials for further processing into Zr chemicals.

Zirconium and hafnium are extracted similar to titanium using the Kroll process, via the intermediate product zircon tetrachloride, $ZrCl_4$.

The main chemical steps here are:

$$ZrSiO_4 + 2\,C + 4\,Cl_2 \rightarrow ZrCl_4 + SiCl_4 + 2\,CO_2$$

$$ZrCl_4 + 2\,Mg \rightarrow Zr + 2\,MgCl_2$$

The zirconium produced is a hard, glossy, grey-white metal with an apparent density of 6.5 g/cm^3, good thermal stability (melting point 1,852 °C), low neutron capture cross-section and superior resistance to corrosion by most acids and caustic solutions, seawater and other substances. Its key area of application with approx. 70 % is therefore – absolutely free of hafnium! – in the form of alloys with Sn, Fe, Cr, Nb and Ni in the linings and frames of nuclear reactors. Minor applications of zirconium are in photographic flash bulbs (cf. below), in the manufacture of special steels and alloys (e.g. for chemical processing), and high-density batteries.

In powder form, zirconium can be ignited by sparks, friction or low electrical discharge. It is therefore used as a heat source in ignition charges, as an igniter mechanism in airbags and flashcubes, and as an alloying aid.

Zr is alloyed with Fe, Si, Ni and also Sn, Cr, Cu and Mo. In steel manufacture, the affinity of Zr to O_2, S and N_2 is used to control sulphides and oxysulphides in inclusions, to bind N_2, and to stop crystal growth and strain ageing. Melted zirconia or zirconia-mullite (pure Zr or with mullite heated to 3,000 °C and then quenched) is used after grinding in refractory, casting and molding applications, as well as in high-tech ceramics.

The most important Zr chemicals (14 % of world share according to Roskill (2011), cf. Table 3, and 18 % of world share according to TZMI (2011), cf. Table 4) include, in the order of their worldwide volume share:

- Zirconium oxychloride (ZOC), $ZrOCl_2 \times 8\,H_2O$, a white crystalline solid with a slightly acrid smell that can be dissolved with the addition of water and heating. The light yellow or colourless liquid produced in this way is used for applying white TiO_2 pigment and is an intermediate product for the manufacture of zirconium catalysts.
- Zirconium basic sulphate (ZBS), $Zr_5O_8(SO_4)_2 \times H_2O$, a solution which is used as an intermediate for other zirconium products.
- Zirconium basic carbonate (ZBC), $ZrOCO_3 \times n\,H_2O$, a moist, white solid. It is used as an aid in paint drying, as a thixotropic agent, as a deodorant, in photo catalysis and in paper manufacture.
- Ammonium zirconium carbonate (AZC), $(NH_4)_2Zr(CO_3)_2(OH)_2$, is a clear or slightly opaque, water-soluble basic solution smelling of ammonia. Its applications are catalysis, paint drying and/or as a thixotropic agent, for waterproof surface coatings for paper and packaging, printing inks, adhesion promoter for plastics and metals, bonding agent and accelerator in adhesives, moulding material binder and for waterproof textiles.
- Zirconium acid sulphate (AZST), $Zr(SO_4)_2 \times 4\,H_2O$ is a moist, white, crumbly paste, which is used as an accelerator in adhesives, a gelatine hardener in photography, paper pigment, catalysis promoter and Cr substitute in leather tanning.
- Organic compounds with zirconium, mainly acetates (ZAC), propionates, octoates, acetylacetonates. They are used in electrical and special ceramics, as a catalytic hardener for epoxy resins and silicones, in paint drying, as a water repellent for paper and non-wovens, as a printing ink adhesion promoter for plastics and metals, as a thixotropic agent in cements, as welding fluids and clay stabilizers, as a Cr substitute in the processing of Al canning metal, as molding material binder and a gelatine hardener in photography.

- Potassium zirconium hexafluoride (KFZ), K_2ZrF_6, is a white to light yellow crystalline powder whose uses are in Fe alloys, refractory, ceramics and glass and electrical materials for the nuclear industry.

Other, currently still insignificant Zr chemicals in terms of volume are:

- Zirconium phosphate, $Zr(HPO_4)_2$, and zirconium phosphate monohydrate, are both odourless white powders. They are used as catalysts in the synthesis of methyl-iso-butyl-ketones and in polymerization, hydrogen-tion, oxidation, hydration and dehydration reactions and in ion exchange (kidney dialysis, water treatment).
- Zirconium hydroxide (ZOH), $Zr(OH)_4$ x n H_2O, is a moist white powder. It is used as high-purity Zr raw material in the production of catalysts and ceramics, in ion exchange, in paints and colorants, in absorb-ents, in deodorants and as an additive in plas-tics and glass.
- Zirconium oxynitrate, $ZrO(NO_3)_2$, is a clear to slightly opaque liquid. It is a high-purity Zr base material for the manufacture of Zr catalysts, chemicals and ceramics, is used as a white pigment and filler, a moulding material binder, a bonding agent and accelerator in adhesives, and reacts with proteins in deodorants.
- Zirconium hydride, ZrH_2, is a grey-black, metallic, odourless powder that is used in various metallurgical and other special areas: oxidation promoter in pyrotechnics, gas binder in the manufacture of vacuum tubes, hardener and bronzer for carbides and in ceramics, reservoir for high-purity hydrogen and hydrogen source in the foaming of metals, additive in the application of ceramics onto metals, and source for zirconium in powder alloys.
- Zirconium fluoride, ZrF_4, is a white, odourless powder that is used in ceramic paints, optical fibres and special glasses, in gemstone processing, metal treatment and in textiles.

Hafnium, possessing very similar properties to zirconium, is used for the manufacture of control rods in nuclear reactors, for propulsion systems in nuclear submarines, as an additive (1.5 %) for Ni-based super-alloys and in metal cutting for plasma cutters. The Hf enriched super-alloys are used in the production of aerospace turbine blades (rotating parts) and vanes (stators), as well as their equivalents in larger cast parts required for industrial gas turbines. HfC is the chemical compound with the best-known fireproof properties (melting point: 3,890 °C), similar to HfN with a melting point of 3,310 °C.

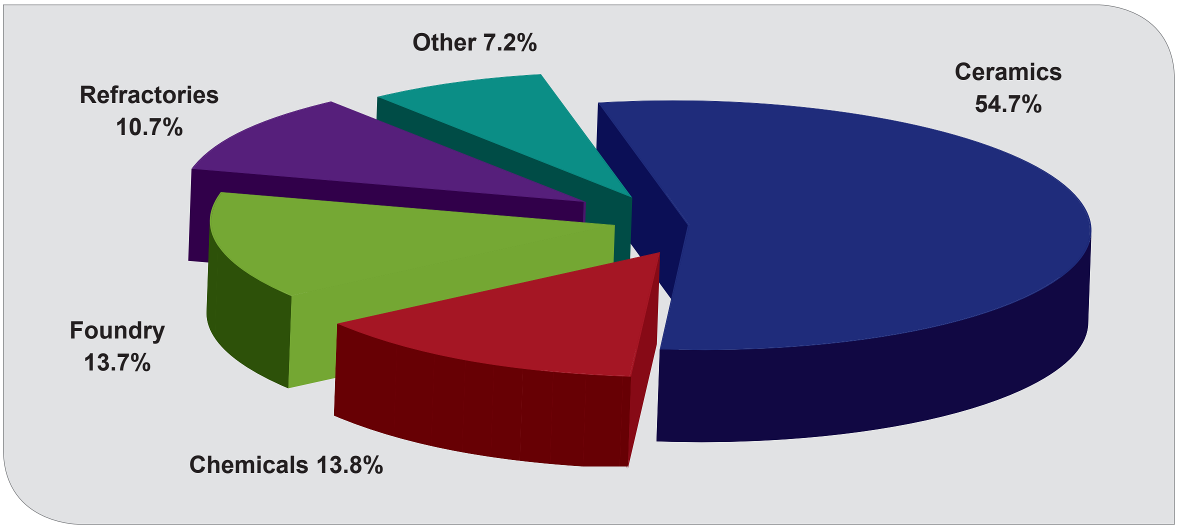


Figure 5: Worldwide consumption of zircon by end-use in 2011 (Roskill 2011).

In cathode ray tubes of televisions and computer monitors, zircon is used as a screen against x-rays. The hardness of zircon is an additional advantage for the stabilization of the tube glass. The previously high demand for CRT's has fallen sharply because of competition with liquid crystal displays (LCD) and more recently light emitting diode (LED) products.

Zircon and zirconia are added to some speciality glass melts e.g. for optical and ophthalmic glasses. Some borosilicate glass fibre formulations contain 4 % ZrO_2 while AR fiberglass may contain 10 % ZrO_2. Zirconia glasses have also been developed as lead-free crystal glasses (0.5 – 17 % ZrO_2).

Despite its high price, zircon flour is used as a filler with functional effects to increase the thermal and electrical resistance of plastics, silicones, epoxies, resins and special paints, due to its chemical stability and its white colour.

For the cleaning of highly sensitive turbine parts, zircon sand is also used as a blasting sand.

3.2 Physical and chemical specifications for zircon sand

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

- A zircon concentrate that is to be used as foundry sand must contain < 3 % by mass kyanite and < 0.1 % by mass staurolite. The corundum content (Al_2O_3) must also be low.
- For the purposes of the refractory and ceramics industry, the limits are < 2 % by mass kyanite and < 0.1 % by mass staurolite.
- For zircon that is used for casting aircraft parts, the following limits apply to trace elements: < 25 ppm Pb, < 75 ppm Zn, < 1 ppm Bi, < 25 ppm Sn and < 160 ppm Ce. Here, Sn is often contained in the spinel gahnite, which can however be separated electromagnetically.
- Zircon for steel casting must be well rounded and calcinated, and have a mean grain diameter of 110 – 150 µm. The concentrate must contain < 0.1 % by mass accompanying minerals with low melting points.
- If zircon is to be ground wet or dry into zircon flour and then used as an opacifier, only zircon concentrates of premium or intermediate grade can be used as feedstock due to the specifications for the Fe content (< 0.04 % Fe).

Table 2: Important physical properties of zircon depending on the application, according to Pirkle & Podmeyer (1992)

Physical properties	Application			
	Ceramics	Abrasives	Refractory	Foundry
AFS # [1)]				x
Grain size distribution		x	x	x
Low LOI	x	x	x	x
pH	x		x	x
Apparent density			x	
Low demand for acid				x
Colour	x			x
Grain shape		x	x	x
Calcination	x			x
High tensile strength				x
High melting point	x		x	x
Great hardness		x		

[1)] The AFS number is a characteristic value developed by the AFS (American Foundrymen´s Society) for characterizing the grain fineness of foundry sands.

4 Demand

4.1 Sources of zircon demand data

Figure 6: Prime zircon ready for shipping by KZN Sands, Republic of South Africa. Photo: DERA.

Estimates and/or calculations of demand for zircon are regularly published by Roskill Information Services Ltd. and TZ Minerals International Pty Ltd. This study utilises the most recent publications by Roskill (2011) and TZMI (2011a, b) as well as TZMI (2008) for past demand data. In addition, demand figures were taken from various presentations by Iluka Resources Ltd. in 2011/2012 which are available for free download from the website of this major zircon producing company.

However, most recent estimates of future zircon demand as presented by Liberal (2012) at the TZMI Congress in November 2012 could not be accounted for in full.

4.2 Comparison of historic zircon demand data

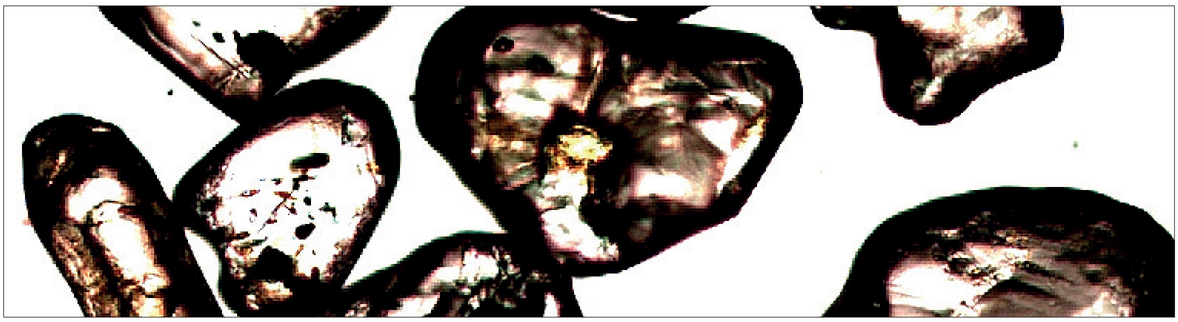
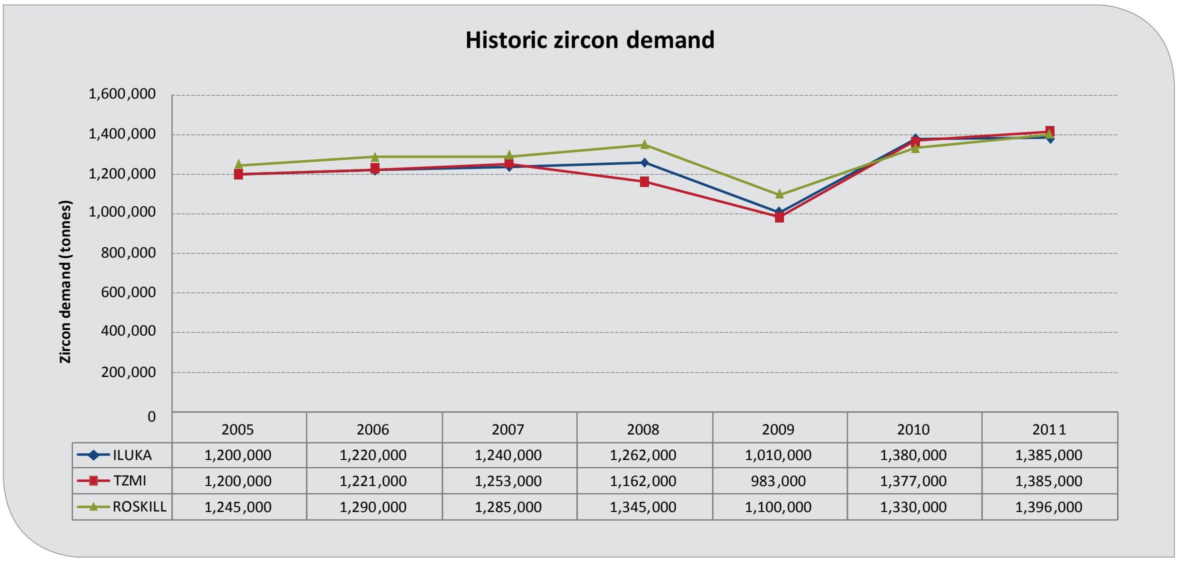


Figure 7: Typical zircon grains under magnification. Photo: DERA.

Historic zircon demand data published by Iluka Resources, TZMI, and Roskill are always close but obviously not the same. Even though Iluka Resources and TZMI regularly exchange data, there is a difference of opinion on past zircon demand of up to 100,000 tonnes (2008). In a small market of only 1.4 to 1.5 million tonnes zircon, a difference of 100,000 tonnes is quite a large anomaly.

In addition, besides in 2010, Roskill reported a higher zircon demand in the past than both TZMI and Iluka Resources. The reason for this is unclear. Obviously however, even past zircon demand figures are rather speculative and should be viewed with due caution.



	2005	2006	2007	2008	2009	2010	2011
ILUKA	1,200,000	1,220,000	1,240,000	1,262,000	1,010,000	1,380,000	1,385,000
TZMI	1,200,000	1,221,000	1,253,000	1,162,000	983,000	1,377,000	1,385,000
ROSKILL	1,245,000	1,290,000	1,285,000	1,345,000	1,100,000	1,330,000	1,396,000

Figure 8: Historic data on worldwide zircon demand after Iluka Resources, TZMI, and Roskill.

4.3 Calculation of future zircon demand

Calculations/estimates of future zircon demand are available from printed publications from TZMI and Roskill for the forthcoming years until 2015 (cf. Tables 3 and 4).

In November 2011, Iluka Resources presented a graph of “Global Zircon Demand Scenarios” for the last time (cf. Figure 9), of which numerical data sets were also read off.

Table 3: World: Forecast demand for zircon by end use, 2011 – 2015 (000 t), reproduced with permission from Roskill (2011). AAGR = Average Annual Growth Rate

	2011	2012	2013	2014	2015	AAGR (%)
Ceramics	763	812	864	921	983	6.5
Chemicals	193	204	216	230	245	6.1
Foundry	191	203	216	227	241	6.0
Refractories	149	157	166	174	185	5.6
Other	100	90	80	75	70	-9.3
Total	1,396	1,466	1,542	1,627	1,724	5.4

Table 4: World: Forecast demand for zircon by end use, 2011 – 2015 (000 t), data from TZMI (2011a). AAGR = Average Annual Growth Rate

	2011	2012	2013	2014	2015	AAGR (%)
Ceramics	765	794	884	938	984	6.5
Chemicals	254	265	n.a.	n.a.	314	5.4
Foundry	n.a.	n.a.	n.a.	n.a.	149	n.a.
Refractories	206	212	217	223	229	3.7
Other	n. a.	n. a.	n. a.	n. a.	38	n. a.
Total	1,414	1,456	1,565	1,643	1,714	4.9

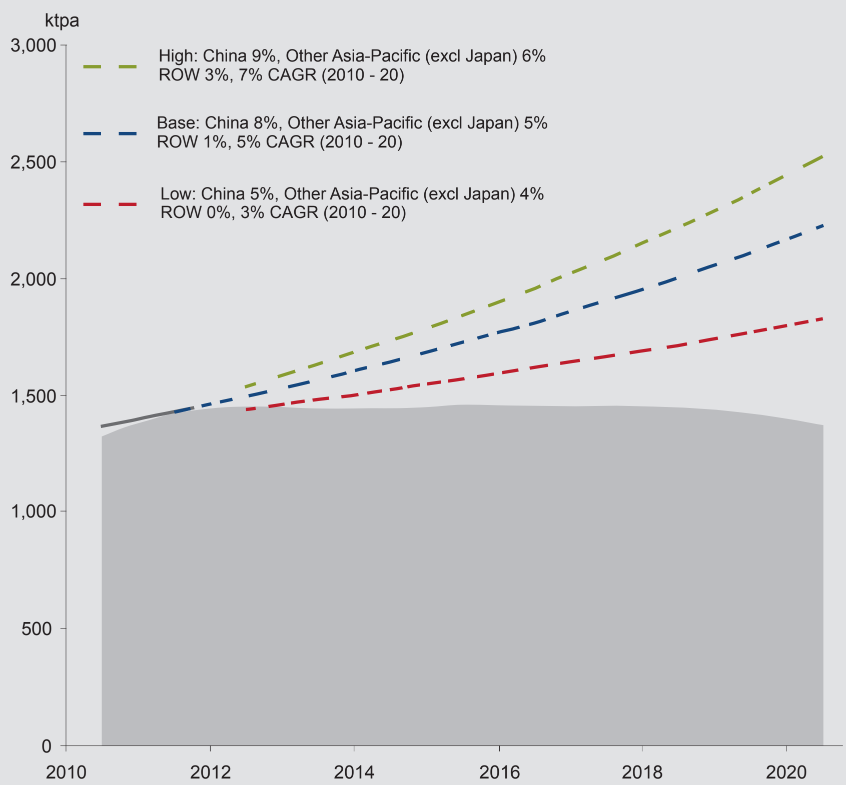
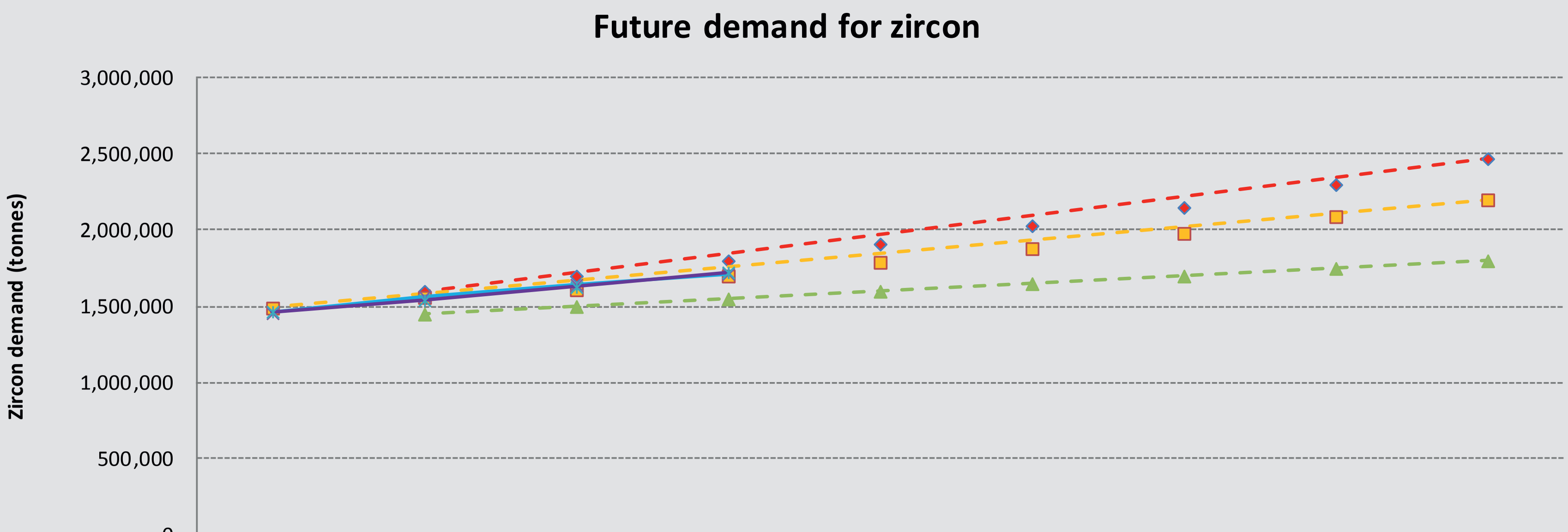


Figure 9: Global zircon demand scenarios, Iluka analysis, from Iluka Resources Ltd. (17 – 18.11.2011): Mineral Sands Briefing Session (www.iluka.com).

4.4 Comparison of published future zircon demand data estimates

It is evident from Figure 10 that zircon demand estimates/calculations from TZMI and Roskill are very similar until 2015 only differing by a maximum of 20,000 tpa. The future zircon demand data by Roskill and TZMI also correlate well with the base case demand estimates by Iluka Resources, although Iluka's estimates are a little bit lower in general.



	2012f	2013f	2014f	2015f	2016f	2017f	2018f	2019f	2020f
Iluka -H igh		1,600,000	1,700,000	1,800,000	1,910,000	2,030,000	2,150,000	2,300,000	2,470,000
Iluka - Base	1,490,000	1,560,000	1,610,000	1,700,000	1,790,000	1,880,000	1,980,000	2,090,000	2,200,000
Iluka -L ow		1,450,000	1,500,000	1,550,000	1,600,000	1,650,000	1,700,000	1,750,000	1,800,000
TZMI	1,456,000	1,565,000	1,643,000	1,714,000					
Roskill	1,466,000	1,542,000	1,627,000	1,724,000					

Figure 10: Future demand for zircon after Roskill (2011), TZMI (2011a), and Iluka Resources Ltd.

Looking at the low case demand scenario by Iluka Resources, this needs to be updated by Iluka due to the recent depressed demand mainly caused by lower customer interest from China, and building up of considerable stocks of zircon and downstream intermediates and finished products in 2011 (A. Macdonald, pers. comm.), as well as and possibly above all by substitution caused by the high zircon prices which continued into 2011.

Most recent and updated estimates of future zircon demand until 2020 as presented by Liberal (2012) at the TZMI Congress in November 2012 could not be accounted for in full.

In Chapter 6, the high case demand scenario by Iluka Resources will be tested against the maximum supply calculations by DERA.

4.5 Influence of substitution

According to industry consultants cited in Macdonald (2011) there are no zircon substitutes for over 80 % of demand:

- the market share of ceramics is 56 %, the substitution potential is 10 %
- the market share of zirconia & chemicals is 18 %, the substitution potential is 10 %
- the market share of refractories is 11 %, the substitution potential is 10 %
- the market share of foundries/casting is 11 %, the substitution potential is 50 %.

While it has always been said that substitution for most of the zircon applications is just not possible (cf. above), the same was initially held true for REE – but was proven wrong for this group of elements. Very similar to the REE market in 2011, high prices for zircon in 2011 – 2012 led customers to investigate substitutes for zircon in more detail in their areas of interest. Although the reduction in zircon demand from 2011 to 2012 has not been determined yet, the very similar decrease in non-Chinese demand for REE is already estimated at 30 %.

Substitutions for zircon are available in many applications, the most important being:

- Tin oxide or alumina as glaze in ceramics: but tin oxide is much more expensive and alumina does not give the same performance. It has a lower refractive index and produces a matt glaze. In addition, the cost of zircon opacifier in floor tiles is less than 3 %, so there is no real need to substitute zircon. In white body or super white body porcelain tiles this is quite different. Here more zircon opacifier is used and it is also a component in the body. Rising zircon costs have added considerably to the production costs of porcelain tiles, so all producers were looking into alumina as an alternative. Also at least to some degree, high-quality low-iron clay and floated feldspar could substitute for some of the zircon in the body. Macdonald (2012) thinks that a substitution rate of 30 % within Chinese porcelain tile producing companies is possibly resulting in a lower zircon demand of 60,000 to 90,000 tpa.
- Standard grade zircon or zirconium from hard rock deposits (not in production yet) instead of premium grade zircon in zirconium chemical production. No other real alternative is possible.
- Fused zirconia instead of zircon in refractories, which however, is not really a substitute based on a different commodity. However, alumina-spinel compositions are a superior substitute for zircon in refractories for steelmaking. Other alternatives at least in some refractory applications are sintered and fused mullites, chromite, magnesite or dolomite, just to name some important ones. However, in the glass industry, chromite cannot be used as a substitute for zircon as chrome impurities can discolour the glass.
- Chromite is the main competitor to zircon in many foundry applications, and although prices are also rising and supply is squeezed, it is still a good alternative where applicable (Li 2012). Other excellent new alternatives are cerabeads (a synthetic cerium stabilized zirconium oxide or aluminium silicate sand) and kerphalite – an aluminium silica sand based on andalusite (Anonymous 2007). Other alternatives with slightly different foundry applications are olivine sand or bauxite sand. If prices remain high, the majority of the foundry customers might switch to alternatives, leaving only high-end precision casting still using zircon sand in foundry applications. A loss of 50 % across the whole foundry sector would result in a reduction in zircon demand of about 100,000 tonnes in 2012!

5 Supply

5.1 Zircon producing countries

Figure 11: Spirals in the Empangeni MSP of KZN Sands, Republic of South Africa. Photo: DERA.

Currently, i.e. in 2012, zircon is produced in Australia, Brazil, China, Indonesia, Kazakhstan, Madagascar, Malaysia, Mozambique, Nigeria, Pakistan, Republic of South Africa, Russia, Sierra Leone (not in 2012), Sri Lanka, Thailand, Ukraine, USA, and Vietnam (in alphabetical order). Within the next few years, production can also be anticipated in Canada, Kenya and Senegal. Baddeleyite is produced in Russia, and minor amounts of caldasite are produced in Brazil. Both baddeleyite and caldasite are zirconium rich minerals.

For many decades, Australia has been the leading producer of zircon (currently by seven companies), followed by South Africa (two companies) (cf. Table 5). This situation will stay unchanged until 2020 – the last year this report is looking at. Third rank in zircon production is held by the USA (three, soon to be four companies). In some years, like in 2011, the USA was outperformed by Indonesia (several dozen companies). Fifth place is held by India (four companies), followed, at a much lower level by Mozambique (one company), China (at least six companies), Ukraine (one company, perhaps two companies in future), Vietnam (seven companies), and Brazil (three companies). In all other countries, normally less than 10,000 tonnes of zircon or baddeleyite are produced annually. In 2011, a production of 10,000 tonnes of zircon corresponded to a share of world-wide production of only 0.6 %.

Figure 12: Floating wet concentration plant at Moma, Mozambique. Photo: DERA.

Table 5: Zircon production by countries from 2005 to 2011

Country	2005	2006	2007	2008	2009	2010	2011
Australia	428,602	485,040	583,606	495,529	437,478	563,396	738,902
RSA	430,600	434,400	380,800	394,000	348,000	382,987	427,000
Indonesia[5)]	10,100	128,350	153,960	65,000	60,000	50,000	127,500
USA[5)]	163,957	142,954	120,967	121,965	82,800	100,200	104,935
India	27,133	20,535	35,977	29,158	31,499	85,309	89,796
Mozambique	0	0	0	6,654	21,100	37,122	43,500
China[5)]	26,000	28,000	25,000	38,000	31,500	33,500	33,500
Ukraine[5)]	33,000	30,000	35,000	35,000	31,000	30,000	27,000
Vietnam	29,100	23,900	24,300	25,303	19,368	23,730	24,020
Brazil	25,440	26,319	26,656	27,258	28,043	23,365	23,765
Russia[1)]	10,025	11,311	10,737	12,193	12,354	12,770	12,778
Madagascar[2)]	0	0	0	0	4,755	7,490	13,075
Pakistan[5)]	0	0	0	0	25	0	6,150
Nigeria[3)5)]	8,980	4,280	1,095	3,240	1,210	1,685	5,630
Sierra Leone[4)]	0	0	0	0	3,340	4,260	5,100
Malaysia	4,954	1,690	7,393	984	1,145	1,267	1,685
Sri Lanka	23,587	8,321	381	1,447	10,267	796	641
Kazakhstan	4,990	3,690	8,680	2,280	0	0	600
Thailand[5)]	100	100	100	100	100	100	100
Gambia	0	410	355	0	0	0	0
Total	1,226,568	1,349,300	1,415,007	1,258,111	1,123,984	1,357,977	1,685,677

[1)] Baddeleyite production converted to zircon equivalent, [2)] Zircon content in Zirsill, [3)] Zircon content in impure zircon pre-concentrate, [4)] Zircon content in zircon product, [5)] in part estimate or official export figure

The Top 10 zircon producing countries will probably include the following countries from the specified years: 2013 Madagascar; 2014 Senegal; 2015 Kenya. In 2015, Senegal should reach 3rd rank and should stay there well beyond 2020.

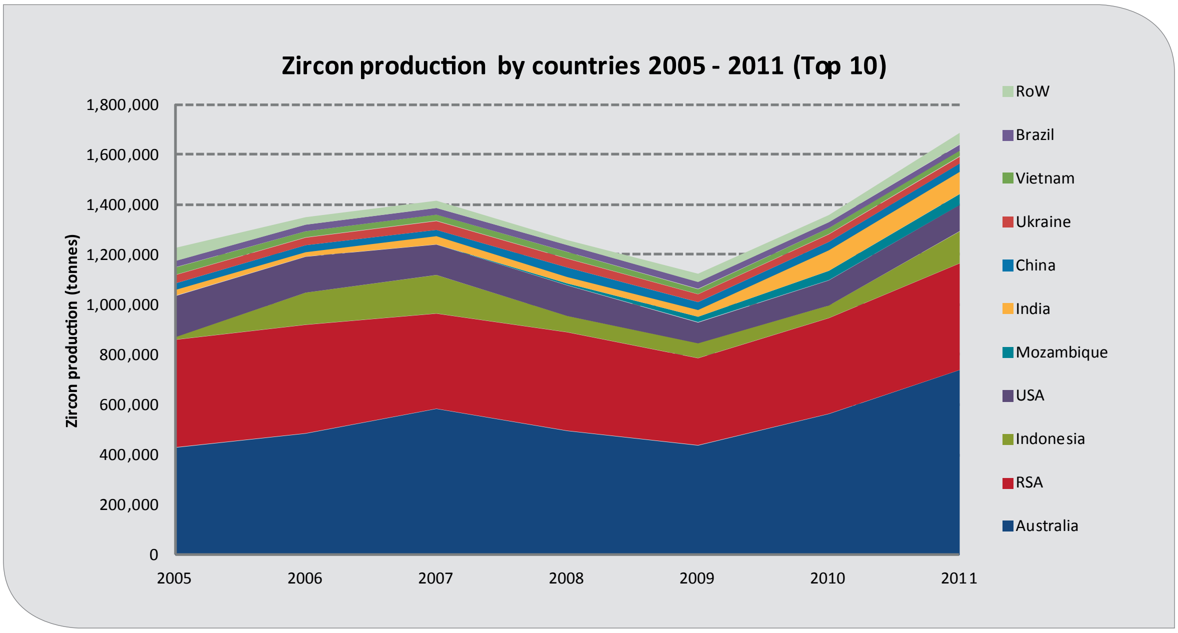


Figure 13: Zircon production by countries 2005 – 2011 (Top 10).

5.2 Origin of zircon

Close to all zircon is separated in heavy mineral (HM) mining operations which also produce ilmenite and rutile, as well as sometimes leucoxene, garnet, monazite, staurolite, sillimanite, kyanite, cassiterite or xenotime. In SE-Asia, i.e. in Thailand, Malaysia, and Indonesia, most of the zircon is produced from the tailings (amang) of cassiterite mining or from gold mining. In Nigeria, zircon is a by-product of cassiterite-columbite mining.

The earliest start of production of zirconium (not zircon!) from a hard-rock deposit is in 2014.

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

5.3 Sources of zircon production data

Collections of zircon production data are available free of charge from the US Geological Survey, the British Geological Survey, and the Federal Ministry of Economics, Family and Youth of Austria. Selected production data can be found in annual reports and stock market information from most of the stock market listed zircon producing companies, as well as in mineral production data collections of some of the Geological Surveys and Bureaux of Mines in zircon producing countries.

Excellent collections of production data and additional information on zircon uses, supply and demand, both past and future, are also regularly published by TZMI and Roskill.

For this report, DERA took great efforts to identify all zircon producing companies worldwide and to also gather the most exact possible information on past zircon production since 2005 and future production plans until 2020. HM mines were visited in South Africa, Mozambique and Australia. Local consultants were commissioned to identify/confirm zircon producers in South America, India, Sri Lanka, Pakistan, Vietnam, Malaysia, Thailand, Indonesia, and China. Most of them were very successful in not only obtaining up-to-date information (cf. Chapter 5.6) but also zircon samples for analysis (cf. Appendix C).

Zircon production data – most of it quite precise – was available for all countries except Indonesia, Thailand, Ukraine, Nigeria, and Pakistan (cf.-Appendix A). For these countries, published trade data on zircon imports/exports proved to be very helpful although it still only provided rough estimates of production. Despite all the efforts taken in analysing the data for the USA, Vietnam, and China, some production data for some companies in some years also had to be estimated.

5.4 Assumptions for future zircon supply calculation

Figure 14: HM mining operation by Kenmare Resources at Moma, Mozambique. Photo courtesy of Kenmare Resources plc.

For calculating/estimating the future supply of zircon until 2020, use was made of published information from established mining companies about life of mine and production rates of producing mines, and about reserves/resources, life of mine and planned production rates of future mines. For countries without publically reporting companies, historic production data for each country was averaged and then used as the assumption for future production.

For the evaluation of possible future zircon 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 probable. In addition, even some probable projects were "postponed for one year" to become more realistic.

This approach is different to many industry consultants who simply include without questioning a proposed start of production year reported by even young exploration companies in order not to displease a potential client. In some cases at least, the approach adopted in this study may be proven wrong simply by the successful start of the proposed production.

Projects without any projected start of production were generally not considered further.

The following assumptions were made for future zircon supply calculations (kt = all data in metric kilotonnes of zircon):

Australia

Iluka Resources:	Eneabba: production of 5 kt in 2013., idled thereafter Tutunup South: production of 5 kt in 2013, idled thereafter Cataby: production of 50 kt in 2014ff., of which probable in 2014 WRP: production of 50 kt in 2013, production of 40 kt in 2014, mined out thereafter Balranald: probable production of 150 kt in 2015ff. Jacinth-Ambrosia: production of 200 kt in 2013, and 300 kt in 2013 thereafter, of which probable in 2019 thereafter
Tronox:	Cooljarloo: production of 50 kt in 2012, 60 kt in 2013 and 65 kt in 2014ff. Dongara: probable production of 30 kt in 2015ff.
Cristal Mining:	Gwindinup: production of 10 kt in 2013 – 2016, mined out thereafter Wonnerup: production of 4 kt in 2013 and 5 kt in 2013 – 2016, mined out thereafter Ginkgo+Snapper: production of 35 kt in 2012, 40 kt in 2013, and 45 kt in 2014ff.
Sibelco AUS+NZ:	North Stradbroke Island: production of 70 kt in 2012 – 2015 and probable production of 40 kt in 2016 – 2019, closed down thereafter
MZI Resources:	Tiwi Islands: production of 14 kt zircon in HMC in 2012 and probable production of 10 kt zircon in HMC in 2015ff. Keysbrook: production of 1.4kt in 2013, 19.6 kt in 2014, 16.8 kt in 2015, 13.4 kt in 2016, 16.8 kt in 2017, 15.7 kt in2018, 13.4 kt in 2019, and 14.6 kt in 2020.
Doral Mineral Sands:	Dardanup, Bunbury+Burekup: production of 15 kt in 2012+2013, 12 kt in 2014, and 10 kt in 2015 – 2017, mined out thereafter
GMA Garnet:	Port Gregory: production of 0.5 kt zircon content in 2012ff.
Alkane Resources:	Dubbo: production of 10 kt zircon-equivalent in 2015 and 23.3 kt zircon–equivalent in 2016ff.
Murray Zircon:	Mindarie: probable production of 22 kt in 2013ff.
Astron:	Donald: not probable production of 90 kt in 2013ff.
Gunson Resources:	Coburn: not probable production of 40 kt in 2015ff.
Image Resources:	North Perth Basin: not probable production of 20 kt in 2015ff. Cyclone Extended, cf. Cyclone
Diatreme Resources:	Cyclone+Cyclone Extended: not probable production of 73.6 kt in 2015, 69.5 kt in 2016+2017, 61.3 kt in 2018+2019, and 65.4 kt in 2020
Oresome Australia:	Urquhart Point: not probable production of 9.5 kt between 2013 and 2016

Brazil

Millennium:	Guaju: production of 22 kt in 2012ff.
INB:	Buena: production of 1 kt in 2012 and 0.5 kt in 2013, mined out thereafter
CBA:	Poços de Caldas: production of 40 tonnes caldasite in 2012 ff.

Canada

Titanium Corp.:	Alberta Oil Sands: not probable production of 70 kt in 2015 – 2017 and 100 kt in 2018ff.

China

Wenchang Sanlian:	Hainan: production of 10 kt in 2012ff.
Jingbang:	Hainan: probable production of 7 kt in 2011, and production of 6 kt in 2012ff.
Wenchang Sheng Sheng:	Hainan: production of 7 kt in 2012 – 2016, and 5 kt in 2017ff.
Wanning Yuehai:	Hainan: production of 1 kt in 2012ff.
Winsheen Minerals:	Hainan: production of 5 kt in 2011ff.
Others:	Hainan: production of 1 kt in 2011ff.
Various:	Guangxi: probable production of 2.5 kt in 2011, 2 kt in 2012 – 2014, 1.5 kt in 2015 – 2017, and 1 kt in 2018ff.

Gambia

probably no production in 2011ff.

India

Indian Rare Earths:	Chavara: production of 8 kt in 2012ff. Manavalakurichi: production of 3 kt in 2012ff. OSCOM: production of 6 kt in 2012ff.
V.V. Mineral:	Tamil Nadu: production of 15 kt zircon incl. zircon in zircon-sillimanite mix in 2011ff.
KMML:	Kerala: probable production of 2.8 kt in 2012, 2.9 kt in 2013, 3.0 kt in 2014, 3.1 kt in 2015, 3.2 kt in 2016, 3.3 kt in 2017, 3.4 kt in 2018, 3.5 kt in 2019, and 3.6 kt in 2020
Trimex Sands:	Srikurmam: production of 65 kt in 2012ff. *Attention: Zircon production of Trimex Sands is not known precisely and can strongly influence any zircon supply estimates!*

Indonesia

Attention: Zircon production in Indonesia is highly variable and can strongly influence any zircon supply estimates!

PT Zirmet Mining: Kalimantan: probable production of 10 kt in 2012, and 30 kt in 2013ff., not probable production of 60 kt in 2014, and 80 kt in 2015ff.

Others: Kalimantan: probable production of 60 kt in 2012 and probable average production of 50 kt in 2013ff.

Kazakhstan

Kazchrome: Shokash: probably no production in 2011ff.

Tioline: Obuhovskoye: probable production of 0.6 kt zircon content in 2011, and 2.4 kt in 2012ff, not probable production of 50 kt in 2014ff.

Kenya

Base Resources: Kwale: probable production of 13 kt in 2014, 25 kt in 2015, and 35 kt in 2015ff.

Madagascar

QMM: Fort Dauphin: production of 17 kt zircon in Zirsill in 2012, and 25 kt zircon in Zirsill in 2013ff.

World Titanium: Toliara Sands: not probable production of 32 kt zircon content in 2014ff.

Malaysia

Various: from amang: probable production of 1.6 kt in 2011 and 1 kt in 2012ff.

Mozambique

Kenmare Resources: Moma: production of 45 kt in 2012 and 70 kt in 2013ff.

Nigeria

Attention: Zircon production in Nigeria is highly variable and can strongly influence any zircon supply estimates!

Various: Jos Plateau: probable production of 10 kt zircon in zircon concentrate in 2011 and probable average production of 2 kt zircon in zircon concentrate in 2012ff., not probable average production of 6 kt zircon in zircon concentrate in 2012ff.

Pakistan

Gulf Minerals: Sonmiani Bay: probable production of 6.5 kt in 2011 and 2 kt in 2012ff.

Republic of South Africa

Richards Bay Minerals: Richards Bay: production of 280 kt in 2012ff.

Tronox: Namakwa Sands: production of 140 kt in 2012ff.
KZN Sands: production of 15 kt in 2012, 1 kt in 2013 and 2014, probable production of 10 kt in 2015, 30 kt in 2016, 50 kt in 2017, and 60 kt in 2018ff.

Russia

Kovdorsky: Kovdor: production of 8.5 kt baddeleyite (i.e. 12.6 kt zircon equivalent) in 2010ff.

Tugansky: Tugansky: probable production of 150 tonnes in 2012ff., not probable production of 17 kt in 2013 – 2014 and 34 kt in 2015ff.

Senegal

Mineral Deposits: Grande Cóte: probable production of 65.7 kt in 2014, 90.2 kt in 2015, 87.3 kt in 2016, 86.4 kt in 2017, 85.9 kt in 2018, 84.0 kt in 2019, and 83.5 kt in 2020

Sierra Leone

Sierra Rutile: Gbangbama-Sembehun: no production in 2012, probable production of 2.5 kt zircon in zircon concentrate in 2013 and 2014, 7.5 kt in 2015, 6 kt in 2016 and 2017, 4 kt in 2018, 3 kt in 2019, and 3.5 kt in 2020.

Sri Lanka

Attention: Zircon production in Sri Lanka is highly variable and can strongly influence any zircon supply estimations!

Lanka Mineral Sands: Pulmoddai: average production of 1 kt in 2012ff.

Thailand

Various: From amang: probable production of 0.1 kt in 2011ff.

Ukraine

Volnogorsk: Malyshev: probable production of 27 kt in 2011, 30 kt in 2012 – 2018 and 25 kt in 2019 – 2020

Velta: Tarasovka: not probable production of 34 kt in 2015ff.

USA

DuPont: Trail Ridge: production of 40 kt in 2011, 30 kt in 2012 and 2013, 25 kt in 2014, 20 kt in 2015 and 2016, and 10 kt in 2017, licensed area mined out thereafter

Iluka Resources: Brink: production of 50 kt in 2013, 40 kt in 2014, and 20 kt in 2015, mined out thereafter
Aurelian Springs or Hickory II: probable production of 20 kt in 2015, 40 kt in 2016, and 60 kt in 2017ff.

Oregon Resources: Coos Bay: probable production of 4,635 tonnes in 2011, 5,478 tonnes in 2012, 5,722 tonnes in 2013, 5,676 tonnes in 2014, 5,000 tonnes in 2015 and 2016, and 2,000 tonnes in 2017, mined out thereafter

Southern Ionics: Mission: probable production of 7.7 kt in 2014 and 14.5 kt in 2015ff.

Vietnam

MITRACO:	Ha Tinh Province: production of 3.5 kt in 2012ff.
HUMEXCO:	Thua Thien-Hue Province: production of 9 kt in 2012ff.
BIMICO:	Binh Dinh Province: production of 2.5 kt in 2012ff.
AMIGO:	Binh Thuan Province: production of 7 kt in 2012ff.
SQC:	Binh Dinh Province: production of 3 kt in 2012ff.
BIOTAN:	Binh Dinh Province: production of 0.5 kt in 2012ff.
DQCL:	Quang Nam Province: production of 0.6 kt in 2012ff.

Important remarks

Zircon production in Indonesia, Nigeria, and Sri Lanka in particular is highly variable and can strongly influence any future zircon supply estimates!

Although no possible new zircon project in the former CIS states was assessed as probable in this study, if the opposite occurs, this could also considerably influence the future supply of zircon.

5.5 Results of future zircon supply calculations

Regardless of depressed demand, there will be a strong drop in zircon production in Australia in 2013. This is mainly caused by lower production by Iluka Resources from its WRP deposits, its mined-out Douglas deposits, and notwithstanding its future Balranald deposits in the Murray Basin. Zircon production from Jacinth-Ambrosia must stay high, or mining may become uneconomic. Starting from 2014/2015, zircon production in Australia should increase considerably before decreasing again in 2020ff. mainly because of the depletion of major mines in the country, including the forced closure of the last HM mining operation on North Stradbroke Island for environmental reasons.

If zircon prices fall considerably, several existing mines, and almost all future zircon projects in Australia, will run into cost problems and might have to close or be postponed.

Zircon production in the US will decrease slowly because the licensed areas of the huge Trail Ridge ore body have been mined by DuPont for several decades and will finally become depleted as the HM grades become lower and lower. Even before 2005, Iluka Resources was the major zircon producing company in the USA as well.

Zircon production in the Ukraine should stay constant until it falls drastically after 2020 if no new project goes into production.
All possible future zircon projects in the Ukraine, Kazakhstan, and Russia are hampered by severe geological obstacles, mainly thick overburden.

Production of HM, including zircon, from Mozambique should increase considerably in 2013ff. and will stay high well beyond 2020ff.

With the commencement of the Grand Cóte HM mining project by Mineral Deposits Ltd. in Senegal in 2014, and to a much lesser degree with the planned commencement of the Kwale HM mining project by Base Resources Ltd. in Kenya in the same year, a considerable amount of zircon will be produced in Africa.
It is possible that more zircon will be produced in Africa than in Australia at the end of this decade. The future of zircon mining lies in Africa because Africa hosts more and bigger and more easily mineable zircon deposits than Australia.

There will be no important changes in zircon production in South Africa (in contrast to many contrary predictions), India, China, Vietnam and many other smaller producing countries in 2012ff.

Country	2012	2013	2014	2015	2016	2017	2018	2019	2020
Australia	496,200	483,900	639,100	794,300	774,240	762,600	751,480	749,240	460,360
RSA	435,000	421,000	421,000	430,000	450,000	470,000	480,000	480,000	480,000
India	99,800	99,900	100,000	100,100	100,200	100,300	100,400	100,500	100,600
USA	84,878	85,722	78,376	79,500	79,500	86,500	74,500	74,500	74,500
Indonesia	40,700	55,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000
Mozambique	46,900	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000
China	32,000	32,000	32,000	31,500	31,500	29,500	29,000	29,000	29,000
Ukraine	30,000	30,000	30,000	30,000	30,000	30,000	30,000	25,000	25,000
Vietnam	24,800	24,800	24,800	24,800	24,800	24,800	24,800	24,800	24,800
Brazil	23,040	22,540	22,040	22,040	22,040	22,040	22,040	22,040	22,040
Madagascar [2)]	17,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Russia [1)]	12,795	12,795	12,795	12,795	12,795	12,795	12,795	12,795	12,795
Kazakhstan	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Pakistan	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Nigeria [3)]	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Sri Lanka	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Malaysia	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Thailand	100	100	100	100	100	100	100	100	100
Sierra Leone [4)]	0	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Senegal	0	0	65,700	90,200	87,300	86,400	85,900	84,000	83,500
Kenya	0	0	13,000	25,000	35,000	35,000	35,000	35,000	35,000
Total	1,351,113	1,373,157	1,624,311	1,830,735	1,836,375	1,848,935	1,832,915	1,822,875	1,534,095

1) **Baddeleyite production converted to zircon equivalent, 2) Zircon in Zirsill, 3) Zircon in impure zircon pre-concentrate, 4) Zircon in zircon product**

Table 6: Probable zircon production by countries from 2012 to 2020

If zircon demand really rises considerably in future, both Iluka Resources and Richards Bay Mining can adjust their zircon output relative easily and strongly within one year. Additionally, zircon output in Nigeria and Indonesia can be increased strongly and even in a short time if necessary.

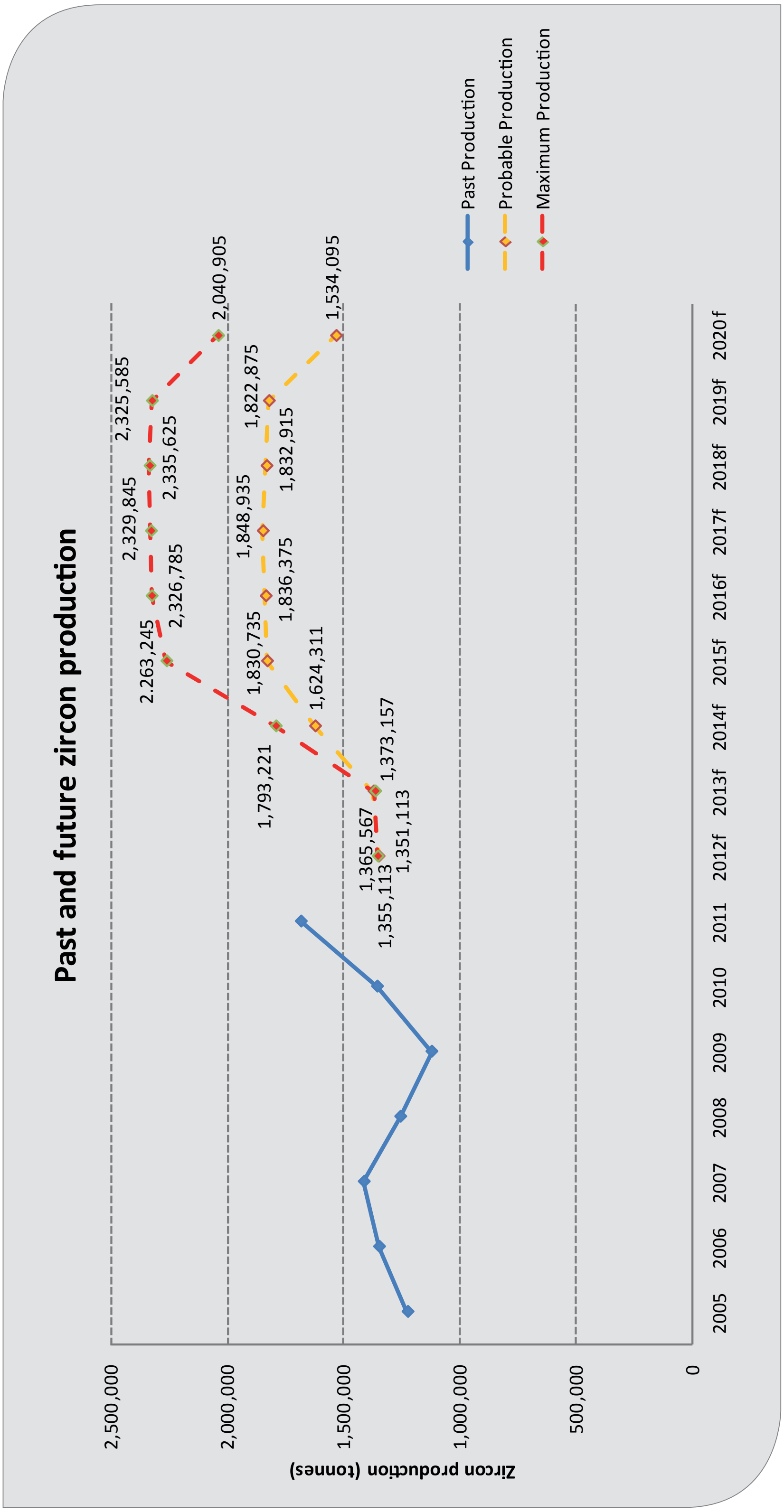
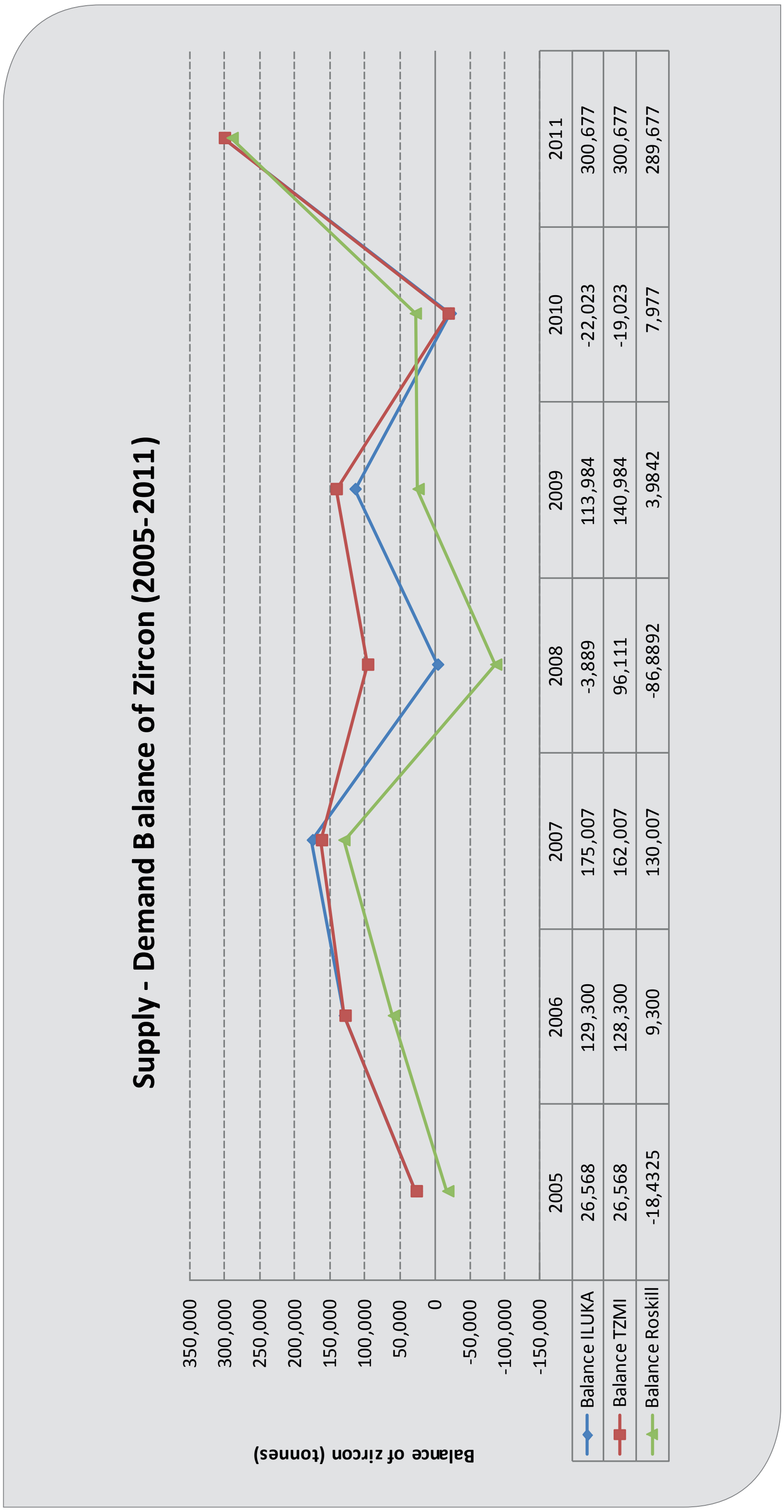


Figure 15: Zircon production between 2005 and 2011, and probable as well as maximum zircon production between 2012 and 2020.

6 Supply – Demand balance

6.1 Supply – demand balance between 2005 and 2011

Figure 16 shows supply data as collected by DERA versus the demand estimates as published by TZMI, Roskill and Iluka Resources (2005 – 2011).



	2005	2006	2007	2008	2009	2010	2011
Balance ILUKA	26,568	129,300	175,007	-3,889	113,984	-22,023	300,677
Balance TZMI	26,568	128,300	162,007	96,111	140,984	-19,023	300,677
Balance Roskill	-18,4325	9,300	130,007	-86,8892	3,9842	7,977	289,677

Figure 16: Supply - demand balance for zircon between 2005 and 2011. Supply data from DERA.

As already outlined in Chapter 4.2, TZMI and Iluka Resources very often had a fairly similar but definitely not the same opinion on past demand. This results in similar trends as shown in Figure 16. However, in 2008, Iluka comes to a more negative (realistic?) opinion on the supply-demand balance.

In 2005, zircon supply and demand were nearly balanced, while in the following two years supply increased with demand remaining steady. This resulted in an overproduction of +130,000 to +175,000 tonnes of zircon in 2007.

For 2008, Iluka Resources and Roskill still identified a small increase in demand, while TZMI noticed a first strong decrease. Notwithstanding the above, zircon production decreased considerably in 2008 due to oversupply in the preceding years, i.e. by some –157,000 tonnes, of which some –90,000 tonnes can be attributed to Indonesia. Due to its small-scale mining structure, Indonesia was, is and most probably will remain for many years to come, the first supplier to react swiftly to changes in zircon demand.

Due to the setback of the supply-demand trend until 2007, the opinions on the balance in 2008 differ strongly. Applying production data by DERA and demand data by Roskill, TZMI and Iluka, different estimates for the supply-demand balance appear. According to Roskill, there was a strong deficit, while according to TZMI there was a very strong surplus. Iluka Resources data shows a balance that is close to even.

In 2009, the Global Financial Crisis (GFC) changed everything with demand plummeting in all countries. Zircon producers did not adjust quickly enough, so worldwide zircon production decreased by only –135,000 tonnes compared to 2008. Together with a lower demand of –200,000 to –250,000 tonnes the result was a zircon surplus of about +114,000 to +141,000 tonnes according to Illuka and TZMI respectively. Roskill data on the other hand indicated a smaller surplus of only +24,000 tonnes.

The global economy recovered quickly in 2010 and demand for zircon rose strongly again – to even higher levels than in the years before the GFC. This year to year rise in demand was estimated as +395,000 tonnes by TZMI, +370,000 tonnes by Iluka Resources, and +230,000 tonnes by Roskill. Because the production of zircon only rose by +234,000 tonnes, the result was a deficit of about –20,000 tonnes. Because Roskill estimated a lower demand, its balance would have been a surplus of +28,000 tonnes, which obviously was not the case: zircon prices started to rise as supply could not cope with demand.

In 2011, zircon supply finally caught up with demand which only rose between +5,000 (Iluka Resources) to +66,000 tonnes (Roskill) compared to 2010. With maximum zircon production in all countries, additionally fired by high and accelerating prices, world zircon production reached a peak of 1.69 million tonnes. Although many consumers obviously stockpiled zircon for fear of even higher prices, supply once again was much higher than demand. This surplus of zircon on the world market in 2011 may have been about +300,000 tonnes.

With the end of 2011, and continuing in H1 2012, the hyped up zircon market started to collapse, with prices until September 2012 kept artificially high by the major zircon producing companies. However, destocking of stockpiles, slightly depressed demand from China, and above all the substitution of zircon (cf. Chapter 4.5) will ultimately bring down the zircon prices to much more moderate levels.

6.2 Supply - demand balance until 2020

According to the data collected by DERA, probable production of zircon will rise up to 1.84 million tonnes in 2016 before it decreases slightly to 1.82 million tonnes in 2019. 2020 shows a strong decrease to 1.53 million tonnes of zircon, which will be caused by depletion/closure of major mines in Australia (cf. Chapter 5.5).

Calculation of maximum production essentially shows the same trend, but production might rise up to 2.33 million tonnes in 2016, not decreasing until 2019, before dropping to 2.04 million tonnes in 2020.

Both TZMI and Roskill estimate very similar trends for the future demand for zircon, which again are very similar to the calculation for base demand by Iluka Resources. Their data differ by a maximum of 33,000 tonnes in 2014.

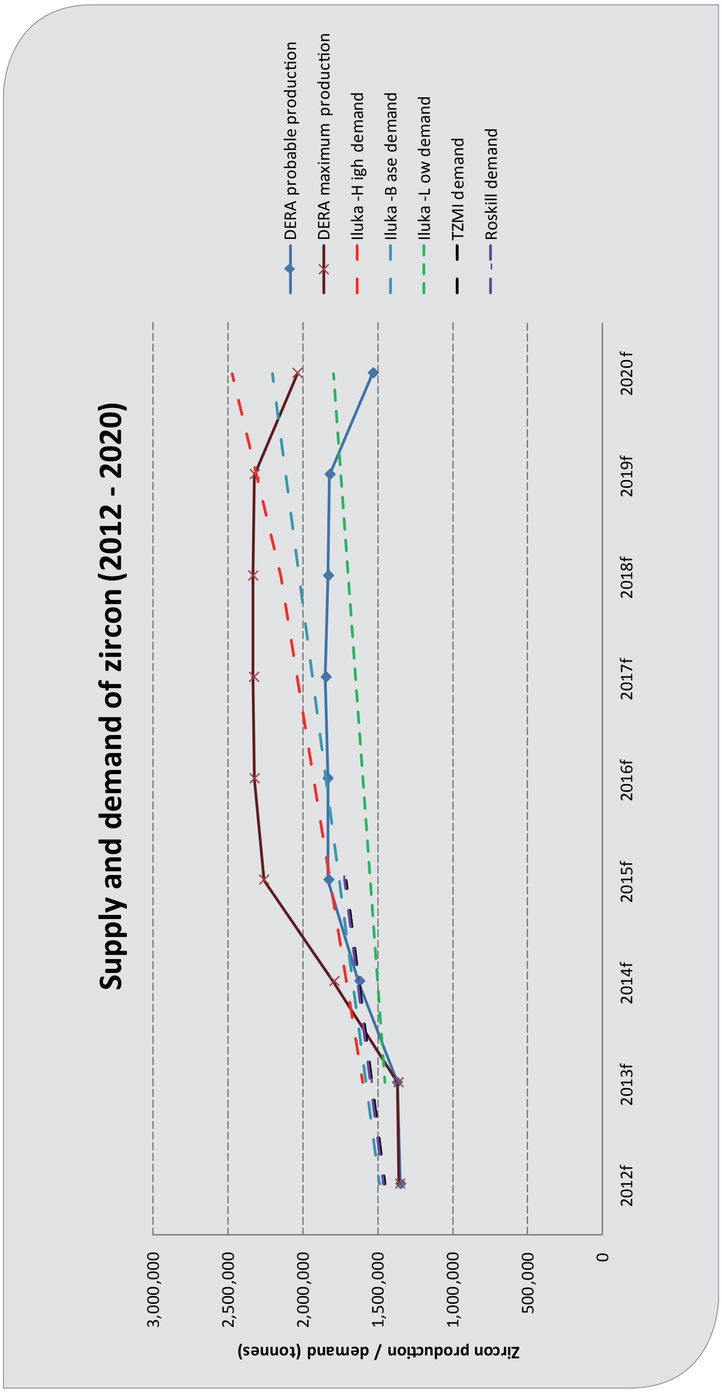


Figure 17: Supply and demand of zircon (2012 – 2020).

Using the data for probable zircon production as calculated by DERA and the similar base demand estimates until 2015 there would have been a deficit in zircon in 2012 of –139,000 tonnes according to Iluka but a smaller deficit according to TZMI and Roskill. However, taking into account most recent demand estimates for 2012 as presented by Liberal (2012) (cf. below) there was a strong surplus in 2012 of +350,000 tonnes!

According to the published estimates in 2013, the deficit might have been between –187,000 tonnes (Iluka) to –192,000 tonnes (TZMI), only Roskill saw a smaller deficit of –169,000 tonnes. For 2014, only Iluka predicted a positive balance with a surplus of about +14,000 tonnes. In 2015, a definite surplus was projectable with a range of between +107,000 tonnes (Roskill) to +131,000 tonnes (Iluka).

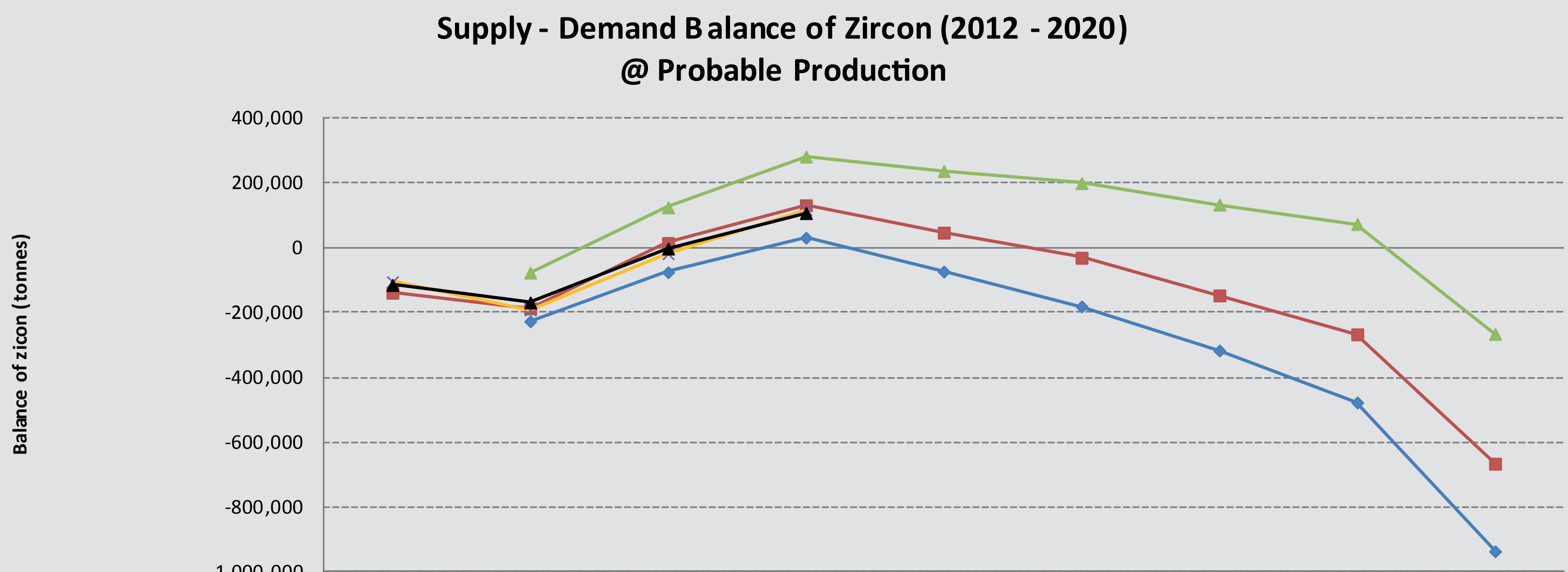
All the base case demand calculations/estimates used in this study were postulated before the decrease in demand in 2011/12 which was due to various reasons, above all substitution. A rate of substitution of only 1.5 % in 2013 would push all supply-demand balances based on probable production levels into the positive side, i.e. into a surplus. As substitution in 2011/12 was apparently much higher than 1.5 %, a strong surplus in the worldwide zircon supply-demand balance can be forecast for all years until 2019.
At the calculated maximum production rates, this surplus would be so large that the zircon market would collapse for many years to come.

With slightly decreasing production but rising demand after 2015, the picture looks different for 2017ff. For these years, the only available demand estimates published are from Iluka Resources.

Most recent estimates of future zircon demand presented at the TZMI Congress in November 2012 (Liberal 2012) are much lower, but could not be accounted for in this study in full. As basic points Liberal estimates an updated zircon demand of only 1,002,000 tonnes in 2012 (i.e. –454,000 tonnes lower than the TZMI estimate in 2011) and 1,500,000 tonnes in 2020 (i.e. –300,000 tonnes lower than the low demand scenario of Iluka Resources as of 2011).

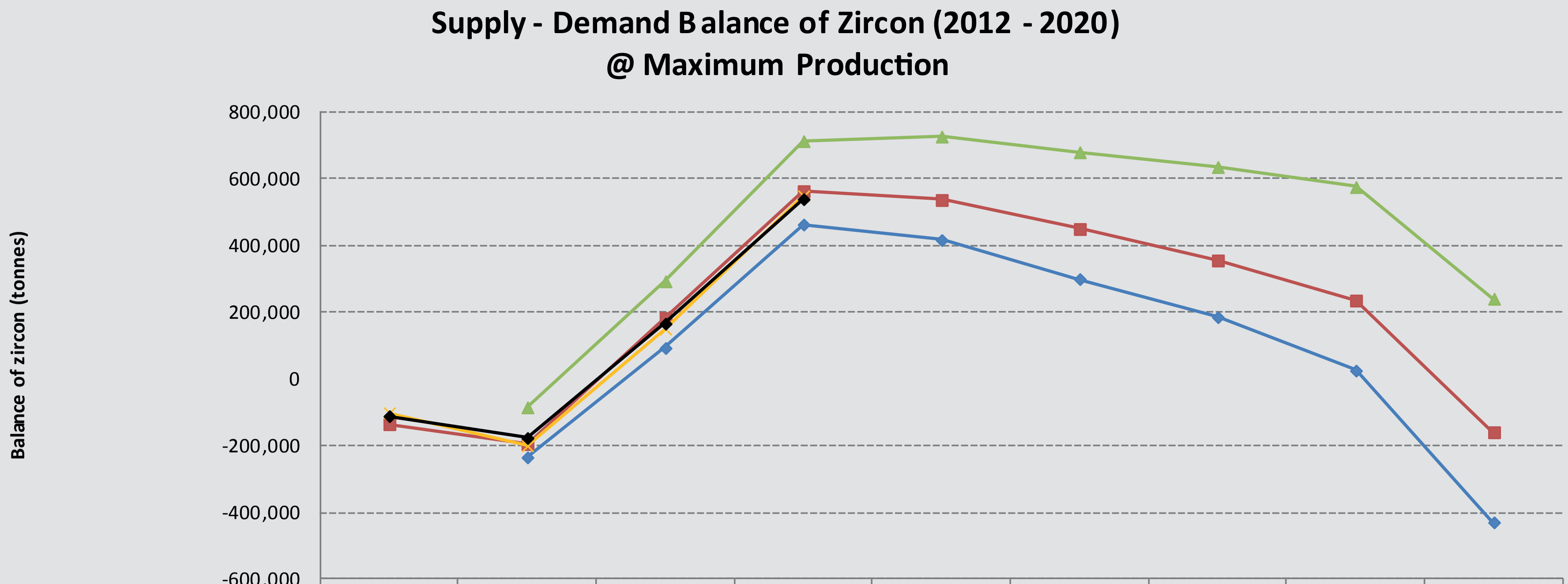
At probable production (DERA) and base case demand without any influence from substitution (cf. above), the zircon surplus of the supply-demand balance will turn into a deficit in 2017 (–31,000 tonnes), getting stronger in 2018 (–147,000 tonnes) and the years thereafter.
Assuming a continued substitution rate of 10 – 15 %, which seems very realistic, at probable production and base case demand, the surplus will turn into a deficit in 2020.

At maximum production (DERA), and even at high demand, there will be a strong surplus of the supply-demand balance until 2019. Even with maximum production at high demand, this surplus could turn into a deficit in 2020ff. However, as high demand will be coupled with high prices, which go hand in hand with maximum substitution at maximum production, there will probably be no deficit in 2012ff. at all.



	2012f	2013f	2014f	2015f	2016f	2017f	2018f	2019f	2020f
Balance Iluka -High demand		-226,843	-75,6893	0,735-	73,625	-181,065	-317,085	-477,125	-935,905
Balance Iluka -Base demand	-138,887	-186,843	14,311	130,735	46,375	-31,065-	147,085	-267,125	-665,905
Balance Iluka -Low demand		-76,843	124,311	280,735	236,375	198,935	132,915	72,875	-265,905
Balance TZMI demand	-104,887	-191,843	-18,689	116,735					
Balance Roskill demand	-114,887	-168,843	-2,689	106,735					

Figure 18: Supply - demand balance of zircon at probable production (2012 – 2020).



	2012f	2013f	2014f	2015f	2016f	2017f	2018f	2019f	2020f
Balance Iluka -High demand		-234,433	93,221	463,245	416,785	299,845	185,625	25,585	-429,095
Balance Iluka -Base demand	-134,887	-194,433	183,221	563,245	536,785	449,845	355,625	235,585	-159,095
Balance Iluka -Low demand		-84,433	293,221	713,245	726,785	679,845	635,625	575,585	240,905
Balance TZMI demand	-100,887	-199,433	150,221	549,245					
Balance Roskill demand	-110,887	-176,433	166,221	539,245					

Figure 19: Supply - demand balance of zircon at maximum production (2012 – 2020)

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Appendix

Appendix A • Supply – Country profiles

Appendix B • Comparative statistics of commercial zircon concentrates

Appendix C • Specifications of commercial zircon concentrates

Appendix A

Supply – Country profiles

AUSTRALIA

Heavy minerals or mineral sands, or black sands as they are called in Australia, which include zircon, have been mined in Australia for over a century. Mining started along the east coast but shifted to the west coast some decades ago. Meanwhile, buried fossil strandlines in the South of Australia (Murray Basin, Eucla Basin) provide the majority of the Australian zircon output.

Currently, there are seven producers of zircon or zircon-rich mineral concentrates in Australia which are mining more than a dozen deposits:
- Iluka Resources Ltd.,
- Tronox Management Pty Ltd.,
- Cristal Mining Australia Ltd. (formerly Bemax Resources Ltd.),
- Sibelco Australia and New Zealand,
- MZI Resources Ltd.,
- Doral Mineral Sands Pty Ltd.,
- GMA Garnet Pty Ltd.

There also are numerous other companies hoping to be able to commission new zircon(ium) projects in the foreseeable future. Among those are:
- Alkane Resources Ltd.,
- Astro Resources NL,
- Astron Ltd.,
- Australian Zircon NL,
- Diatreme Resources Ltd.,
- Gunson Resources Ltd.,
- Image Resources NL,
- Oresome Australia Pty Ltd.,
- Sheffield Resources Ltd.

Alkane Resources Ltd., based in Burswood, Western Australia, will commission its Dubbo Zirconia project in New South Wales in late 2015. Total resources of the Toongi trachyte intrusion at Dubbo down to 100 m depth are 73.2 Mt of ore grading 1.94 % ZrO_2 and 0.04 % HfO_2. Most of the zirconium/hafnium is bound to the mineral eudialyte. Besides zirconium and hafnium, production will also include niobium, tantalum, and mixed LREE and HREE products. By various physical and chemical separation processes, zirconium basic sulphate (ZBS) will be produced, out of which zirconium hydroxide (ZOH), zirconium oxychloride (ZOC, 36 % ZrO_2), and zirconium basic carbonate (ZBC) can be generated. Anticipated production by Alkane Resources is 15,700 tonnes of ZrO_2 equivalent zirconium products annually.

Astro Resources NL, based in West Perth, focuses on the exploration of the Scott Coastal Plain Mineral Sands Project located within the Augusta region of south-west Western Australia. The most important individual deposit is Governor Broome containing inferred resources of 51 Mt of ore sand grading 5 % HM, of which 4.3 % is zircon. There is no information about any possible start of mining.

Astron Ltd., based in Sydney, but soon to be based in Hong Kong, owns the Jackson (formerly known as WIM 200) and Donald (formerly known as WIM 250) HM deposits in the Murray Basin of Victoria. Current resources in the huge Donald minerals project area stand at 4.04 billion tonnes of ore sand with an average grade of 4.8 %, though very fine HM. The average grade of zircon within the HM suite is 18.3 %. This is equivalent to a content of 194 Mt of HM and 35.5 Mt of zircon. However, both the U+Th content in the zircon (approx. 1,000 ppm) and also the slime content in the ore sand is quite high, the latter reported as 15.1 % on average. The HM concentrate produced is to be processed in China. Mining could start as early as 2013 and last for more than 30 years if no obstacles arise in the funding and permitting processes. Production is to be 103 ktpa of primary zircon, 14 ktpa of secondary zircon, and 4 ktpa of 60/63 zircon.

Australian Zircon NL, based in Adelaide, is engaged in developing both the WIM 150 and the Mindarie HM projects.
The company is entitled to earn an 80 % equity interest in the WIM 150 HM deposit located near Horsham in western Victoria by completing a bankable feasibility study for development of the project. The deposit comprises indicated and inferred resources of 727 Mt of ore sand at 3.9 % HM, i.e. 28.4 Mt of HM, which are very fine-grained. No information about the possible start of this project is available.

In June 2011, a joint venture between Australian Zircon NL (35 %) and Guangdong Orient Zirconic Science and Technology Industry Co. Ltd. (OZC, 65 %), known as Murray Zircon Pty Ltd. (MZ), was established. Australian Zircon NL sold its share to the majority shareholder in September 2012. Murray Zircon Pty Ltd. will resume mining at Mindarie in the Murray Mallee of South Australia, 148 km east of Adelaide, in November 2012. The Mindarie

HM project involves the mining of eight mineral sand strandlines located in nine separate mineral leases and two exploration licenses. Developement of the Mindarie mine commenced in 2006 with production of the first shipment in November 2007. Due to exchange rate rises and higher than expected costs, the mine was placed on care and maintenance in October 2009. 5,959 tonnes of zircon were produced in 2008, and 9,553 tonnes of zircon in 2009. As of July 2009, the remaining HM resources in all categories at a cut-off grade of 1 % HM were 171 Mt of ore sand containing 5.5 Mt of HM of which 18.6 % is zircon. When mining restarts, 120,000 tonnes of HMC is to be produced annually and separated in China. Thus, zircon production may be 22,000 tpa.

Diatreme Resources Ltd. is based in Brisbane. The company intends to develop the Cyclone deposit in the western part of the Eucla Basin. The Cyclone Extended deposit, which is owned by Image Resources NL, could be developed together with the Cyclone deposit. The Cyclone deposit resource stands at 132.1 Mt of ore sand with 2.33 % HM (cut-off grade 1 % HM), i.e. containing 3.1 Mt of HM, of which 998,000 tonnes is zircon (32.4 %). Project construction could start in 2014, and mining in 2015, with a proposed mining rate of 10 Mt of ore sand per annum. During the 9.7 year lifetime of the deposit, the forecast is to produce 630,000 tonnes of zircon product (66 % $Zr(Hf)O_2$, 369 ppm U+Th) (thus 65,000 tpa), 90,000 tonnes of HiTi 87 titanium product (thus 10,000 tpa), and 440,000 tonnes of HiTi 67 titanium product (thus 46,000 tpa).

Diatreme has also identified the Zephyr deposit, which is located within 2 km of the Cyclone deposit. An initial inferred resource estimate was given as 106 Mt of ore sand with 1.5 % HM (cut-off grade 1 % HM), i.e. containing 1.6 Mt of HM.

Table 9: Planned HM and zircon production (in kilotonnes) during the lifetime of the Cyclone deposit, after Diatreme Resources pre-feasibility study.

Year	1	2	3	4	5	6	7	8	9	10
HM	250	270	255	205	210	270	280	290	230	155
Zircon	73.6	69.5	69.5	61.3	61.3	61.3	65.4	65.4	61.3	36.8

Gunson Resources Ltd. is a junior exploration company based in West Perth. Among deposits of other commodities, the company has focused for many years on developing the Coburn fossil dune HM deposit, located about 700 km north of Perth in Western Australia. This deposit lies very remote from any settlements or infrastructure on the edge of the Shark Bay World Heritage area, so a mine would have to be operated on a fly-in/fly-out basis, similar to the mines in the Eucla Basin. The thickness of the ore body at Coburn averages 15 m, with an average 9 m of overburden. 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 Amy Zone, now have governmental environmental approval for mining. This area has reserves of 308 Mt of ore sand averaging 1.2 % HM, i.e. containing 3.7 Mt of HM. Resources including reserves amount to 979 Mt of ore sand grading 1.26 % HM (cut-off grade 0.8 % HM) on average, i.e. containing 12.3 Mt of HM. Zircon comprises 23 % of the HM suite. These reserves are sufficient to support a mine life of 17.5 years at a mining rate of 17.5 Mtpa. Planned annual zircon (66 % $Zr(Hf)O_2$, 340 ppm U+Th) production is 41,000 tonnes. The northern third of Amy Zone has not yet been approved for mining but contains a potentially mineable resource of 106 Mt averaging 1.3 % HM. Mining of this resource would sustain the operation for a further six years. As soon as full financing can be secured, start of production could optimistically be 18 months later. In March 2012, DuPont signed an off-take agreement for the ilmenite from the Coburn deposit.

Image Resources NL, based in West Perth, holds numerous HM exploration licenses at and south of Cooljarloo in the North Perth Basin in Western Australia. As of October 2011, the total resources of nine deposits suitable for dry mining were 47.4 Mt of ore sand grading 6.5 % HM (and 10.1 % slimes) on average, i.e. containing close to 3.1 Mt of HM.

Additional resources suitable for dredge mining encompassed 233 Mt of ore sand, grading 2.0 % HM on average, i.e. containing 4.7 Mt of HM of which 9 % is zircon. Of the many regions explored, the Cooljarloo and Gingin areas are the most promising, and Image Resources hopes to be able to start HM production in 2014.

Image Resources also explores in the Eucla Basin, with the Cyclone Extended deposit (Cyclone deposit owned by Diatreme Resources Ltd.) being the most interesting one. Initial resources of this deposit stand at 86.3 Mt of ore sand with 1.9 % HM (cut-off grade 1.0 % HM) on average, i.e. containing 1.64 Mt of HM, of which 21.1 % is zircon. The Cyclone Extended deposit is to be developed together with the Cyclone deposit.

Oresome Australia Pty Ltd. is a fully owned subsidiary of Metallica Minerals Ltd., both located in East Brisbane. Oresome Australia currently has two HM projects: Urquhart Point located in the far north of Queensland, and Gippsland located in Victoria.
The Cape York mineral sands project area covers some 2,000 km^2 and encompasses the Urquhart Point deposit. This small deposit holds resources of some 2.8 Mt of ore sand at 7 % HM (of which 20 % is zircon) to a maximum depth of 3 m. The life of mine will be about four years.
While no information on the possible start of production is available for the Gippsland project, HM production in North Queensland could start in 2013.

Sheffield Resources Ltd. is also based in West Perth and engaged in exploration of tungsten/REE, iron, iron/bauxite, talc and HM deposits. All of the more advanced HM projects are located in the North Perth Basin. Total resources of the most advanced West Mine North, Yandanooka (cut-off grade 0.9 % HM), and Ellengail deposits are 160.81 Mt of ore sand grading 2.5 % HM (and 14.5 % slimes) on average, or containing 4.08 Mt of HM of which 9.8 % (400,000 tonnes) is zircon. No commencement date for production has been established yet.

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Iluka Resources Ltd., based in Perth, Australia, is the world's largest producer of HM, including zircon. The company was formed in December 1998 by 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 USA. In addition to its mineral sand operations – which involve mining and processing – Iluka maintains warehouses in Europe, USA, 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. Currently in Australia, Iluka mines HM in Western Australia, in the Murray Basin in Victoria/New South Wales, 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 traditionally used to be 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 Narngulu, near Geraldton. The Narngulu mineral separation plant (MSP) was recently upgraded (two plants) to be able to process HMC from the Eucla Basin as well as from the Eneabba and the Capel regions

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 25,000 tpa of zircon, 25,000 tpa of rutile, and 140,000 tpa 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 it was decided to idle the Eneabba operations again from March 2013. In addition to Eneabba, 1.4 Mt of HM were mined at Gingin between mid 2005 and May 2009.

Approximately half way between Perth and Narngulu lies the Cataby deposit where Iluka hopes to commence mining as early as the beginning of 2014. Originally, mining was planned to start in 2019. The expected mine life is +6 years. The Cataby HM deposit contains reserves of 156.8 Mt of ore sand grading 4.8 % THM, of which 9 % is zircon.

The South-West operations consist of mining and processing facilities around Capel, some 200 km south of Perth. Mining in this area was interrupted in 2010 as the Cloverdale deposit was closed in September 2008, followed by the Wagerup deposit in January 2009 and the Waroona deposit in September 2009. It was succeeded by the Tutunup South deposit which is located 195 km south of Perth and 15 km south-east of Busselton township. This deposit was opened in June 2011 and has a life of mine of about five to six years. Reserves are about 10.4 Mt of ore sand grading

11.0 % HM on average. The ilmenite from Tutunup South is processed at the company's Capel dry mill before being exported from the port of Bunbury. Non-magnetic materials (zircon and rutile) are processed at the Narngulu MSP, depending on plant availability, and exported via the port of Geraldton.

As of 31 December 2011, resources (including reserves) held by Iluka in Western Australia stood at 1,142.1 Mt of ore sand grading 5.3 % HM on average, i.e. containing 60.84 Mt of HM, of which 10 % was zircon. At the same time, the reserves held by Iluka in Western Australia stood at 327.8 Mt of ore sand grading 5.5 % HM on average, i.e. containing 17.97 Mt of HM, of which 10 % was zircon.

Murray Basin

The Murray Basin stretches from South Australia to Victoria and New South Wales. All of Iluka's current operations are 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.

In the northern part of the Murray Basin, the Kulwin HM deposit was the first to be developed. It commenced production in October 2009 and ceased production in February 2012. Mining and concentrating activities commenced in May 2012 at the Woornack, Rownack and Pirro (WRP) group of deposits, located 30 km south-east of Ouyen, and containing 5.4 Mt of ore sand grading 26.0 % HM. This involved the relocation of mining equipment from Kulwin to WRP, including mining unit plant, pre-concentrator and concentrator plant.

Feasibility work is underway for the potential development of the large Balranald deposit, and associated deposits, including Nepean, both 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. 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 combined indicated and inferred resources at West Balranald are 36.8 Mt of ore sand grading 33.0 % HM on average, of which 11.0 % is zircon. The Nepean deposit is located approximately 30 km to the north of the West Balranald deposit. It contains inferred resources of 8.9 Mt of ore sand at 26.5 % HM, of which 14 % is zircon. 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. Construction and commencement of the Balranald project could occur from late 2014 to 2015.
Following this, there is a potential for 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).

Output from the former southern Murray Basin mines as well as WRP in the north, is transported by road to Hamilton where a mineral separation plant has been producing ilmenite, rutile, and a premium grade zircon since February 2007. Cassiterite and magnetite concentrates have also been produced as by-products from the southern deposits. Zircon capacity at Hamilton is given as about 165,000 tpa. Mineral products are trucked to the Port of Portland, some 85 km to the south, or in containers to Melbourne.

As of 31 December 2011, resources (including reserves) held by Iluka in the Murray Basin stood at 229.5 Mt of ore sand grading 16.6 % HM on average, i.e. containing 38.04 Mt of HM, of which 10 % was zircon.
As of 31 December 2011, reserves held by Iluka in the Murray Basin stood at 23.3 Mt of ore sand grading 20.8 % HM on average, i.e. containing 4.83 Mt of HM, of which 12 % was zircon.

Eucla Basin

In November 2009, Iluka produced the first commercial HMC from Jacinth-Ambrosia, which was discovered in 2004 and is 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 m to 45 m.

Jacinth-Ambrosia is expected to have a lifetime of ten years and produce an average of 300,000 tpa of zircon in its initial years, together with smaller amounts of rutile and ilmenite. The Jacinth-Ambrosia operation was commenced with the capacity to produce at least 600,000 tonnes of HMC per annum. The concentrate 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 2010, Jacinth-Ambrosia contained resources of 8.3 Mt of HM including reserves of 6.4 Mt of HM, of which some 50 % was zircon.
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, discovered in 2005 and containing inferred resources of 39.5 Mt of ore sand grading 2.3 % HM (0.91 Mt of HM), of which 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 grading 6.1 % HM (cut-off grade 3 % HM), i.e. 1.34 Mt of HM, of which 14 % is zircon. 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 inferred resources of 29.2 Mt of ore sand grading 11.3 % HM, i.e. 3.3 Mt of HM, of which 15 % is zircon.
- Sonoran, discovered in 2012 and located 9 km south-east of Jacinth-Ambrosia. This deposit contains 30.1 Mt of ore sand grading 7.3 % HM (cut-off grade 3 % HM) of which 17 % is zircon. The thickness of overburden varies between 20 to 45 m.

As of 31 December 2011, resources (including reserves) held by Iluka in the Eucla Basin stood at 422.3 Mt of ore sand grading 4.3 % HM on average, i.e. containing 18.33 Mt of HM, of which 32 % was zircon.
As of 31 December 2011 reserves held by Iluka in the Eucla Basin stood at 143.1 Mt of ore sand grading 4.5 % HM on average, i.e. containing 6.38 Mt of HM, of which 50 % was zircon.

Figure 21: Jacinth mine pit of Iluka in the Eucla Basin of South Australia. Photo courtesy of Iluka Resources Ltd.

Table 10: Production of zircon by Iluka Resources Ltd. in Australia [in tonnes], after Iluka Annual Reports. WA = Western Australia, MB = Murray Basin, EB = Eucla Basin

<table>
<tr><th colspan="2"></th><th>2005</th><th>2006</th><th>2007</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th></tr>
<tr><td rowspan="3">WA</td><td>Tutunup South</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>9,300</td><td rowspan="2">15,000</td></tr>
<tr><td>Eneabba + Gingin</td><td>203,843</td><td>245,106</td><td>197,169</td><td>167,797</td><td rowspan="2">145,600</td><td>46,200</td><td>0</td></tr>
<tr><td>Waroona, Cloverdale + Wagerup</td><td>62,242</td><td>64,559</td><td>47,294</td><td>20,206</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="4">MB</td><td>Douglas</td><td>–</td><td>–</td><td>128,254</td><td>112,728</td><td rowspan="2">69,900</td><td rowspan="3">157,600</td><td rowspan="3">218,200</td><td rowspan="3">135,600</td></tr>
<tr><td>Kulwin</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Echo</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Woornack, Rownack, Pirro</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>EB</td><td>Jacinth-Ambrosia</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>150,900</td><td>313,700</td><td>143,200</td></tr>
</table>

Currently, Iluka produces a standard, a premium, a coarse and a chemical grade zircon from Eneabba (in the Narngulu MSP), a Eucla standard and a premium grade zircon (from Jacinth-Ambrosia in the Narngulu MSP), and a premium and a chemical (standard) grade zircon from the Murray Basin (in the Hamilton MSP) (cf. Appendix C for analysis).

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Figure 22: HM dredge and wet concentration plant (concentrator) at Cooljarloo, Western Australia. Photo courtesy of Tronox Ltd.

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 will acquire Exxaro's mineral sands operations in South Africa and Australia. This included Exxaro's 50 % interest in the Tiwest JV. The transaction closed in June 2012.

Currently, the Tronox mineral sands operations in Western Australia comprise:

- a mineral sands mine at Cooljarloo, in the Lancelin to Gingin area, 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 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 in 1996. The life of mine including all extensions is about 38 years. Currently, the mining operation consists of two dredges operating in the southern part of the lease, and a dry mine in the north. Each mine has a designated concentrator. The south floating concentrator follows the dredge in its operating pond, while the north concentrator is land-based, and is occasionally relocated to minimise ore transport distances. From the mine, the HMC is trucked some 110 km south to a dry separation plant at Chandala. The MSP at Chandala has an annual processing capacity of 750,000 tonnes of HMC and 80,000 tonnes of zircon.

As of 31 December 2011, Exxaro reported reserves at Cooljarloo of 264.7 Mt of ore sand grading 2.2 % THM on average, of which 9.4 % was zircon. Additional resources were 399.9 Mt of ore sand grading 2.1 % THM. Resources in the Cooljarloo West project were 197.0 Mt of ore sand at 1.8 % THM.

Tronox is also the license owner of the Jurien and the Dongara projects. For Jurien, Tronox holds the mining rights, while Dongara is an exploration prospect.
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 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 10.0 % was zircon. Resources at Jurien stood at an additional 25.6 Mt of ore sand grading 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 2011, it had reserves of 29.5 Mt of ore sand at 7.3 % THM, of which 10.1 % was zircon. Resources were much larger at 83.1 Mt of ore sand grading 4.5 % THM on average. Mining at Dongara might start in 2014 supporting a mining operation for seven years. Zircon production from Dongara is estimated to reach 30,000 tpa.

Besides various grades of ilmenite, leucoxene, and rutile, mainly used as internal feedstock for the production of titanium dioxide pigment, Tronox also produces two grades of zircon (cf. Appendix C for analysis) and staurolite, which is used as an abrasive. Zircon flour products of varying particle size can be sourced from an external milling facility.

Table 11: Production of zircon by Tiwest Pty Ltd. at Cooljarloo [in tonnes], after Exxaro Annual Reports.

	2005	2006	2007	2008	2009	2010	2011
Cooljarloo	70,000	72,000	72,000	58,000	65,000	69,000	64,000

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BEMAX Resources Ltd., now Cristal Mining Australia Ltd., was incorporated in Australia in 1987, and was listed on the Australian Stock Exchange in 1990. Also in 1990, BEMAX 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 the name of BEMAX Resources Ltd. was changed to Cristal Mining Australia Ltd.

The company's operations in the Murray Basin include the Ginkgo and Snapper mines and a mineral separation plant at Broken Hill in western New South Wales. The Ginkgo mine, located 220 km from Broken Hill, opened in December 2005 and was the first commercial mineral sand mining operation in the Murray Basin of NSW. The mine exploits a deposit discovered in 1998, containing initial proven reserves of 131 Mt of ore sand grading 3.5 % HM, of which some 10 % is zircon. Probable reserves were 52 Mt of ore sand grading 1 % HM, and additional indicated resources were a further 43 Mt of ore sand at 2.0 % HM. In February 2006, processing of the first HMC at the Broken Hill MSP started.

Production at Broken Hill is an ilmenite and leucoxene product for final sale through Port Adelaide, and a zircon/rutile rich non magnetic concentrate sent to Bunbury in Western Australia for final processing into zircon, rutile and leucoxene products.

The Ginkgo mine is expected to be depleted in 2025. The Snapper mine is 10 km from the Ginkgo mine. Proven reserves at Snapper are 117 Mt of ore sand grading 5.0 % HM on average, of which 10 % is zircon. 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 Ginkgo mine and will not be depleted before 2027.
Cristal Mining also owns several other promising prospects and concessions in the Murray Basin which could come into production in the more distant future. The last time the company reported its total resources was in 2009; in the Murray Basin, these amounted to 95.1 Mt of net HM.

Cristal Mining's Western Australian operations are operated through wholly owned subsidiaries that make up the Cable Sands Group. Many of the operations run by Cristal Mining or Cable Sands in Western Australia were relatively small and had operating lives of just a few years. The most recent 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. The Gwindinup operations are about 30 km south of the company's mineral separation plant at Bunbury, and have a lifespan of around 9 years. The Gwindinup and Happy Valley deposits contain proven reserves of approximately 1.9 Mt HM, of which about 10 % is zircon.

Cristal Mining's next HM mining operation in Western Australia will be at Wonnerup, where a deposit contains inferred resources of 6.4 Mt of ore sand grading 5.2 % HM on average, of which 7.2 % is zircon. Mining was expected to begin in min 2013.

Currently, the Bunbury MSP produces two major zircon products: one from Ginkgo/Snapper and one from Gwindinup (cf. Appendix C for analysis).

Table 12: Production of zircon by Cristal Mining Ltd. in Western Australia (WA) (Tutunup, Ludlow,Gwindinup, Gwindinup South+Happy Valley South) and in the Murray Basin (MB) (Ginkgo, Snapper) [in tonnes], after various sources.

<table>
<tr><th></th><th></th><th>2005</th><th>2006</th><th>2007</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th></tr>
<tr><td rowspan="3">WA</td><td>Tutunup</td><td rowspan="2">23,128</td><td rowspan="2">18,749</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Ludlow</td><td>20,910</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Gwindinup</td><td>–</td><td>–</td><td>–</td><td>13,985</td><td>13,983</td><td>15,468</td><td>9,958</td><td>6,223</td></tr>
<tr><td rowspan="2">MB</td><td>Ginkgo</td><td>–</td><td>19,663</td><td>45,068</td><td>52,585</td><td>48,355</td><td>32,564</td><td rowspan="2">46,647</td><td rowspan="2">46,677</td></tr>
<tr><td>Snapper</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
</table>

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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) 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 Sibelco Australia and New Zealand is very restrictive.

CRL has operated a 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 will end by 31 December 2019. The last mining lease at Yarraman, which expires in 2026, will be terminated at the end of 2015. Mining at Enterprise has to end by 31 December 2019 instead of 2027.

At the end of 2008, reserves and resources figures quoted by Iluka Resources for the North Stradbroke Island operations were:

- Total proven + probable reserves: 730.8 Mt of ore sand at 0.86 % HM, i.e. 6.27 Mt HM, with 47 % ilmenite, 11 % zircon, and 14 % rutile;
- Total measured + indicated + inferred resouces: 1,195.7 Mt of ore sand at 0.87 % HM, i.e. 10.36 Mt HM, with 47 % ilmenite, 11 % zircon, and 14 % rutile.

Thus, at the end of 2008, reserves of zircon on North Stradbroke Island were 690,000 tonnes, while resources of zircon amounted to 1.14 Mt.

Current operations on North Stradbroke Island consist of two floating dredges located in artificial ponds at the Yarraman and Enterprise mining sites, with the dredged sand pumped through pipelines to each floating wet mill. Waste sand is pumped behind the pond and stacked to be reshaped into dunes. Supplementary dry mining by dozers and excavators is used to access small high-grade deposits near the mine. The HMC is sent by barge across Moreton Bay for final separation at a MSP located at Pinkenba near the mouth of the Brisbane River. The Pinkenba plant has a capacity of 230,000 tpa of upgraded ilmenite, 110,000 tpa of rutile, and 90,000 tpa of zircon. Bulk products are shipped from Hamilton on the Brisbane River.

At its Pinkenba plant, Sibelco produces up to four grades of rutile, six grades of ilmenite, and three grades of zircon: “CRUZOR Coarse Zircon Sand”, “CRUZOR Premium Zircon Sand” and “Zircon Mags”, the latter being essentially a mixture of tourmaline, zircon, and monazite as well as some quartz and leucoxene. No samples were available for analysis. However, basic information on CRUZOR Premium Zircon Sand which is still distributed by Iluka Resources on behalf of Sibelco can be found in Appendix C.

Figure 23: Satellite image of a typical HM mining operation on North Stradbroke Island. Photo courtesy of Google Earth.

Table 13: Production of zircon from North Stradbroke Island [in tonnes]. Data until 2008 after CRL company website. 2009/10, 2010/11, and 2011/12 data after Queensland Mineral Production And Coal Industry Statistics.

	2005	2006	2007	2008	2009/10	2010/11	2011/12
North Stradbroke Island	53,389	52,963	60,561	52,644	69,712	71,364	60,897

MZI Resources Ltd.

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Contact pers.:	Stephen Quinn, General Manager Operations

MZI Resources Ltd., formerly known as Matilda Zircon Ltd., is a specialised resource company focused on the development of mineral sand operations to feed zircon and titanium minerals into the expanding Chinese market.

In 2010, MZI mined the Lethbridge West deposit on Melville Island, the eastern island of the Tiwi Islands, some 50 km north of Darwin. This was a small deposit and produced 11,400 tonnes of HMC (containing approx. 50 % zircon and 30 % rutile) from 134,500 tonnes of ore sand mined. Of the production, 10,500 damp tonnes of concentrate was shipped to Tricoastal International at Haikou on Hainan Island in China. MZI has an off-take agreement with China's largest mineral sands processor, Tricoastal Minerals, to acquire all the HMC from Lethbridge South and MZI's other operations on the Tiwi Islands.
4 km south east of the Lethbridge West deposit is the Lethbridge South deposit. This is four times the size of Lethbridge West but is only half the grade at 2.5 % HM. Mining of this deposit started in January 2012 and will continue until January 2013. 15,861 tonnes of HMC including the remaining Lethbridge West concentrate was shipped to Haikou in May and August 2012. A final shipment followed in January 2013.

Following drilling carried out in the first half of 2011, MZI has identified a large inferred resource at Kilimiraka in the southwest of Bathurst Island on the Tiwi Islands. The resource is in four large dunal systems behind the current beach. The deposit contains 56.2 Mt of ore sand with an average HM content of 1.6 %. The inferred resource has been established with >890 kt of HM. This resource has the potential to underpin an 8-10 year mining operation assuming mining rates of approximately 700 tph. The dunal nature of the deposit makes it very suitable for low cost dozer trap mining. MZI has commenced environmental studies at Kilimiraka to gain approvals for mining which could start in 2014.

In addition, MZI has an advanced project at Keysbrook, approximately 70 km south of Perth in Western Australia. This deposit has an unusual HM suite which has leucoxene as its major constituent. Expressed in terms of the mineral products produced, the deposit contains: 46.3 % high grade leucoxene (> 88 % TiO_2), 28.4 % low grade leucoxene (> 70 % TiO_2), 14.3 % zircon, and 11.0 % non-valuable HM, i.e. mainly aluminosilicates. The total resources are 49.1 Mt of ore sand grading 2.6 % HM, but also 8.02 % slimes on average. The total HM content is 1.62 Mt, of which some 180,000 tonnes is zircon. Production is targeted for Q4 2013 with an anticipated average annual production of 62,200 tonnes of leucoxene and 28,700 tonnes of zircon concentrate comprising 56 % zircon, i.e. 16,000 tonnes of zircon. The life of mine will be about seven years.

In May 2012, it was announced that the Picton MSP of Doral Mineral Sands will undertake the toll processing of the HM concentrate produced at Keysbrook. In addition, MZI has an off-take agreement with DuPont for all of its titanium products from Keysbrook.

Doral Mineral Sands Pty Ltd.

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Figure 24: Pit with slime-rich HM sands mined by Doral Mineral Sands in Western Australia, Photo: DERA.

Doral is an unlisted public company, wholly owned by Iwatani Corporation of Japan. It is an integrated zirconium producer with downstream processing operations that use 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 started in June 2002. The MSP is located 9 km to the northwest at Picton.

In mid 2004, Doral purchased the assets of Millennium Specialty Chemicals, i.e. its Rockingham operations. Doral Specialty Chemicals (DSC) used to produce a range of ultra high purity zirconium powders and chemicals, as well as provide toll milling capacity to support DMS. The zirconium powders component of the operation ceased in mid 2008 with the business eventually being sold in February 2009. Fused materials (fused alumina, fused zirconium and silica fume) are still being produced at Rockingham.

The Dardanup and Bunbury mines will be depleted by 2017. The Dardanup western extension, called Burekup, was acquired from Iluka Resources in 2008 and will be depleted by 2014. For these reasons, Doral is actively engaged in securing new sources of HM supply in the foreseeable future. In May 2012, it was announced that the Picton plant will do the toll processing of the HM concentrate produced from the Keysbrook deposit owned by MZI Resources Ltd.

Table 14: Estimated production of zircon by Doral Mineral Sands in Western Australia [in tonnes],after various sources incl. company information.

<table>
<tr><th></th><th>2005</th><th>2006</th><th>2007</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th></tr>
<tr><td>Dardanup + Bunbury</td><td>16,000</td><td>12,000</td><td>12,000</td><td>11,000</td><td rowspan="2">15,000</td><td rowspan="2">15,000</td><td rowspan="2">15,000</td></tr>
<tr><td>Burekup</td><td></td><td></td><td></td><td></td></tr>
</table>

Two zircon grades are being produced at Picton of which only the premium grade zircon is for sale, while the standard grade is used for internal zirconia production only (cf. Appendix C for analysis).

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Figure 25: Easy mining of garnet-rich fossil dune sands by GMA Garnet at Port Gregory, Western Australia. Photo: DERA.

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

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.

Here various garnet products are being produced for use as abrasives, blast cleaning and water jet cutting, as well as ilmenite and a zircon/rutile mix. This zircon/rutile mix was formerly sold to Iluka Resources for processing in its Geraldton plant, but some years ago GMA Garnet decided to sell this mix directly to its Chinese customers. Due to the high zircon prices in 2011, GMA Garnet started thinking about separating the zircon from the rutile in its Geraldton plant itself, but has not come to a final decision yet.

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

Table 15: Production of zircon/rutile mix by GMA Garnet [in tonnes], after company information.

	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12
Geraldton	0	0	873	1,557	932	762	2,986

BRAZIL

In Brazil there are currently two producers of zircon:

- Millennium Inorganic Chemicals Mineração Ltda., the mining subsidiary of Millennium Inorganic Chemicals do Brasil S.A.
- Indústrias Nucleares do Brasil S.A.

In addition, there is a minor producer of caldasite which is a uraniferous zirconium ore:

- Companhia Brasileira de Aluminio

Other companies known to the National Department of Mineral Production (DNPM) holding zircon concessions are:

- Mineração Taboca S.A., which has been mining alluvial cassiterite at Pitinga Village in the State of Amazonas since 1982. The ore and the tailings of this mine are rich in niobium, tantalum, xenotime, and zircon (resources of 1.7 Mt of zircon).
  As the zircon is strongly radioactive (1.48 % ThO_2 on average), a mining permit needs to be issued by the National Nuclear Energy Commission (CNEN). However, permission is also needed by the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) which does not consi der these zircon resources as feasibly mineable.
- VALE S.A., one of world's leading mining companies, also has various zircon mining concessions (Estreito, Rio Dourado, Baú, Sapucaí Ribeirão, Fijão and others). However, all of the zircon concessions only contain rather small resources of zircon and are classified as "paralysed mines"!
- MITO Tocantins Ltda. owns a small mine in Novo Horizonte at Jau do Tocantins, in the State of Tocantins. Here, 150 – 200 tpa of zircon were produced as a by-product of gemstone mining until 2006.

Table 16: Zircon production in Brazil [in tonnes], after National Department of Mineral Production (DNPM). Note: In most years, this data is not consistent with the sum of the production data reported by the individual companies.

	2005	2006	2007	2008	2009	2010	2011
Brazil	25,657	25,120	26,739	25,346	28,000	23,235	23,283

Millennium Inorganic Chemicals do Brasil S.A.

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Millennium Inorganic Chemicals Mineração Ltda., the mining subsidiary of Millennium Inorganic Chemicals do Brasil S.A. (MIC), which is a subsidiary of The National Titanium Dioxide Company Ltd. (Cristal) of The Kingdom of Saudi -Arabia, produces HM at its Guaju mine at Mataraca, in the State of Paraiba. The Guaju mine is about 1,100 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 since 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, Millennium Inorganic Chemicals of the USA took over, which in May 2007 was sold to Cristal Company, an affiliate of Saudi Arabia's National Industrialisation Company.

During a nationwide exploration programme for HM deposits in the late 1970s, Guaju at Mataraca was identified as the best site to open up a mine. 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. In April 1983, ilmenite was produced for the first time, followed by zircon and rutile in 1988, and kyanite in 1998. The mining operation at Guaju consists of a dredge, a flotation wet mill and a stationary MSP.

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

Millennium Inorganic Chemicals produces four grades of zircon (cf. Appendix C for analysis).

Table 17: Zircon production by Millennium Inorganic Chemicals at Guaju [in tonnes], after company information.

	2005	2006	2007	2008	2009	2010	2011
Guaju	20,400	22,011	23,081	24,218	25,378	21,892	22,325

Indústrias Nucleares do Brasil S.A.

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Indústrias Nucleares do Brasil S.A. (INB) is a state-owned company. It succeeded its predecessor Nuclebras in 1988, and incorporated 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. The former HM mines of Nuclemon, now INB, located in the States of Baia (Cumuruxatiba) and Espírito Santo (Boa Vista), were closed many years ago. In recent years, the company operated only one HM mine, located at Buena in the State of Rio de Janeiro. Mining uses conventional hydraulic excavators and dump trucks. After extraction, the ore sand is trucked to the MSP at Buena, located in the municipality of Sao Francisco de Itabapoana, State of Rio de Janeiro. In the MSP, ilmenite, rutile, zircon and monazite are separated, of which monazite is sent for further processing to the company's Caldas unit. However, processing of monazite at Caldas was stopped in 1996 and all the monazite has been stockpiled since. In 2010, 10,800 tonnes of the stockpiled monazite were sold to China. The other HM produced are marketed in the domestic market. Due to the depletion of the mine, the HM production of INB has been decreasing for many years. INB is actively searching for alternative sources - if unsuccessful, it will go out of business mining and processing HM.

Table 18: Zircon production by Indústrias Nucleares do Brasil at Buena [in tonnes], after annual company reports and company information.

	2005	2006	2007	2008	2009	2010	2011
Buena	5,046	4,268	3,535	3,000	2,625	1,343	approx. 1,400

Figure 26: HM mine and MSP of Indústrias Nucleares do Brasil S.A. at Buena, State of Rio de Janeiro. Photo courtesy of Indústrias Nucleares do Brasil S.A.

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Companhia Brasileira do Alumínio (CBA) was established in June 1955 and is a subsidiary of Votorantim Investimentos Industriais S.A. Today, CBA is the largest aluminium producer in Brazil with a total annual production of around 409,000 tonnes (2011).

CBA is exclusively dedicated to the extraction and processing of bauxite, with mines in Poços de Caldas (Minas Gerais) and other states of Brazil. The bauxite ore at Poços de Caldas also contains the mineral caldasite which is a mixture of zircon and fibrous baddeleyite. However, as the caldasite is often radioactive and enriched in Fe_2O_s, its use is limited, especially in ceramic products.

Much of the caldasite that existed in the form of veins and lodes was extracted by Mineração Curimbaba mainly in the 1940s and 1950s. Limited production was also recorded until the 1990s. Today, the remaining caldasite is just hand-picked during the mining and beneficiation processes of the bauxite ore with no plans for future economic exploitation because the caldasite veins are distributed quite irregularly, and the reserves, as determined during a survey in 2004, are very small.

The current production of caldasite of about 40 tpa is stockpiled. The total production from 2005 to 2011 was about 280 tonnes. CBA has no customers for this material.

CANADA

Figure 27: Oil sands tailings ponds with HM recovery pilot plant in northern Alberta. Photo courtesy of Titanium Corporation Inc.

Currently, there is no production of zircon or zirconium minerals in Canada.

In future, two sources of zirconium may be of economic interest:

- zircon production from the Athabasca oil sands in Alberta
- production of zirconium dioxide as a by-product from one of the rare earths deposits in Canada

For more than a decade, Titanium Corporation Inc. of Canada has been developing technology to recover heavy minerals and bitumen contained in the waste tailings streams of oil sands mining operations near Fort McMurray, Alberta.
The HM in the tailings contain about 12 % zircon, of which some 65 – 75 % might be recovered. This would amount to some 170,000 tonnes of recoverable zircon from the four oil sands mining sites in operation at present.

As oil sands production is expected to rise, and a fifth and sixth mining site will be opened in future, potential zircon production capacity in 2020 is estimated to be as high as 360,000 tonnes. Construction and commissioning of the first commercial HM separation plant in northern Alberta is expected any time after 2014.

There are numerous rare earths projects in Canada, some of which contain noteworthy amounts of zirconium dioxide which can be produced as a by-product. However, none of those rare earths projects in Canada has found a strategic investor yet. This means that no reliable time for the start of production can be given and used for calculations of future zirconium supply.

Rare earths projects under discussion include:

- Nechalacho at Thor Lake in Northwest Territories owned by Avalon Rare Metals Inc.
  (315 million tonnes of ore grading 1.36 % TREO and 2.62 % ZrO_2, i.e. containing 8.25 million tonnes of ZrO_2)
- Strange Lake in Quebec owned by Quest Rare Minerals Ltd.
  (50.8 million tonnes of ore grading 1.15 % TREO and 2.15 % ZrO_2, i.e. containing 1.09 million tonnes of ZrO_2)
- Kipawa/Zeus in Quebec owned by Matamec Explorations Ltd.
  (24.5 million tonnes of ore grading 0.42 % TREO and 0.90 % ZrO_2, i.e. containing 220,000 tonnes of ZrO_2).

China

Although China is the biggest consumer of zircon worldwide, only about 5 % of the zircon demand is satisfied by domestic mining operations. Limited domestic reserves, elevated radioactivity levels of Chinese zircon concentrates, and high domestic demand mean that no Chinese zircon is exported.

Zircon imports to western China are mainly from Vietnam, Indonesia, and Malaysia, while eastern China is being supplied by Australia and Indonesia. Many processing and upgrading plants have sprung up all along the Chinese coasts specialising in producing zircon from low-grade pre-concentrates, and tin, gold, or HM tailings.

For this study, a local consultant acquired valuable information on domestic zircon production from the China Geological Survey, the Geological Survey of Hainan, and the Department of Land Environment & Resources of Hainan Province. In addition, all the major zircon mining companies on Hainan Island were visited. They all kindly and openly provided samples and more up to date information.

Unfortunately, no statistical information on zircon reserves in mainland China after 2007 is currently available. At the end of 2007, proven zircon reserves in China were still rising and had reached 621,200 tonnes. On the other hand, mine depletion between 1998 and 2005 led to the closure of many mining operations. However, new mining companies were founded when new zircon mining licenses became available. The three biggest mining companies on Hainan Island, still producing today, were founded between 2002 and 2005. During these years, the provincial government of Hainan, where most of the Chinese zircon reserves are found, granted mining licenses running for 8 – 10 years with the possibility of extension. In addition to Hainan Province, one zircon mining company is still officially registered in Guangdong Province. This is the Lufengjinyi Mining Company in Lufeng District – however, the company does not exist anymore.

In Gungxi Province, several small zircon mining companies, e.g. Guanghaiyuan Mining Industry Co., Ltd., are still in operation. Like all their local competitors, its zircon production is very low as reported by its manager, Mr. Wu, with an output of less than 50 tonnes per month. The reasons are the depletion of existing mines and the lack of new mining licences.

All other former major zircon mining companies in Guangdong and Guangxi Provinces are now exclusively involved in upgrading raw material imported from Australia or SE-Asia. Of the 14 zircon producing companies in China listed by Roskill (2011, p. 91), only two are still mining HM themselves (cf. below).

Today, more than 80 % of the Chinese zircon production comes from Hainan Island. Of this, 90 % comes from Wenchang City, while the rest is from Wanning City. All of the HM deposits currently 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.

There are four major zircon mining companies on Hainan Island, three of which are located in Wenchang City:

- Hainan Wenchang Sanlian Mining Co., Ltd.,
- Hainan Jingbang Mining Co., Ltd.,
- Wenchang Sheng Sheng Mining Co., Ltd.,
- Wanning Yuehai Mining Industry & Technology, Ltd. in Wanning City

Table 19: Zircon and ilmenite production in Hainan Province, after Department of Land Environment & Resources of Hainan Province [in tonnes].

	2006	2007	2008	2009	2010	2011
Zircon	25,000	22,000	35,000	29,000	31,000	n. a.
Ilmenite	84,000	86,000	77,000	72,000	75,000	n. a.

Mining by Hainan Jinshan Zircon Titanium Mining Co., Ltd. in Wenchang City only occurs in response to incoming orders. According to its manager, Mr. Tang, its maximum production rate is 2,000 tonnes of zircon per month – weather permitting!

The major processing company on Hainan Island is:

- Hainan Winsheen Minerals Co., Ltd.

The other two zircon mining companies mentioned by Roskill (2011), i.e. Hainan Quinglan Titanium Mine (in Wenchang City) and Hainan Wuchang Titanium mine (in Wanning City) are running out of resources and will be forced to shut down soon. The mining site operated by Hainan Minbao Co. was already abandoned many years ago.

In the future, these companies will be joined by the state-owned Taixing Mining Company which is planning to start mining in 2013/2014. However, initial zircon production will only be 100 tpa. Its mining area will be offshore, south-east of Wanning City, in the shallow waters of the South China Sea where its license area covers 38.51 km².

The ore sand is located 9.2 m to 33.7 m below sea-level and has an average thickness of 9 m. The net reserves are 529,300 tonnes of zircon, and 2,239,900 tonnes of ilmenite. Average grades were established as 1.86 kg of zircon per m³ and 7.87 kg of ilmenite per m³ of ore sand.

Figure 28: Satellite image of typical HM mining operations north-east of Wenchang City, Hainan Island, PRC. Photo courtesy of Google Earth.

Hainan Wenchang Sanlian Mining Co., Ltd. (Huangguan Group)

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Chen Mingqian, Managing Director

Hainan Wenchang Sanlian Mining Co., Ltd. is a joint-stock enterprise with its head office located in Haikou City. It was founded in 2002 and has around 90 employees. It had to close down temporarily in 2011 because of its bad public reputation. It was reopened in 2012 under the new name of Huangguan Group but is still much better known under its former name.

Hainan Wenchang Sanlian Mining Co., Ltd. is engaged in HM mining, separation, beneficiation and sales. It is the biggest HM mining company in China. Sanlian has a mining license covering an area of 16.6 km^2 at Wenchang City with initial proven reserves of 230,000 tonnes of zircon and 540,000 tonnes of ilmenite. As of the end of 2010, the remaining unmined area covered approximately 7.3 km^2, with remaining proven reserves of 160,000 tonnes of zircon and 340,000 tonnes of ilmenite.

In November 2007, Sanlian acquired the prospecting rights for two additional unexploited areas in Wengtian Town, Wenchang City, covering an area of 2.13 km^2. Applications for mining licenses have been submitted. The proven reserves in those areas are 26,000 tonnes of zircon and 100,000 tonnes of ilmenite. The life of mine of this operation can be extended to approximately 12 – 13 years.

The current processing capacity of Hainan Wenchang Sanlian Mining Co., Ltd. is 70,000 tonnes of HMC which will result in an annual production of some 10,000 tonnes of zircon (cf. Appendix C for analysis), 25,000 tonnes of ilmenite, and 3,000 tonnes of rutile, with all products sold directly into the domestic market.

The sales network of Sanlian covers 12 Chinese provinces and cities, including large domestic zirconium, titanium, sand mining and dressing manufacturers.

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Hainan Jingbang Mining Co., Ltd. is a private company and was established in April 2002. Its head office is located in Haikou City while its mining plant is in Changsa Town, Wenchang City. The company owns two mining licenses, both in Wenchang City, covering a total area of around 20 km^2. Proven reserves available to the company are approximately 200,000 tonnes of zircon, and 800,000 tonnes of titanium minerals. This means it has the biggest HM reserves in Hainan Province of any currently active company.
At its mining site, the company can produce up to 60,000 tonnes of HMC per annum, of which some 40,000 tpa of HM products can be produced. Final products separated and sold include ilmenite, zircon, rutile, monazite, and cassiterite, which are all sold within the domestic market. In 2010, some 1,300 tonnes of zircon plus titanium minerals were produced per month. As Hainan Jingbang Mining Co., Ltd. is interested in sustainable development, it does not plan to increase production within the next five years.

Hainan Jingbang Mining Co., Ltd. can produce up to five grades of zircon of which one grade was made available for analysis (cf. Appendix C).

Table 20: Zircon and ilmenite production in Wenchang City, Hainan Province, by Hainan Jingbang Mining Co., Ltd. [in tonnes], after company information.

	2004	2005	2006	2007	2008	2009	2010	2011
Zircon	8,000	6,000	6,000	5,000	5,000	8,000	6,000	n.a.
Ilmenite	13,000	11,000	11,000	12,000	9,000	12,000	10,000	n.a.

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Figure 29: Typical floating wet mill used for HM concentration on Hainan Island, PRC. Photo courtesy of Wenchang Sheng Sheng Mining Co., Ltd.

Similar to Hainan Jingbang Mining Co., Ltd., Wenchang Sheng Sheng Mining Co., Ltd. is a private company. It also has its head office in Haikou City, Hainan province, while its mine is in the northeast of Changsa Town, Wenchang City. It used to be a subsidiary of Hainan Jingbang Mining Co., Ltd., but now has subsidiaries of its own including Wenchang Yuehai Mining and Wenchang Hongsen Mining Co., Ltd. Sheng Sheng holds two mining licenses measuring 6 km^2 and 2 km^2 in Wenchang, and containing mineral reserves of approximately 100,000 tonnes of zircon and 350,000 tonnes of ilmenite.

Sheng Sheng has a production capacity of about 40,000 tonnes of HMC per annum, of which some 30,000 tonnes of various grades of zircon, rutile, and ilmenite can be separated. The current production rate of zircon and titanium minerals is lower, i.e. about 12,000 to 15,000 tonnes per annum. In addition, minor amounts of monazite and cassiterite are being produced. In 2011, Sheng Sheng's production increased remarkably. The reason for this is the government plans to build a new highway with a 2 km wide buffer zone extending onto its license area. With official permission, Sheng Sheng Mining accelerated the mining speed in its affected mining license area and will keep up this increased mining speed and combined raised mineral output until 2016.

In 2011, Sheng Sheng was the first mining company in Hainan to also import zircon from Kalimantan Island in Indonesia. During 2011, it imported 5,000 tonnes of Indonesian prime zircon (66% $Zr(Hf)O_2$) (cf. Appendix C for analysis) which is of better quality than Hainan zircon. Sheng Sheng has delegated a specialist to Kalimantan Island to arrange the zircon exports, and plans to increase the zircon imports from Indonesia to 10,000 tonnes in 2012.

Wenchang Sheng Sheng Mining Co., Ltd. produces up to three grades of zircon of which the advanced grade was made available for analysis (cf. Appendix C). Additionally, the prime zircon product from Indonesia was also analysed.

Table 21: Zircon and ilmenite production in Wenchang City, Hainan Province, by Wenchang Sheng Sheng Mining Co., Ltd. [in tonnes], after company information.

	2004	2005	2006	2007	2008	2009	2010	2011
Zircon	4,000	4,000	5,000	4,000	4,000	5,000	5,000	7,000
Ilmenite	12,000	10,000	10,000	10,000	10,000	10,000	8,000	15,000

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Wanning Yuehai Mining Industry & Technology, Ltd. is a private company and started business in 2005. It focuses on HM mining and processing and has acquired three mining rights in Hainan province. One is in Wenchang City and two are in Wanning City, where Yuehai's Wan Ning MSP can also be found.

The mining area in Wenchang is about 2 km^2 in size and the ore sand 20 m in thickness. On average, it contains 4.23 kg ZrO_2 and 12.17 kg titanium minerals per m^3. The mining area in Wanning is of the same size but higher in grade. On average, the ore sand contains 6.09 kg ZrO_2 and 17.8 kg titanium minerals per m^3. The production rate from both sites is around 3,000 tonnes of zircon and titanium minerals per year.

In 2011, Yuehai was able to acquire a second mining license of equal size in Dongao Town, Wanning City. However, due to a land right conflict with local farmers, mining at this site has not started yet. As long as the conflict continues, Yuehai will not be able to raise production, however, once it is solved, production may be doubled.

Figure 30: HM mining operation by Wanning Yuehai on Hainan Island, PRC. Photo courtesy of Wanning Yuehai Mining Industry & Technology, Ltd.

Figure 31: Shaking tables in use by Wanning Yuehai on Hainan Island, PRC. Photo courtesy of Wanning Yuehai Mining Industry & Technology, Ltd.

Table 22: Zircon and ilmenite production in Hainan Province, by Wanning Yuehai Mining Industry & Technology, Ltd. [in tonnes], after company information.

	2005	2006	2007	2008	2009	2010	2011
Zircon	3,000	3,000	3,000	3,000	1,000	1,000	1,000
Ilmenite	5,000	5,000	5,000	5,000	2,000	2,000	2,000

Wanning Yuehai Mining Industry & Technology, Ltd. produces ilmenite and zircon (cf. Appendix C for analyses) as well as minor amounts of rutile and monazite from its operations.

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Wen Dong, Managing Director

Hainan Winsheen Mining Co., Ltd. was founded in 2003 and has its head office in Haikou City, Hainan province. Winsheen's core business is mineral processing and trading but it does not undertake mining in China. During recent years, the company has established Haikou Wensheng Mining Co., with subsidiaries including 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.
All of these companies are subsidiaries of Hainan Wencheng High-Tech Materials Co., Ltd., which also holds controlling interests in the Fangcheng Wensheng plant, the Fujian Wensheng plant, the Sichuan Yaan Chemical plant, Tricoastal (HK) Co., Ltd., and Lao PDR New Material.

The parent company of Winsheen is engaged in processing, producing and downstream manufacturing of HM and HM-based products. These include zircon (capacity: 80 ktpa), ilmenite (400 ktpa), rutile (30 ktpa), kyanite, monazite, ZOC and ZrO_2 (5 ktpa). Hainan Wencheng High-Tech Materials Co., Ltd. is one of the major suppliers of these materials to China.
Annual production varies considerably: mainly because of changing demand, but not for lack of resources. Processed material is sourced from various countries, with most zircon originating in Hainan, Australia, Indonesia, Vietnam, and Sri Lanka. Ilmenite mainly comes from Hainan and Vietnam, rutile from Hainan and Australia, kyanite from Australia, and monazite from Hainan.

Hainan zircon makes up about 15 – 20 % of the total amount of zircon processed by Winsheen, and some 500 – 600 tonnes of Hainan zircon are always kept as an inventory.
However, as zircon from Indonesia and Australia is preferred by Chinese customers because of its better quality, Winsheen prefers to rely on imports instead of domestic material.

A "standard" and a "high-grade" zircon are produced by Hainan Winsheen Mining Co., Ltd. from Hainan raw material (cf. Appendix C for analysis).

Table 23: Zircon production from Hainan raw material by Hainan Winsheen Minerals Co., Ltd. [in tonnes], after company information.

	2005	2006	2007	2008	2009	2010	2011
Zircon	n.a.	n.a.	n.a.	5,000	5,000	6,000	n.a.

India

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

The current zircon resources of India as of August 2009 stand at 32.28 million tonnes, with 12.60 million tonnes located in Andhra Pradesh, 9.46 million tonnes in Tamil Nadu, 6.52 million tonnes in Kerala, 3.16 million tonnes in Odisha, and 0.54 million tonnes in West Bengal, Maharashtra, and Bihar. Additionally, there are also very large resources of ilmenite, rutile, garnet, monazite, and sillimanite.
As of 2009, 64.68 % (3,779 km) of a total of 5,843 km of Indian coastline remain unsurveyed.

At present, there are four producers of zircon in India which are mining at six different locations:

- Indian Rare Earths 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).

Beach Minerals Company (BMC) Pvt. Ltd. produces various HM from its Kuttram operation situated about 90 km east of the southern tip of India in Tamil Nadu. It does not separate zircon, however.

Cochin Minerals and Rutile Ltd., which also mines beach sands in Kerala but currently only produces ilmenite, also might produce zircon, if the required equipment were installed.

Although none of the HM producers in India faces the problem of insufficient reserves, other impediments have been mentioned by local company and/or government representatives:

- Land acquisition is becoming an increasing issue, as areas under lease have decreased owing to various social, cultural and environmental issues.
- Backfilling of monazite rich tailings will be met with more criticism in future as cancer and other health problems have been recorded in affected villages.
- HM are classified as a strategic asset so secrecy is often maintained with regards to shipment and production data. The lease areas are cordoned off to safeguard the precious deposits and to prevent illegal mining.
- The Costal Regulation Zone (CRZ) notification of 2011 has deprived IREL and other potentially interested mining companies of dredging areas within 100 meters of the High Tide Line.

Indian Rare Earths Ltd.

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Under the Indian Companies Act, 1913, Indian Rare Earths Limited (IREL) 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 the mineral 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).

As the then beach sand mineral operations were suspended over the period 1955 – 1960 due to market and management problems, IREL at the instance of the central government decided to also take 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; its construction started in 1975 and its mining operations commenced in 1984. Today, IREL operates these three units and produces six heavy minerals: ilmenite, 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 (erstwhile 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 length of 22.54 km and a width of 225 m between the two tidal channels at Neendakara in the south and Kayamkulam in the north. For mining, the coastal strip from Neendakara to Kayamkulam was divided into 8 blocks. The area has been under intensive mining 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 km², 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.
The Neendakara-Kayamkulam Eastern Extension (Phase I) between the T.S. Canal and 1 km to the east covers an area of 19.22 km² and reports THM grades in the order of 10 %. The HM concentration depletes gradually to the east. The Neendakara-Kayamkulam Eastern Extension (Phase II) extends 6 km inland or up to the end of the sandy stretch. The northern sector of phase II covers an area of 45.8 km², with an average THM grade of 7.4 %. The southern sector is spread over an area of 50.4 km² reporting THM grades of 7.5 %.

Extensive exploration also has been carried out to the east of the Kayal (canal). That area, however, is densely populated and these plans have created some social unrest. In the past, only the surface dunes have been exploited, leaving most of the deposit untouched.

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, engaged in dry as well as wet mining (in barrier beach areas) and mineral separation, stands at 200 kt of ilmenite (Q Grade 58 % TiO_2 min.), 9.5 kt of rutile (Q Grade 95.0 % TiO_2 min.), 124 kt of zircon (Q Grade, cf. Appendix C), 7 kt of sillimanite (Q Grade 58.0 % Al_2O_3 min.) and leucoxene. Although the head grade is relatively low, monazite might also be separated in future. In addition, the plant already has facilities for the production of ground zircon (64.0 $Zr(Hf)O_2$ min.) called Zirflor (– 45 µm) at 6 ktpa, and Microzir (1 – 3 µm) at 0.5 ktpa. Synthetic rutile, TiO_2 pigment, and titanium slag are also being produced

Manavalakurichi

The Manavalakurichi (MK) deposit stretches for 6 km from the mouth of the Valliyar River to Colachal in Manavalakurichi and into the Kanyakumari 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 grading around 20 % HM are also mined by 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 all weather major seaport Tuticorin and the nearest airport at Thiruvananthapuram are equidistant, about 65 km from the plant site. Nagercoil is at a distance of 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 55 % TiO_2 min.), 3.5 kt of rutile (MK Grade 94.0 % TiO_2 min.) and 10 kt of zircon (MK Grade, cf. Appendix C) in addition to leucoxene (“brown ilmenite), 3 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.

OSCOM

The Chatrapur HM deposit extends along the Ganjam district of the Odisha coast between the River Rushikulya and the Gopalpur lighthouse over a length of about 18 km and a width of about 1.5 km (24.64 km^2). 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 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 at Chatrapur by IREL. It is about 150 km from the capital of Orissa – Bhubaneswar – and about 320 km from the all-weather seaport Vishakhapatanam. The OSCOM MSP has an annual production capacity of 220 kt of ilmenite (OR Grade 50.25 % TiO_2 min.) as well as 10 kt of rutile (OR grade 94.25 % TiO_2 min.), 8.5 kt of zircon (OR grade, cf. Appendix C), 10 kt of sillimanite (OR Grade 56.5 % Al_2O_3 min.), 4 kt of monazite, and 24 kt of garnet (OR Grade 93.5 % garnet min.). In addition, a thorium plant has been in operation since 1992 at OSCOM to produce 240 tpa of mantle grade thorium nitrate. The OSCOM plant capacity is undergoing a staged expansion, commencing with a new dredge. The expansion is expected to increase production to 500 ktpa of ilmenite and co-products. Zircon production capacity has already been expanded from 5 ktpa before 2007 to 8.5 kt since then, and will ultimately rise to 11 ktpa.

Table 24: Production of zircon by Indian Rare Earths Ltd. [in tonnes], after Indian Minerals Yearbook and company information.

	2005/6	2006/7	2007/8	2008/9	2009/10	2010/11	2011/12
Chavara	8,287	4,033	12,396	7,772	8,124	7,500	5,231
Manavalakurichi	10,311	9,180	8,404	5,813	4,527	3,542	3,182
Chatrapur (OSCOM)	6,671	5,558	5,477	5,807	5,906	5,979	6,170

Figure 32: Satellite image of the OSCOM HM mining, separation and beneficiation complex north-east of Gopalpur, Orissa, India. Photo courtesy of Google Earth.

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The history of the beaches of Sankarmangalam and 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 & 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 was placed under the control of the industries department. The unit was subsequently converted to a limited company in 1972 with the name ‘The Kerala Minerals and Metals Ltd.’.

In 1979, KMML started with the construction work for its chloride TiO_2 pigment plant at Sankaramangalam 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 with the first batch of titanium sponge 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 3.6 kt of sillimanite by the treatment of tailings from the existing MSP have also been approved by the Kerala government.

At its industrial complex in Sankarmangalam, KMML currently produces sulphate grade ilmenite (58 % TiO_2 min.), rutile (92 % TiO_2 min.), zircon (cf. Appendix C), leucoxene (75 % TiO_2 min.), 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.

KMML produces two grades of zircon, both of which were made available for analysis (cf. Appendix C).

Table 25: Production of zircon by Kerala Minerals & Metals Ltd. [in tonnes], after Indian Minerals Yearbook and company information.

	2005/6	2006/7	2007/8	2008/9	2009/10	2010/11	2011/12
Kerala	1,864	1,764	2,175	2,445	2,592	2,838	5,213

V. V. Mineral Pvt. Ltd.

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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 2007/8. 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 holds a 40-year mining lease over 9.3 km^2 of dunes, and along a 15 km stretch of beach in Kanyakumari district of Tamil Nadu at the Gulf of Mannar. Here the beach sands are continuously replenished with HM washed onshore. V.V. Mineral has been active in five seaside villages – Kurumpanai, Keezhmidalam, Midalam, Melmidalam, and Helen Nagar - in the Vilavancode taluk of the Kanyakumari district. The villagers mine the HM enriched beach sand by hand to ensure maximum local employment. After separation, the now barren beach sand is returned to the mining area for reclamation.

At each of the villages, the company owns a wet plant (total: 5) and a dry plant (total: 6) with state-of-the-art machinery. The total capacity of the plants is about 14 kt of garnet, 20 kt of ilmenite, 1 kt of zircon, and 0.5 kt of rutile per month. Annual production capacity is reported by V.V. Mineral as 150 kt of garnet, 225 kt of ilmenite (55.5 % TiO_2 min.), 12 kt of zircon (cf. Appendix C), and 5 kt of rutile (94 % TiO_2 min.), or 450 kt HM in total.

V.V. Mineral owns three big warehouses situated near Tuticorin seaport i.e. 5 km from the loading berth of the seaport, with a combined storage capacity of 300,000 - 450,000 tonnes of HM products.

V.V. Mineral produces two grades of zircon: premium and standard grade quality (cf. Appendix C for analysis).

Table 26: Production of zircon and zircon-sillimanite mix by V.V.Mineral [in tonnes], after Indian Minerals Yearbook.

	2005/6	2006/7	2007/8	2008/9	2009/10	2010/11	2011/12
Zircon	0	0	7,526	7,321	6,900	13,350	
Sillmanite-zircon mix	0	0	0	0	7,900	8,200	

Trimex Sands Pvt. Ltd.

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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. In India, Trimex Industries commenced operations 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. In 2004, Trimex Sands Pvt. Ltd. was founded to diversify into the extraction and beneficiation of HM.

In February 2004, a first 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. In June 2010, after first meeting stiff opposition from local farmers, the Srikurmam project commenced operations producing ilmenite (capacity 180,000 tpa), garnet (39,000 tpa), sillimanite (46,000 tpa), rutile (6,000 tpa), and zircon (5,000 tpa, cf. Appendix C) from beach sands.

In its first year of operation, the MSP did not run at maximum capacity, but in its second year it already surpassed the rated capacity (210,000 tonnes of ilmenite in 2011-12). In the light of the operational success and continuing demand for titanium feedstock, Trimex Sands has initiated capacity enhancement of the MSP from 180,000 tpa of ilmenite to 300,000 tpa of ilmenite, which is to commence from Q4 2012. Plans are 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).

Mining at Srikurmam is done by excavators, and the ore sand is transported to a wet mill (pre-concentration plant) by tippers. The ilmenite-rutile-zircon, garnet, and sillimanite concentrates produced by wet gravity concentration processes are then transported to the dry mill by tippers. The five final HM concentrates are produced after drying, and electrostatic as well as 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 licenses for the Kalingapatnam (15.39 km^2) and Bhavanpadu (17.95 km^2) deposits were also granted. The projected MSP at Bhavanpadu is to have a capacity of 300,000 tpa of ilmenite, 50,000 tpa of garnet, 50,000 tpa of sillimanite, 8,000 tpa of rutile and 7,000 tpa 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 a titanium dioxide pigment, a titanium slag, and a titanium metal plant in Indonesia within the next ten years.

Table 27: Production of zircon by TRIMEX Sands Private Ltd. [in tonnes], after company information (www.optimisresources.com/sands.html). Obviously, zircon production is much higher than expected!

	2008/9	2009/10	2010/11	2011/12
Andhra Pradesh		0	approx. 48,000	approx. 55,000

INDONESIA

Indonesia became famous for its zircon potential when Indonesian zircon suddenly "flooded" the world or rather Chinese market in 2006 and 2007. An excellent description and explanation of what happened during those years was given by TZMI in 2008 in its study "Kalimantan and its impact on global zircon supply and demand". According to this study, almost all the zircon in Indonesia came from Kalimantan Island, where zircon was produced from gold tailings. Several tailings processing and zircon upgrading plants, most of them with Chinese investors, were commissioned in 2007 and 2008. A record tonnage of 19,438 tonnes of zircon was exported from Indonesia in June 2007. In the months and years thereafter, zircon processing declined considerably and many plants went out of business.

However, obviously many plants were just placed on care and maintenance and its Chinese investors reacted swiftly when zircon prices increased strongly during 2011. Although no official data on zircon production in Indonesia in 2011 is available, export figures again show a strong increase in zircon exports starting in April 2011 and reaching another high of 16,410 tonnes in February 2012.

Zircon was and is produced in Central Kalimantan and West Kalimantan, and to a lesser extent in South Kalimantan and East Kalimantan. Investigations by the Government of Central Kalimantan showed that close to all zircon production in this province is illegal as no production was recorded, nor fees or taxes paid. On the other hand, as of March 2012, 63 exploration companies, 26 exploiting companies, and 34 producing companies were officially registered. (West Kalimantan: 15 producing, and 5 exploration companies). Mineral resources estimated for Central Kalimantan are 1,174,663,000 m^3 of tailings containing 6,556,630 tonnes of HM of which 2,615,509 tonnes are zircon (www.kaltengmining.com).

One of the characteristics of the Indonesian zircon market is that most zircon companies only produce low-grade zircon products, i.e. concentrates containing 42 % $Zr(Hf)O_2$ on average ("traditional grade", TZMI 2008), while the "processed grade" (TZMI 2008) averages 50 % $Zr(Hf)O_2$. The remainder of the minerals in these rough concentrates are quartz, ilmenite, rutile, and aluminosilicates. However, these impure zircon concentrates are upgraded by other companies with final products containing 58 – 65 % $Zr(Hf)O_2$ ("export grade", TZMI 2008). In the beginning of 2012, the Indonesian government decided to stop the export of low-grade zircon products in the near future. Because of this new regulation, many zircon mining companies are in the process of upgrading their plants to be able to produce high-grade zircon concentrates (> 99 % zircon in concentrate) as required in the future. As of the beginning of 2012, there were just two producers of zircon in Indonesia for which more than just contact data was available. Most of the others are Indonesian-Chinese joint-ventures which are not interested in providing any data to anyone at all:

- PT Zirmet Mining, cf. extra page
- Kartika Kharisma Kencana PT is an Indonesian ore trading company which also has a mining license covering 8.1 km^2 in Kalimantan. It currently produces around 1,000 tonnes of low-grade zircon products annually. Kartika Kharisma Kencana PT is also upgrading its separation plant for the production of higher-grade zircon. Additionally, it expects approval of two more mining licenses at the end of 2012 which will allow production to double in 2013.

All other companies mentioned by Roskill (2011) are not producing zircon any more. No information is available about the production of zircon from "amang" in Indonesia. While the potential must be high, it does not seem to be of interest to the Indonesian companies.

Table 28: Estimated zircon production in Kalimantan after TZMI (2008) and in Central Kalimantan after www.kaltengmining.com [in tonnes].

Production	2004	2005	2006	2007	2008	2009	2010	2011
Kalimantan	2,200	10,100	128,350	153,960				
Central K.				78,890	59,575	51,020	6,224	

Table 29: Zircon exports from Indonesia after Roskill (2011) and Bps-Statistics Indonesia as well as zircon imports from Indonesia into China after UN Comtrade [all data in tonnes].

Trade	2004	2005	2006	2007	2008	2009	2010	2011
Export	462	2,616	65,628	111,031	64,579	62,617	49,548	127,079
Import China	2,153	9,997	124,855	150,930	65,004	58,629	50,381	110,141

PT Zirmet Mining

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Website www.mineralenterprises.co.in

Contact pers. Cyriac Joseph, Director
Email cyriacjosh@gmail.com

The Indonesian subsidiary of Mineral Enterprises Limited (MEL), India, is PT Zirmet Mining, a joint-venture company between MEL and PT Tunas Artha Perkasa, Indonesia. The company was established in 2008 and owns three mining concessions in central Kalimantan extending over 27.2 km^2.

PT Zirmet Mining uses state-of-the-art mining facilities and the latest technologies from India, Australia, South Africa and China to process and produce premium grade zircon, but also ilmenite and rutile.

Production from the current pilot plant was 500 tonnes in 2011 and is estimated to be 700 tonnes in 2012. Plans to increase production in 2012 much further had to be stopped due to certain pending clearances from the government of Indonesia. Updated plans include an increased production of 500 – 800 tonnes per month starting March 2013 with a further upscaling to 1,000 tonnes per month as soon as possible. In 2014 a production capacity of 18,000 tpa may be realized. Ultimate plans for the plant are to gradually reach a capacity of 80,000 tpa of premium grade zircon.

Currently, PT Zirmet Mining is already the largest producer of premium grade zircon (cf. Appendix C for analyses) in Indonesia, presently exporting to China, Taiwan, Vietnam, India, etc., but also looking for other international customers.

KAZAKHSTAN

There is no active producer, but there was one past producer of zircon in Kazakhstan:
- OAO TNC “Kazchrome”

However, in addition to OAO TNC “Kazchrome”, two other companies are preparing to start mining for zircon:
- TOO “Altyn-Kulager” (Tobolskoye placer deposit in Kostanay region in Ordzhonikidze district),
- TOO “Tioline” (Obuhovskoye placer deposit in Taiynshinskiy district of North-Kazakhstan region).

The Obuhovskoye placer is located some 40 km north of Kokshetau City in northern Kazakhstan. A pilot plant at the deposit produced about 1,200 tonnes of mixed zircon-rutile concentrate in 2011, and is set to produce 2,400 tonnes of zircon in 2012.

The full-scale processing plant is scheduled to go into production in 2013 and hit full capacity in 2014, producing rutile, ilmenite and 50,000 tpa of zircon. The operation is to be managed in a joint-venture with OAO TNC “Kazchrome”.

No information is available about the planned start of production at the Tobolskoye deposit, but its zircon reserves/resources are quite low with 1,100 tonnes in category A, 46,300 tonnes in category B+C1, and 900 tonnes in category C2. Plans are to mine 50,000 tones of ore sand per year resulting in 7,000 tonnes of final concentrates (ilmenite, rutile, and zircon).

OAO TNC "Kazchrome"

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Website www.enrc.com/en-GB/Our-Divisions/Ferroalloys/
Email kospanov@kazchrome.enrc.com

Contact pers. Murat Kospanov, Head of Department Strategic and Innovation Development

OAO TNC "Kazchrome" is a subsidiary of Eurasian Natural Resources Corporation plc based in London and Almaty. Among others, OAO TNC "Kazchrome" is also the owner of the Shokash placer deposit in north-eastern Kazakhstan. Mining of the Shokash placer deposit started in 1999 and was halted in 2009.

Currently, the deposit is up for sale. The most recent information is that TOO "Tioline" also plans to mine the Shokash deposit and to upgrade the HMC at its new MSP at Obuhovskoye. VHM in the Shokash placer are ilmenite, rutile, and zircon, with leucoxene and anatase occurring as minor Ti-minerals. The average grade of ZrO_2 in the ore sand at Shokash varies between 0.58 and 0.8 %, i.e. the zircon grade varies between 0.86 and 1.23 %.

No sample is available as only a mixed zircon-rutile concentrate was produced, but a lab zircon concentrate is stated in the literature as containing 65.8 % $Zr(Hf)O_2$ and to have been of very fine grain size.

As of 1999, i.e. before the start of mining, the reserves of the Shokash placer deposit were reported as 2.661 million m^3 in category B, 6.744 million m^3 in category C1, and 587,000 m^3 of ore sand in category C2.

This would convert into around only 86 to 123 kt of zircon in the B+C1+C2-categories. The production figures from Shokash are given below:

Table 30: Production and beneficiation of ore sand, and production of heavy mineral concentrates at the Shokash placer deposit [in tonnes], after company website.

	2001	2002	2003	2004	2005	2006	2007	2008
Mining of ore sand	16,900	37,100	63,200	125,100	139,000	122,500	120,600	99,900
Beneficiation of ore sand	16,600	37,120	61,213	114,580	112,100	138,930	120,810	95,757
Ilmenite	3,570	3,142	5,993	12,867	14,220	12,685	10,350	8,272
Rutile-zircon	n. a.	9,316	17,635	6,795	7,560	5,596	3,843	3,451

KENYA

Currently, there is no production of zircon in Kenya, but one company,

- Base Resources Ltd.,

is hoping to start production in the second half of 2013 – or later.

Base Resources Ltd.

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Australia

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Fax +61-8-9322-8912

Website www.baseresources.com.au
Email info@baseresources.com.au

Contact pers. Colin Bwye, Executive Director Operations and Development

The Kwale HM project is located about 48 km southwest of the port of Mombasa in Kenya and is some 12 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, spending US$ 60 million on it. 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. Meanwhile, prior impediments to development, in particular the resettlement of approximately 400 families, are said by Base Resources to have been successfully resolved, and all farmers are now compensated and resettled and the Special Mining Lease has been issued.

Proven and probable reserves at Kwale are 140.6 million tonnes of ore sand grading 4.9 % THM and 0.29 % zircon, i.e. the HM concentrate contains 5.9 % zircon on average. In total, 319,700 tonnes of zircon will be produced during the 13 year mine life of the project. Major other saleable products will be ilmenite and rutile.
In 2014, around 13,000 tonnes, and in 2015 around 25,000 tonnes of zircon are to be produced. The maximum annual capacity will be 35,000 tonnes of zircon during the first six years, declining to 25,000 tonnes in the years thereafter.

Additionally to Kwale, there are three extension projects to the north at Vipingo, Kilifi (Sokoke) (980 kt zircon), and Mambrui (300 kt zircon) containing indicated and inferred resources of an additional 1,338,800 tonnes of ore sand, grading 3.80 % THM. Furthermore, recent coastal dunes at Sabaki contain more than 72 million tonnes of HM enriched sand.

MADAGASCAR

Currently, there is one producer of zircon in Madagascar:

- QIT Madagascar Minerals (QMM) S.A.

Another company plans to start production of zircon anytime in or after 2014:

- World Titanium Resources (Toliara mineral-sands project in the south-west of Madagascar)

World Titanium Resources Ltd. (formerly Madagascar Resources NL) owns the Toliara Sands project some 55 km north of the port of Toliara in south-west Madagascar.

Total ore sand tonnage within the exploration permit areas at Ranobé, Ankililoaka, Basibasy and Morombe are suggested to be about 4.7 billion tonnes. Estimated total resources in the Ranobé project area are 1,475 million tonnes of ore sand grading 4.7 % HM on average, including a JORC resource of 959 million tonnes at 6.10 % THM.

The HM fraction in these areas is made up of 72.2 % ilmenite and leucoxene, 2.3 % rutile, and 5.6 % zircon. The first stage ("starter pit") of the project will focus on a 15 km^2 area with measured and indicated resources of 176 million tonnes of sand grading 8.13 % HM on average.

Within the "starter pit" area, proven and probable ore reserves comprise 161 million tonnes of ore sand at 8.20 % HM which will sustain a mine lifetime of 21 years at an average mining rate of 7.7 million tpa.

Some 44,000 tonnes of zircon-rutile mix (74 % zircon, 16 % rutile, 10 % other) could be produced per annum, containing some 32,000 tonnes of zircon. First production is targeted for H2 2014.

QIT Madagascar Minerals (QMM) Ltd.

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Contact pers.	Gudrun Rexroth-Jabs, Rio Tinto Iron & Titanium GmbH
Phone	+49-6196-9600-21

Figure 33: HM mining operation with separation and beneficiation complex of QMM near Fort-Dauphin at the south-east tip of Madagascar. Photo courtesy of Rio Tinto plc.

QIT Madagascar Minerals (QMM) Ltd. is 80 % owned by QIT-Fer et Titane Inc., a wholly owned subsidiary of the Rio Tinto Group, and 20 % by the Government of Madagascar. QMM is the license owner of the Fort Dauphin HM project at the very environmentally sensitive south-east tip of Madagascar.

Construction of the necessary buildings and infrastructure for this project started in January 2006 and the first shipment of ilmenite was sent via the newly completed Port of Ehoala southwest of Fort Dauphin in May 2009. Most of the ilmenite will be used for titanium slag production at Rio Tinto's Sorel smelter in Quebec, Canada. Current mining activity is at the 2,000 ha Mandena site to the north of Fort Dauphin and some 14 km to the north of the Port of Ehoala.

The ore sand contains between 4.5 – 5.5 % HM with the HM suite strongly dominated by ilmenite (75 – 80 %), and zircon, rutile, sillimanite, and monazite (1.5 %) being of minor importance.

Production on this site will eventually ramp up to 750,000 tonnes of ilmenite and 60,000 tonnes of Zirsill (a mixture of zircon and sillimanite) containing about 25,000 tonnes of zircon a year.

Later phases will be at the adjacent 4,000 ha Sainte-Luce deposit (600 million tonnes of ore sand at 5.5 % HM) and Petriky deposit (400 million tonnes of ore sand at 4.5 % HM).

There is also potential to expand production to 2.2 million tonnes of ilmenite a year. At the end of 2009, the initial resources of the Fort Dauphin project (Madena site only) were reported as 38.1 million tonnes of HM (24 million tonnes of ilmenite) with reserves of 11.9 million tonnes of HM. At maximum capacity, this will sustain a mine lifetime at Madena of about 20 to 25 years.

Table 31: Production of Zirsill by QMM in Madagascar [in tonnes], after Malagasy newspaper reports.

	2009	2010	2011
Zirsill	8,000	12,600	22,000

MALAYSIA

The biggest resources of zircon 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 are produced, which are called “amang”, 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 VHM. 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 zircon are still being produced in Malaysia. Limited resources due to drastically fallen tin production forced many of the mining and separation companies which existed between 1990 and 2010 to go out of business. Only some 20 % of the zircon produced is consumed domestically, while most is exported to China, India and to a limited extent to Taiwan.

Currently, the Ministry of Natural Resources and Environment of Malaysia is aware of the following amang processing companies:

- Johana Bersatu Sdn. Bhd., which currently is not in production for unknown reasons,
- Kesuma Global Sdn. Bhd., which stopped producing zircon because of depletion of resouces,
- Dollar Valley Sdn. Bhd, which only produces very small amounts of zircon,
- Kepayang Resources Sdn. Bhd.,
- Beh Minerals Sdn. Bhd.

Other amang processing companies mentioned by Roskill (2011), i.e. LSK Enterprise, MW Chemicals and Asiaway, are no longer producing zircon.

According to Mr. Wong Puanfoo, Managing Director of Kepayang Resources in Ipoh, his company is engaged in the exploration and extraction of tin but also in the separation of amang. At present, his production is around 200 tonnes of ilmenite and 2 tonnes of zircon per month. Current stocks are about 1,200 tonnes of ilmenite, 20 tonnes of zircon, and 4 tonnes of xenotime.

Table 32: Zircon production in Malaysia [in tonnes], after Bgs Mineral Production Statistics after Ministry of Natural Resources and Environment of Malaysia.

	2005	2006	2007	2008	2009	2010	2011
Malaysia	4,954	1,690	7,393	984	1,145	1,267	1,685

Beh Minerals Sdn. Bhd.

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Website n. a.
Email behminerals@po.jaring.my

Contact pers. Mr. Choe, Sales Manager

Beh Minerals Sdn. Bhd. is a privately owned company and was founded in 1970. It is the largest processor of tin tailings, i.e. amang, in Malaysia, with its raw material is sourced from various alluvial tin mining operations.

As Beh Minerals is very flexible, but dependent on the quality and quantity of the raw material available, the annual production rate at its specialized plant just outside Ipoh in the State of Perak varies considerably between 120 to 480 tonnes of zircon (cf. Appendix C for analysis) . Also zircon enriched pre-concentrate is not processed further if the market price is too low.

In addition to zircon, the company also produces ilmenite, rutile, cassiterite, monazite, xenotime, and struverite as commercial products.

MOZAMBIQUE

Due to its long coastline, Mozambique has a huge potential for HM placers and there have been many state organisations/companies engaged in exploration for interesting deposits. Despite exploration by so many parties, just one producer of zircon has evolved so far:

- Kenmare Resources plc.

While there will be no other producer coming online within the foreseeable future, the following describes the key data of the most notable of the known HM deposits in Mozambique (from south to north):

- Corridor Sands between Chibuto and Xai-Xai
  About 180 km north of Maputo; exploration history since 1997 by Southern Mining Corp., WMC Resources Ltd. and BHP Billiton; an exploration license issued in summer 2011 to Rock Forage Titanium Ltda. of Canada Mozambique was cancelled in November 2011; current exploitation license granted to Delta Zambeze Consortium in June 2012; fossil dunal sands with very high slime content; total resources in 10 deposits of 16.593 billion tonnes of ore sand grading 5.3 % HM on average with the largest deposit containing 2.672 billion tonnes of ore sand grading 7.39 % HM on average, i.e. containing 197.5 million tonnes of HM; on average 2.0 % zircon in the HM concentrate; projected total mine lifetime > 100 years; planned initial zircon production 21,500 tpa, planned final zircon capacity 62,500 tpa.

- Pebane (including Idugo I, Idugo II, Gurai and Melai)
  About 1,000 km northeast of Maputo and 140 km northeast of Quelimane; area of first commercial production of HM in Mozambique in 1959/1960, HM concentrate: 70 % ilmenite @ 53 % TiO_2, 10 – 13 % zircon, 3 – 5 % monazite, high in Al-silicates, low in rutile, traces of chromite; indicated resources of 81 million tonnes of ore sand grading 10 % HM on average + inferred resources of 250 million tonnes of ore sand grading 5 % HM.

- Moebase (including deposits Moebase M1+M2, Molocue, Lipobane L1+L2+L3, Decksand D1+D2) + Naburi
  About 1,100 km northeast of Maputo and 210 km northeast of Quelimane; exploration history since 1988 by Edlow Resources Ltd., followed by Gencor and BHP Billiton; current licenses held by Pathfinder Minerals plc. of UK; active and fossil dunal sands with high slime content; on average 4.8 % THM in the coastal deposits, 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 billion tonnes of ore sand grading 3.55 % HM on average, i.e. containing 71.72 million tonnes of HM; projected total mine lifetime 33 years; projected annual production of 65,000 tpa zircon, 24,000 tpa rutile, and 1,245,000 tpa ilmenite.

- Moma
  About 1,200 km northeast of Maputo, cf. Kenmare Resources plc.

Kenmare Resources plc.

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Contact pers.	Eamonn Keenan, Marketing Manager

Figure 34: Ship loader at the end of the jetty at Moma, Mozambique. Photo courtesy of Kenmare Resources plc.

Kenmare Resources plc. 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 being a joint venture partner between 1993 and 1999. Upon withdrawal of BHP, Kenmare acquired 100 % of the project.

Construction at Moma began in August 2004 and mining started in April 2007 followed by mineral separation five months later. Currently, Kenmare is mining the Namalope deposit with mining carried out by two dredges.

Final products (ilmenite, zircon, and rutile) are stored in a 145,000 tonne capacity warehouse with facilities for loading onto a 2.4 km long overland conveyor, which leads to a 400 m 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 tran-shipment vessels. These vessels then transport the products to a deep water transhipment point 10 km offshore, where they self-discharge into customer vessels.

Initial planned capacities at Moma were 800,000 tpa of ilmenite, 50,000 tpa of zircon, and 14,000 tpa of rutile from an operation with a lifetime of 20 years. In the first years of mining, production rates were much lower, but meanwhile the rated capacity has been reached and a first expansion is being

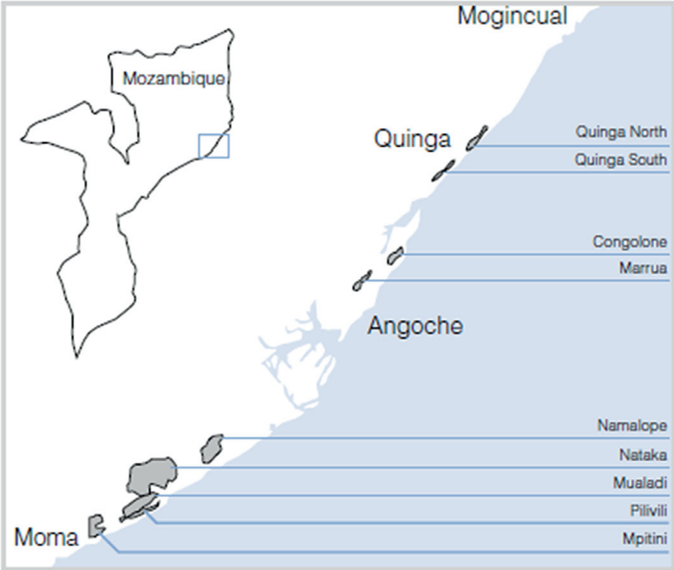

Figure 35: Map showing Kenmare's HM licenses in north-eastern Mozambique. Courtesy of Kenmare Resources plc.

planned. That expanded operation could reach full capacity of 1,200,000 tpa of ilmenite, 75,000 tpa of zircon, and 21,000 tpa of rutile by mid 2013.

Currently, four different ilmenite grades, two rutile grades, and three zircon grades (Standard, Special, and Hi-Al, cf. Appendix C for analysis) are being produced. Also, monazite may be separated in the future.

At the end of 2011, the total reserves in the Namalope and Nataka deposits under license to Kenmare were 869 million tonnes of ore sand grading 3.7 % THM on average, i.e. 32.1 million tonnes of HM, of which 1.8 million tonnes are zircon. Additional resources at Namalope, Nataka, Congolone, Pilivili, Mualadi, Mpitini, Marrua, Quinga North and Quinga South deposits were 7.4 billion tonnes of ore sand at an average grade of 2.9 % THM, i.e. some 215 million tonnes HM of which 12 million tonnes are zircon. This means that even at maximum expanded capacity the mine lifetime at Moma will be well over a century!

Projected zircon production in 2012 is 35,000 tonnes of Standard and Special Zircon grades and 10,000 tonnes of Hi-Al-Zircon grade.

Table 33: HM production by Kenmare Resources plc. in Mozambique [in tonnes], after company reports, checked by company representatives in May 2012.

	2007	2008	2009	2010	2011	2012
Ilmenite	77,401	276,543	471,524	678,220	636,800	574,400
Rutile	0	1,029	2,310	4,374	6,500	
Zircon	0	7,754	21,100	37,122	43,500	46,900*

* + including 19,500 tonnes of secondary zircon.

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, including zircon, 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 1,000 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."

This is a very good description by Futua & Elegba (2008) of the origin of zircon from Nigeria. It also explains why there are so many Nigerian zircon marketing companies even though Nigeria does not report any official zircon production at all.

The biggest problem with zircon and many other HM concentrates from Nigeria is that due to poor beneficiation most of them are strongly radioactive which does not allow them to be imported into most countries. Exceptions to the rule are India and China, although there are many reports that even Chinese customs had to reject shipments from Nigeria because of highly elevated radioactivity levels. For this study, one raw zircon sample from Nigeria could be analysed, and this showed the highest level of U+Th of all zircon concentrates on the market.

Table 34: Zircon imports from Nigeria into India and China after Roskill (2011), Department of Commerce India and UN Comtrade [in tonnes].

	2005	2006	2007	2008	2009	2010	2011
China	14,240	5,241	185	5,127	1,592	2,867	9,516
India	2,086	2,545	1,784	771	594	195	720
Italy	0	0	0	0	20	0	0
Japan	0	0	20	0	0	0	0
UK	1	0	0	0	0	0	0

PAKISTAN

There is no reliable information on zircon producing companies in Pakistan. However, Pakistan exported larger amounts of zircon in 2011, and at least one company states to be producing zircon in Pakistan.

This zircon producing company is Gulf Minerals fze (Pvt) Ltd. in Karachi. Gulf Minerals was established in 2006 by a UAE businessman. Besides trading various mineral commodities like marble, earth pigments, sulphur, barite, and chromite, it holds an exploration license over 978 km^2 along Sonmiani Bay northwest of Karachi.

Resources of zircon in its exploration area are given by Gulf Minerals as 15.58 million tonnes. Reserves are said to be about 1.3 million tonnes of zircon.

Mining of the HM rich sands started in 2006, with ilmenite, rutile, leucoxene, magnetite, and zircon (65 % $Zr(Hf)O_2$ min.) being produced as final products. Zircon capacity is said to be 5,000 tpa.

Table 35: Zircon imports from Pakistan into China after UN Comtrade [in tonnes].

	2005	2006	2007	2008	2009	2010	2011
China	0	0	0	0	22	0	6,147

REPUBLIC OF SOUTH AFRICA

Figure 36: HM mining operation by Namakwa Sands with the Atlantic Ocean in the distance. Photo: DERA.

The Republic of South Africa hosts two HM mining companies which operate three HM mines:

- Richards Bay Mining (Pty) Ltd. (RBM) mining HM deposits north of Richards Bay in KwaZulu-Natal
- Tronox Ltd. with two HM mines; Namakwa Sands in the Western Cape Province and KZN Sands in KwaZulu-Natal

A future additional HM producer might be:

- Mineral Commodities Pty. Ltd. (Tormin mineral sands project in the Western Cape province).

Mineral Commodities Pty. Ltd., based in Welshpool, Western Australia, had been hoping to develop the world-class Xolobeni HM project (346 million tonnes of ore sand @ 5.14 % HM) in the Eastern Cape since 2001, but its conditional mining rights were revoked in 2011 for environmental reasons.

The second HM project of Mineral Commodities in South Africa is the Tormin project some 400 km north of Cape Town and south of the Namakwa Sands HM mine. There, the HM deposits have accumulated along the ~12 km long, 100 m wide beach, to a maximum depth of 12 m, and are still being supplemented through erosion of an 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 heavy mineral assemblage. The HM placers overlie diamond bearing gravel beds.

Several feasibility studies on the Tormin project have been completed: the last one in 2009 assumed the operational processing of 1.6 million tonnesof ore sand annually yielding 30,000 – 40,000 tpa HM concentrate with up to 80 % zircon and 10 % rutile.
As the revised resource estimate is 2.71 million tonnes of ore sand containing only 76,100 tonnes of zircon and 18,300 tonnes of rutile, the operation will be short-lived. Mineral Commodities is proceeding with the project with no starting time published yet.

Richards Bay Mining (Pty) Ltd.

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Richards Bay Minerals

Figure 37: Welcome to Richards Bay Minerals. Photo: DERA..

Richards Bay Mining (Pty) Ltd. (RBM) is a HM mining and processing operation, which was 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 by an employee's trust (2 %).

Since 1977, RBM has been mining elevated dunal sand deposits stretching from 10 to 50 km north of Richards Bay in KwaZulu-Natal. Mining is performed by six 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, rutile (3 grades), and zircon (4 grades, cf. below) are being produced. The current capacity of this dry mill is estimated at up to 2 million tpa of ilmenite, 300,000 tpa of zircon, and 90,000 tpa of rutile.

Since 1983, up to 160,000 tpa of zircon can be acid leached to produce a premium grade zircon. Thus, the zircon grades currently produced are a premium calcined grade (ZPG), an uncalcined grade (ZUG), a standard grade (ZSG), and an intermediate (refractory) grade (ZIG) (cf. Appendix C for analysis). Production of foundry grade zircon (ZFG) was reduced drastically in 2012.

Most of the Tisand lease just north of Richards Bay has already been mined and rehabilitated by RBM. Currently, the Zulti North mining lease is being mined. Mining in this lease should last until 2030. 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 2043.The last year of full production will be 2032.

Mining in the Zulti South area could start as early as 2016. Estimated resources for the latter lease are given as 22.3 million tonnes of net VHM.

In March 2011, RBM commissioned a tailings treatment plant (TTP) with production beginning in April 2011. In 2011, this TTP treated 415,034 tonnes of old tailings and 730,654 tonnes of new tailings from the MSP (Rbm Abriged Sustainable Development Report 2011).
On average, the TTP is to treat 2.2 million tonnes of tailings annually yielding 60,000 tpa of zircon among others.

Projected zircon production in 2012 is 280,000 to 300,000 tonnes of all grades.

Table 36: Zircon production by RBM [in tonnes], after company information. 2010 production figures after Rbm Sustainable Development Report (2010).

	2005	2006	2007	2008	2009	2010*	2011
RBM	255,200	256,000	232,000	230,000	196,000	221,987	264,000

* together with 75,733 tonnes of rutile, 1,730,540 tonnes of ilmenite, and 522,460 tonnes of pig iron

Tronox Ltd.

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Figure 38: Mining of HM rich sands at Namakwa Sands in Namaqualand, Republic of South Africa. Photo: DERA.

In South Africa, Tronox Ltd. owns two HM mining operations: Namakwa Sands and KZN Sands. Namakwa Sands was formerly owned by Anglo American plc., while KZN Sands was once owned by South African steel giant ISCOR Ltd. and Ticor Ltd. of Australia (Ticor SA). After 2005, both Namakwa Sands and KZN Sands were owned by Exxaro Resources Ltd., but at the end of 2011, the mineral sands business of Exxaro Resources was taken over by Tronox Ltd. based in Stamford, CT, USA.

The Namakwa (Namaqualand) Sands operations are located in the Western Cape province of South Africa. Here, mining by Anglo American started in September 1994. Mining (at two mine sites) and pre-concentration (in two primary and one secondary concentration plants) is done at Brand se Baai, around 385 km north of Cape Town, with the MSP located 52 km from the mine and 7 km west of Koekenaap.

At Saldanha Bay, Namakwa Sands also operates two furnaces where ilmenite is smelted to produce titanium slag and pig iron. Current capacity is 135,000 tpa of zircon, 190,000 tpa of titanium slag (chloride and sulphate), 100,000 tpa of pig iron, and 31,000 tpa of rutile/leucoxene. In addition, garnet is being separated. Total resources at the end of 2011 stood at 877.4 million tonnes of ore sand grading 2.79 % ilmenite and 0.64 % zircon. This figure includes total reserves of 457.9 million tonnes of ore sand grading 8.57 % HM on average of which 9.57 % is zircon, i.e zircon reserves are 3.8 million tonnes. At Namakwa Sands, a premium grade zircon, a zircon product called "Zirkwa", and zircon rejects containing about 30 % zircon are being produced (see Appendix C for analysis). The latter product was previously sold to China but it is planned to be beneficiated by Tronox itself in the near future.

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 commenced in 2001 by Ticor SA, and is expected to end due to depletion in the Braeburn Extension deposit in late 2012. Original plans to open the Fairbreeze deposit 25 km to the south-west soon afterwards were postponed in December 2009 but reactivated in March 2011.

Therefore, as production at Fairbreeze cannot start before the second half of 2014, there will be a gap in HM production by KZN Sands for about 2 years. KZN Sands considers scavenging or mining the Kidney Dam deposit (4 – 5 million tonnes of sand @ 1 % HM) to extend the life of the Hillendale mine. KZN Sands produces ilmenite, titanium chloride slag, slag fines, zircon (2 grades, cf. below), rutile (2 grades), leucoxene and low manganese pig iron.

The MSP and the furnaces for ilmenite smelting are located at a central processing complex at Empangeni, 20 km west of Richards Bay. Currently, the zircon production capacity is about 45,000 – 50,000 tpa, but will rise to 60,000 tpa when the Fairbreeze deposit starts production. Total resources for the Fairbreeze deposit (A, B, C, C Extension and D Blocks) stand at 220.9 million tonnes of ore sand, including proven and probable reserves of 139.7 million tonnes of ore sand grading 7.24 % HM on average, of which 8.39 % is zircon. Thus, zircon reserves at Fairbreeze are 850,000 tonnes. The expected minimum mine lifetime is 12 years. Currently, a standard grade (30 – 40 vol.-%), and a ceramic grade zircon (60 – 70 vol.-%) are being produced at KZN Sands (cf. Appendix C for analysis).

Projected zircon production in 2012 at Namakwa Sands is higher than in 2011, and at KZN Sands is 24,000 tonnes of all grades.

Figure 39: Hydraulic mining of HM rich sands at KZN Sands in KwaZulu-Natal, Republic of South Africa. Photo: DERA.

Table 37: Zircon production by Tronox Ltd. in South Africa [in tonnes], after Exxaro Resources Ltd. Company Reports.

	2005	2006	2007	2008	2009	2010	2011
Namakwa	128,600	128,400	114,800	130,000	116,000	129,000	135,000
KZN	47,000	50,000	34,000	34,000	36,000	32,000	28,000

RUSSIA

Currently, there are two producers of zirconium minerals in Russia:

- OAO “Kovdorskyi GOK”,
- OAO Tuganskyi “GOK “Ilmenite””

Three other companies are looking into the possibilities of entering zircon mining:

- OOO “PKP Titan” (Tsentralnoe placer deposit in Tambov region),
- OOO Company “Geostar” (Lukoyanovskoye placer deposit in Nizhny Novgorod region),
- OAO “Gornye tekhnologii” (Katuginskoye hard rock deposit in Zabaikalskyi territory).

Figure 40: Baddeleyite-rich ore is only mined in the Kovdor pit, Kola Peninsula, Russia, Photo courtesy of MCC EuroChem OJSC.

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Website www.eurochem.ru/about_eurochem_2/operations/production/kovdorskiy_gok
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OAO “Kovdorskyi GOK”, a member of the Russian Eurochem Group since 2002, mines the Kovdor hard rock deposit in the Kola Peninsula. Mining for iron ore from this near to unique deposit started in 1961. The commercial production of phlogopite (1963), vermiculite (1974), apatite (1975), and baddeleyite (1976) followed some years later.

At Kovdor, baddeleyite (ZrO_2) is separated by flotation from material lost while dressing the apatite rich magnetite ore. Additionally, the old heaps which have been dumped at Kovdor since 1962 have been recycled for baddeleyite since 1976. In the magnetite ore, the baddeleyite grade is very low, ranging from 0.14 – 0.17 %. As the baddeleyite is of fine to very fine grain size, the recovery is also very low, i.e. between 20 – 30 % on average. The baddeleyite concentrates from Kovdor are of high purity with the combined content of Fe, Mg, Si, Ti and Ca oxides not surpassing 2.0 – 2.5 %.

The average composition of the most common grade produced is reported in the literature as 98 % ZrO_2+HfO_2, 0.6 % SiO_2, 0.47 % MgO, 0.3 % CaO, 0.2 % Fe_2O_3, 0.18 % P_2O_5 and 0.14 % TiO_2. On the other hand, higher grades with 99.2 – 99.4 % ZrO_2 and very low contents of Fe, Mg, Al, Ti, P, S, Ca, U and Th are also produced on demand (cf. Appendix C).

As of 1 January 2010, OAO “Kovdorskyi GOK” held 5.9 % of the Russian reserves of ZrO_2, i.e. 436,700 tonnes in A+B+C1 categories and 104,500 tonnes in category C2. The baddeleyite concentrate capacity is 8,850 tpa. The production and export figures of baddeleyite from Kovdor are given below:

Table 38: Production of baddeleyite-rich material, baddeleyite concentrate, export of baddeleyite concentrate and domestic use of baddeleyite in Russia [in tonnes], after http://www.mineral.mu/facts/russia/147/425/23_zr.pdf

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Baddeleyite-rich material						22,800	25,400	25,300	21,900	25,400
Baddeleyite concentrate	2,777	2,231				6,739	7,514	7,136	8,123	8,249
Export	3,500	3,800	3,200	3,300	7,700	7,700	7,500	7,600	6,800	5,000
Domestic	200	200	200	200	600	400	700	750	290	500

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Email ilmenite@ilmenite.ru; pashkova@ilmenite.ru

Contact pers. Olga Adeshina, Sales and Marketing Manager

Since 2005, JSC Tuganskyi "GOK "Ilmenite mines the heavy mineral enriched Tuganskyi quartz sand/gravel deposit around 40 km from Tomsk in Tomsk province. 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. Besides rutile and ilmenite, the quartz sand is enriched in zircon. The average grade of ZrO_2 in the deposit is given as 7.72 kg (equivalent to 11.5 kg of zircon) per m^3 of ore sand.

As of 1 January 2010, JSC Tuganskyi "GOK "Ilmenite held 10.3 % of the Russian reserves of ZrO_2, i.e. 981,400 t (i.e. 1.46 million tonnes of zircon) in A+B+C1 categories. Production figures of various minerals from Tuganskyi "GOK "Ilmenite, which still has pilot plant status, are given below. Current plans are to reach a capacity of 17,000 tonnes of zircon in 2013, and full capacity of 34,000 tonnes of zircon in 2015.

Table 39: Production of zircon, ilmenite, quartz sand, and quartz gravel from the Tuganskyi deposit [in tonnes], after company annual reports.

	2006	2007	2008	2009	2010	2011
Ore sand	22,628	37,000	51,984	29,337	51,129	61,472
Zircon	133	121	109	82	125	133
Ilmenite	361	518	564	315	504	522
Quartz sand	8,117	10,199	16,121	10,708	19,572	23,000
Quartz gravel	6,821	10,121	11,851	6,377	10,777	13,962

SENEGAL

Currently, there is no HM production in Senegal, but two companies, Mineral Deposits Ltd., and Astron Ltd., both based in Australia, plan to produce zircon in future.

Astron Ltd. holds the exploration licence for the Niafarang deposit in southwestern Senegal. This deposit stretches for 75 km along the coast, of which 6 km have been explored in a first step. Established resources stand at 4.8 Mt of ore sand grading 12.4 % THM, of which 13.7 % is zircon. Thus, zircon resources in this 6 km coastal stretch amount to 82,000 tonnes. Anytime in the future, a dredge mining operation could produce 80 kt of ilmenite and 15 kt of zircon per annum.

Mineral Deposits Ltd.

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Website	www.mineraldeposits.com.au
Email	mdlmail@mineraldeposits.com.au
Contact pers.	Martin Ackland, Chairman of Grande Cóte Operations SA.

Mineral Deposits Ltd. (MDL), which has a long history of HM mining in eastern Australia, is hoping to commission its Grande Côte Project in Senegal in late 2013 or 2014 at the latest. The second partner in this project via the JV TiZir Ltd. is ERAMET S.A. of France, while 10 % is held by the Government of Senegal. The Grande Côte mineral sands project is located on a mobile coastal dune system starting about 50 km north-east of Dakar and extending northward for more than 100 km. The mineralised dune system averages 4 km in width. The project area is 445.7 km^2 with the main heavy mineral deposits identified to date being Diogo, Mboro, Fass Boye and Lompoul. Estimated measured and indicated resources are 1,030 million tonnes of ore sand at 1.7 % HM at a 1.25 % cut-off grade. Proven and probable reserves included in the resources are 751 million tonnes of ore sand grading 1.8 % HM. The HM concentrate contains 8.3 – 11.0 % zircon, with 10.6 % calculated on average. The other main saleable products will be rutile, leucoxene, and ilmenite.

At design capacity, the mining rate of 55 mtpa will produce approximately 85,000 tonnes of zircon annually, and 550,000 – 600,000 tonnes of ilmenite.
In more detail, as assumed in the Technical Report of the Grande Côte project, average production for more than 25 years is scheduled to be 79,500 tonnes of zircon per year, divided up into 32,000 tonnes of premium grade, 25,000 tonnes of intermediate grade, 20,000 tonnes of standard grade, and 2,500 tonnes of secondary (foundry grade) zircon.

Table 40: Planned HM and saleable zircon production (in kilotonnes) in the first ten years from the Grande Côte project, after MDL Technical Report.

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
HM	760	1,040	1,010	990	990	970	960	1,010	940	990
Zircon	65.7	90.2	87.3	86.4	85.9	84.0	83.5	87.8	81.6	85.9

SIERRA LEONE

There is one producer of zircon in Sierra Leone: Sierra Rutile Ltd.

Sierra Rutile Ltd.

Sierra Rutile Limited

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Contact pers. Neil Gawthorpe, Marketing Director

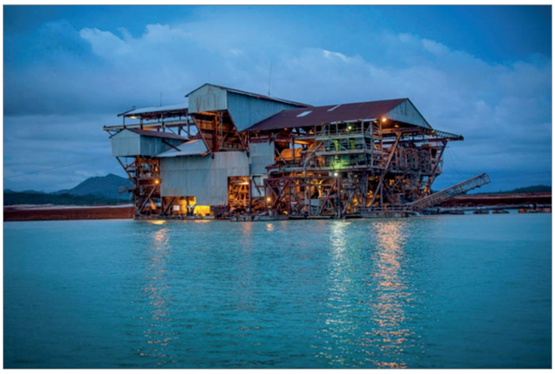

Figure 41: Dredge 1 of Sierra Rutile Ltd. Photo courtesy of Sierra Rutile Ltd.

Sierra Rutile Ltd. (SRL) operates a mine and a plant in Sierra Leone but is incorporated in the British Virgin Islands. The Sierra Rutile mine is located in the southwest of 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 over a land area of 580 km^2 in which 19 separate rutile deposits have been identified. Most deposits are located in two areas: Gbangbama and Sembehun.

At the end of 2005, the Titanium Resources Group (now SRL) announced that it had also acquired the Rotifunk mineral sands prospect, the second largest known mineral sands deposit in Sierra Leone. Rotifunk is located 65 km southeast of Freetown and lies approximately 40 km northwest of the Sierra Rutile mine. Records of work undertaken by both Bayer-Preussag and Hazcare have provided inferred mineral resource estimates of 207 million tonnes at 0.49 % rutile, and 163 million tonnes at 0.48 % rutile, respectively. Exploration work undertaken in 2003 – 2004 by the former owner Gondwana (Investments) S.A. has identified 170 million tonnes of inferred mineral resources at 0.70 % rutile, 0.84 % ilmenite, and 0.06 % zircon.

After the end of the civil war in Sierra Leone, SRL reopened its mine in 2005. Currently, the mine operates just one bucket ladder dredge, D1, as a second one, D2, capsized in July 2008. A new second large dredge, D3, is to be constructed in future. Conventional mineral processing methods are used to produce rutile, ilmenite and small amounts of zircon concentrate.

At the end of October 2012 Sierra Rutile announced that it changed its expansion strategy by fast-tracked development of a new project, the dry mining of the Gbangbama deposit. Assuming full-scale construction of Gbangbama Dry Mining begins in Q1 2013 production could start 12 months later. Average annual production will be 84,400 tonnes of rutile, 46,000 tonnes of ilmenite, and 9,500 tonnes of zircon over a life of 6 years.

A zircon-rich (60 % zircon, 40 – 43 % ZrO_2) concentrate was produced from 2009 to 2011 (cf. Table 41) in a batch process, limiting the production opportunities of expanded rutile production. As this expansion is scheduled to happen in 2012, SRL does not plan to produce any zircon this year.

The mineral separation plant's availability will be fully dedicated to the increased production of SRL's core rutile product and associated ilmenite. However, SRL will continue to assess the future potential of on-stream production of a premium zircon product.

Measured and indicated resources held by SRL for the Gbangbama and Sembehun areas as of January 2011 were 441.0 million tonnes of ore sand grading 6.14 % HM, of which zircon is 5.0 %. Thus, it contains zircon resources of 1.385 million tonnes.

Table 41: Production of rutile, ilmenite, and zircon-rich concentrates by SRL [in tonnes], after company information.

	2006	2007	2008	2009	2010	2011
Rutile	73,802	82,527	78,908	63,864	68,198	67,916
Ilmenite	13,819	15,750	17,528	15,161	18,206	15,946
Zircon-rich concentrate	0	0	0	5,560	7,092	8,496

SRI LANKA

There is just one official producer of HM in Sri Lanka, the state owned:

- Lanka Mineral Sands Ltd. mining HM at Pulmoddai in the north-east of the island.

Lanka Mineral Sands Ltd.

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Lanka Mineral Sands Ltd. is a state-owned company and is the successor to Ceylon Mineral Sands Corporation which was established in 1957 under the Industrial Corporation Act. In 1992, Ceylon Mineral Sands Corporation was converted to Lanka Mineral Sands Ltd., which is controlled by the Ministry of State Resources and Enterprise Development.

Ceylon Mineral Sands installed an ilmenite processing plant at Pulmoddai in 1961 which commenced commercial production in 1963 at the same time as commercial HM mining. In 1968, rutile and zircon were separated for the first time from Pulmoddai tailings, but 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 could not reopen before 2004, and was then affected by another 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. At that time, the company had already stopped producing HM for a long time 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.

While the head office of Lanka Mineral Sands is located in Colombo, its MSP is located in Kanijapura in Pulmoddai on the north-east coast of Sri Lanka, 54 km north of Trincomalee.

The beach sands south of Pulmoddai are very rich in HM, reaching 50 – 60 % on average, of which some 8 – 15 % is zircon. Total HM resources at Pulmoddai are estimated at about 12.5 Mt, of which some 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 beach sands are currently mined at four locations near Pulmoddai Nayaru, Kokkilai, Poduwakattu and Periyakarachchi, by old excavator draglines and new front-end wheel loaders.

Mining traditionally starts around February after the monsoon replenishes the beach placers mined the years before.
At Yan Oya and Periyakarachchi, the raw sand is washed and screened to remove trash and shell fragments, and put through a series of concentrators to separate the heavy minerals.

Figure 42: Beach mining of HM at Pulmoddai. Photo courtesy of Lanka Mineral Sands Ltd.

Sales are finalized by a Tender Board following the government tender procedures. Minerals are shipped from Trincomalee harbour in bulk or in bags, and through Colombo in bags on FOB or CFR terms.

The products and annual production capacity are reported by Lanka Mineral Sands as 90,000 tonnes of ilmenite (50 – 51 % TiO_2), 9,000 tonnes of rutile, 4,000 tonnes of high-titanium ilmenite (> 61 % TiO_2), 5,500 tonnes of zircon (cf. Appendix C for analysis), and 100 tonnes of monazite.

Table 42: Zircon production by Lanka Mineral Sands Ltd. [in tonnes], after BGS World Mineral Statistics.

	2004	2005	2006	2007	2008	2009	2010	2011
Pulmoddai	12,826	23,587	8,321	381	1,447	10,267	796	641

Thailand

Very similar to Malaysia, all of the zircon in Thailand that is not imported comes from alluvial tin mining operations, where it is produced from "amang" (cf. Malaysia). First production of zircon in Thailand was recorded in 1967, immediately followed by the maximum production of 2,920 tonnes in 1968.

Alluvial tin deposits have been mined in Thailand for over 1,000 years. The most important areas have been in Phang-nga and Phuket provinces in the south-west 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.

There was just one domestic HM mining operation also producing zircon 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 tonnes of zircon.

According to the Mineral Statistics of Thailand 2006 – 2010 of the Department of Primary Industry and Mines, the last domestic mining of zircon was in 2007 when 1,023 tonnes were produced in Yala province. However, no one in Thailand is aware of any zircon mining company ever having operated in Yala province!

Processing of amang is not recorded in Thailand as it is not classified as primary zircon production by mining. There are also no officially registered amang processing companies in Thailand.
On the other hand, zircon imports into Thailand were always much larger than zircon exports (to China, India, Taiwan, and Philippines). This, however, is explained by local experts as not being attributable to large domestic consumption but by imports of zircon rich tailings which, after processing, are exported as zircon concentrates.

A local consultant identified four companies which are still all engaged in the processing of tailings and the production of zircon:

- Sakorn Minerals Co. Ltd., cf. extra page.
- Ratanarungsiwat Co. Ltd., established in 1988, which operates an award-winning (2009, Ministry of Industry) processing plant in Amphur Kapong, Phang-nga province. With a capacity of 1,200 tonnes of raw material per month, it mainly processes amang from south Thailand for the production of cassiterite, columbite-tantalite, wolframite, struverite, monazite, xenotime, zircon, rutile, garnet, and ilmenite.
- PLD Group Co. Ltd., founded in 1985, which has a diversified portfolio ranging from turnkey construction, trading agricultural products, and processing of amang, from which it mainly produces zircon and rutile. No information about capacity or production is available.
- Siamratanapa Co. Ltd., of which there is also not much information available, but which is also engaged in the production of cassiterite, zircon (> 65 % $Zr(Hf)O_2$, < 0.5 % Fe_2O_3, 0.5 – 1.0 % TiO_2) and ilmenite from amang in its own processing plant(s).

Sakorn Minerals Co. Ltd.

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Sakorn Minerals Co. Ltd. is a privately owned company and was founded in 1985. It has always been and is still the largest producer of HM (zircon, rutile, and leucoxene, to a lesser extent also ilmenite, monazite, xenotime, kyanite, tantalite, struverite, and cassiterite) in Thailand, which are separated from amang (SE-Asia), gold tailings (Indonesia) and from HM tailings from Australia, India, Indonesia, South Africa (since 2012) and to lesser extent from Vietnam.

At its processing plant in Prachuabkhirikhan, where its own mining operations stopped in 2000, Sakorn Minerals can treat up to 180,000 tonnes of tailings, and produce up to 20,000 tonnes of zircon per year. Currently all final products are exported to China.

Sakorn Minerals produces three different grades of zircon (premium, standard, and foundry) which were kindly provided for analysis for this study (cf. Appendix C).

UKRAINE

Currently, there is only one producer of zircon in Ukraine:

- Volnogorsk State Mining and Metallurgical Integrated Works

Two other companies are mentioned as potential zircon producers in the future:

- Dimurinsky GOK (Volchanske placer deposit in the Dnipropetrovsk region), and
- Rutile-Ilmenite Company (Tarasovka placer deposit in the Volodarskiy district in the southwest part of Kiev region).

Velta Group Global Ltd. is a company registered in London. Via its subsidiary Velta LLC, it commenced mining the Birzulovo (Birzulivske) placer deposit in Ukraine in December 2011. The Birzulovo deposit hardly contains any zircon and is dominated by ilmenite.

However, also in December 2011, Velta bought the Tarasovka placer deposit formerly owned by the Rutile-Ilmenite Company (RICO). Velta plans to start-up production at Tarasovka in Q2 2014 and has now commissioned TZMI of Australia to come up with a new JORC compliant resource of this deposit. At Tarasovka, the ore sand (2.2 – 2.4 % VHM) has a thickness of 3 to 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 million m^3 in category A, 79.975 million m^3 in category C1, and 35.5 million m^3 of ore sand in category C2. Non-JORC compliant zircon resources were 171,746 tonnes in category B, 592,418 tonnes in category C1, and 229,800 tonnes in category C2.

RICO planned to produce 5 million m^3 of ore sand containing 240,000 tonnes of HMC annually for a minimum of 20 years. Plans were to produce 55,000 tonnes of rutile, 22,000 tonnes of ilmenite, 80,000 tonnes of leucoxene, 32,000 tonnes of zircon, 10,000 tonnes of staurolite, and 15,000 tonnes of kyanite-sillimanite annually.
Velta currently plans to produce 45,000 tpa of zircon and to market a coarse zircon product as standard grade zircon, and a fine zircon product as premium grade zircon. Detailed analyses of the zircon to be produced were kindly provided by Velta for this report (cf. Appendix C).

Volnogorsk State Mining and Metallurgical Integrated Works

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The Volnogorsk (in Ukrainian: Vilnohirsk) State Mining and Metallurgical Integrated Works (VGMK, VSMMP) is a mining and metallurgical company, owned by the Government of Ukraine. It was leased to Crimea Titan CJSC, owned by the Government of Ukraine and OstChem Germany, a subsidiary of OstChem Holdings, Austria, in September 2004. The lease period officially ended five years later, but VGMK has still not been released by Crimea Titan.

Production of heavy minerals from the Malyshev placer deposit on the banks of the Samotkan river near Volnogorsk started in 1961. The ore sand, which is covered by thick overburden, is being mined by excavators and draglines. A new deposit, Matronvoskoe, is said to be evaluated for future mining.

VGMK produces rutile, ilmenite, zircon, staurolite, and kyanite-sillimanite concentrates, as well as quartz sand for glass production, and foundry sand. Also, numerous other zircon based products (zircon flour, zirconia, stabilised zirconia, various zirconium chemicals) together with a variety of noble metal chemicals are being distributed.

Zircon capacity is estimated at 35,000 tpa, although production in recent years has obviously been a little bit less (cf. Table 43). Currently, a standard and a premium grade is being produced (see Appendix C for analysis).

No current reserve figures are available, but the life of mine is said to be about 10 years at a maximum.

Table 43: Estimated production of zircon in Ukraine and export of zircon from Ukraine [in tonnes], after Roskill (2011) and UN Comtrade.

	2005	2006	2007	2008	2009	2010	2011
Zircon production	33,000	30,000	35,000	35,000	31,000	30,000	
Zircon export	31,574	26,837	37,027	35,614	30,786	30,223	26,407

USA

The USA has a long history of heavy mineral mining, with zircon production in north-eastern Florida starting as early as 1922.

Currently there are three producers of zircon in the US:

- E. I. du Pont de Nemours & Co., Inc
- Iluka Resources Inc., and
- Oregon Resources Corporation.

A fourth company is planning to start production in Q4 2013. This is Southern Ionics Inc. based in West Point, MS, USA, which is specialised in zirconium and other inorganic chemicals. It will utilize the zircon produced at its Mission mine in southern Georgia internally but will sell the titanium minerals that are produced on the open market.

The Mission mine will be located 15 km south of Lulaton and 15 km north of Folkston both having been HM mines in the past. Zircon makes up 28.1 % of the VHM produced at Mission, together with ilmenite (39.5 %), HiTi (22.4 %), staurolite (5.3 %), kyanite/sillimanite (3.2 %), and monazite (0.86 %).

When it starts production in 2014, the Mission mine is expected to produce some 7,700 tonnes of zircon in the first year, and 14,500 tonnes of zircon in the years thereafter. The life of mine will be 8 – 10 years.

The mine will use a dry mining method but a conventional floating concentrator located in a central water-filled canal running the length of the ore body. As mining moves further away from the concentrator mill, the mill is simply pulled along the canal to the closest point to the active mining site.

A detailed analysis of the zircon to be produced was kindly provided by Southern Ionics Inc. and can be found in Appendix C.

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Contact pers. James R. Kanicky, PhD, PE, Ore Products Business Manager
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E.I. du Pont de Nemours & Company, Inc. (DuPont) mines the aeolian Trail Ridge placer deposit in north-eastern 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) with its minerals separated in the Trail Ridge plant. Shortly afterwards, the mined-out Highland site was abandoned and restored. The Trail Ridge site is also no longer being mined.

Plans to develop a 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 to extend the mine life to at least 2017.

Original mineable reserves from the three combined Trail Ridge sites (without Maxville extension) were some 49.1 million tonnes of HM including 7.4 million tonnes of zircon.

Zircon from Trail Ridge was first sold in 1950, and nine years later, in 1959, 54,000 tonnes of zircon were produced. However, in 1992 maximum production with some 85,000 tonnes of zircon was achieved. Since 2004, zircon production has fallen considerably due to the closure of mine sites and decreasing head-grades (cf. Table 44).

Table 44: Estimated zircon production by DuPont in the US [in tonnes], mainly after BGS World Mineral Statistics (2010).

	2005	2006	2007	2008	2009	2010	2011
Trail Ridge	65,200	59,900	40,400	37,500			

Zircon from Trail Ridge is quite uniform, relatively coarse, well rounded, and of high purity. Six different grades are currently being produced (cf. Appendix C for analysis):

- Premium zircon
- Standard zircon
- Low alumina zircon
- Zircon M (zircon + some magnetic minerals)
- Zircon T (zircon + 2 % titanium minerals sold as a special foundry sand)
- Zircore (zircon + kyanite, sillimanite, corundum is another special foundry sand)

Formerly also Zirclean, containing staurolite, was produced as an abrasive.

Iluka Resources Inc.

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Iluka Resources Inc. is a subsidiary of Iluka Resources Ltd. based in Perth, Australia. In February 2006, Iluka ended HM mining at its Green Cove Springs deposit in north-eastern Florida, but continued to produce zircon from its accumulated dry mill tailings until 2009. The Lulaton deposit in south Georgia was also only in production from January 2004 to June 2006.

Iluka's operations in Virginia commenced in 1997 with the commissioning of the Old Hickory project. Two mines with separate concentrators (Old Hickory, commissioned in 1997 and Concord, commissioned in 2002) produced heavy mineral concentrate (HMC) which was then trucked 20 km to the dry processing plant located at Stony Creek, 69 km south of Richmond. The mining and concentrating operations at Old Hickory ceased in January 2009 when the available reserves were depleted.

In December 2007, the Iluka Board approved the development of the Brink deposit. This project involved the establishment of a new mine, and relocation of the Old Hickory concentrator, located 48 km to the south. First production from Brink was achieved in April 2009. The Brink deposit is expected to extend the economic life of the Virginia operations to 2014/15.

As of 31 December 2011, the resources (including reserves) of Iluka in Virginia stood at 58.8 Mt of ore sand grading 6.1 % HM on average, i.e. containing 3.58 Mt of HM, of which 10 % was zircon. As of 31 December 2011, the reserves of Iluka in Virginia stood at 27.6 Mt of ore sand grading 4.6 % HM on average, i.e. containing 1.26 Mt of HM, of which 15 % was zircon.

Iluka hopes to be able to move to the Aurelian Springs HM deposits in Halifax County, North Carolina after the Brink deposit is mined out. The deposits are located approximately 64 km south of Iluka's MSP at Stony Creek. They contain 4.4 Mt of HM with an average assemblage of 6.6 % zircon, 63 % ilmenite, and 19 % staurolite. Based on this resource, the development of the deposits could entail an economic life of at least 11 years dependent on production levels. The mining and processing methods will be identical to those used at the current sites, with the wet concentrator plants from Concord and Brink scheduled for relocation to Aurelian Springs.

As an alternative, returning to the Hickory deposit site has now evolved as an interesting option. Two factors have prompted a review of reactivation of mining in that area. Iluka has recently obtained approval from landowners to access previously unmined areas, while higher ilmenite prices have lowered the cut-off grades for economically mineable ore. The Hickory project (480,000 tonnes of HM of which 16.4 % is zircon) therefore forms one of Iluka's enhanced production projects, with the benefits of utilising the existing infrastructure and delivering a capital-efficient new production source.

Given the current economic life of the existing Virginia operations to 2014/2015, both Hickory and Aurelian Springs, if proceeded with, will significantly extend the economic life of the company's mineral sand operations in the US.

Table 45: Production of zircon by Iluka in the US [in tonnes], after Iluka website.

<table>
<tr><th></th><th>2005</th><th>2006</th><th>2007</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th></tr>
<tr><td>Green Cove Springs/ Lulaton</td><td>29,568</td><td>15,419</td><td>17,030</td><td>13,786</td><td>2,300</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Old Hickory/ Concord</td><td>69,189</td><td>67,635</td><td>63,537</td><td>70,679</td><td rowspan="2">47,500</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Brink</td><td></td><td></td><td></td><td></td><td>58,200</td><td>60,300</td><td>49,400</td></tr>
</table>

Two zircon grades are being produced at Stony Creek, VA: Ultra and Premium (cf. Appendix C for analysis).

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Figure 43: Mining of fossil strandlines in Oregon. Photo courtesy of Oregon Resources Corp.

Oregon Resources Corporation (ORC) is a subsidiary of IDM International Ltd., which is based in Perth, Australia.

ORC mines some elevated coastal placer deposits in southern Oregon with the ore sand trucked and processed at Coos Bay. Mining commenced in April 2011. Processing of the screened ore sand in the Coos Bay plant started in late 2011.

Primary commodity is foundry-grade chromite with zircon, garnet, and titanomagnetite produced as by-products. The zircon grade in the fossil placers is quite low averaging 1.4 to 2.9 % of the HM suite.

As of 31 December 2011, proven reserves were 7.88 Mt of ore sand grading 21.5 % HM but with only 0.4 % zircon, with measured reserves given as 383,000 tonnes of ore sand grading 0.3 % zircon, i.e. total reserves of only 33,000 tonnes of zircon.

Table 46: Planned production of zircon by Oregon Resources Corporation [in tonnes], after company website.

	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17
Coos Bay	4,635	5,478	5,722	5,676		

One zircon product of foundry grade is being produced at Coos Bay (cf. Appendix C for analysis).

Vietnam

Recent 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.

Currently there are seven zircon mining companies in Vietnam:

- HaTinh Minerals and Trading Corporation (MITRACO), province-owned.
- Thua Thien Hue Minerals Corporation (HUMEXCO), province-owned,
- Binh Dinh Minerals Joint Stock Company (BIMICO), province-owned,
- Amigo Minerals Joint Stock Company (AMIGO), privately-owned,
- Saigon – Quy Nhon Mining Corporation (SQC), privately owned,
- Biotan Mineral Joint Stock Company (BIOTAN), privately owned,
- Dat Quang Chu Lai Minerals Joint Stock Company (DQCL), privately owned

As of 2012, the officially approved reserves and resources of zircon and titanium minerals attributed to the first six officially registered HM mining companies are 6.578 million tonnes (cf. below). However, there are additional mineable HM placers in the provinces where mining currently takes place, as well as in the provinces of Bà Rịa-Vũng Tàu, Quảng Nam (DQCL), and Khánh Hòa. The reserves/resources of DQCL in Quảng Nam province have not been officially approved yet.

Many of the HM placers along the coast of Vietnam which are easy to reach and unguarded are the target of illegal mining operations which produce a mixed HMC which is sold to illegal separation companies or directly to Chinese customers.

In 2011, in addition to the well-known placers along the coast, the fossil mineralized “Red Sands” were explored in detail. The “Red Sands” are of Pleistocene age and spread along the coastal inland basin from Bình Thuận and Ninh Thuận provinces to Bà Rịa-Vũng Tàu province in the south. The width of the “Red Sands” varies from 500 to 1,500 m and their thickness from some 10 m to 100 m, with an average calculated thickness of 40 m. The area of distribution o the “Red Sands” is some 1,200 km^2 of which 200 km^2 are covered by Holocene sands.

The average grade of zircon and titanium minerals in the ore sand is 0.9 %. The ore sand is very fine with only 28.75 % above 0.1 mm. The average grade of zircon in the HM suite is 35.19 % (9.17 – 59.47 %), and the average grade of ilmenite (49.9 % TiO_2) is 33.73 % (22.22 – 50.36 %).

Estimated mineral resources in the “Red Sands” are 501 million tonnes of ilmenite and 78 million tonnes of zircon.

Table 47: Zircon exports from Vietnam and imports by China from Vietnam after UN Comtrade [all data in tonnes].

Trade	2005	2006	2007	2008	2009	2010	2011
Export Vietnam	19,127	15,438	11,578	12,643	7,753	12,065	
Import China	32,543	26,089	21,746	21,845	6,819	6,852	13,862

For this study, a local consultant received valuable information on domestic zircon production from the Department of Geology and Minerals of Vietnam and from all of the active mining companies. Nevertheless, care has to be taken when rounded and constant production figures are given as they may represent projected figures which were never updated!

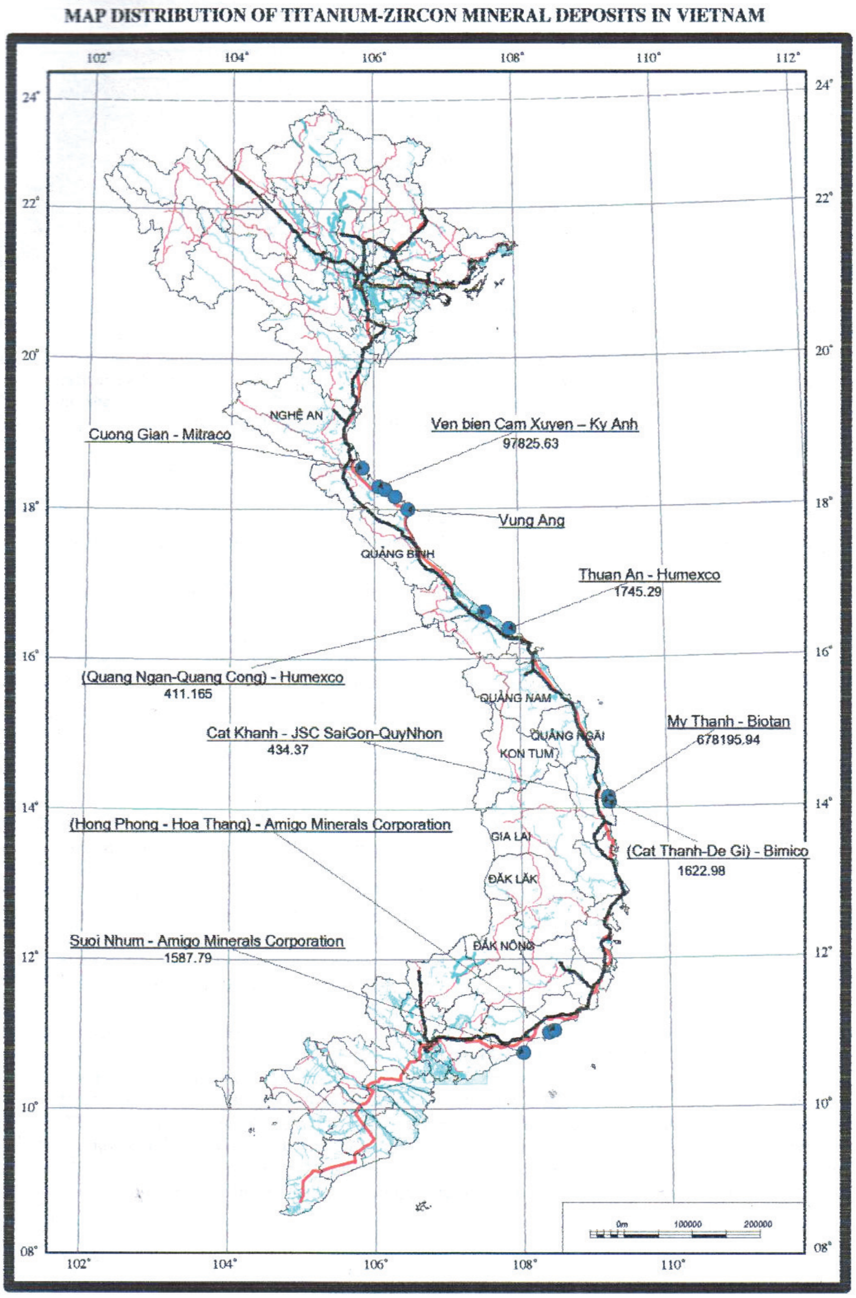

Figure 44: Map of zircon producing companies in Vietnam with officially approved reserves/ resource data as explained in the company profiles.

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HaTinh Minerals and Trading Corporation (MITRACO) is a state-owned enterprise directly under the control of Hà Tĩnh Province. It is engaged in production and business activities of various kinds from mining via road building to travel services.

The HM mining operation in the Hà Tĩnh Province of Vietnam was initially established in 1992 as a joint venture, 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 company, Minerals and Trading Company, founded in 1991. The name changed to Minerals and Trading Corporation (MITRACO) in 2000. In 2012, MITRACO's stated target is a revenue of 1,300 billion VND and an export turnover of 8 million US$.

MITRACO produces ilmenite, zircon, and rutile (83 % TiO_2 min.) from over ten mineral sands operations in Hà Tĩnh province. It owns four wet concentration plants with a total capacity of between 200,000 and 250,000 tonnes of HMC per annum.

MITRACO produces two grades of zircon. Only the Class 1 grade (65 % $Zr(Hf)O_2$ min.) is suitable for export (cf. Appendix C) while the Class 2 grade (57 – 58% $Zr(Hf)O_2$) is only used domestically.
In 2003, the company began producing zircon flour with a capacity of 6,000 tpa, which was raised to 12,000 tpa in 2011. The zircon flour has a guaranteed minimum of 65 % $Zr(Hf)O_2$ and is produced in four grain sizes grading 5, 10, 45 and 75 µm on average.

The total approved zircon and titanium mineral reserves and resources attributed to MITRACO as of 2012 are only 97,825 tonnes. However, the company has a resource base of around 2 million tonnes of HM contained in the sands along the coast of Hà Tĩnh Province.

Table 48: Zircon, ilmenite, and rutile production by MITRACO in Hà Tĩnh Province [in tonnes], after company information.

MITRACO	2005	2006	2007	2008	2009	2010	2011
Zircon	6,600	3,400	3,800	4,300	3,500	3,200	3,000
Ilmenite	96,000	87,000	84,000	66,000	43,000	35,000	20,000
Rutile	2,800	2,100	3,200	2,500	1,300	2,100	1,700

Thua Thien Hue Minerals Corporation (HUMEXCO)

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Thua Thien Hue Minerals Corporation (HUMEXCO) was established in 1983. It is controlled by Thừa Thiên-Huế Province.

The company's main products are sulfate grade ilmenite (52 % TiO_2 min.), rutile (85 % TiO_2 min.), monazite (50 % TREO min.), zircon (standard and premium grade, cf. Appendix C), zircon flour (65 % $Zr(Hf)O_2$ min.), titanium slag (92 % TiO_2 min.), pig iron and TiO_2 pigment. Official titanium slag and pig iron production started in January 2011. Also in 2011, HUMEXCO invested in two zircon grinding lines with a total capacity of 4,500 tpa.

The company has four facilities in the Thừa Thiên-Huế Province area and exports its products to countries including Japan, China, Malaysia and others in SE-Asia.

Total approved zircon and titanium mineral reserves and resources attributed to HUMEXCO as of 2012 are 1,745,285 tonnes at Thuan An, and 411,165 tonnes at Quảng Ngan – Quảng Cong, both in Thừa Thiên-Huế Province.

Table 49: Production statistics of Humexco in Thừa Thiên-Huế Province [in tonnes], after company information.

HUMEXCO	2005	2006	2007	2008	2009	2010	2011
Zircon	n. a.	18,000	15,000	15,000	9,000	9,000	9,000
Ilmenite	n. a.	62,000	50,000	55,000	41,000	50,000	50,000
Rutile	n. a.	3,400	3,200	3,000	3,000	3,000	3,000
Monazite	n. a.	1,120	1,200	1,200	1,200	1,200	1,200
Zircon flour	n. a.	1,650	2,000	2,000	2,000	2,000	2,000
Titanium slag	–	–	–	–	–	–	10,000

Binh Dinh Minerals Joint Stock Company (BIMICO)

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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, called Bimal Minerals Co. Ltd., went into production at the end of 1996. BIMICO transferred all of its mining licenses to Bimal Minerals. This joint venture stopped production in early 2011 when its license expired.

BIMICO mines HM from its Degi mine in Cát Khánh Village, Phu Cat District of Bình Định Province. Currently, the production license covers an area of 150 ha and expires in 2021. Since 2007, HM placers have also been explored to the south of Cát Khánh and Cat Hai Villages. The company owns one MSP with a capacity of 80,000 tpa of ilmenite, 2,500 tpa of zircon, 1,200 tpa of rutile, 400 tpa of monazite, and 2,000 tpa of magnetite, as well as one titanium slag factory with a capacity of 12,000 tonnes of titanium slag and 7,000 tonnes of pig iron per year.
The company's main product is ilmenite (52 % TiO_2 min.), and it also produces rutile (85 % TiO_2 min.), zircon (cf. Appendix C for analysis) – most of which is milled to zircon flour (65 % $Zr(Hf)O_2$ min., capacity 4,500 tpa) – monazite (57 % TREO min.), magnetite (85 % Fe_3O_4 min.), titanium slag (90 % TiO_2 min.) and pig iron (97 – 98 % Fe).
More than 95 % of the company's products are exported to Japan, Malaysia and China.

Total approved zircon and titanium mineral reserves and resources attributed to BIMICO as of 2012 are 1,622,980 tonnes.

Table 50: Production statistics of BIMICO in Bình Định Province [in tonnes], after company information.

BIMICO	2005	2006	2007	2008	2009	2010	2011
Zircon flour	2,500	2,500	2,500	1,403	1,168	1,180	1,070
Ilmenite	40,000	43,000	45,000	52,230[1)]	51,490	41,900	47,300
Rutile	1,200	1,200	1,200	632	588	700	750
Monazite	400	400	400	410	317	330	330
Titanium slag	–	–	–	–	1,715	1,380	4,070

1) Contradictory company information for this year is 57,090 tonnes of ilmenite.

Amigo Minerals Joint Stock Company (AMIGO)

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Amigo Minerals Joint Stock Company is a subsidiary of Amigo Investment Holdings which is a private equity investment group formed in Hanoi, Vietnam in June 2006.

Since 2007, Amigo Minerals operates a HM mining operation near Phan Thiết in Bắc Bình District of Bình Thuận Province. Using modern mining and separation equipment from Australia, the USA and Ukraine, it produces ilmenite (52 % TiO_2 min.), zircon (cf. Appendix C), rutile (90 % TiO_2 min), and monazite as final products. Current capacity is 80,000 tpa of ilmenite, 15,000 tpa of zircon, 4,000 tpa of rutile, and 300 tpa of monazite, although current production is much lower.

Currently, Amigo Minerals is planning to set up its own pigment plant with a design capacity of 120,000 tpa.
An in-house professional 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.

The total approved zircon and titanium mineral reserves and resources attributed to Amigo Minerals in Bắc Bình District of Bình Thuận Province as of 2012 are 1,587,790 tonnes.

Table 51: Zircon and ilmenite production by Amigo Minerals JSC in Bình Thuận Province [in tonnes], after company information.

AMIGO	2005	2006	2007	2008	2009	2010	2011
Zircon	–	–	3,000	4,000	5,000	7,000	7,000
Ilmenite	–	–	30,000	35,000	40,000	45,000	42,000

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Saigon – Quy Nhon Mining Corporation (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, and three years later, in December 2009, was listed on the Hanoi Stock Exchange. The current chartered capital of SQC is 2,200 billion VND.

SQC operates a HM mine in Cát Khánh Village, Phù Cát District, Bình Định Province. Its main mineral is ilmenite (52 % TiO_2 min.) most of which is 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, Phú Mỹ District, Bình Định Province.
The plant which has capacity of 60,000 tpa of titanium slag (93 % TiO_2 min.), and 30,000 tpa of pig iron became fully operational in July 2009. Since late 2009, SQC also produces zircon (62 – 63 % $Zr(Hf)O_2$, capacity 3,000 tpa), rutile (83 % TiO_2 min., 1,800 tpa), and monazite (58 % TREO, 1,800 tpa).

The total approved zircon and titanium mineral reserves and resources attributed to SQC as of 2012 are 434,370 tonnes.

Table 52: HM and titanium slag production by Saigon – Quy Nhon Mining Corporation in Bình Định Province [in tonnes], after company information.

SQC	2005	2006	2007	2008	2009	2010	2011
Zircon	–	–	–	–	–	2,500	3,000
Ilmenite	–	–	–	–	–	14,500	15,300
Rutile	–	–	–	–	–	1,500	1,800
Monazite	–	–	–	–	–	1,500	1,800
Titanium slag	–	–	–	–	24,000	24,000	24,000

Biotan Mineral Joint Stock Company (BIOTAN)

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Contact pers. Le Thanh Nam, General Director

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, Phú Mỹ District, 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 (52 % TiO_2 min.), monazite, rutile, and zircon (cf. Appendix C). It also holds a share in the titanium slag plant in My Thanh Village, Phú Mỹ District, Bình Địn Province (cf. Saigon – Quy Nhon Mining Corporation).

The total approved zircon and titanium mineral reserves and resources attributed to BIOTAN as of 2012 are 678,195 tonnes.

Table 53: HM and titanium slag production by Biotan in Bình Định Province [in tonnes], after company information. The figures for 2008 were achieved during trial production.

SQC	2005	2006	2007	2008	2009	2010	2011
Zircon	–	–	–	300	350	400	450
Ilmenite	–	–	–	16,500	19,250	22,000	24,750
Rutile	–	–	–	1,500	1,750	2,000	2,250
Monazite	–	–	–	6,000	7,000	8,000	9,000
Titanium slag	–	–	–	–	6,650	7,600	8,550

Dat Quang Chu Lai Minerals Joint Stock Company (DQCL)

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DAT QUANG CHU LAI

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 owns Dat Quang – Ninh Thuan Minerals JSC (DQNT) which is a major shareholder of Amigo Investment Holdings (cf. Amigo Minerals Corporation). In November 2011, it was agreed that Hyundai Welding Company of South Korea will be entitled to acquire a share of 20 % in DQCL and in return will receive rutile and titanium slag from DQCL between 2012 and 2014. Besides HM mining in Quảng Nam Province, DQCL is engaged in the tourism services, entertainment, and real estate sectors.
After having erected a HM separation plant with a capacity of 50,000 tpa in Bac Chu Lai Industry Park, Quảng Nam Province, DQCL still has ambitious goals and is planning to:

- build a TiO_2 pigment plant with a capacity of 42,000 tpa in Vung Ang Industrial Zone, Hà Tĩnh Province. Both rutile-grade TiO_2 (70 %) and anatase-grade TiO_2 (30 %) are to be produced. Building started in 2009 and was planned to be completed in 2012.
- construct its own titanium slag plant with a capacity of 20,000 tpa in Bac Chu Lai Industry Park, Quảng Nam Province. Construction started in 2010 and is scheduled for completion in 2012. The plant will use domestic ilmenite as well as imported raw material.
- construct a titanium sponge plant with a capacity of 5,000 tpa in Bac Chu Lai Industry Park, Quảng Nam Province. Construction started in 2011 and should be completed in 2013. This plant is also to use domestic ilmenite as well as imported raw material.

Currently, DQCL produces ilmenite (52 % TiO_2 min.), monazite (58 % TREO min.), rutile (84 % TiO_2 min.), zircon (cf. Appendix C), zircon flour (65 % $Zr(Hf)O_2$ min.), and titanium slag. Final products are exported to Japan, China, Malaysia and other Southeast Asian countries.

The total non-approved HM reserves and resoures attributed to Dat Quang Chu Lai JSC in Quảng Nam Province are more than 5 million tonnes.

Table 54: HM and titanium slag production by DQCL in Quảng Nam Province [in tonnes], after company information.

SQC	2005	2006	2007	2008	2009	2010	2011
Zircon	–	–	–	300	350	450	500
Zircon flour	–	–	–	300	350	450	500
Ilmenite	–	–	–	16,500	19,250	24,750	27,500
Rutile	–	–	–	1,500	1,750	2,250	2,500
Monazite	–	–	–	6,000	7,000	9,000	10,000
Titanium slag	–	–	–	–	6,300	8,100	9,000

Appendix B

Comparative statistics of commercial zircon concentrates

Comparative statistics of commercial zircon concentrates

1. Colour
2. $Zr(Hf)O_2$ content
3. TiO_2 content
4. Al_2O_3 content
5. Fe_2O_3 content
6. P_2O_5 content
7. Radioactivity (U+Th)
8. Purity (zircon content)
9. Quartz content
10. Grain size (mean)

1. Colour

Pure white:	DuPont Premium Grade DuPont Standard Grade DuPont ZirconT DuPont Low Alumina Grade
Pure white mottled:	DuPont Zircon M
Grey:	DuPont Zircore
Light pinkish:	RBM Prime Grade calcined Lanka Zircon
Dark pinkish:	KZN Sands Standard Grade
Pinkish grey:	KZN Sands Premium Grade Iluka Virginia Ultra Grade Iluka Eucla Premium Grade RBM Prime Grade uncalcined RBM Intermediate Grade MITRACO Zircon Namakwa Sands Zirkwa Namakwa Sands Premium Grade Namakwa Sands Standard Grade
Dark pinkish grey:	PT Zirmet Prime Zircon Wenshang Sheng Sheng Prime Grade (Indonesia)
Pinkish grey brown:	Tronox Zircon HTZ Grade
Light brown:	Millennium Zirconita Tipo E Millennium Zirconita Tipo I Millennium Zirconita Tipo II Millennium Zirconita Tipo III
Light brown mottled:	Nigeria Zircon
Yellowish brown:	Cristal Gwindinup Zircon
Yellowish brown mottled:	Oregon Resources Zircon
Light yellowish grey with pinkish hue:	HUMEXCO Premium Grade HUMEXCO Standard Grade Wanning Yuehai Zircon Hainan Sanlian Zircon DQCL Zircon Hainan Jingbang Zircon

Light yellowish grey with pinkish hue:	Tronox MKT 64 Grade Iluka Enebabba Premium Grade QMM Zirsill Vilnohirsk Standard Grade
Light brownish grey with pinkish hue:	Sakorn Standard Grade Sakorn Foundry Grade Sakorn Premium Grade Iluka Eneabba Standard Grade Namakwa Sands Zircon Rejects IREL „MK" Grade
Brownish with pinkish hue:	Doral Premium Grade Doral Standard Grade KMML I Grade KMML II Grade IREL „Q" Grade Iluka Virginia Premium Grade Iluka Murray Basin Premium Grade Cristal Murray Basin Zircon Amigo Zircon
Light brownish mottled:	Moma Hi-Al Grade
Greyish brown:	Hainan Winsheen High Grade Wenshang Sheng Sheng Advanced Grade RBM Standard Grade Vilnohirsk Premium Grade
Orange brown:	Trimex Zircon V.V. Mineral Standard Grade V.V. Mineral Premium Grade IREL „OR" Grade INB Zirconita
Reddish brown:	BIMICO Premium Grade BIMICO Standard Grade Biotan Zircon Beh Minerals Zircon Moma Standard Grade Moma Special Grade

2. Zr(Hf)O_2 content

Name	Zr(Hf)O_2 (wt.-%)
PT Zirmet Premium Grade	66.9
Wenchang Sheng Sheng Prime Grade	66.7
DuPont Standard Grade	66.7
KZN Sands Prime Grade	66.7
V.V. Mineral Standard Grade	66.7 – 66.3
Iluka Virgina Ultra Grade	66.6
RBM Prime Grade uncalcined	66.6
DuPont Low Alumina Grade	66.6
Namakwa Sands Premium Grade	66.6
BIMICO Premium Grade	66.6
BIMICO Standard Grade	66.6
DuPont Premium Grade	66.6 – 66.1
Tronox MKT 64 Grade	66.5
HUMEXCO Premium Grade	66.5
Iluka Virginia Premium Grade	66.5
RBM Intermediate Grade	66.4
BIOTAN Zircon	66.4
Iluka Eucla Premium Grade	66.4 – 66.2
V.V. Mineral Premium Grade	66.4 – 66.2
CRUZOR Premium Grade	66.3
Doral Premium Grade	66.3
Hainan Sanlian Zircon	66.3
DQCL Zircon	66.3
RBM Standard Grade	66.3
RBM Prime Grade calcined	66.3 – 66.2
Sakorn Foundry Grade	66.2
Amigo Zircon	66.2
Wenchang Sheng Sheng Advanced Grade	66.2
Sakorn Premium Grade	66.1
Beh Minerals Zircon	66.1
KZN Sands Standard Grade	66.1
Wanning Yuehai Zircon	66.1
Cristal Murray Basin Zircon	66.1 – 66.0
Hainan Jingbang Zircon	66.0

Name	$Zr(Hf)O_2$ (wt.-%)
Tronox HTZ Grade	66.0
Iluka Murray Basin Premium Grade	65.9
Iluka Eneabba Standard Grade	65.9
Hainan Winsheen High Grade	65.9
Millennium Zirconita Tipo E	65.8
KMML I Grade	65.8
Cristal Gwindinup Zircon	65.7
Trimex Zircon	65.7
MITRACO Zircon	65.6
Moma Special Grade	65.5
Millennium Zirconita Tipo II	65.5
Millennium Zirconita Tipo I	65.4
Doral Standard Grade	65.3
INB Zirconita	65.2
DuPont Zircon T	65.1
DuPont Zircon M	65.1
Vilnohirsk Premium Grade	65.1
Iluka Eneabba Premium Grade	65.1
Southern Ionics Mission Zircon	65.1
Sakorn Standard Grade	65.0
IREL “OR” Grade	65.0
Namakwa Sands Standard Grade	65.0
Namakwa Sands Zirkwa	64.9
Vilnohirsk Standard Grade	64.9
Lanka Zircon	64.4
KMML II Grade	63.9
IREL “MK” Grade	63.3
Moma Standard Grade	62.9
Millennium Zirconita Tipo III	62.6
HUMEXCO Standard Grade	61.8
IREL “Q” Grade	61.5
Oregon Resources Zircon	59.5
QMM Zirsill	52.7
DuPont Zircore	37.9
Nigeria Zircon	37.4
Namakwa Sands Zircon Rejects	28.8
Moma High-Al Zircon	26.3

3. TiO_2 content

Name	TiO_2 (wt.-%)
BIMICO Premium Grade	0.04
Doral Premium Grade	0.05
BIMICO Standard Grade	0.06
DQCL Zircon	0.07
Wenchang Sheng Sheng Prime Grade	0.07
Tarasovka Coarse Grade	0.08
Tarasovka Fine Grade	0.08
Millennium Zirconita Tipo E	0.08
Vilnohirsk Premium Grade	0.08
CRUZOR Premium Grade	0.09
Namakwa Sands Premium Grade	0.09 – 0.11
V.V. Mineral Premium Grade	0.09 – 0.17
Vilnohirsk Standard Grade	0.10
PT Zirmet Premium Grade	0.10
Iluka Virgina Ultra Grade	0.10
Wenchang Sheng Sheng Advanced Grade	0.10
IREL “OR” Grade	0.10
KZN Sands Prime Grade	0.11
RBM Prime Grade calcined	0.11 – 0.12
V.V. Mineral Standard Grade	0.12 – 0.19
RBM Prime Grade uncalcined	0.13
KMML I Grade	0.13
Iluka Eucla Premium Grade	0.13 – 0.14
DuPont Premium Grade	0.13 – 0.15
Iluka Virginia Premium Grade	0.13 – 0.19
MITRACO Zircon	0.14
Hainan Winsheen High Grade	0.14
DuPont Standard Grade	0.15
Tronox MKT 64 Grade	0.15
Iluka Eneabba Premium Grade	0.15
Iluka Murray Basin Premium Grade	0.16
Hainan Sanlian Zircon	0.16
Millennium Zirconita Tipo III	0.16
Doral Standard Grade	0.17

Name	TiO_2 (wt.-%)
HUMEXCO Premium Grade	0.17
Sakorn Standard Grade	0.17
IREL “MK” Grade	0.17
Millennium Zirconita Tipo I	0.18
Iluka Eneabba Standard Grade	0.19
Sakorn Foundry Grade	0.20
Cristal Murray Basin Zircon	0.20 – 0.24
Cristal Gwindinup Zircon	0.21
KMML II Grade	0,21
Sakorn Premium Grade	0.22
RBM Standard Grade	0.22
DuPont Low Alumina Grade	0.23
KZN Sands Standard Grade	0.25
INB Zirconita	0.25
Wanning Yuehai Zircon	0.28
Beh Minerals Zircon	0.30
Lanka Zircon	0.32
Millennium Zirconita Tipo II	0.34
RBM Intermediate Grade	0.34
DuPont Zircon T	0.36
Amigo Zircon	0.38
Moma Special Grade	0.48
IREL “Q” Grade	0.51
Southern Ionics Mission Zircon	0.58
BIOTAN Zircon	0.58
Namakwa Sands Zircon Rejects	0.61
QMM Zirsill	0.70
Tronox HTZ Grade	0.75
Namakwa Sands Standard Grade	0.76
Namakwa Sands Zirkwa	0.78
Trimex Zircon	0.85
Hainan Jingbang Zircon	1.03
DuPont Zircon M	1.94
Moma Standard Grade	2.57
Nigeria Zircon	2.59
Oregon Resources Zircon	3.12
HUMEXCO Standard Grade	3.24
Moma High-Al Zircon	4.60
DuPont Zircore	8.07

4. Al_2O_3 content

Name	Al_2O_3 (wt.-%)
RBM Prime Grade uncalcined	0.07
Namakwa Sands Premium Grade	0.08 – 0.19
KZN Sands Prime Grade	0.10
BIOTAN Zircon	0.11
RBM Intermediate Grade	0.14
PT Zirmet Premium Grade	0.15
RBM Standard Grade	0.15
RBM Prime Grade calcined	0.16 – 0.18
Hainan Jingbang Zircon	0.17
V.V. Mineral Standard Grade	0.18 – 0.56
Wenchang Sheng Sheng Prime Grade	0.19
DuPont Standard Grade	0.21
DuPont Premium Grade	0.21 – 0.30
Iluka Eucla Premium Grade	0.22 – 0.30
HUMEXCO Premium Grade	0.25
Hainan Sanlian Zircon	0.28
Iluka Virgina Ultra Grade	0.30
KZN Sands Standard Grade	0.31
Tarasovka Fine Grade	0.32
BIMICO Premium Grade	0.35
Doral Standard Grade	0.37
Tronox MKT 64 Grade	0.38
Amigo Zircon	0.39
Beh Minerals Zircon	0.40
Wenchang Sheng Sheng Advanced Grade	0.40
Wanning Yuehai Zircon	0.42
DuPont Low Alumina Grade	0.43
CRUZOR Premium Grade	0.43
BIMICO Standard Grade	0.43
Sakorn Foundry Grade	0.45
Iluka Eneabba Premium Grade	0.46
Doral Premium Grade	0.47
V.V. Mineral Premium Grade	0.47 – 0.60
Iluka Virginia Premium Grade	0.49 – 0.65

Name	Al_2O_3 (wt.-%)
Iluka Murray Basin Premium Grade	0.51
DQCL Zircon	0.51
Namakwa Sands Standard Grade	0.52
DuPont Zircon M	0.56
Tronox HTZ Grade	0.57
Namakwa Sands Zirkwa	0.61
Trimex Zircon	0.63
Sakorn Premium Grade	0.64
Cristal Murray Basin Zircon	0.65 – 0.68
Cristal Gwindinup Zircon	0.73
Iluka Eneabba Standard Grade	0.78
Millennium Zirconita Tipo II	0.87
Moma Special Grade	0.89
Hainan Winsheen High Grade	0.94
Tarasovka Coarse Grade	0.97
Millennium Zirconita Tipo E	1.02
MITRACO Zircon	1.07
KMML I Grade	1.13
Lanka Zircon	1.14
Vilnohirsk Premium Grade	1.19
Millennium Zirconita Tipo I	1.22
Southern Ionics Mission Zircon	1.65
DuPont Zircon T	1.68
Moma Standard Grade	1.68
HUMEXCO Standard Grade	1.75
Vilnohirsk Standard Grade	1.80
Sakorn Standard Grade	1.81
Oregon Resources Zircon	1.88
INB Zirconita	2.01
IREL “OR” Grade	2.21
KMML II Grade	2,83
IREL “MK” Grade	3.39
Millennium Zirconita Tipo III	4.01
IREL “Q” Grade	4.51
Nigeria Zircon	5.94
Moma High-Al Zircon	8.31
QMM Zirsill	8.66
Namakwa Sands Zircon Rejects	9.74
DuPont Zircore	22.62

5. Fe_2O_3 content

Name	Fe_2O_3 (wt.-%)
DuPont Standard Grade	0.03
DuPont Premium Grade	0.03 – 0.04
Southern Ionics Mission Zircon	0.04
PT Zirmet Premium Grade	0.05
Iluka Virgina Ultra Grade	0.05
Tronox MKT 64 Grade	0.05
Wenchang Sheng Sheng Prime Grade	0.06
Hainan Sanlian Zircon	0.06
DuPont Zircon T	0.06
DuPont Low Alumina Grade	0.06
Iluka Eneabba Premium Grade	0.06
Tarasovka Coarse Grade	0.06
Tarasovka Fine Grade	0.06
KZN Sands Prime Grade	0.06
Namakwa Sands Premium Grade	0.06 – 0.07
Cristal Murray Basin Zircon	0.06 – 0.07
Iluka Eucla Premium Grade	0.06 – 0.08
Vilnohirsk Premium Grade	0.07
Vilnohirsk Standard Grade	0.07
Iluka Murray Basin Premium Grade	0.07
HUMEXCO Premium Grade	0.07
KMML II Grade	0,07
Tronox HTZ Grade	0.08
V.V. Mineral Premium Grade	0.08
KMML I Grade	0.08
MITRACO Zircon	0.08
Hainan Winsheen High Grade	0.08
Wenchang Sheng Sheng Advanced Grade	0.08
RBM Prime Grade uncalcined	0.08
Iluka Virginia Premium Grade	0.08 – 0.09
V.V. Mineral Standard Grade	0.08 – 0.10
RBM Intermediate Grade	0.09
IREL “MK” Grade	0.09
IREL “Q” Grade	0.09

Name	Fe_2O_3 (wt.-%)
Hainan Jingbang Zircon	0.10
KZN Sands Standard Grade	0.10
BIOTAN Zircon	0.10
Doral Premium Grade	0.10
Iluka Eneabba Standard Grade	0.10
RBM Prime Grade calcined	0.10
Wanning Yuehai Zircon	0.10
Lanka Zircon	0.10
Doral Standard Grade	0.11
Beh Minerals Zircon	0.11
DQCL Zircon	0.11
Sakorn Standard Grade	0.12
Sakorn Premium Grade	0.12
Millennium Zirconita Tipo III	0.12
BIMICO Standard Grade	0.12
BIMICO Premium Grade	0.13
Amigo Zircon	0.13
QMM Zirsill	0.13
Namakwa Sands Zirkwa	0.14
Namakwa Sands Standard Grade	0.14
Millennium Zirconita Tipo I	0.14
Millennium Zirconita Tipo E	0.14
DuPont Zircon M	0.15
Moma Special Grade	0.15
RBM Standard Grade	0.17
Trimex Zircon	0.17
Cristal Gwindinup Zircon	0.18
Millennium Zirconita Tipo II	0.18
Sakorn Foundry Grade	0.19
HUMEXCO Standard Grade	0.20
Moma Standard Grade	0.26
IREL “OR” Grade	0.26
Moma High-Al Zircon	0.28
INB Zirconita	0.30
DuPont Zircore	0.83
Oregon Resources Zircon	1.15
Nigeria Zircon	3.31
Namakwa Sands Zircon Rejects	9.10

6. P_2O_5 content

Name	P_2O_5 (wt.-%)
Millennium Zirconita Tipo III	0.056
Doral Premium Grade	0.058
Doral Standard Grade	0.060
Iluka Virginia Premium Grade	0.062 – 0.066
V.V. Mineral Premium Grade	0.063 – 0.065
Millennium Zirconita Tipo E	0.064
Iluka Virgina Ultra Grade	0.065
V.V. Mineral Standard Grade	0.067
Cristal Gwindinup Zircon	0.069
DuPont Premium Grade	0.070 – 0.072
Southern Ionics Mission Zircon	0.07
Millennium Zirconita Tipo I	0.072
DuPont Standard Grade	0.073
DuPont Low Alumina Grade	0.075
KMML II Grade	0.076
Tronox HTZ Grade	0.076
DuPont Zircon T	0.076
DuPont Zircore	0.078
PT. Zirmet Premium Grade	0.081
Millennium Zirconita Tipo II	0.086
KMML I Grade	0.086
DuPont Zircon M	0.088
Oregon Resources Zircon	0.088
Tronox MKT 64 Grade	0.089
Vilnohirsk Premium Grade	0.089
Vilnohirsk Standard Grade	0.090
Iluka Eucla Premium Grade	0.090 – 0.095
KZN Sands Prime Grade	0.094
Moma Special Grade	0.101
BIMICO Premium Grade	0.101
Namakwa Sands Premium Grade	0.101 – 0.108
Iluka Eneabba Premium Grade	0.105
Iluka Murray Basin Premium Grade	0.107
KZN Sands Standard Grade	0.110

Name	P_2O_5 (wt.-%)
Tarasovka Coarse Grade	0.11
BIMICO Standard Grade	0.110
DQCL Zircon	0.110
Cristal Murray Basin	0.110 – 0.113
Iluka Eneabba Standard Grade	0.111
Sakorn Standard Grade	0.113
RBM Intermediate Grade	0.118
RBM Prime Grade uncalcined	0.119
IREL “MK” Grade	0.122
QMM Zirsill	0.124
Tarasovka Fine Grade	0.13
RBM Prime Grade calcined	0.133 – 0.141
Sakorn Premium Grade	0.134
Wenchang Sheng Sheng Prime Grade	0.140
IREL “OR” Grade	0.142
RBM Standard Grade	0.144
INB Zirconita	0.146
Lanka Zircon	0.149
IREL “Q” Grade	0.151
Amigo Zircon	0.153
Hainan Jingbang Zircon	0.153
Moma High-Al Zircon	0.157
Wenchang Sheng Sheng Advanced Grade	0.159
MITRACO Zircon	0.161
BIOTAN Zircon	0.161
Hainan Sanlian Zircon	0.168
Sakorn Foundry Grade	0.178
Hainan Winsheen High Grade	0.191
CRUZOR Premium Grade	0.20
Wanning Yuehai Zircon	0.200
Namakwa Sands Standard Grade	0.215
Trimex Zircon	0.216
Namakwa Sands Zirkwa	0.218
Beh Minerals Zircon	0.257
Moma Standard Grade	0.318
HUMEXCO Premium Grade	0.348
Nigeria Zircon	1.198
HUMEXCO Standard Grade	1.267
Namakwa Sands Zircon Rejects	3.279

7. Radioactivity (U+Th)

Name	U+Th (ppm)
Iluka Virginia Premium Grade	217 – 220
Iluka Virgina Ultra Grade	231
Vilnohirsk Premium Grade	283
Vilnohirsk Standard Grade	295
DuPont Zircore	301
Doral Premium Grade	306
Doral Standard Grade	319
Cristal Gwindinup Zircon	333
Southern Ionics Mission Zircon	344
DuPont Premium Grade	346 – 356
DuPont Standard Grade	353
DuPont Low Alumina Grade	353
DuPont Zircon M	379
PT Zirmet Premium Grade	380
Tarasovka Coarse Grade	385
Tronox HTZ Grade	387
KMML II Grade	387
DuPont Zircon T	392
Millennium Zirconita Tipo III	392
Tarasovka Fine Grade	399
Iluka Eucla Premium Grade	402 – 406
Tronox MKT 64 Grade	408
Namakwa Sands Premium Grade	422 – 442
Millennium Zirconita Tipo E	425
V.V. Mineral Standard Grade	428 – 459
V.V. Mineral Premium Grade	430 – 442
Iluka Eneabba Premium Grade	435
Iluka Murray Basin Premium Grade	443
Cristal Murray Basin Zircon	449 – 450
Iluka Eneabba Standard Grade	452
KMML I Grade	452
Oregon Resources Zircon	460
QMM Zirsill	463
RBM Intermediate Grade	467

Name	U+Th (ppm)
RBM Prime Grade calcined	463 – 488
RBM Prime Grade uncalcined	469
Sakorn Standard Grade	480
Millennium Zirconita Tipo I	484
KZN Sands Prime Grade	492
Wenchang Sheng Sheng Prime Grade	501
Lanka Zircon	507
Sakorn Premium Grade	526
INB Zirconita	539
RBM Standard Grade	545
KZN Sands Standard Grade	556
Millennium Zirconita Tipo II	572
Sakorn Foundry Grade	579
Moma Special Grade	581
Moma High-Al Zircon	601
IREL “MK” Grade	631
IREL “Q” Grade	677
Namakwa Sands Standard Grade	686
Namakwa Sands Zirkwa	693
IREL “OR” Grade	701
Wenchang Sheng Sheng Advanced Grade	752
Trimex Zircon	842
Hainan Sanlian Zircon	852
Hainan Jingbang Zircon	858
DQCL Zircon	869
MITRACO Zircon	889
BIMICO Premium Grade	895
Wanning Yuehai Zircon	946
Hainan Winsheen High Grade	976
Amigo Zircon	1,014
BIOTAN Zircon	1,021
BIMICO Standard Grade	1,041
HUMEXCO Premium Grade	1,286
Moma Standard Grade	1,364
Beh Minerals Zircon	1,648
HUMEXCO Standard Grade	3,227
Namakwa Sands Zircon Rejects	8,152
Nigeria Zircon	16,944

8. Purity (zircon content)

Name	Zircon (%)
DuPont Standard Grade	99.50
Iluka Virgina Ultra Grade	99.49
DuPont Premium Grade	99.48 – 99.33
Namakwa Sands Premium Grade	99.44 – 98.87
KZN Sands Premium Grade	99.42
Namakwa Sands Standard Grade	99.40
BIMICO Premium Grade	99.35
RBM Prime Grade uncalcined	99.34
Tronox MKT 64 Grade	99.27
Iluka Eucla Premium Grade	99.12 – 98.80
DuPont Low Alumina Grade	99.06
Iluka Virginia Premium Grade	99.06 – 98.74
PT Zirmet Premium Grade	99.02
BIMICO Standard Grade	98.98
V.V. Mineral Standard Grade	98.96 – 98.79
V.V. Mineral Premium Grade	98.85 – 91.19
Wenchang Sheng Sheng Prime Grade	98.74
DQCL Zircon	98.57
RBM Intermediate Grade	98.56
Hainan Sanlian Zircon	98.52
Tronox HTZ Grade	98.50
RBM Standard Grade	98.50
HUMEXCO Premium Grade	98.46
Iluka Eneabba Standard Grade	98.38
Cristal Murray Basin	98.34 – 97.74
Wanning Yuehai Zircon	98.34
Hainan Winsheen High Grade	98.30
Hainan Jingbang Zircon	98.22
Doral Premium Grade	98.17
KZN Sands Standard Grade	98.13
Sakorn Foundry Grade	98.13
Iluka Murray Basin Premium Grade	98.08
Amgio Zircon	98.07
Cristal Gwindinup Zircon	97.99

Name	Zircon (%)
Biotan Zircon	97.95
Iluka Eneabba Premium Grade	97.93
Wenchang Sheng Sheng Advanced Grade	97.92
Beh Minerals Zircon	97.61
Trimex Zircon	97.48
RBM Prime Grade calcined	97.40 – 97.13
Millennium Zirconita Tipo II	97.29
Vilnohirsk Premium Grade	97.25
KMML I Grade	97.21
Vilnohirsk Standard Grade	97.13
DuPont Zircon M	96.93
Doral Standard Grade	96.83
Millennium Zirconita Tipo E	96.77
DuPont Zircon T	96.64
IREL “OR” Grade	96.32 – 90.66
Sakorn Premium Grade	96.18
MITRACO Zircon	96.15
Millennium Zirconita Tipo I	96.03
Moma Special Grade	95.99
INB Zirconita	95.98
Namakwa Sands Zirkwa	95.24
Sakorn Standard Grade	94.65
Moma Standard Grade	92.86
KMML II Grade	92.65
Lanka Zircon	91.32
Millennium Zirconita Tipo III	91.09
IREL “MK” Grade	90.74
HUMEXCO Standard Grande	89.32
Oregon Resources Zircon	87.78
IREL “Q” Grade	83.56
QMM Zirsill	59.44
Nigeria Zircon	55.07
DuPont Zircore	47.97
Namakwa Sands Zircon Rejects	29.67
Moma High-Al Grade	13.27 (?)

9. Quartz content

Name	Quartz (%)
DuPont Zircon M	0.00
DuPont Zircon T	0.00
DuPont Standard Grade	0.02
DuPont Premium Grade	0.02-0.03
Iluka Virginia Premium Grade	0.02-0.04
DuPont Low Alumina Grade	0.03
V.V. Mineral Premium Grade	0.03-0.04
Iluka Virgina Ultra Grade	0.04
Tronox MKT 64 Grade	0.04
Tronox HTZ Grade	0.04
V.V. Mineral Standard Grade	0.04-0.07
INB Zirconita	0.05
Sakorn Premium Grade	0.08
IREL “OR” Grade	0.08-0.12
Trimex Zircon	0.09
BIMICO Premium Grade	0.09
Hainan Winsheen High Grade	0.09
Vilnohirsk Premium Grade	0.10
Vilnohirsk Standard Grade	0.10
KZN Sands Premium Grade	0.10
RBM Prime Grade calcined	0.10-11.14
Millenium Zirconita Tipo III	0.11
HUMEXCO Premium Grade	0.11
BIMICO Standard Grade	0.11
Biotan Zircon	0.13
Iluka Eneabba Standard Grade	0.14
Sakorn Standard Grade	0.14
Cristal Murray Basin Zircon	0.15-0.25
KMML I Grade	0.17
Millenium Zirconita Tipo E	0.17
Moma Standard Grade	0.18
Sakorn Foundry Grade	0.18
Namakwa Sands Premium Grade	0.19-0.35
Beh Minerals Zircon	0.22

Name	Quartz (%)
Hainan Jingbang Zircon	0.22
RBM Intermediate Grade	0.23
RBM Prime Grade uncalcined	0.24
Millenium Zirconita Tipo I	0.28
Iluka Eucla Premium Grade	0.28-0.44
Doral Premium Grade	0.30
DQCL Zircon	0.30
PT. Zirmet Premium Grade	0.32
RBM Standard Grade	0.32
MITRACO Zircon	0.33
Amgio Zircon	0.33
Wanning Yuehai Zircon	0.34
Moma Special Grade	0.35
Millenium Zirconita Tipo II	0.36
KMML II Grade	0.39
Namakwa Sands Zircon Rejects	0.41
Wenchang Sheng Sheng Prime Grade	0.46
KZN Sands Standard Grade	0.48
Iluka Murray Basin Premium Grade	0.51
Hainan Sanlian Zircon	0.53
HUMEXCO Standard Grade	0.53
IREL “MK” Grade	0.53
Namakwa Sands Zirkwa	0.68
Cristal Gwindinup Zircon	0.70
Wenchang Sheng Sheng Advanced Grade	0.97
DuPont Zircore	1.04
Iluka Eneabba Premium Grade	1.05
Namakwa Sands Standard Grade	1.42
Doral Standard Grade	1.88
Oregon Resources Zircon	2.05
IREL “Q” Grade	2.57
Lanka Zircon	4.31
QMM Zirsill	14.95
Nigeria Zircon	22.36
Moma High-Al Grade	69.30 (?)

10. Grain size (mean)

Name	Grain size (mean) (µm)
Nigeria Zircon	299.1
Wenchang Sheng Sheng Prime Grade	177.6
Tronox HTZ Grade	176.1
V.V. Mineral Premium Grade	175.2
PT Zirmet Premium Grade	170.9
Millennium Zirconita Tipo III	164.4
IREL “OR” Grade	157.2 – 154.7
Iluka Eneabba Standard Grade	155.6
V.V. Mineral Standard Grade	154.9
Beh Minerals Zircon	152.6
DuPont Zircore	152.0
IREL “Q” Grade	149.5
IREL “MK” Grade	149.1
BIMICO Standard Grade	147.2
KMML I Grade	146.3
Doral Premium Grade	144.7
Doral Standard Grade	143.3
KMML II Grade	143.0
BIOTAN Zircon	142.9
Cristal Gwindinup Zircon	142.6
Tronox MKT 64 Grade	142.0
BIMICO Premium Grade	140.3
Moma High-Al Grade	137.7
Moma Standard Grade	135.7
Moma Special Grade	135.2
Trimex Zircon	134.8
Oregon Resources Zircon	131.3
DuPont Zircon T	127.6
RBM Intermediate Grade	126.5
DuPont Zircon M	125.5
INB Zirconita	122.7
Iluka Murray Basin Premium Grade	121.8
Iluka Eneabba Premium Grade	121.6
DuPont Premium Grade	121.1 – 116.2

Name	Grain size (mean) (μm)
DuPont Low Alumina Grade	120.5
DuPont Standard Grade	120.0
Sakorn Zircon Standard Grade	119.3
RBM Premium Grade uncalcined	116.7
Millennium Zirconita Tipo E	116.4
Iluka Virginia Premium Grade	116.4 – 114.0
Millennium Zirconita Tipo I	116.0
Hainan Winsheen High Grade	115.6
KZN Sands Standard Grade	115.4
KZN Sands Prime Grade	114.3
RBM Prime Grade calcined	114.2 – 114.1
Iluka Virgina Ultra Grade	114.1
RBM Standard Grade	111.8
Vilnohirsk Premium Grade	108.8
Millennium Zirconita Tipo II	106.9
Sakorn Zircon Foundry Grade	106.7
Namakwa Sands Zircon Rejects	106.3
Sakorn Zircon Premium Grade	106.1
Vilnohirsk Standard Grade	103.9
Namakwa Sands Premium Grade	103.3 – 99.4
QMM Zirsill	102.8
Cristal Murray Basin Zircon	99.4 – 98.8
Hainan Sanlian Zircon	97.7
Amigo Zircon	97.0
Namakwa Sands Standard Grade	96.0
Iluka Eucla Premium Grade	95.3 – 88.1
Namakwa Sands Zirkwa	94.8
Wenchang Sheng Sheng Advanced Grade	94.3
HUMEXCO Standard Grade	93.4
Wanning Yuehai Zircon	93.2
DQCL Zircon	91.7
HUMEXCO Premium Grade	91.2
Hainan Jingbang Zircon	87.8
MITRACO Zircon	81.5
Lanka Zircon	77.8

Appendix C

Specifications of commercial zircon concentrates

Methodology

Incoming zircon samples were checked for elevated radioactivity levels, and if unproblematic, were split for chemical, mineralogical and grain size analyses.

Grain size analysis samples with elevated radioactivity levels were reduced to about 50 g weight subsamples.

Chemical analysis

Sample preparation of fused beads:
A 1,000 mg finely ground sample was used to determine the loss on ignition by heating to a final temperature of 1,000 °C using a temperature-controlled muffle furnace.

A 200 mg separate sub-sample was mixed with 2,500 mg Lithiummetaborate and 2,415 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 done 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 mineralogical composition was quantitatively determined using a scanning electron microscope (SEM) Quanta 600 FEG ESEM (FEI), equipped with an Apollo XL Silicon Drift Detector (EDAX Inc.) energy dispersive X-ray spectroscopy (EDS) system. SEM / MLA (Mineral Liberation Analysis – Version 3.1) techniques were applied.

In each concentrate, up to several 1,000 grains were identified depending on the grain size, using a combined backscattered electron imaging (BSE) / EDS approach.

Grain size analysis

Subsamples for grain size analysis were not split further (cf. above) and were shaken in a Ro-Tap shaking machine using a commercial sieve set with sieves with ¼-phi-intervals. Sieving time was 30 minutes for each sample.

After sieving, the sieves were thoroughly cleaned and their content weighed to a tenth of a milligram. Weights were recorded in the Granplots Spreadsheet for Sieved Data Application available as freeware from the website of the Florida Geological Survey:
(http://www.dep.state.fl.us/geology/geologictopics/analytic_gran_tools/analytic_gran.htm)
This spreadsheet automatically calculates frequency weights and all granulometric statistical data, including mean and median.

Name: **Amigo Zircon**

Deposit: Phan Thiết, Bắc Bình District, Bình Thuận Province, Vietnam

Producer: Amigo Minerals Corporation Joint Stock Company

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Amigo Analysis	**DERA Analysis**
ZrO_2+HfO_2		65.5		66.2
ZrO_2				64.8
HfO_2				1.34
SiO_2		32.2		32.5
TiO_2		0.40		0.38
Al_2O_3		0.90		0.39
Fe_2O_3		0.20		0.13
Cr_2O_3		0.02		26 ppm
P_2O_5				0.153
CaO		0.134		0.03
MgO		0.09		
LOI (@ 950 °C)				0.17
U		367 ppm		574 ppm
Th				440 ppm

Typical: 0.05 % SnO_2, 0.17 % Y_2O_3; Sample (DERA Analysis): 368 ppm Sn

Mineralogical composition:
Typical (Amigo analysis): 98.9 % zircon, 0.30 % rutile, 0.80 % other minerals, 0.0 % quartz

Smple (DERA analysis): 98.07 % zircon, 0.53 % various Al-silicates, 0.45 %rutile, 0.06 % apatite, 0.06 % monazite, 0.05 % cassiterite, 0.33 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			Amigo Analysis	**DERA Analysis**
> 355		0.1		< 0.01
300				0.01
250				0.04
212		0.2		0.61
180		0.2		0.46
150				1.57
125		47.2		6.51
106		38.3		19.68
90				30.84
75				29.05
63		13.5		8.88
53				1.81
45		0.6		0.25
< 45				0.29
Mean (µm)				97.0
D50 (µm)				102.1

Name: **Baddeleyite PB-XOM Grade**

Deposit: Kovdor, Kola Peninsula, Russia

Producer: OAO “Kovdorskyi GOK”, Eurochem Group

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Eurochem Analysis	DERA Analysis
ZrO_2+HfO_2		99.3		No sample available for analysis
ZrO_2				
HfO_2				
SiO_2		0.4		
TiO_2		0.10		
Al_2O_3		0.02		
Fe_2O_3		0.09		
P_2O_5		0.05		
CaO		0.10		
MgO		0.10		
Moisture (@ 105 °C)		0.5		
LOI (@ 950 °C)				
U		260 ppm		
Th				
Parent activity U+Th		30 Bq/g		

Grain size distribution µm	Guaranteed	Typical	Sample	
			Eurochem Analysis	DERA Analysis
> 710		4.2		No sample available for analysis
600				
500				
420				
355				
300				
250				
212				
180		5.5		
150				
125		39.8		
106				
90				
75				
63		20.7		
53				
45				
< 45		29.8		
Mean (µm)				
D50 (µm)		3.5-4.6		

Name: **Beh Minerals Zircon**

Deposit: Amang, Malaysia

Producer: Beh Minerals Sdn. Bhd.

Chemical composition	Guaranteed	Typical	Sample	
wt.-%			Beh Minerals Analysis	DERA Analysis
ZrO_2+HfO_2				66.1
ZrO_2				64.6
HfO_2				1.46
SiO_2				32.4
TiO_2				0.30
Al_2O_3				0.40
Fe_2O_3				0.11
Cr_2O_3				18 ppm
P_2O_5				0.257
CaO				0.02
MgO				
LOI (@ 950 °C)				0.17
U				1,126 ppm
Th				522 ppm
Parent activity U+Th				

Sample (DERA Analysis): 659 ppm Ta, 3,066 ppm W

Mineralogical composition (DERA Analysis):
Sample: 97.61 % zircon, 1.03 % various Al-silicates, 0.36 % rutile, 0.08 % monazite, 0.22 % quartz

Grain size distribution	Guaranteed	Typical	Sample	
µm			Beh Minerals Analysis	DERA Analysis
> 420				
355				0.01
300				0.07
250				1.58
212				12.11
180				16.37
150				22.19
125				17.96
106				10.88
90				8.00
75				6.66
63				2.79
53				1.06
45				0.24
< 45				0.07
Mean (µm)				152.6
D50 (µm)				165.3

Name: **BIMICO Premium Zircon**

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	**DERA Analysis**
ZrO_2+HfO_2	≥ 65.0			66.6
ZrO_2				65.2
HfO_2				1.38
SiO_2				32.5
TiO_2	< 0.3			0.04
Al_2O_3				0.35
Fe_2O_3	< 0.1			0.13
Cr_2O_3				18 ppm
P_2O_5				0.101
CaO				< 0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.13
U				619 ppm
Th				276 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
Sample: 99.35 % zircon, 0.24 % various Al-silicates, 0.09 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			BIMICO Analysis	**DERA Analysis**
> 355				
300				0.02
250				0.28
212				3.29
180				8.13
150				24.99
125				31.93
106				16.86
90				8.79
75				4.50
63				1.05
53				0.14
45				0.02
< 45				0.00
Mean (µm)				140.3
D50 (µm)				151.4

Name: **BIMICO Standard Zircon**

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	**DERA Analysis**
ZrO_2+HfO_2	≥ 62.0			66.6
ZrO_2				65.2
HfO_2				1.38
SiO_2				32.5
TiO_2				0.06
Al_2O_3				0.43
Fe_2O_3				0.12
Cr_2O_3				23 ppm
P_2O_5				0.110
CaO				< 0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.15
U				712 ppm
Th				329 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
Sample: 98.98 % zircon, 0.46 % various Al-silicates, 0.11 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			BIMICO Analysis	**DERA Analysis**
> 420				
355				
300				0.05
250				0.88
212				2.22
180				10.76
150				25.55
125				29.29
106				15.55
90				7.35
75				3.58
63				0.67
53				0.08
45				< 0.01
< 45				0.00
Mean (µm)				147.2
D50 (µm)				156.3

Name: **BIOTAN Zircon**

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	DERA Analysis
ZrO_2+HfO_2	$\geq$ 62.0			66.4
ZrO_2				65.0
HfO_2				1.37
SiO_2				32.4
TiO_2				0.58
Al_2O_3				0.11
Fe_2O_3				0.10
Cr_2O_3				25 ppm
P_2O_5				0.161
CaO				< 0.01
LOI (@ 950 °C)				0.18
U				554 ppm
Th				477 ppm

Sample (DERA Analysis): 453 ppm Sn

Mineralogical composition (DERA Analysis):
Sample: 97.95 % zircon, 1.18 % rutile, 0.21 % various Al-silicates, 0.20 % monazite, 0.13 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			BIOTAN Analysis	DERA Analysis
> 420				0.01
355				0.03
300				0.10
250				0.38
212				2.28
180				6.58
150				27.83
125				38.31
106				16.51
90				5.64
75				1.92
63				0.36
53				0.06
45				< 0.01
< 45				0.00
Mean (µm)				142.9
D50 (µm)				153.5

Name: **Cristal Gwindinup Zircon**

Deposit: Gwindinup, Western Australia, Australia

Producer: Cristal Mining Australia Ltd.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Cristal Analysis	**DERA Analysis**
ZrO_2+HfO_2			65.7	65.7
ZrO_2				64.5
HfO_2				1.24
SiO_2			32.7	32.7
TiO_2			0.20	0.21
Al_2O_3			0.75	0.73
Fe_2O_3			0.17	0.18
Cr_2O_3				23 ppm
P_2O_5			0.08	0.069
CaO				< 0.01
MgO				
LOI (@ 950 °C)				0.42
U			206 ppm	196 ppm
Th			150 ppm	137 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
Sample: 97.99 % zircon, 0.91 % various Al-silicates, 0.17 % rutile, 0.70 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			Cristal Analysis	**DERA Analysis**
> 500				
420				< 0.01
355				0.01
300				0.10
250				1.03
212				5.33
180				8.95
150				22.81
125				29.25
106				17.70
90				7.99
75				4.26
63				1.15
53				1.38
45				0.03
< 45				< 0.01
Mean (µm)				142.6
D50 (µm)				151.7

Name: **Cristal Murray Basin Zircon**

Deposit: Gingko-Snapper, New South Wales, Australia

Producer: Cristal Mining Australia Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample I (II)	
			Cristal Analysis	DERA Analysis
ZrO_2+HfO_2			65.9	66.2 (66.1)
ZrO_2				64.8 (64.7)
HfO_2				1.30 (1.30)
SiO_2			32.5	32.5 (32.6)
TiO_2			0.20	0.20 (0.24)
Al_2O_3			0.74	0.65 (0.68)
Fe_2O_3			0.05	0.06 (0.07)
Cr_2O_3				22 ppm (20 ppm)
P_2O_5			0.13	0.113 (0.110)
CaO				<0.01 (<0.01)
LOI (@ 950 °C)				0.31 (0.32)
U			299 ppm	271 ppm (274 ppm)
Th			194 ppm	178 ppm (176 ppm)

Mineralogical composition (DERA Analysis):
Sample I (II): 97.74 (98.34) % zircon, 1.76 (1.01) % var. Al-silicates, 0.15 (0.25) % rutile, 0.15 (0.25) % quartz

Grain size distribution µm	Guaranteed	Typical	Sample I (II)	
			Cristal Analysis	DERA Analysis
> 710				< 0.01
600				< 0.01
500				< 0.01
420				< 0.01 (< 0.01)
355				< 0.01 (< 0.01)
300				0.02 (< 0.01)
250				0.05 (0.02)
212				0.16 (0.09)
180				0.33 (0.31)
150				2.45 (2.15)
125				9.98 (10.48)
106				20.82 (19.94)
90				29.03 (30.16)
75				27.72 (25.98)
63				8.06 (9.25)
53				1.28 (1.44)
45				0.09 (0.12)
< 45				0.01 (0.05)
Mean (µm)				99.4 (98.8)
D50 (µm)				104.5 (104.3)

Name: **CRUZOR Zircon Premium Grade**

Deposit: North Stradbroke Island, Queensland, Australia

Producer: Sibelco Australia and New Zealand

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Sibelco Analysis	DERA Analysis*
ZrO_2+HfO_2	> 66.0			66.30
ZrO_2				65.23
HfO_2				1.07
SiO_2		32.5-32.8		31.57
TiO_2	< 0.15			0.09
Al_2O_3		0.20-0.40		0.43
Fe_2O_3	< 0.07			n.a.
P_2O_5		0.11-0.14		0.20
CaO				< 0.005
MgO				< 0.01
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.40
U		265-330 ppm		232 ppm
Th		140-175 ppm		n. a.
Parent activity U+Th				

* Historic sample provided by CRL in 1997

Typical mineralogical composition (Iluka Analysis): 98-99 % zircon, 0.1-0.5 % kyanite, 0.16 % leucoxene, 0.02 % rutile, 0.02 % ilmenite, 0.02 % monazite, <0.3 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Sibelco Analysis	DERA Analysis
> 420				No sample available for analysis
355				
300				
250				
212				
180				
150				
125				
106				
90				
75				
63				
53				
45				
< 45				
Mean (µm)				
D50 (µm)				

Name: **Doral Zircon Standard Grade**

Deposit: Dardanup, Bunbury & Burekup, Western Australia, Australia

Producer: Doral Mineral Sands Pty Ltd.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Doral Analysis	**DERA Analysis**
ZrO_2+HfO_2				66.3
ZrO_2				64.2
HfO_2				1.21
SiO_2				33.7
TiO_2				0.17
Al_2O_3				0.37
Fe_2O_3				0.11
Cr_2O_3				20 ppm
P_2O_5				0.060
CaO				< 0.01
MgO				
LOI (@ 950 °C)				0.14
U				177 ppm
Th				142 ppm

Sample (DERA Analysis): 1,871 ppm Ba

Mineralogical composition (DERA Analysis):
Sample: 96.83 % zircon, 0.47 % barite, 0.45 % various Al-silicates, 0.16 % rutile, 0.03 % monazite, 1.88 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			Doral Analysis	**DERA Analysis**
> 420				
355				0.02
300				0.14
250				0.57
212				2.77
180				6.91
150				25.29
125				39.61
106				17.20
90				5.32
75				1.73
63				0.35
53				0.08
45				0.02
< 45				< 0.01
Mean (µm)				143.3
D50 (µm)				152.8

Name: **Doral Zircon Premium Grade**

Deposit: Dardanup, Bunbury & Burekup, Western Australia, Australia

Producer: Doral Mineral Sands Pty Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Doral Analysis	DERA Analysis
ZrO_2+HfO_2	> 65.0	66.5		66.3
ZrO_2				65.1
HfO_2				1.23
SiO_2		33.0		32.7
TiO_2	≤ 0.25	0.19 – 0.23		0.05
Al_2O_3		0.7 – 1.3		0.47
Fe_2O_3	≤ 0.15	0.10		0.10
Cr_2O_3		0.01		19 ppm
P_2O_5		0.08		0.058
CaO		0.02		< 0.01
LOI (@ 950 °C)				0.26
U	< 500 ppm	180 – 230 ppm		178 ppm
Th		130 – 180 ppm		128 ppm
Parent activity U+Th		2.7 – 3.6 Bq/g		

Typical: 0.02 % MnO, 0.03 % V_2O_5
Sample (DERA Analysis): 2,353 ppm Ba

Mineralogical composition (DERA Analysis):
Sample: 98.17 % zircon, 0.65 % barite, 0.43 % various Al-silicates, 0.30 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Doral Analysis	DERA Analysis
> 420		0.05		
355				0.01
300				0.08
250		1.71		0.54
212				3.14
180		26.88		7.32
150				25.42
125		57.84		41.76
106				15.39
90		13.27		4.65
75				1.38
63		0.25		0.26
53				0.05
45				0.01
< 45				< 0.01
Mean (µm)				144.7
D50 (µm)				153.8

Name: **DQCL Zircon**

Deposit: Quảng Nam Province, Vietnam

Producer: Dat Quang Chu Lai Minerals Joint Stock Company (DQCL)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			DQCL Analysis	DERA Analysis
ZrO_2+HfO_2	> 65.0			66.3
ZrO_2			65.63	64.9
HfO_2				1.37
SiO_2	< 32.0			32.7
TiO_2	< 0.12		0.08	0.07
Al_2O_3	< 0.20			0.51
Fe_2O_3	< 0.08		0.131	0.11
Cr_2O_3				18 ppm
P_2O_5	< 0.01			0.110
CaO				< 0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.15
U	< 300 ppm			603 ppm
Th				266 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
Sample: 98.57 % zircon, 0.83 % various Al-silicates, 0.04 % rutile, 0.30 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			DQCL Analysis	DERA Analysis
> 420				
355				
300				
250				0.01
212				0.03
180				0.06
150				0.86
125				8.17
106				17.67
90				22.02
75				27.67
63				16.13
53				6.19
45				0.95
< 45				0.24
Mean (µm)				91.7
D50 (µm)				95.7

Name: **DuPont Low Alumina Zircon**

Deposit: Maxville/Trail Ridge, Florida, USA

Producer: E.I. du Pont de Nemours & Co., Inc.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			DuPont Analysis	DERA Analysis
ZrO_2+HfO_2	> 66.3	66.5		66.6
ZrO_2				65.3
HfO_2				1.25
SiO_2				32.5
TiO_2	< 0.25	0.21		0.23
Al_2O_3	< 0.80	0.50		0.43
Fe_2O_3	< 0.05	0.04		0.06
Cr_2O_3				20 ppm
P_2O_5				0.075
CaO				< 0.01
MgO				
LOI (@ 950 °C)				0.13
U				234 ppm
Th				119 ppm
Parent activity U+Th				

Mineralogical composition:
Typical (DuPont Analysis): 99.0 % zircon, 0.8 % kyanite, 0.2 % rutile, <0.1 % miscellaneous minerals, 0.05 % quartz
Sample (DERA Analysis): 96.06 % zircon, 0.65 % various Al-silicates, 0.16 % rutile, 0.03 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			DuPont Analysis	DERA Analysis
> 420				
355				< 0.01
300		< 1		< 0.01
250		< 1		0.02
212				0.10
180		10		0.59
150				7.55
125		68		35.14
106				31.23
90		21		17.67
75				6.62
63		1		0.92
53				0.14
45		< 1		0.02
< 45				0.01
Mean (µm)				120.5
D50 (µm)		125		131.7

Name: **DuPont Premium Zircon**

Deposit: Maxville/Trail Ridge, Florida, USA

Producer: E.I. du Pont de Nemours & Co., Inc.

Chemical composition wt.-%	Guaranteed	Typical	Sample I (II)	
			DuPont Analysis	DERA Analysis
ZrO_2+HfO_2	> 66.5	66.7		66.6 (66.1)
ZrO_2				65.3 (64.8)
HfO_2				1.25 (1.25)
SiO_2				32.5 (33.2)
TiO_2	< 0.15	0.13		0.13 (0.15)
Al_2O_3	< 0.50	0.24		0.21 (0.30)
Fe_2O_3	< 0.05	0.02		0.04 (0.03)
Cr_2O_3				13 ppm (19 ppm)
P_2O_5				0.072 (0.070)
CaO				< 0.01 (< 0.01)
LOI (@ 950 °C)				0.47 (0.15)
U				237 ppm (230 ppm)
Th				119 ppm (116 ppm)

Mineralogical composition:
Typical (DuPont Analysis): 99.3 % zircon, 0.5 % kyanite, 0.1 % rutile, <0.1 % miscellaneous minerals, 0.01 % quartz
Sample I (II) (DERA Analysis): 99.48 (99.33) % zircon, 0.28 (0.39) % various Al-silicates, 0.13 (0.15) % rutile, 0.02 (0.03) % quartz

Grain size distribution µm	Guaranteed	Typical	Sample I (II)	
			DuPont Analysis	DERA Analysis
> 500				(< 0.01)
420				(< 0.01)
355				< 0.01 (< 0.01)
300		< 1		0.02 (< 0.01)
250		< 1		0.08 (0.01)
212				0.24 (0.05)
180		8		0.72 (0.25)
150				8.24 (4.37)
125		71		33.86 (29.20)
106				32.30 (35.64)
90		21		16.91 (21.33)
75				6.36 (7.69)
63		1		1.05 (1.22)
53				0.18 (0.21)
45		< 1		0.03 (0.02)
< 45				0.01 (< 0.01)
Mean (µm)				121.1 (116.2)
D50 (µm)		125		131.7 (126.5)

Name: **DuPont Standard Zircon**

Deposit: Maxville/Trail Ridge, Florida, USA

Producer: E.I. du Pont de Nemours & Co., Inc.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			DuPont Analysis	DERA Analysis
ZrO_2+HfO_2	>65.0	65.9		66.7
ZrO_2				65.4
HfO_2				1.26
SiO_2				32.6
TiO_2	<0.35	0.27		0.15
Al_2O_3	<2.00	1.15		0.21
Fe_2O_3	<0.05	0.04		0.03
Cr_2O_3				16 ppm
P_2O_5				0.073
CaO				<0.01
MgO				
LOI (@ 950 °C)				0.25
U				235 ppm
Th				118 ppm
Parent activity U+Th				

Mineralogical composition:
Typical (DuPont Analysis): 97.0 % zircon, 2.0 % kyanite, 0.3 % rutile, <1.0 % miscellaneous minerals, 0.10 % quartz
Sample (DERA Analysis): 99.50 % zircon, 0.20 % various Al-silicates, 0.17 % rutile, 0.02 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			DuPont Analysis	DERA Analysis
>355				< 0.01
300		< 1		< 0.01
250		< 1		0.02
212				0.18
180		14		0.64
150				7.89
125		63		33.46
106				31.47
90		21		17.73
75				7.14
63		1		1.23
53				0.18
45		< 1		0.03
< 45				0.01
Mean (µm)				120.0
D50 (µm)		125		130.9

Name: **DuPont Zircon M**

Deposit: Maxville/Trail Ridge, Florida, USA

Producer: E.I. du Pont de Nemours & Co., Inc.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			DuPont Analysis	DERA Analysis
ZrO_2+HfO_2	> 60.5	62.5		65.1
ZrO_2				63.9
HfO_2				1.23
SiO_2				31.9
TiO_2		2.6		1.94
Al_2O_3		0.8		0.56
Fe_2O_3		0.5		0.15
Cr_2O_3				32 ppm
P_2O_5				0.088
CaO				< 0.01
LOI (@ 950 °C)				0.14
U				236 ppm
Th				143 ppm
Parent activity U+Th				

Mineralogical composition:
Typical (DuPont Analysis): 93.0 % zircon, 1.3 % kyanite, 0.5 % rutile, <1.0 % miscellaneous minerals, 0.1 % quartz
Sample (DERA Analysis): 96.93 % zircon, 1.79 % rutile, 0.40 % various Al-silicates, 0.30 % ilmenite, 0.08 % monazite, 0.02 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			DuPont Analysis	DERA Analysis
> 355				< 0.01
300		< 1		< 0.01
250		< 1		0.04
212				0.50
180		7		2.28
150				11.38
125		61		35.26
106				30.31
90		29		15.13
75				4.35
63		2		0.65
53				0.09
45		< 1		0.01
< 45				< 0.01
Mean (µm)				125.5
D50 (µm)		120		135.9

Name: **DuPont Zircon T**

Deposit: Maxville/Trail Ridge, Florida, USA

Producer: E.I. du Pont de Nemours & Co., Inc.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			DuPont Analysis	DERA Analysis
ZrO_2+HfO_2	> 64.0	65.2		65.2
ZrO_2				63.9
HfO_2				1.24
SiO_2				32.6
TiO_2	< 2.0	1.00		0.36
Al_2O_3	< 2.5	1.10		1.68
Fe_2O_3	< 0.5	0.07		0.06
Cr_2O_3				23 ppm
P_2O_5				0.076
CaO				< 0.01
LOI (@ 950 °C)				0.12
U				258 ppm
Th				134 ppm
Parent activity U+Th				

Mineralogical composition:
Typical (DuPont Analysis): 97.0 % zircon, 1.5 % kyanite, 1.0 % rutile, <1.0 % miscellaneous minerals, 0.10 % quartz
Sample: 96.64 % zircon, 2.81 % various Al-silicates, 0.32 % rutile, 0.05 % monazite, 0.02 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			DuPont Analysis	DERA Analysis
> 420				< 0.01
355				< 0.01
300		< 1		0.01
250		1		0.26
212				2.84
180		13		5.40
150				12.80
125		62		27.18
106				24.48
90		23		16.32
75				8.45
63		1		1.96
53				0.27
45		< 1		0.02
< 45				< 0.01
Mean (µm)				127.6
D50 (µm)		124		135.0

Name: **DuPont Zircore**

Deposit: Maxville/Trail Ridge, Florida, USA

Producer: E.I. du Pont de Nemours & Co., Inc.

Chemical composition	**Guaranteed**	**Typical**	**Sample**	
wt.-%			**DuPont Analysis**	**DERA Analysis**
ZrO_2+HfO_2	> 27	38		37.9
ZrO_2				37.1
HfO_2				0.75
SiO_2				30.3
TiO_2				8.07
Al_2O_3		23		22.62
Fe_2O_3				0.83
Cr_2O_3				167 ppm
P_2O_5				0.078
CaO				< 0.01
LOI (@ 950 °C)				0.27
U				197 ppm
Th				104 ppm

Mineralogical composition:
Typical (DuPont Analysis): 57 % zircon, 3 % staurolite, 35 % other Al-silicates, 3 % quartz
Sample (DERA Analysis): 47.97 % zircon, 37.32 % various Al-silicates, 12.26 % rutile, 0.43 % ilmenite, 1.04 % quartz

Grain size distribution	**Guaranteed**	**Typical**	**Sample**	
µm			**DuPont Analysis**	**DERA Analysis**
> 600				0.01
500				< 0.01
420				< 0.01
355				0.02
300		< 1		0.19
250		8		2.02
212				9.36
180		39		11.05
150				21.83
125		45		30.85
106				13.38
90		7		7.19
75				3.16
63		1		0.74
53				0.16
45		< 1		0.03
< 45				0.01
Mean (µm)				152.0
D50 (µm)				157.5

Name: **Hainan Jingbang Zircon**

Deposit: Changsa Town, Wenchang City, Hainan Island, PR China

Producer: Hainan Jingbang Mining Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Jingbang Analysis	DERA Analysis
ZrO_2+HfO_2	> 66.0			66.0
ZrO_2				64.6
HfO_2				1.36
SiO_2				32.3
TiO_2				1.03
Al_2O_3				0.17
Fe_2O_3				0.10
Cr_2O_3				20 ppm
P_2O_5				0.153
CaO				< 0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.17
U				552 ppm
Th				306 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
Sample: 98.22 % zircon, 0.98 % rutile, 0.22 % various Al-silicates, 0.04 % monazite, 0.22 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Jingbang Analysis	DERA Analysis
> 300				
250				
212				0.05
180				0.04
150				0.36
125				4.08
106				13.58
90				24.40
75				33.85
63				15.48
53				6.25
45				1.40
< 45				0.51
Mean (µm)				87.8
D50 (µm)				93.0

Name: **Hainan Sanlian Zircon 65 %**

Deposit: Wenchang City, Hainan Island, PR China

Producer: Hainan Wenchang Sanlian Mining Co., Ltd.

Chemical composition	**Guaranteed**	**Typical**	**Sample**	
wt.-%			**Sanlian Analysis**	**DERA Analysis**
ZrO_2+HfO_2				66.3
ZrO_2			65.00	64.9
HfO_2				1.37
SiO_2				32.8
TiO_2			0.137	0.16
Al_2O_3				0.28
Fe_2O_3			0.085	0.06
Cr_2O_3				19 ppm
P_2O_5				0.168
CaO				< 0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.20
U				547 ppm
Th				305 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
Sample: 98.52 % zircon, 0.50 % various Al-silicates, 0.12 % rutile, 0.53 % quartz

Grain size distribution	**Guaranteed**	**Typical**	**Sample**	
µm			**Sanlian Analysis**	**DERA Analysis**
> 420				
355				
300				
250				0.01
212				0.03
180				0.08
150				0.90
125				9.20
106				22.95
90				30.50
75				25.76
63				8.15
53				2.09
45				0.19
< 45				0.14
Mean (µm)				97.7
D50 (µm)				104.6

Name: **Hainan Winsheen High Grade Zircon**

Deposit: Hainan Island, PR China

Producer: Hainan Winsheen Minerals Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Winsheen Analysis	DERA Analysis
ZrO_2+HfO_2	> 65.0			65.9
ZrO_2				64.5
HfO_2				1.36
SiO_2				32.4
TiO_2	< 0.15			0.14
Al_2O_3				0.94
Fe_2O_3	< 0.1			0.08
Cr_2O_3				20 ppm
P_2O_5				0.191
CaO				< 0.01
MgO				
LOI (@ 950 °C)				0.24
U				630 ppm
Th				346 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
Sample: 98.30 % zircon, 0.90 % various Al-silicates, 0.09 % rutile, 0.09 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Winsheen Analysis	DERA Analysis
> 500				
420				< 0.01
355				< 0.01
300				0.01
250				0.04
212				0.08
180				0.36
150				7.39
125				30.51
106				27.24
90				18.22
75				10.96
63				3.58
53				1.29
45				0.24
< 45				0.07
Mean (µm)				115.6
D50 (µm)				127.1

Name: **HUMEXCO Standard Zircon**

Deposit: Thừa Thiên-Huế Province, Vietnam

Producer: Thua Thien Hue Minerals Corporation (HUMEXCO)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			HUMEXCO Analysis	DERA Analysis
ZrO_2+HfO_2	> 65.0			61.8
ZrO_2				60.5
HfO_2				1.25
SiO_2		33.5		31.2
TiO_2	< 0.15			3.24
Al_2O_3	< 0.8			1.75
Fe_2O_3	< 0.1			0.20
Cr_2O_3				29 ppm
P_2O_5	< 0.12			1.267
CaO				0.04
MgO				
LOI (@ 950 °C)				0.22
U				836 ppm
Th				2,391 ppm
Parent activity U+Th				

Sample (DERA Analysis): 120 ppm As

Mineralogical composition (DERA Analysis):
Sample: 89.32 % zircon, 3.85 % rutile, 2.67 % monazite, 2.36 % various Al-silicates, 0.14 % xenotime, 0.05 % ilmenite, 0.53 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			HUMEXCO Analysis	DERA Analysis
> 355				
300				0.01
250				0.01
212				0.03
180				0.07
150				0.66
125				5.27
106				18.02
90				29.87
75				33.76
63				10.22
53				1.67
45				0.26
< 45				0.15
Mean (µm)				93.4
D50 (µm)				98.8

Name: **HUMEXCO Premium Zircon**

Deposit: Thừa Thiên-Huế Province, Vietnam

Producer: Thua Thien Hue Minerals Corporation (HUMEXCO)

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			HUMEXCO Analysis	DERA Analysis
ZrO_2+HfO_2	> 65.0			66.5
ZrO_2				65.1
HfO_2				1.36
SiO_2		33.5		32.4
TiO_2	< 0.15			0.17
Al_2O_3	< 0.8			0.25
Fe_2O_3	< 0.1			0.07
Cr_2O_3				19 ppm
P_2O_5	< 0.12			0.348
CaO				< 0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.15
U				592 ppm
Th				694 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
Sample: 98.46 % zircon, 0.61 % monazite, 0.21 % various Al-silicates, 0.10 % rutile, 0.11 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			HUMEXCO Analysis	DERA Analysis
> 420				
355				
300				0.01
250				0.01
212				0.02
180				0.02
150				0.15
125				2.84
106				15.70
90				31.77
75				37.25
63				10.88
53				1.24
45				0.08
< 45				0.03
Mean (µm)				91.2
D50 (µm)				96.7

Name: **Iluka Eneabba Zircon Premium Grade**

Deposit: Eneabba, Western Australia, Australia

Producer: Iluka Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Iluka Analysis	DERA Analysis
ZrO_2+HfO_2			66.2	65.1
ZrO_2				63.8
HfO_2				1.28
SiO_2			32.3	33.8
TiO_2			0.12	0.15
Al_2O_3			0.70	0.46
Fe_2O_3			0.05	0.06
Cr_2O_3				28 ppm
P_2O_5			0.09	0.105
CaO				< 0.01
Moisture (@ 105 °C)			0.01	
LOI (@ 950 °C)				0.27
U		300-500 ppm		270 ppm
Th				165 ppm

Mineralogical composition (DERA Analysis):
Sample: 97.93 % zircon, 0.54 % various Al-silicates, 0.09 % rutile, 1.05 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Iluka Analysis	DERA Analysis
> 600				< 0.01
500				< 0.01
420				< 0.01
355				< 0.01
300				0.01
250			17.0	0.09
212			32.9	1.35
180				3.33
150			38.4	10.57
125				25.13
106			10.2	27.43
90				21.03
75			1.6	9.22
63				1.46
53				0.30
45				0.06
< 45				0.02
Mean (µm)				121.6
D50 (µm)				128.8

Name: **Iluka Eneabba Zircon Standard Grade**

Deposit: Eneabba, Western Australia, Australia

Producer: Iluka Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Iluka Analysis	DERA Analysis
ZrO_2+HfO_2			66.0	65.9
ZrO_2				64.6
HfO_2				1.29
SiO_2			32.2	32.6
TiO_2			0.17	0.19
Al_2O_3			0.66	0.78
Fe_2O_3			0.10	0.10
Cr_2O_3				37 ppm
P_2O_5				0.111
CaO				< 0.01
Moisture (@ 105 °C)			0.02	
LOI (@ 950 °C)				0.26
U		300-500 ppm		234 ppm
Th				218 ppm

Sample (DERA Analysis): 411 ppm Ba

Mineralogical composition (DERA Analysis):
Sample: 98.38 % zircon, 0.77 % various Al-silicates, 0.26 % rutile, 0.13 % barite, 0.14 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Iluka Analysis	DERA Analysis
> 500				< 0.01
420				< 0.01
355				0.02
300			0.3	0.69
250			3.9	5.13
212			8.6	12.54
180			7.0	9.20
150			30.0	21.02
125			18.8	24.71
106			9.0	8.09
90			9.7	7.69
75			9.5	7.85
63			3.0	2.46
53				0.50
45				0.06
< 45				0.02
Mean (µm)				155.6
D50 (µm)			150	160.6

Name: **Iluka Eucla Zircon Chemical Grade**

Deposit: Jacinth-Ambrosia, Eucla Basin, South Australia, Australia

Producer: Iluka Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Iluka Analysis	DERA Analysis
ZrO_2+HfO_2	> 64.0	64.5 – 65.5		Due to elevated radioactivity sample not available for analysis
ZrO_2				
HfO_2				
SiO_2		31.0 – 32.5		
TiO_2	< 0.15	0.2 – 0.9		
Al_2O_3		0.5 – 1.0		
Fe_2O_3	< 0.08	0.10 – 0.20		
Cr_2O_3				
P_2O_5		0.20 – 0.40		
CaO		0.05 – 0.10		
MgO		0.01 – 0.10		
Moisture (@ 105 °C)		0.01 – 0.2		
LOI (@ 950 °C)		0.1 – 0.5		
U		700 – 900 ppm		
Th				
Parent activity U+Th		3.6 – 4.3 Bq/g		

Mineralogical composition (DERA Analysis): Due to elevated radioactivity sample not available for analysis

Grain size distribution µm	Guaranteed	Typical	Sample	
			Iluka Analysis	DERA Analysis
> 420				Due to elevated radioactivity sample not available for analysis
355				
300				
250				
212				
180	0 – 2	0		
150	0 – 5	0		
125	0 – 10	1		
106	5 – 20	9		
90	30 – 50	40		
75	30 – 50	38		
63	2 – 20	12		
53				
45				
< 45				
Mean (µm)				
D50 (µm)		90		

Name: **Iluka Eucla Zircon Premium Grade**

Deposit: Jacinth-Ambrosia, Eucla Basin, South Australia, Australia

Producer: Iluka Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample I (II) [III]	
			Iluka Ana.	DERA Analysis
ZrO_2+HfO_2	> 66.0	66.0 – 67.0	66.4 (66.6)	66.4 (66.5) [66.5]
ZrO_2				65.1(65.1) [64.9]
HfO_2			1.31	1.33 (1.34) [1.35]
SiO_2		32.2 – 32.8	32.2 (32.4)	32.9 (32.8) [32.8]
TiO_2	< 0.15	0.10 – 0.15	0.13 (0.12)	0.14 (0.13) [0.14]
Al_2O_3		0.20 – 0.50	0.39 (0.25)	0.30 (0.22) [0.28]
Fe_2O_3	< 0.08	0.03 – 0.08	0.06 (0.05)	0.06 (0.06)[0.08]
Cr_2O_3				19 ppm (20 ppm) [18 ppm]
P_2O_5		0.10 – 0.13	0.11	0.095 (0.090) [0.092]
CaO		0.01 – 0.04		< 0.01 (< 0.01) [< 0.01]
MgO		0.01 – 0.05		
Moisture (@ 105 °C)		0.01 – 0.10	0.02 (0.02)	
LOI (@ 950 °C)		0.1 – 0.3		0.08 (0.26) [0.35]
U		230 – 270 ppm	237 ppm	217 ppm (216 ppm) [220 ppm]
Th		180 – 220 ppm	195 ppm	188 ppm (186 ppm) [186 ppm]
Parent activity U+Th		3.6 – 4.3 Bq/g	3.7 Bq/g	

Mineralogical composition (DERA Analysis):
Samples I (II) [III]: 98.80 (99.12) [99.05] % zircon, 0.42 (0.19) [0.35] % various Al-silicates, 0.10 (0.06) [0.04] % rutile, 0.44 (0.28) [0.38] % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Iluka Analysis	DERA Analysis
> 420				< 0.01 (<0.01) [<0.01]
355				< 0.01 (<0.01) [<0.01]
300			< 0.1 (0.01)	< 0.01 (<0.01) [<0.01]
250			< 0.1 (0.0)	0.01 (0.01) [0.01]
212			< 0.1 (0.0)	0.02 (0.05) [0.02}
180	0 – 2	< 1	< 0.1 (0.0)	0.03 (0.04) [0.02]
150	0 – 5	< 1	0.3 (0.2)	0.15 (0.13) [0.08]
125	0 – 10	1	1.0 (0.4)	1.67 (0.64) [0.60]
106	2 – 20	7	22.5 (6.8)	19.92 (7.13) [6.48]
90	25 – 45	37	48.2 (38.3)	50.16 (38.16) [43.33]
75	30 – 50	43	21.0 (40.0)	19.71 (41.21) [35.98]
63	5 – 20	12	7.0 (14.3)	6.87 (10.89) [11.70]
53				1.37 (1.60) [1.66]
45				0.08 (0.11) [0.09]
< 45				0.02 (0.02) [0.03]
Mean (µm)				95.3 (88.1) [88.4]
D50 (µm)		88	97 (88)	104.4 (95.0) [96.6]

Name: **Iluka Murray Basin Zircon Premium Grade**

Deposit: Douglas-Kulwin-Echo, Victoria, Australia

Producer: Iluka Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Iluka Analysis	DERA Analysis
ZrO_2+HfO_2	> 65.5	66.0 – 67.0	66.4	65.9
ZrO_2				64.6
HfO_2				1.30
SiO_2			32.2	32.9
TiO_2	< 0.15	0.10 – 0.15	0.15	0.16
Al_2O_3		0.30 – 0.60	0.49	0.51
Fe_2O_3	< 0.06	0.03 – 0.05	0.04	0.07
Cr_2O_3				37 ppm
P_2O_5				0.107
CaO				< 0.01
Moisture (@ 105 °C)			0.03	
LOI (@ 950 °C)				0.25
U		300 – 500 ppm		275 ppm
Th				168 ppm

Mineralogical composition (DERA Analysis):
Sample: 98.08 % zircon, 0.94 % various Al-silicates, 0.12 % rutile, 0.51 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Iluka Analysis	DERA Analysis
> 600				< 0.01
500				< 0.01
420				< 0.01
355				< 0.01
300			< 0.1	0.02
250			0.1	0.14
212			1.1	1.28
180			6.5	3.10
150			13.5	11.18
125			33.2	25.74
106			21.2	27.30
90			15.7	19.85
75			6.1	9.04
63			2.5	1.67
53				0.41
45				0.10
< 45				0.16
Mean (µm)				121.8
D50 (µm)			128	129.5

Name: **Iluka Murray Basin Zircon Standard Grade**

Deposit: Douglas-Kulwin-Echo, Victoria, Australia

Producer: Iluka Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Iluka Analysis	DERA Analysis
ZrO_2+HfO_2	> 65.0	65.5 – 66.5		No sample available for analysis
ZrO_2				
HfO_2				
SiO_2				
TiO_2		0.10 – 0.15		
Al_2O_3		0.1 – 1.0		
Fe_2O_3		0.04 – 0.12		
Cr_2O_3				
P_2O_5				
CaO		0.02 – 0.05		
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				
U				
Th				
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
No sample available for analysis

Grain size distribution µm	Guaranteed	Typical	Sample	
			Iluka Analysis	DERA Analysis
> 300				No sample available for analysis
250				
212				
180				
150				
125				
106				
90				
75				
63				
53				
45				
< 45				
Mean (µm)				
D50 (µm)				

Name: **Iluka Virginia Zircon Premium Grade**

Deposit: Brink, Virginia, USA

Producer: Iluka Resources Inc.

Chemical composition wt.-%	Guaranteed	Typical	Sample I (II)	
			Iluka Analysis	DERA Analysis
ZrO_2+HfO_2		65.0 – 67.0	68.0	66.5 (66.4)
ZrO_2			66.7	65.1 (65.1)
HfO_2			1.30	1.27 (1.27)
SiO_2		32.0 – 34.0	32.2	32.6 (32.7)
TiO_2	< 0.25	0.06 – 0.25	0.20	0.19 (0.13)
Al_2O_3		0.20 – 1.20	0.48	0.49 (0.65)
Fe_2O_3	< 0.15	0.04 – 0.15	0.095	0.09 (0.08)
Cr_2O_3				18 ppm (18 ppm)
P_2O_5		0.06 – 0.10	0.07	0.066 (0.062)
CaO		0.01 – 0.04	0.01	< 0.01 (< 0.01)
MgO		0.01 – 0.05		
Moisture (@ 105 °C)		0.01 – 0.07		
LOI (@ 950 °C)		0.02 – 0.12		0.17 (-0.02)
U		100 – 200 ppm	155 ppm	141 ppm (140 ppm)
Th		50 – 160 ppm	69 ppm	79 ppm (77 ppm)
Parent activity U+Th		1.4 – 3.2 Bq/g		

Mineralogical composition (DERA Analysis): Sample I (II): 99.06 (98.74) % zircon, 0.57 (0.96) % various Al-silicates, 0.17 (0.10 %) rutile, 0.03 (0.03) % monazite, 0.02 (0.04) % quartz

Grain size distribution µm	Guaranteed	Typical	Sample I (II)	
			Iluka Analysis	DERA Analysis
> 600				< 0.01
500				< 0.01
420				< 0.01 (< 0.01)
355				< 0.01 (< 0.01)
300				< 0.01 (< 0.01)
250				0.01 (0.01)
212	0 – 2	< 1		0.04 (0.09)
180	4 – 20	12		0.35 (0.49)
150				6.59 (5.46)
125	35 – 56	45		29.08 (24.42)
106				31.53 (32.90)
90	28–36	32		20.54 (23.92)
75	4 – 10	7		9.70 (10.20)
63	1 – 9	4		1.80 (2.00)
53				0.32 (0.44)
45	trace	< 1		0.03 (0.06)
< 45				0.01 (0.01)
Mean (µm)				116.4 (114.0)
D50 (µm)	113			126.7 (123.4)

Name: **Iluka Virginia Zircon Ultra Grade**

Deposit: Brink, Virginia, USA

Producer: Iluka Resources Inc.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Iluka Analysis	**DERA Analysis**
ZrO_2+HfO_2	> 66.0	66.0 – 67.0	68.0	66.6
ZrO_2			66.7	65.3
HfO_2			1.30	1.28
SiO_2		32.0 – 34.0	32.4	32.6
TiO_2	< 0.15	0.06 – 0.15	0.09	0.10
Al_2O_3		0.20 – 0.70	0.23	0.30
Fe_2O_3	< 0.075	0.04 – 0.07	0.045	0.05
Cr_2O_3				19 ppm
P_2O_5		0.06 – 0.10	0.07	0.065
CaO		0.01 – 0.04	0.01	< 0.01
MgO		0.01 – 0.05		
Moisture (@ 105 °C)		0.01 – 0.07		
LOI (@ 950 °C)		0.02 – 0.12		0.32
U		100 – 200 ppm	162 ppm	143 ppm
Th		50 – 160 ppm	83 ppm	88 ppm
Parent activity U+Th		1.4 – 3.2 Bq/g		

Mineralogical composition (DERA Analysis):
99.49 % zircon, 0.24 various Al-silicates, 0.12 % rutile, 0.02 % monazite, 0.04 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			Iluka Analysis	**DERA Analysis**
> 420				< 0.01
355				< 0.01
300				0.01
250				0.01
212	0 – 2	< 1		0.03
180	4 – 20	12		0.16
150				4.57
125	35 – 56	45		26.86
106				33.06
90	28 – 36	32		22.69
75	4 – 10	7		10.38
63	1 – 9	4		1.76
53				0.40
45	trace	< 1		0.05
< 45				0.02
Mean (µm)				114.1
D50 (µm)	113			124.3

Name: **INB Zirconita**

Deposit: Buena, Rio de Janeiro, Brazil

Producer: Indústrias Nucleares do Brasil S.A.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			INB Analysis	DERA Analysis
ZrO_2+HfO_2	> 58.0		64.2	65.1
ZrO_2				63.9
HfO_2				1.27
SiO_2				31.8
TiO_2	< 1.50		0.71	0.25
Al_2O_3				2.01
Fe_2O_3	< 0.45		0.22	0.30
Cr_2O_3				29 ppm
P_2O_5				0.146
CaO				0.01
LOI (@ 950 °C)				0.24
U				271 ppm
Th				268 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
95.98 % zircon, 0.39 % various Al-silicates, 0.22 % rutile, 0.08 % monazite, 0.05 % ilmenite, 0.05 % goethite/limonite, 0.05 % apatite, 0.05 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			INB Analysis	DERA Analysis
> 500			0.0	
420				< 0.01
355			0.1	< 0.01
300				< 0.01
250			0.6	0.02
212				0.12
180			8.1	0.81
150				13.48
125			42.8	28.25
106				23.44
90			43.8	18.43
75				10.28
63			4.6	1.90
53				0.34
45			0.0	0.02
< 45				0.00
Mean (µm)				122.7
D50 (µm)				132.2

Name: **IREL Zircon "MK" Grade**

Deposit: Manavalakurichi, Tamil Nadu, India

Producer: Indian Rare Earth Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			IREL Analysis	DERA Analysis
ZrO_2+HfO_2	> 65.00	65.80		63.3
ZrO_2				62.0
HfO_2				1.26
SiO_2		32.50		32.8
TiO_2		0.25		0.17
Al_2O_3		1.20		3.39
Cr_2O_3		0.001		91 ppm
Fe_2O_3		0.10		0.09
P_2O_5		0.05		0.122
CaO				<0.01
LOI (@ 950 °C)				0.16
U		500 ppm		316 ppm
Th				315 ppm

Mineralogical composition:
Typical (IREL Analysis): 97.5 % zircon, 1.5 % sillimanite+kyanite, 0.25 % rutile, 0.20 % monazite, 0.10 % ilmenite, trace of leucoxene, 0.3 % quartz,
Sample (DERA Analysis): 90.74 % zircon, 8.05 % various Al-silicates, 0.13 % rutile, 0.09 % monazite, 0.53 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			IREL Analysis	DERA Analysis
> 500		0.5 – 1.0		0.04
420				0.24
355				1.17
300				1.61
250		6.0 – 33.0		2.67
212				6.21
180		26.0 – 56.0		7.77
150				16.78
125		27.0 – 64.5		26.39
106				19.68
90		< 3.0		11.92
75				4.72
63				0.71
53				0.08
45				0.01
< 45				< 0.01
Mean (µm)				149.1
D50 (µm)				148.9

Name: **IREL Zircon “OR” Grade**

Deposit: Chatrapur, Orissa, India

Producer: Indian Rare Earth Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample I	
			IREL Analysis	DERA Analysis
ZrO_2+HfO_2	> 64.25	64.50 – 64.80		
ZrO_2				63.6
HfO_2				1.35
SiO_2		32.00 – 32.10		32.0
TiO_2		0.70 – 0.80		0.10
Al_2O_3				2.21
Fe_2O_3		0.30		0.26
Cr_2O_3				56 ppm
P_2O_5		0.10		0.142
CaO				< 0.01
LOI (@ 950 °C)				0.30
U				304 ppm
Th				397 ppm

Mineralogical composition:
Typical (IREL Analysis): 97.4 % zircon, 1.7 % sillimanite, 0.4 % rutile, 0.3 % monazite, 0.2 % others, traces of ilmenite, garnet and quartz,
Samples I (II) (DERA Analysis): 96.32 (90.66) % zircon, 2.45 (7.12) % various Al-silicates, (0.40) % rutile, 0.05 (0.04) % monazite, 0.08 (0.12) % quartz

Grain size distribution µm	Guaranteed	Typical	Samples I (II)	
			IREL Analysis	DERA Analysis
> 420		0.8		(0.01)
355				0.01 (0.04)
300				0.19 (0.37)
250		11.5		2.73 (2.27)
212				10.09 (7.74)
180		46.3		12.31 (10.86)
150				25.06 (27.60)
125		38.5		28.53 (30.57)
106				14.25 (13.66)
90		0.9		5.40 (5.05)
75		1.9		1.33 (1.64)
63		0.1		0.10 (0.18)
53				< 0.01 (0.01)
45				0.00 (0.00)
< 45				0.00 (0.00)
Mean (µm)				157.2 (154.7)
D50 (µm)				162.6 (161.2)

Name: **IREL Zircon "Q" Grade**

Deposit: Chavara, Kerala, India

Producer: Indian Rare Earth Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			IREL Analysis	DERA Analysis
ZrO_2+HfO_2	> 65.00	65.30		61.5
ZrO_2				60.3
HfO_2				1.22
SiO_2		32.80		32.9
TiO_2		0.27		0.51
Al_2O_3				4.51
Fe_2O_3	< 0.30	0.12		0.09
Cr_2O_3				143 ppm
P_2O_5				0.151
CaO				< 0.01
LOI (@ 950 °C)				0.23
U				281 ppm
Th				396 ppm

Mineralogical composition:
Typical (IREL Analysis): 97.3 % zircon, 1.0 % sillimanite, 0.30 % rutile, 0.10 % monazite, 1.2 % others, 0.1 % quartz,
Sample (DERA Analysis): 83.56 % zircon, 12.62 % various Al-silicates, 0.59 % rutile, 0.15 % monazite, 2.57 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			IREL Analysis	DERA Analysis
> 600		0.00 – 0.10		< 0.01
500				0.02
420				0.07
355				0.53
300				1.29
250		0.20 – 1.50		3.30
212				7.75
180		19.80 – 34.80		8.55
150				16.59
125		35.00 – 70.00		24.24
106				21.89
90		5.00 – 19.00		11.87
75				3.49
63		1.00 – 1.50		0.34
53				0.06
45				0.01
< 45				< 0.01
Mean (µm)				149.5
D50 (µm)				149.4

Name: **KMML Zircon I Grade**

Deposit: Sankarmangalam, Kerala, India

Producer: The Kerala Minerals & Metals Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			KMML Analysis	DERA Analysis
ZrO_2+HfO_2				65.8
ZrO_2	> 64.0	64.81		64.5
HfO_2				1.30
SiO_2		30.33		32.5
TiO_2		0.30		0.13
Al_2O_3		2.51		1.13
Fe_2O_3		0.86		0.08
Cr_2O_3				44 ppm
P_2O_5		0.10		0.086
CaO		0.46		< 0.01
MgO				
LOI (@ 950 °C)		0.3		0.15
U				276 ppm
Th				176 ppm
Parent activity U+Th				

Typical: 0.03 % Na_2O, 0.02 % K_2O

Mineralogical composition (DERA Analysis):
97.21 % zircon, 2.13 % various Al-silicates, 0.05 % rutile, 0.17 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			KMML Analysis	DERA Analysis
> 355				0.01
300				0.13
250				1.47
212				7.07
180				9.48
150				20.36
125				29.25
106				21.29
90				8.21
75				2.40
63				0.30
53				0.03
45				< 0.01
< 45				0.00
Mean (µm)				146.3
D50 (µm)				152.0

Name: **KMML Zircon II Grade**

Deposit: Sankarmangalam, Kerala, India

Producer: The Kerala Minerals & Metals Ltd.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			KMML Analysis	**DERA Analysis**
ZrO_2+HfO_2				63.9
ZrO_2				62.6
HfO_2				1.27
SiO_2				32.7
TiO_2				0.21
Al_2O_3				2.83
Fe_2O_3				0.07
Cr_2O_3				45 ppm
P_2O_5				0.076
CaO				<0.05
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.26
U				273 ppm
Th				114 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
92.65 % zircon, 6.64 % various Al-silicates, 0.14 % rutile, 0.39 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			KMML Analysis	**DERA Analysis**
> 420				
355				0.01
300				0.16
250				1.36
212				6.70
180				8.79
150				18.06
125				28.57
106				21.48
90				10.93
75				3.37
63				0.49
53				0.08
45				0.01
<45				<0.01
Mean (µm)				143.0
D50 (µm)				148.6

Name: **KZN Prime Zircon**

Deposit: Hillendale, KwaZulu-Natal, Republic of South Africa

Producer: Tronox Ltd., KZN Sands

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Tronox Analysis	DERA Analysis
ZrO_2+HfO_2	> 66.0	66.3 – 66.6		66.7
ZrO_2				65.4
HfO_2				1.33
SiO_2		32.5 – 32.7		32.6
TiO_2	< 0.15	0.11 – 0.15		0.11
Al_2O_3		0.05 – 0.21		0.10
Fe_2O_3	< 0.07	0.05 – 0.07		0.06
Cr_2O_3		< 0.01		22 ppm
P_2O_5		0.09 – 0.12		0.094
CaO		< 0.01 – 0.10		< 0.01
MgO		< 0.01 – 0.04		
Moisture (@ 105 °C)	< 1.0			
LOI (@ 950 °C)				0.22
U	< 500	500 – 669 ppm		339 ppm
Th				153 ppm
Parent activity U+Th		4.38 – 4.96 Bq/g		

Mineralogical composition (DERA Analysis):
99.42 % zircon, 0.17 % various Al-silicates, 0.08 % rutile, 0.10 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Tronox Analysis	DERA Analysis
> 500				0.02
420				0.01
355				< 0.01
300				0.03
250				0.10
212		0.5		0.45
180		5.7		1.50
150				5.71
125		10.9		20.70
106		27.8		32.26
90		40.0		28.14
75		12.3		10.52
63		2.9		0.94
53				0.07
45		0.0		< 0.01
< 45				0.01
Mean (µm)				114.3
D50 (µm)		106		121.6

Name: **KZN Standard Zircon**

Deposit: Hillendale, KwaZulu-Natal, Republic of South Africa

Producer: Tronox Ltd., KZN Sands

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Tronox Analysis	DERA Analysis
ZrO_2+HfO_2	> 65.0	65.8 – 66.3		66.1
ZrO_2				64.8
HfO_2				1.33
SiO_2		32.4 – 32.8		32.7
TiO_2	< 0.35	0.15 – 0.35		0.25
Al_2O_3		0.13 – 0.64		0.31
Fe_2O_3	< 0.12	0.07 – 0.12		0.10
Cr_2O_3		< 0.03 %		25 ppm
P_2O_5		0.11 – 0.15		0.110
CaO		0.07 – 0.13		0.05
MgO		< 0.01 – 0.04		
Moisture (@ 105 °C)	< 1.0			
LOI (@ 950 °C)				0.26
U	< 680	500 – 669 ppm		381 ppm
Th				175 ppm
Parent activity U+Th		4.96 – 6.48 Bq/g		

Mineralogical composition (DERA Analysis):
98.13 % zircon, 0.50 % various Al-silicates, 0.18 % rutile, 0.18 % sphene, 0.08 % strueverite, 0.48 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Tronox Analysis	DERA Analysis
> 420				< 0.01
355				< 0.01
300				0.03
250				0.40
212		0.8		2.74
180		7.8		6.32
150				8.18
125		10.7		16.64
106		25.6		23.45
90		38.9		21.58
75		12.8		10.88
63		3.5		12.29
53				0.17
45		0.1		0.02
< 45				0.01
Mean (µm)				115.4
D50 (µm)		104		119.3

Name: **Lanka Zircon**

Deposit: Pulmoddai, Sri Lanka

Producer: Lanka Mineral Sands Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Lanka Mineral Analysis	DERA Analysis
ZrO_2+HfO_2				64.4
ZrO_2			64.27	63.1
HfO_2				1.26
SiO_2				33.6
TiO_2				0.32
Al_2O_3				1.14
Fe_2O_3				0.10
Cr_2O_3				45 ppm
P_2O_5				0.149
CaO				<0.01
Moisture (@ 105 °C)	<0.50			
LOI (@ 950 °C)				0.18
U				244 ppm
Th				263 ppm

Mineralogical composition (DERA Analysis):
91.32 % zircon, 2.72 % various Al-silicates, 0.30 % rutile, 0.14 % apatite, 0.14 % monazite, 4.31 % quartz

<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>Lanka Mineral Analysis</th><th>DERA Analysis</th></tr>
<tr><td>>600</td><td></td><td rowspan="2">0</td><td rowspan="2"><0.01</td><td></td></tr>
<tr><td>500</td><td></td><td></td></tr>
<tr><td>420</td><td></td><td rowspan="4">0</td><td rowspan="4"><0.01</td><td><0.01</td></tr>
<tr><td>355</td><td></td><td><0.01</td></tr>
<tr><td>300</td><td></td><td>0.01</td></tr>
<tr><td>250</td><td></td><td>0.02</td></tr>
<tr><td>212</td><td></td><td rowspan="3">0.15</td><td rowspan="3">0.38</td><td>0.03</td></tr>
<tr><td>180</td><td></td><td>0.02</td></tr>
<tr><td>150</td><td></td><td>0.17</td></tr>
<tr><td>125</td><td></td><td rowspan="2">7.15</td><td rowspan="2">7.14</td><td>1.25</td></tr>
<tr><td>106</td><td></td><td>5.65</td></tr>
<tr><td>90</td><td></td><td>32.78</td><td>40.67</td><td>13.80</td></tr>
<tr><td>75</td><td></td><td>51.02</td><td>37.94</td><td>34.82</td></tr>
<tr><td>63</td><td></td><td>6.74</td><td>9.90</td><td>24.10</td></tr>
<tr><td>53</td><td></td><td rowspan="3">2.15</td><td rowspan="3">3.90</td><td>16.79</td></tr>
<tr><td>45</td><td></td><td>3.09</td></tr>
<tr><td><45</td><td></td><td>0.28</td></tr>
<tr><td>Mean (µm)</td><td></td><td></td><td></td><td>77.8</td></tr>
<tr><td>D50 (µm)</td><td></td><td></td><td></td><td>83.6</td></tr>
</table>

Name: **Millenium Zirconita Tipo E (Premium Grade)**

Deposit: : Mataraca, Paraiba, Brazil

Producer: Millenium Inorganic Chemicals Mineração Ltda.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Millenium Analysis	**DERA Analysis**
ZrO_2+HfO_2				65.8
ZrO_2	>65.5			64.5
HfO_2				1.29
SiO_2	<33.0			32.6
TiO_2	<0.08			0.08
Al_2O_3	<2.00			1.02
Fe_2O_3	<0.12			0.14
Cr_2O_3				22 ppm
P_2O_5	<0.05			0.064
CaO				<0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.23
U				260 ppm
Th				165 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
96.77 % zircon, 2.66 % various Al-silicates, 0.12 % rutile, 0.17 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			Millenium Analysis	**DERA Analysis**
>710				
600				
500				
420				
355				
300				0.01
250				0.08
212				0.46
180				1.02
150				6.15
125				26.14
106				32.08
90				22.24
75				9.84
63				1.73
53				0.24
45				0.02
<45				0.00
Mean (µm)				116.4
D50 (µm)				125.4

Name: **Millenium Zirconita Tipo I**

Deposit: : Mataraca, Paraiba, Brazil

Producer: Millenium Inorganic Chemicals Mineração Ltda.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Millenium Analysis	DERA Analysis
ZrO_2+HfO_2				65.4
ZrO_2	>65.5			64.1
HfO_2				1.29
SiO_2	<33.0			32.6
TiO_2	<0.08			0.18
Al_2O_3	<2.00			1.22
Fe_2O_3	<0.12			0.14
Cr_2O_3				23 ppm
P_2O_5	<0.05			0.072
CaO				<0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.30
U				293 ppm
Th				191 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
96.03 % zircon, 3.34 % various Al-silicates, 0.14 % rutile, 0.28 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Millenium Analysis	DERA Analysis
>300				
250				0.05
212				0.45
180				1.25
150				8.02
125				24.79
106				29.18
90				21.37
75				11.91
63				2.51
53				0.43
45				0.04
<45				<0.01
Mean (µm)				116.0
D50 (µm)				124.8

Name: **Millenium Zirconita Tipo II**

Deposit: : Mataraca, Paraiba, Brazil

Producer: Millenium Inorganic Chemicals Mineração Ltda.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Millenium Analysis	DERA Analysis
ZrO_2+HfO_2				65.5
ZrO_2	>65.5			64.2
HfO_2				1.30
SiO_2	<33.0			32.6
TiO_2	<0.08			0.34
Al_2O_3	<2.00			0.87
Fe_2O_3	<0.12			0.18
Cr_2O_3				23 ppm
P_2O_5	<0.05			0.086
CaO				<0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.35
U				333 ppm
Th				239 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
97.29 % zircon, 1.58 % various Al-silicates, 0.49 % rutile, 0.36 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Millenium Analysis	DERA Analysis
>355				
300				
250				0.01
212				0.07
180				0.17
150				2.10
125				17.48
106				31.61
90				27.88
75				16.28
63				3.58
53				0.71
45				0.09
<45				0.02
Mean (µm)				106.9
D50 (µm)				115.6

Name: **Millenium Zirconita Tipo III**

Deposit: : Mataraca, Paraiba, Brazil

Producer: Millenium Inorganic Chemicals Mineração Ltda.

Chemical composition	Guaranteed	Typical	Sample	
wt.-%			Millenium Analysis	DERA Analysis
ZrO_2+HfO_2				62.6
ZrO_2	>65.5			61.4
HfO_2				1.22
SiO_2	<33.0			32.8
TiO_2	<0.08			0.16
Al_2O_3	<2.00			4.01
Fe_2O_3	<0.12			0.12
Cr_2O_3				35 ppm
P_2O_5	<0.05			0.056
CaO				<0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.25
U				246 ppm
Th				156 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
91.09 % zircon, 8.47 % various Al-silicates, 0.09 % rutile, 0.11 % quartz

Grain size distribution	Guaranteed	Typical	Sample	
µm			Millenium Analysis	DERA Analysis
>355				0.01
300				0.24
250				2.34
212				11.65
180				16.64
150				30.70
125				25.64
106				8.78
90				2.96
75				0.92
63				0.11
53				0.01
45				<0.01
<45				0.00
Mean (µm)				164.4
D50 (µm)				173.7

Name: **MITRACO Zircon Class 1**

Deposit: Hà Tĩnh Province, Vietnam

Producer: HaTinh Minerals and Trading Corporation (MITRACO)

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			MITRACO Analysis	**DERA Analysis**
ZrO_2+HfO_2		63.0-65.0		65.6
ZrO_2				64.2
HfO_2				1.36
SiO_2				32.8
TiO_2				0.14
Al_2O_3				1.07
Fe_2O_3				0.08
Cr_2O_3				34 ppm
P_2O_5				0.161
CaO				<0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.13
U		200-300 ppm		642 ppm
Th				247 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
Sample: 96.15 % zircon, 0.05 % rutile, 2.91 % various Al-silicates, 0.33 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			MITRACO Analysis	**DERA Analysis**
>355				
300				0.01
250				0.03
212				0.05
180				0.07
150				0.40
125				1.92
106				6.96
90				17.50
75				35.04
63				27.57
53				9.32
45				1.04
<45				0.10
Mean (µm)				81.5
D50 (µm)				86.3

Name: **Moma Zircon High-Al Grade**

Deposit: Namalope/Moma, Mozambique

Producer: Kenmare Resources plc.

Chemical composition	Guaranteed	Typical	Sample	
wt.-%			Kenmare Analysis	DERA Analysis
ZrO_2+HfO_2				26.3
ZrO_2				25.7
HfO_2				0.56
SiO_2				59.9
TiO_2				4.60
Al_2O_3				8.31
Fe_2O_3				0.28
Cr_2O_3				134 ppm
P_2O_5				0.157
CaO				< 0.01
MgO				
LOI (@ 950 °C)				0.40
U				205 ppm
Th				396 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis): 13.27 % (?) zircon, 10.20 % various Al-silicates, 2.36 % rutile, 0.41 % albite, 0.06 % monazite, 0.04 % strueverite, 69.30 % (?) quartz

Grain size distribution	Guaranteed	Typical	Sample	
µm			Kenmare Analysis	DERA Analysis
> 500				0.01
420				0.01
355				0.01
300				0.09
250				0.68
212				3.55
180				7.79
150				23.79
125				27.94
106				15.01
90				11.48
75				7.15
63				1.80
53				0.45
45				0.13
< 45				0.10
Mean (µm)				137.7
D50 (µm)				149.1

Name: **Moma Zircon Special Grade**

Deposit: Namalope/Moma, Mozambique

Producer: Kenmare Resources plc.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Kenmare Analysis	DERA Analysis
ZrO_2+HfO_2				65.5
ZrO_2				64.2
HfO_2				1.33
SiO_2				32.5
TiO_2				0.48
Al_2O_3				0.89
Fe_2O_3				0.15
Cr_2O_3				37 ppm
P_2O_5				0.101
CaO				< 0.01
LOI (@ 950 °C)				0.30
U				369 ppm
Th				212 ppm

Mineralogical composition (DERA Analysis):
95.99 % zircon, 2.21 % various Al-silicates, 0.45 % rutile, 0.35 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Kenmare Analysis	DERA Analysis
> 710				> 0.01
600				< 0.01
500				< 0.01
420				< 0.01
355				< 0.01
300				0.03
250				0.55
212				3.42
180				5.70
150				16.89
125				31.52
106				25.78
90				11.86
75				3.76
63				0.44
53				0.04
45				< 0.01
< 45				0.00
Mean (µm)				135.2
D50 (µm)				143.0

Name: **Moma Zircon Standard Grade**

Deposit: Namalope/Moma, Mozambique

Producer: Kenmare Resources plc.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Kenmare Analysis	DERA Analysis
ZrO_2+HfO_2		65.0-66.0		62.9
ZrO_2				61.6
HfO_2				1.31
SiO_2		31.0 – 33.5		31.6
TiO_2		0.05 – 0.25		2.57
Al_2O_3		0.5 – 1.0		1.68
Fe_2O_3		0.05 – 0.20		0.26
Cr_2O_3		< 0.0035		79 ppm
P_2O_5		0.06 – 0.15		0.318
CaO		0.01 – 0.05		0.02
MgO		0.01 – 0.05		
LOI (@ 950 °C)				0.50
U		430 – 500 ppm		515 ppm
Th				849 ppm

Mineralogical composition:
Typical (Kenmare Analysis): 98-99 % zircon, 0.1-1.5 % kyanite, 0.2 % monazite, 0-0.2 % rutile, 0-0.2 % leucoxene, <0.5 % quartz
Sample (DERA Analysis): 92.86 % zircon, 3.02 % various Al-silicates, 2.69 % rutile, 0.39 % monazite, 0.04 % ilmenite, 0.18 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Kenmare Analysis	DERA Analysis
> 420				< 0.01
355				0.01
300				0.17
250				1.41
212				3.98
180				5.16
150				15.55
125				30.90
106				24.90
90				12.65
75				4.34
63				0.74
53				0.17
45				0.02
< 45				0.00
Mean (µm)				135.7
D50 (µm)		55 – 100		142.3

Name: **Namakwa Sands Premium Zircon**

Deposit: Brand se Baai, Western Cape, Republic of South Africa

Producer: Tronox Ltd., Namakwa Sands

Chemical composition wt.-%	Guaranteed	Typical	Sample I (II)	
			Tronox Analysis	DERA Analysis
ZrO_2+HfO_2				66.6 (66.6)
ZrO_2		65.0		65.3 (65.3)
HfO_2		1.30		1.31 (1.31)
SiO_2		32.8		32.7 (32.8)
TiO_2		0.11		0.09 (0.11)
Al_2O_3		0.25		0.19 (0.08)
Fe_2O_3		0.05		0.07 (0.06)
Cr_2O_3		<0.01		19 ppm (42 ppm)
P_2O_5		0.11		0.108 (0.101)
CaO		0.04		<0.01 (<0.01)
LOI (@ 950 °C)				0.15 (0.17)
U		270 ppm		290 ppm (280 ppm)
Th		140 ppm		152 ppm (142 ppm)
Parent activity U+Th		3.89 Bq/g		

Typical: <0.01 % V_2O_5, <0.01 % As

Mineralogical composition (DERA Analysis):
Sample I (II): 98.87 (99.44) % zircon, 0.39 (0.07) % various Al-silicates, 0.06 (0.08) % rutile, 0.05 % sphene, 0.35 (0.19) % quartz

Grain size distribution µm	Guaranteed	Typical	Sample I (II)	
			Tronox Analysis	DERA Analysis
>500				0.01
420				0.01 (<0.01)
355				0.01 (<0.01)
300				0.01 (0.02)
250				0.04 (0.04)
212				0.11 (0.09)
180				0.40 (0.24)
150				2.47 (1.53)
125				13.66 (9.35)
106				24.41 (20.89)
90				29.08 (34.98)
75				24.63 (25.40)
63				4.73 (6.88)
53				0.42 (0.53)
45				0.02 (0.03)
<45				<0.01 (0.01)
Mean (µm)				103.3 (99.4)
D50 (µm)				109.1 (105.3)

Name: **Namakwa Sands Standard Zircon**

Deposit: Brand se Baai, Western Cape, Republic of South Africa

Producer: Tronox Ltd., Namakwa Sands

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Tronox Analysis	DERA Analysis
ZrO_2+HfO_2				65.0
ZrO_2				63.7
HfO_2				1.31
SiO_2				32.8
TiO_2				0.76
Al_2O_3				0.52
Fe_2O_3				0.14
Cr_2O_3				28 ppm
P_2O_5				0.215
CaO				0.19
LOI (@ 950 °C)				0.28
U				358 ppm
Th				328 ppm

Mineralogical composition (DERA Analysis):
94.40 % zircon, 1.98 % various Al-silicates, 0.94 % rutile, 0.35 % sphene, 0.15 % monazite, 0.11 % strueverite, 0.05 % albite, 1.42 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Tronox Analysis	DERA Analysis
>600				0.02
500				<0.01
420				0.01
355				<0.01
300				0.01
250				0.02
212				0.06
180				0.14
150				0.80
125				5.00
106				14.83
90				28.19
75				37.90
63				11.58
53				1.32
45				0.10
<45				0.02
Mean (µm)				92.4
D50 (µm)				96.0

Name: **Namakwa Sands Zircon Rejects**

Deposit: Brand se Baai, Western Cape, Republic of South Africa

Producer: Tronox Ltd., Namakwa Sands

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Tronox Analysis	DERA Analysis
ZrO_2+HfO_2				28.8
ZrO_2				28.2
HfO_2				0.57
SiO_2				31.2
TiO_2				0.61
Al_2O_3				9.74
Fe_2O_3				9.10
Cr_2O_3				284 ppm
P_2O_5				3.279
CaO				4.08
MgO				
LOI (@ 950 °C)				-0.04
U				650 ppm
Th				7,502 ppm
Parent activity U+Th				

Sample (DERA Analysis): 292 ppm As, 23,271 ppm Ce, 637 ppm Dy, 262 ppm Er, 51 ppm Eu, 41 ppm Ga, 1,221 ppm Gd, 102 ppm Ho, 10,424 ppm La, 7,204 ppm Mn, 10,429 ppm Nd, 385 ppm Pb, 2,865 ppm Pr, 1,760 ppm Sm, 63 ppm Sr, 141 ppm Tb, 84 ppm V, 2,757 ppm Y, 405 ppm Zn

Mineralogical composition (DERA Analysis):
29.67 % zircon, 58.13 % various Al-silicates, 5.98 % monazite, 0.50 % sphene, 0.24 % rutile, 0.16 % ilmenite, 0.15 % goethite, 0.10 % xenotime, 0.05 % strueverite, 0.41 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Tronox Analysis	DERA Analysis
>300				0.02
250				0.07
212				0.31
180				0.65
150				4.12
125				18.35
106				24.72
90				21.91
75				21.82
63				6.66
53				1.18
45				0.14
<45				0.05
Mean (µm)				106.3
D50 (µm)				113.2

Name: **Namakwa Sands Zirkwa (Secondary Grade Zircon)**

Deposit: Brand se Baai, Western Cape, Republic of South Africa

Producer: Tronox Ltd., Namakwa Sands

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Tronox Analysis	DERA Analysis
ZrO_2+HfO_2				64.9
ZrO_2		64.2		63.6
HfO_2		1.30		1.30
SiO_2		33.5		32.8
TiO_2		0.65		0.78
Al_2O_3		0.50		0.61
Fe_2O_3		0.15		0.14
Cr_2O_3		<0.01		28 ppm
P_2O_5		0.20		0.218
CaO		0.15		0.20
LOI (@ 950 °C)				0.25
U		400 ppm		366 ppm
Th		300 ppm		327 ppm
Parent activity U+Th		6.14 Bq/g		

Typical: <0.01 % V_2O_5, <0.01 % As

Mineralogical composition (DERA Analysis):
95.24 % zircon, 2.07 % various Al-silicates, 0.86 % rutile, 0.32 % sphene, 0.23 % monazite, 0.05 % strueverite, 0.68 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Tronox Analysis	DERA Analysis
>500				0.04
420				0.03
355				0.02
300				0.05
250				0.08
212				0.16
180				0.23
150				1.06
125				6.02
106				16.33
90				28.83
75				36.34
63				9.80
53				0.93
45				0.07
<45				0.01
Mean (µm)				94.8
D50 (µm)				98.2

Name: **Nigeria Zircon**

Deposit: Northern Jos Plateau, Nigeria

Producer: A.M. Dung Nigeria Ltd.

Chemical composition	**Guaranteed**	**Typical**	**Sample**	
wt.-%			**A.M. Dung Analysis**	**DERA Analysis**
ZrO_2+HfO_2				37.4
ZrO_2			40.40	35.9
HfO_2			2.14	1.46
SiO_2			42.6	38.7
TiO_2			3.89	2.59
Al_2O_3				5.94
Fe_2O_3			4.96	3.31
Cr_2O_3			0.37	0.138
P_2O_5				1.198
CaO			0.43	0.03
MgO				
LOI (@ 950 °C)				1.15
U			1.866 ppm	1,930 ppm
Th			8.181 ppm	15,014 ppm

Sample (A.M. Dung Analysis): 1.3 % Ag_2O, 1.02 % Nb_2O_5, 0.63 % K_2O, 0.501 % Y_2O_3, 0.12 % Yb_2O_3, 0.10 % MnO, 970 ppm V_2O_5, 860 ppm Bi_2O_3, 850 ppm Au, 510 ppm PbO, 340 ppm Rb_2O, 200 ppm NiO, 200 ppm ZnO, 200 ppm As_2O_3, 200 ppm SeO_2, 100 ppm Re_2O_7

Sample (DERA Analysis): 86 ppm As, 82 ppm Ba, 21 ppm Be, 7,128 ppm Ce, 513 ppm Dy, 669 ppm Er, 17 ppm Eu, 45 ppm Ga, 368 ppm Gd, 137 ppm Ho, 3,492 ppm La, 347 ppm Lu, 7,026 ppm Nb, 2,577 ppm Nd, 47 ppm Ni, 598 ppm Pb, 758 ppm Pr, 47 ppm Rb, 19 ppm Sb, 470 ppm Sm, 7,922 ppm Sn, 2,083 ppm Ta, 66 ppm Tb, 187 ppm Tm, 241 ppm W, 3,188 ppm Y, 1,969 ppm Yb

Mineralogical composition (DERA Analysis): 55.07 % zircon, 9.16 various Al-silicates (garnet!), 2.85 % monazite, 2.40 % ilmenite, 1.42 % columbite, 0.71 % rutile, 0.54 % cassiterite, 0.22 % chromite, 0.18 % rutile, 0.15 % albite, 0.15 % Fe-oxides, 0.06 % xenotime, 22.36 % quartz

Name: **Nigeria Zircon**

Deposit: Northern Jos Plateau, Nigeria

Producer: A.M. Dung Nigeria Ltd.

Grain size distribution µm	Guaranteed	Typical	Sample	
			A.M. Dung Analysis	DERA Analysis
>840				0.31
710				1.38
600				1.54
500				6.69
420				6.92
355				12.37
300				13.49
250				14.06
212				13.67
180				8.41
150				9.96
125				7.11
106				2.57
90				1.07
75				0.42
63				0.05
53				0.01
45				<0.01
<45				0.00
Mean (µm)				299.1
D50 (µm)				297.4

Name: **Oregon Zircon**

Deposit: Coos Bay, Oregon, USA

Producer: Oregon Resources Corporation

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			ORC Analysis	DERA Analysis
ZrO_2+HfO_2			58.94	59.5
ZrO_2				58.3
HfO_2			1.16	1.17
SiO_2			31.63	32.2
TiO_2			3.08	3.12
Al_2O_3			1.77	1.88
Fe_2O_3			1.28	1.15
Cr_2O_3			1.20	1,03
P_2O_5				0.088
CaO			0.74	0.66
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.19
U *as U_3O_8			262 ppm*	306 ppm
Th *as ThO_2				154 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
Sample: 87.78 % zircon, 3.01 % rutile, 2.72 % various Al-silicates, 2.28 % chromite, 0.51 % sphene, 0.20 % albite, 0.13 % barite,2.05 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			ORC Analysis	DERA Analysis
>355				<0.01
300				0.03
250				0.27
212				1.18
180				1.87
150				12.02
125				43.56
106				32.09
90				8.02
75				0.97
63				0.00
53				0.00
45				0.00
<45				0.00
Mean (µm)				131.3
D50 (µm)				141.6

Name: **PT. Zirmet Premium Grade Zircon**

Deposit: Kalimantan Island, Indonesia

Producer: PT. Zirmet Mining

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Zirmet Analysis	DERA Analysis
ZrO_2+HfO_2		66.11		66.9
ZrO_2		64.74		65.5
HfO_2				1.35
SiO_2		32.33		32.7
TiO_2		0.10		0.10
Al_2O_3		0.12		0.15
Fe_2O_3		0.05		0.05
Cr_2O_3				18 ppm
P_2O_5		0.08		0.081
CaO				<0.01
LOI (@ 950 °C)		0.02		0.12
U		30.6 ppm		228 ppm
Th		62.7 ppm		152 ppm

Mineralogical composition (DERA Analysis):
Sample: 99.02 % zircon, 0.13 various Al-silicates, 0.12 % rutile, 0.06 % monazite, 0.32 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Zirmet Analysis	DERA Analysis
>710		5.9		0.01
600				<0.01
500				<0.01
420				0.01
355				0.35
300				1.69
250				5.19
212		23.0		13.02
180				18.60
150		24.3		25.36
125		15.6		19.06
106		10.2		8.70
90		16.0		4.52
75				2.48
63		5.0		0.75
53				0.22
45				0.04
<45				0.01
Mean (µm)				170.9
D50 (µm)				179.3

Name: **QMM Zirsill**

Deposit: Mandena, Fort Dauphin, Madagascar

Producer: QIT Madagascar Minerals (QMM) Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			QMM Analysis	DERA Analysis
ZrO_2+HfO_2				52.7
ZrO_2	>45	50		51.6
HfO_2		1.6		1.05
SiO_2		37		37.4
TiO_2	<2	1.2		0.70
Al_2O_3		10		8.66
Fe_2O_3	<0.1	0.05		0.13
Cr_2O_3				83 ppm
P_2O_5		0.1		0.124
CaO		0.05		<0.01
MgO		0.27		
Moisture (@ 105 °C)				
LOI (@ 950 °C)		0.2		0.26
U	<480 ppm	465 ppm		282 ppm
Th				281 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
59.44 % zircon, 18.64 % various Al-silicates, 0.81 % rutile, 0.10 % albite, 14.95 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			QMM Analysis	DERA Analysis
>420		0.01		<0.01
355		0.09		<0.01
300				0.01
250		1.06		0.03
212				0.21
180		9.13		0.52
150				3.23
125		21.59		13.63
106		18.44		23.32
90		25.25		27.55
75		17.25		22.53
63		7.15		7.00
53				1.62
45				0.26
<45				0.08
Mean (µm)				102.8
D50 (µm)				108.6

Name: **Richards Bay Calcined Prime Zircon**

Deposit: Richards Bay, KwaZulu-Natal, Republic of South Africa

Producer: Richards Bay Mining

Chemical composition wt.-%	Guaranteed	Typical	Samples I (II)	
			RBM Analysis	DERA Analysis
ZrO_2+HfO_2			66.2	66.3 (66.2)
ZrO_2	>65.00	66.00		65.0 (64.9)
HfO_2				1.31 (1.31)
SiO_2		32.50	32.7	32.9 (33.0)
TiO_2	<0.15	0.12	0.11	0.12 (0.11)
Al_2O_3		0.12	0.21	0.16 (0.18)
Fe_2O_3	<0.10	0.06	0.07	0.10 (0.10)
Cr_2O_3		0.002		32 ppm (31 ppm)
P_2O_5		0.12	0.12	0.133 (0.141)
CaO		0.11	0.15	0.08 (0.09)
MgO		0.02	0.02	
Moisture (@ 105 °C)		0.05	0.03	
LOI (@ 950 °C)		0.10	0.11	0.15 (0.13)
U	<500 ppm		331 ppm	316 ppm (299 ppm)
Th			151 ppm	172 ppm (164 ppm)
Parent activity U+Th			4.7 Bq/g	

Mineralogical composition (DERA Analysis):
Samples I (II): 97.40 (97.13) % zircon, 0.73 (2.53) % various Al-silicates, 0.20 % apatite, 0.14 % sphene, 0.06 (0.05) % rutile, 0.05 % albite, 1.14 (0.10) % quartz

Grain size distribution µm	Guaranteed	Typical	Samples I (II)	
			RBM Analysis	DERA Analysis
>420		0.4	0.3	(<0.01)
355				(<0.01)
300				0.01 (0.01)
250				0.06 (0.04)
212				0.30 (0.30)
180		1.9	1.1	0.86 (0.91)
150		8.7	6.8	5.22 (5.71)
125		21.0	20.6	22.27 (22.15)
106		30.0	32.3	32.80 (32.10)
90		28.0	27.1	26.73 (26.33)
75		9.0	10.4	10.47 (11.15)
63		1.0	1.4	1.13 (1.15)
53				0.14 (0.12)
45				0.01 (0.02)
<45				<0.01 (0.01)
Mean (µm)				114.1 (114.2)
D50 (µm)				122.2 (122.2)

Name: **Richards Bay Uncalcined Prime Zircon**

Deposit: Richards Bay, KwaZulu-Natal, Republic of South Africa

Producer: Richards Bay Mining

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			RBM Analysis	DERA Analysis
ZrO_2+HfO_2			66.3	66.6
ZrO_2	>66.00	66.20		65.3
HfO_2				1.32
SiO_2		32.50	32.7	32.8
TiO_2	<0.15	0.12	0.107	0.13
Al_2O_3		0.12	0.121	0.07
Fe_2O_3	<0.10	0.06	0.068	0.08
Cr_2O_3		0.002		26 ppm
P_2O_5		0.12	0.124	0.119
CaO		0.11	0.071	0.02
MgO		0.02		
Moisture (@ 105 °C)		0.05	0.04	
LOI (@ 950 °C)		0.22	0.29	0.17
U	<500 ppm		312 ppm	299 ppm
Th			150 ppm	170 ppm
Parent activity U+Th			4.5 Bq/g	

Typical: 0.003 % PbO, 0.002 % S

Mineralogical composition (DERA Analysis):
99.34 % zircon, 0.14 % various Al-silicates, 0.05 % apatite, 0.04 % rutile, 0.04 % monazite, 0.24 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			RBM Analysis	DERA Analysis
>300		0.4	0.1	0.01
250				0.03
212				0.27
180		1.9	0.6	0.92
150		8.7	5.7	6.61
125		21.0	18.1	26.09
106		30.0	34.5	32.78
90		28.0	28.3	23.18
75		9.0	11.4	9.01
63		1.0	1.3	1.01
53				0.08
45				0.00
<45				0.00
Mean (µm)				116.7
D50 (µm)				125.7

Name: **Richards Bay Zircon Intermediate Grade**

Deposit: Richards Bay, KwaZulu-Natal, Republic of South Africa

Producer: Richards Bay Mining

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			RBM Analysis	DERA Analysis
ZrO_2+HfO_2			66.2	66.4
ZrO_2	>65.00	66.00		65.1
HfO_2				1.32
SiO_2		32.70	32.7	32.6
TiO_2	<0.30	0.25	0.30	0.34
Al_2O_3		0.12	0.16	0.14
Fe_2O_3	<0.10	0.12	0.07	0.09
Cr_2O_3		0.002		23 ppm
P_2O_5		0.13	0.11	0.118
CaO		0.11	0.10	0.05
MgO		0.02	0.01	
Moisture (@ 105 °C)		0.05	0.04	
LOI (@ 950 °C)		0.30	0.32	0.18
U	<500 ppm		318 ppm	302 ppm
Th			150 ppm	165 ppm
Parent activity U+Th			4.6 Bq/g	

Typical: 0.003 % PbO, 0.002 % S

Mineralogical composition (DERA Analysis):
98.56 % zircon, 0.32 % rutile, 0.27 % various Al-silicates, 0.16 % sphene, 0.10 % albite, 0.23 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			RBM Analysis	DERA Analysis
>300		0.4	2.5	0.03
250				0.29
212				1.80
180		1.9	4.4	3.29
150		8.7	15.3	12.16
125		21.0	25.9	29.61
106		30.0	28.3	28.79
90		28.0	17.7	17.59
75		9.0	5.3	5.72
63		1.0	0.6	0.63
53				0.08
45				0.01
<45				0.00
Mean (µm)				126.5
D50 (µm)				134.2

Name: **Richards Bay Standard Zircon**

Deposit: Richards Bay, KwaZulu-Natal, Republic of South Africa

Producer: Richards Bay Mining

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			RBM Analysis	DERA Analysis
ZrO_2+HfO_2			66.1	66.3
ZrO_2	>65.00	66.00		65.0
HfO_2				1.31
SiO_2		32.70	32.7	32.7
TiO_2	<0.30	0.25	0.182	0.22
Al_2O_3		0.18	0.188	0.15
Fe_2O_3	<0.25	0.20	0.159	0.17
Cr_2O_3		0.002		31 ppm
P_2O_5		0.14	0.138	0.144
CaO		0.15	0.115	0.07
MgO		0.03	0.025	
Moisture (@ 105 °C)		0.05	0.03	
LOI (@ 950 °C)		0.30	0.28	0.21
U	<500 ppm		321 ppm	312 ppm
Th			156 ppm	233 ppm
Parent activity U+Th			4.6 Bq/g	

Typical: 0.003 % PbO, 0.002 % S

Mineralogical composition (DERA Analysis):
98.50 % zircon, 0.39 % various Al-silicates, 0.19 % rutile, 0.19 % monazite, 0.12 % apatite, 0.06 % sphene, 0.32 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			RBM Analysis	DERA Analysis
>300		0.4	0.2	0.01
250				0.03
212				0.19
180		1.9	0.8	0.61
150		8.7	6.3	4.44
125		21.0	18.2	19.72
106		30.0	31.7	33.02
90		28.0	28.8	28.10
75		9.0	12.3	12.31
63		1.0	1.7	1.40
53				0.16
45				0.01
<45				0.00
Mean (µm)				111.8
D50 (µm)				119.9

Name: **Sakorn Zircon ZAIL 1/12 (Standard Grade)**

Deposit: Mixed sources

Producer: Sakorn Minerals Co. Ltd.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Sakorn Analysis	**DERA Analysis**
ZrO_2+HfO_2	>65.0		65.2	65.0
ZrO_2				63.7
HfO_2				1.28
SiO_2	32-33		32.7	32.6
TiO_2	<0.2		0.17	0.17
Al_2O_3			1.37	1.81
Fe_2O_3	<0.15		0.115	0.12
Cr_2O_3				23 ppm
P_2O_5			0.12	0.113
CaO				<0.01
LOI (@ 950 °C)			0.15	0.21
U			281 ppm	291 ppm
Th			180 ppm	189 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):

94.65 % zircon, 4.65 % various Al-silicates, 0.16 % rutile, 0.14 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			Sakorn Analysis	**DERA Analysis**
>600		0.00		0.01
500				0.03
420		0.01		0.03
355				0.03
300				0.15
250				1.13
212		1.23		4.44
180				4.29
150				8.05
125		29.37		13.75
106		26.65		20.48
90		42.01		24.96
75				17.10
63				4.43
53		0.66		0.87
45				0.17
<45		0.06		0.07
Mean (µm)				119.3
D50 (µm)				117.2

Name: **Sakorn Zircon ZAMB 5/11 (Premium Grade)**

Deposit: Mixed sources

Producer: Sakorn Minerals Co. Ltd.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Sakorn Analysis	**DERA Analysis**
ZrO_2+HfO_2	>66.0		65.8	66.1
ZrO_2				64.8
HfO_2				1.31
SiO_2	32-22		32.6	32.6
TiO_2	<0.1		0.22	0.22
Al_2O_3			0.63	0.64
Fe_2O_3	<0.1		0.107	0.12
Cr_2O_3				23 ppm
P_2O_5			0.15	0.134
CaO				<0.01
MgO				
LOI (@ 950 °C)			0.17	0.21
U			304 ppm	310 ppm
Th			208 ppm	216 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):

96.18 % zircon, 3.11 % various Al-silicates, 0.31 % rutile, 0.08 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			Sakorn Analysis	**DERA Analysis**
>500		0.00		<0.01
420		0.01		<0.01
355				0.01
300				0.07
250				0.21
212		1.23		0.76
180				1.72
150				6.30
125		29.37		13.12
106		26.65		20.17
90		42.01		25.17
75				23.09
63				7.05
53		0.66		1.68
45				0.46
<45		0.06		0.20
Mean (µm)				106.1
D50 (µm)				109.1

Name: **Sakorn Zircon ZAU 5/11 (Foundry Grade)**

Deposit: Mixed sources

Producer: Sakorn Minerals Co. Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Sakorn Analysis	DERA Analysis
ZrO_2+HfO_2	>65.0		65.8	66.2
ZrO_2				64.9
HfO_2				1.28
SiO_2			32.5	32.5
TiO_2	<0.6		0.19	0.20
Al_2O_3			0.46	0.45
Fe_2O_3	<0.3		0.187	0.19
Cr_2O_3				23 ppm
P_2O_5			0.20	0.178
CaO				<0.01
LOI (@ 950 °C)			0.18	0.23
U			278 ppm	285 ppm
Th			289 ppm	294 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):

98.13 % zircon, 0.67 % various Al-silicates, 0.12 % monazite, 0.09 % ilmenite, 0.07 % rutile, 0.07 % limonite, 0.18 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Sakorn Analysis	DERA Analysis
>500		0.00		<0.01
420		0.01		<0.01
355				0.01
300				0.03
250				0.04
212		1.23		0.11
180				0.16
150				3.09
125		29.37		21.50
106		26.65		23.40
90		42.01		24.93
75				20.15
63				5.19
53		0.66		1.21
45				0.14
<45		0.06		0.02
Mean (µm)				106.7
D50 (µm)				113.4

Name: **Southern Ionics Mission Zircon**

Deposit: Mission, Georgia, USA

Producer: Southern Ionics Inc.

<table>
<tr><th rowspan="2">Chemical composition
wt.-%</th><th rowspan="2">Guaranteed</th><th rowspan="2">Typical</th><th colspan="2">Sample</th></tr>
<tr><th>Southern Ionics Analysis</th><th>DERA Analysis</th></tr>
<tr><td>ZrO_2+HfO_2</td><td></td><td></td><td>65.1</td><td rowspan="16">No sample available for analysis</td></tr>
<tr><td>ZrO_2</td><td></td><td></td><td>63.87</td></tr>
<tr><td>HfO_2</td><td></td><td></td><td>1.25</td></tr>
<tr><td>SiO_2</td><td></td><td></td><td>32.14</td></tr>
<tr><td>TiO_2</td><td></td><td></td><td>0.58</td></tr>
<tr><td>Al_2O_3</td><td></td><td></td><td>1.65</td></tr>
<tr><td>Fe_2O_3</td><td></td><td></td><td>0.037</td></tr>
<tr><td>Cr_2O_3</td><td></td><td></td><td><0.01</td></tr>
<tr><td>P_2O_5</td><td></td><td></td><td>0.07</td></tr>
<tr><td>CaO</td><td></td><td></td><td>0.01</td></tr>
<tr><td>MgO</td><td></td><td></td><td><0.01</td></tr>
<tr><td>Moisture (@ 105 °C)</td><td></td><td></td><td></td></tr>
<tr><td>LOI (@ 950 °C)</td><td></td><td></td><td></td></tr>
<tr><td>U</td><td></td><td></td><td>250 ppm</td></tr>
<tr><td>Th</td><td></td><td></td><td>94 ppm</td></tr>
<tr><td>Parent activity U+Th</td><td></td><td></td><td></td></tr>
</table>

Sample (Southern Ionics Analysis): 0.01 % V_2O_5, 0.1 % Y_2O_3, <0.01 % CeO_2, < 0.01 % La_2O_3, <0.01 % S, 10 ppm Zn, 33 ppm Pb

Mineralogical composition:
No sample available for analysis

<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>Southern Ionics Analysis</th><th>DERA Analysis</th></tr>
<tr><td>>355</td><td></td><td></td><td rowspan="4">0.0</td><td rowspan="16">No sample available for analysis</td></tr>
<tr><td>300</td><td></td><td></td></tr>
<tr><td>250</td><td></td><td></td></tr>
<tr><td>212</td><td></td><td></td></tr>
<tr><td>180</td><td></td><td></td><td rowspan="2">0.09</td></tr>
<tr><td>150</td><td></td><td></td></tr>
<tr><td>125</td><td></td><td></td><td>3.07</td></tr>
<tr><td>106</td><td></td><td></td><td>11.98</td></tr>
<tr><td>90</td><td></td><td></td><td>42.52</td></tr>
<tr><td>75</td><td></td><td></td><td>26.52</td></tr>
<tr><td>63</td><td></td><td></td><td rowspan="2">14.78</td></tr>
<tr><td>53</td><td></td><td></td></tr>
<tr><td>45</td><td></td><td></td><td rowspan="2">0.20</td></tr>
<tr><td><45</td><td></td><td></td></tr>
<tr><td>Mean (µm)</td><td></td><td></td><td></td></tr>
<tr><td>D50 (µm)</td><td></td><td></td><td></td></tr>
</table>

Name: **Tarasovka Fine Zircon**

Deposit: Tarasovka, Volodarskiy district, Ukraine

Producer: Velta LLC

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Velta Analysis	DERA Analysis
ZrO_2+HfO_2				No sample available for analysis
ZrO_2			66.2	
HfO_2				
SiO_2			32.5	
TiO_2			0.08	
Al_2O_3			0.32	
Fe_2O_3			0.06	
Cr_2O_3			0.003	
P_2O_5			0.133	
CaO			0.03	
MgO			<0.01	
Moisture (@ 105 °C)				
LOI (@ 950 °C)			0.17	
U			266 ppm	
Th			133 ppm	
Parent activity U+Th				

Sample: 0.016 % CeO_2, 0.003 % Nb_2O_5, <0.01 % MnO, 0.11 % SO_2, <0.01 % V_2O_5

Mineralogical composition (DERA Analysis):
No sample available for analysis

Grain size distribution µm	Guaranteed	Typical	Sample	
			Velta Analysis	DERA Analysis
>710				No sample available for analysis
600				
500				
420				
355				
300				
250				
212				
180				
150				
125				
106				
90				
75				
63				
53				
45				
<45				
Mean (µm)				
D50 (µm)				

Name: **Tarasovka Coarse Zircon**

Deposit: Tarasovka, Volodarskiy district, Ukraine

Producer: Velta LLC

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Velta Analysis	DERA Analysis
ZrO_2+HfO_2	>65.0			No sample available for analysis
ZrO_2			65.4	
HfO_2				
SiO_2		32.0	32.6	
TiO_2		0.2-0.3	0.08	
Al_2O_3		1.2-1.5	0.97	
Fe_2O_3		0.09	0.06	
Cr_2O_3			0.003	
P_2O_5		0.12	0.113	
CaO	<0.1		0.03	
MgO			<0.01	
Moisture (@ 105 °C)	<0.1			
LOI (@ 950 °C)			0.2	
U	<320 pm		248 ppm	
Th			137 ppm	
Parent activity U+Th				

Sample: 0.016 % CeO_2, < 0.001 % Nb_2O_5, <0.01 % MnO, 0.12 % SO_2, <0.01 % V_2O_5

Mineralogical composition (DERA Analysis):
No sample available for analysis

Grain size distribution µm	Guaranteed	Typical	Sample	
			Velta Analysis	DERA Analysis
>355				No sample available for analysis
300				
250				
212				
180				
150				
125				
106				
90				
75				
63				
53				
45				
<45				
Mean (µm)				
D50 (µm)				

Name: **Toliara Zircon**

Deposit: Toliara, Madagascar

Producer: World Titanium Resources Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			WTR Analysis	DERA Analysis
ZrO_2+HfO_2		66.5		No sample available for analysis
ZrO_2				
HfO_2				
SiO_2		32.4		
TiO_2		0.10		
Al_2O_3		0.02		
Fe_2O_3		0.06		
P_2O_5		0.10		
CaO				
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				
U		562 ppm		
Th				
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
No sample available for analysis

Grain size distribution µm	Guaranteed	Typical	Sample	
			WTR Analysis	DERA Analysis
>710				No sample available for analysis
600				
500				
420				
355				
300				
250				
212				
180				
150				
125				
106				
90				
75				
63				
53				
45				
<45				
Mean (µm)				
D50 (µm)				

Name: **Trimex Zircon**

Deposit: Srikurmam, Srikakulam District Andhra Pradesh, India

Producer: Trimex Sands Pvt. Ltd.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Trimex Analysis	**DERA Analysis**
ZrO_2+HfO_2				65.7
ZrO_2	>63			64.3
HfO_2				1.38
SiO_2	<34			32.1
TiO_2				0.85
Al_2O_3	<1.5			0.63
Fe_2O_3	<0.4			0.17
Cr_2O_3				47 ppm
P_2O_5				0.216
CaO				<0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.23
U				313 ppm
Th				529 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
Sample: 97.48 % zircon, 0.98 % rutile, 0.61 % various Al-silicates, 0.33 % monazite, 0.10 % sphene, 0.09 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			Trimex Analysis	**DERA Analysis**
>710				
600				
500				
420				
355				
300				0.02
250				0.25
212				2.17
180				5.75
150				19.65
125				32.53
106				23.37
90				11.99
75				3.88
63				0.38
53				0.02
45				<0.01
<45				0.00
Mean (µm)				134.8
D50 (µm)				144.5

Name: **Tronox Zircon HTZ Grade**

Deposit: Cooljarloo, Western Australia, Australia

Producer: Tronox Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Tronox Analysis	DERA Analysis
ZrO_2+HfO_2	>65.0	65.9	66.37	66.0
ZrO_2			65.08	64.7
HfO_2			1.29	1.27
SiO_2		31.7	32.48	32.4
TiO_2	<1.0	0.65	0.73	0.75
Al_2O_3		1.15	0.56	0.57
Fe_2O_3	<0.10	0.06	0.072	0.08
Cr_2O_3				28 ppm
P_2O_5		0.12	0.09	0.076
CaO			0.02	<0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.15
U		270 ppm	230 ppm	220 ppm
Th		150 ppm	200 ppm	167 ppm
Parent activity U+Th				

Sample (Tronox Analysis): 0.01 % CeO_2, 0.009 % PbO_2

Mineralogical composition (DERA Analysis):
Sample: 98.50 % zircon, 0.72 % rutile, 0.36 % various Al-silicates, 0.14 % barite, 0.04 % quartz

<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>DERA Analysis</th></tr>
<tr><td>>710</td><td></td><td rowspan="6">0.3</td><td rowspan="8">21.50</td><td></td></tr>
<tr><td>600</td><td></td><td></td></tr>
<tr><td>500</td><td></td><td></td></tr>
<tr><td>420</td><td></td><td><0.01</td></tr>
<tr><td>355</td><td></td><td>0.04</td></tr>
<tr><td>300</td><td></td><td>0.80</td></tr>
<tr><td>250</td><td></td><td>7.2</td><td>5.84</td></tr>
<tr><td>212</td><td></td><td>8.1</td><td>15.21</td></tr>
<tr><td>180</td><td></td><td>31.3</td><td>21.89</td><td>16.58</td></tr>
<tr><td>150</td><td></td><td>36.4</td><td>32.97</td><td>32.08</td></tr>
<tr><td>125</td><td></td><td>13.0</td><td>16.70</td><td>23.56</td></tr>
<tr><td>106</td><td></td><td rowspan="3">3.6</td><td rowspan="3">6.93</td><td>4.76</td></tr>
<tr><td>90</td><td></td><td>0.89</td></tr>
<tr><td>75</td><td></td><td>0.22</td></tr>
<tr><td>63</td><td></td><td rowspan="4">0.1</td><td rowspan="4">0.02</td><td>0.02</td></tr>
<tr><td>53</td><td></td><td><0.01</td></tr>
<tr><td>45</td><td></td><td>0.00</td></tr>
<tr><td><45</td><td></td><td>0.00</td></tr>
<tr><td>Mean (µm)</td><td></td><td></td><td></td><td>176.1</td></tr>
<tr><td>D50 (µm)</td><td></td><td></td><td></td><td>181.8</td></tr>
</table>

Name: **Tronox Zircon West Coast Premium Grade (MKT 64)**

Deposit: Cooljarloo, Western Australia, Australia

Producer: Tronox Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Tronox Analysis	DERA Analysis
ZrO_2+HfO_2	>66.0	66.6	66.37	66.5
ZrO_2				65.2
HfO_2				1.29
SiO_2		32.2	32.47	32.6
TiO_2	<0.15	0.14	0.14	0.15
Al_2O_3		0.45	0.46	0.38
Fe_2O_3	<0.07	0.06	0.05	0.05
Cr_2O_3				18 ppm
P_2O_5		0.12	0.10	0.089
CaO			0.02	<0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.29
U			250 ppm	234 ppm
Th			160 ppm	174 ppm
Parent activity U+Th				

Sample (Tronox Analysis): 0.01 % CeO_2, 0.003 % PbO_2

Mineralogical composition (DERA Analysis):
Sample: 99.27 % zircon, 0.39 % various Al-silicates, 0.07 % rutile, 0.07 % monazite, 0.04 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Tronox Analysis	DERA Analysis
>710		0.5	0.30	
600				
500				
420				
355				
300				0.01
250				0.03
212				0.36
180		6.6	5.60	4.37
150		43.2	37.40	31.21
125		33.3	36.00	45.27
106		16.2	20.50	13.35
90				4.24
75				0.99
63		0.2	0.20	0.14
53				0.02
45				<0.01
<45				0.00
Mean (µm)				142.0
D50 (µm)				154.1

Name: **Vilnohirsk Zircon Premium Grade**

Deposit: Malyshev, Dniepropetrovsk region, Ukraine

Producer: Vilnohirsk State Mining and Metallurgical Integrated Works

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			VSMMP Analysis	DERA Analysis
ZrO_2+HfO_2	>65.0	66.0		65.1
ZrO_2				63.9
HfO_2				1.22
SiO_2		32.0		33.3
TiO_2	<0.20	0.20		0.08
Al_2O_3	<2.00	1.00		1.19
Fe_2O_3	<0.10	0.09		0.07
Cr2O3				7 ppm
P_2O_5		0.12		0.089
CaO		<0.10		<0.01
MgO				
Moisture (@ 105 °C)	<0.50	0.10		
LOI (@ 950 °C)				0.17
U	<1000 ppm	320 ppm		177 ppm
Th				106 ppm
Parent activity U+Th		2.19 bq/g		

Mineralogical composition (DERA Analysis):
Sample: 97.25 % zircon, 2.52 % various Al-silicates, 0.10 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			VSMMP Analysis	DERA Analysis
>700		0.1		
600				
500				<0.01
420				<0.01
355				<0.01
300				<0.01
250				<0.01
212				0.01
180		0.9		0.04
150				0.92
125		24		14.72
106				41.37
90		74		32.53
75				9.96
63		1		0.43
53				0.02
45				<0.01
<45				<0.01
Mean (µm)				108.8
D50 (µm)				118.3

Name: **Vilnohirsk Zircon Standard Grade**

Deposit: Malyshev, Dniepropetrovsk region, Ukraine

Producer: Vilnohirsk State Mining and Metallurgical Integrated Works

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			VSMMP Analysis	**DERA Analysis**
ZrO_2+HfO_2	>65.0	65.7		64.9
ZrO_2				63.7
HfO_2				1.22
SiO_2		32.0		32.7
TiO_2	<0.40	0.2-0.3		0.10
Al_2O_3	<2.00	1.2-1.5		1.80
Fe_2O_3	<0.10	0.09		0.07
Cr_2O_3				28 ppm
P_2O_5		0.12		0.090
CaO		<0.10		<0.01
MgO				
Moisture (@ 105 °C)	<0.50	0.10		
LOI (@ 950 °C)				0.35
U	<1000 ppm	320 ppm		183 ppm
Th				112 ppm
Parent activity U+Th		2.19 bq/g		

Mineralogical composition (DERA Analysis):
Sample: 97.13 % zircon, 2.49 % various Al-silicates, 0.05 % rutile, 0.10 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			VSMMP Analysis	**DERA Analysis**
>700		0.1		
600				
500				
420				
355				
300				0.01
250				0.02
212				0.03
180		0.9		0.07
150				0.84
125		24		12.39
106				30.98
90		74		34.25
75				18.17
63		1		2.83
53				0.37
45				0.04
<45				0.01
Mean (µm)				103.9
D50 (µm)				111.6

Name: **V.V. Mineral Premium Grade Zircon**

Deposit: Kanyakumari District, Tamil Nadu, India
Producer: V.V. Mineral Pvt. Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Samples I (II)	
			V.V. Mineral Analysis	DERA Analysis
ZrO_2+HfO_2	>66.0	66.51	66.50	66.4 (66.2)
ZrO_2				65.1 (64.9)
HfO_2				1.33 (1.33)
SiO_2	<32.70	32.46	32.32	32.5 (32.7)
TiO_2	<0.15	0.10	0.10	0.09 (0.17)
Al_2O_3	<1.00	0.52	0.47	0.60 (0.47)
Fe_2O_3	<0.10	0.06	0.05	0.08 (0.08)
Cr_2O_3				22 ppm (31 ppm)
P_2O_5	<0.10	0.06	0.07	0.065 (0.065)
CaO				< 0.01 (<0.01)
Moisture (@ 105 °C)			0.08	
LOI (@ 950 °C)			0.009	0.13 (0.21)
U	<300 ppm	242 ppm		286 ppm (279 ppm)
Th	<200 ppm	121 ppm		156 ppm (151 ppm)

V_2O_5 guaranteed: <0.02 %, typical: 0.01 %

Mineralogical composition:
Guaranteed (V.V. Mineral Analysis): >98.5 % zircon, <1.20 % sillimanite, <0.20 % rutile, <0.30 % quartz
Typical (V.V. Mineral Analysis): 99.0 % zircon, 0.78 % sillimanite, 0.10 % rutile, 0.12 % quartz
Sample (V.V. Mineral Analysis): 99.32 % zircon, 0.40 % sillimanite, 0.12 % rutile, 0.16 % quartz
Samples I (II) (DERA Analysis): 91.19 (98.79) % zircon, 8.49 (0.84) % various Al-silicates, (0.18) % rutile, 0.04(0.03) % quartz

Grain size distribution µm	Guaranteed	Typical	Samples I (II)	
			V.V. Mineral Analysis	DERA Analysis
>710	0	0	0.0	(<0.01)
600				(<0.01)
500	<1	0.02	0.36	<0.01 (<0.01)
420				0.02 (0.05)
355	1-5	1.34	3.78	0.26 (0.52)
300				1.56 (2.08)
250	1-10	3.82	6.36	6.65 (5.59)
212	5-15	10.22	10.24	14.54 (13.12)
180	10-25	15.31	13.78	15.01 (15.03)
150	20-40	26.77	25.94	26.82 (28.77)
125	15-40	30.34	29.10	23.72 (25.91)
106	4-15	10.48	7.88	8.89 (7.47)
90	0-5	1.52	2.56	2.18 (1.31)
75	<3	0.18		0.34 (0.15)
63				0.01 (0.01)
53				0.00 (<0.01)
<45				0.00 (<0.01)
Mean (µm)				174.9 (175.2)
D50 (µm)				179.1 (178.3)

Name: **V.V. Mineral Standard Grade Zircon**

Deposit: Kanyakumari District, Tamil Nadu, India
Producer: V.V. Mineral Pvt. Ltd.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Samples I (II)**	
			V.V. Mineral Analysis	**DERA Analysis**
ZrO_2+HfO_2	>65.0	65.44	65.83	66.7 (66.3)
ZrO_2				65.4 (65.0)
HfO_2				1.34 (1.33)
SiO_2	<32.70	32.49	32.15	32.6 (32.6)
TiO_2	<0.25	0.19	0.17	0.12 (0.19)
Al_2O_3	<1.50	1.02	1.15	0.18 (0.56)
Fe_2O_3	<0.10	0.07	0.06	0.08 (0.10)
Cr_2O_3				15 ppm (34 ppm)
P_2O_5	<0.10	0.064	0.066	0.063 (0.067)
CaO				< 0.01 (<0.01)
Moisture (@ 105 °C)			0.08	
LOI (@ 950 °C)				0.16 (0.15)
U	<300 ppm	284 ppm	158 ppm	294 ppm (282 ppm)
Th	<200 ppm	148 ppm	307 ppm	165 ppm (146 ppm)

V_2O_5 guaranteed: <0.02 %, typical: 0.012 %

Mineralogical composition:
Guaranteed (V.V. Mineral Analysis): >97.50 % zircon, <2.00 % sillimanite, <0.30 % rutile, <0.20 % quartz
Typical (V.V. Mineral Analysis): 98.10 % zircon, 1.56 % sillimanite, 0.22 % rutile, 0.12 % quartz
Sample I (V.V. Mineral Analysis): 99.28 % zircon, 0.38 % sillimanite, 0.18 % rutile, 0.16 % quartz
Samples I (II) (DERA Analysis): 98.96 (98.85) % zircon, 0.46 (0.86) % various Al-silicates, 0.06 (0.12) % rutile, 0.46 (0.07) % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Samples I (II)**	
			V.V. Mineral Analysis	**DERA Analysis**
> 600	0	0	0.0	
500	<1	0.04	0.10	
420				0.01 (0.01)
355	1-5	2.20	3.40	0.07 (0.18)
300				0.53 (0.68)
250	2-10	5.22	7.08	3.00 (2.18)
212	5-20	10.74	12.18	10.30 (6.84)
180	10-25	17.40	17.74	13.57 (10.11)
150	20-40	26.92	28.36	29.84 (26.89)
125	15-35	24.80	21.14	30.34 (33.84)
106	2-15	9.20	7.10	10.07 (14.64)
90	0-5	2.04	2.90	2.04 (3.85)
75	<3	1.44		0.23 (0.71)
63				<0.01 (0.04)
53				0.00 (0.02)
45				0.00 (<0.01)
<45				0.00 (0.00)
Mean (µm)				163.4 (154.9)
D50 (µm)				169.6 (159.7)

Name: **Wanning Yuehai Zircon**

Deposit: Changsa Town, Wenchang City, Hainan Island, PR China

Producer: Wanning Yuehai Mining Industry & Technology, Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Yuehai Analysis	DERA Analysis
ZrO_2+HfO_2	≥65.0			66.1
ZrO_2				64.7
HfO_2				1.36
SiO_2	<34.00			32.6
TiO_2	<0.15			0.28
Al_2O_3	<1.00			0.42
Fe_2O_3	<0.10			0.10
Cr_2O_3				19 ppm
P_2O_5	<0.25			0.200
CaO				0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.18
U				553 ppm
Th				393 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
Sample: 98.34 % zircon, 0.56 % various Al-silicates, 0.18 % rutile, 0.09 % monazite, 0.04 % apatite, 0.38 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Yuehai Analysis	DERA Analysis
>355				
300				0.01
250				0.01
212				0.04
180				0.08
150				0.76
125				5.45
106				18.85
90				29.70
75				30.03
63				11.00
53				2.85
45				0.67
<45				0.53
Mean (µm)				93.2
D50 (µm)				99.4

Name: **Wenchang Sheng Sheng Advanced Zircon 65 %**

Deposit: Changsa Town, Wenchang City, Hainan Island, PR China

Producer: Wenchang Sheng Sheng Mining Co., Ltd.

Chemical composition wt.-%	**Guaranteed**	**Typical**	**Sample**	
			Sheng Sheng Analysis	**DERA Analysis**
ZrO_2+HfO_2	>65.0			66.2
ZrO_2				64.8
HfO_2				1.35
SiO_2	<33.0			32.9
TiO_2	<0.15			0.10
Al_2O_3	<0.80			0.40
Fe_2O_3	<0.10			0.08
Cr_2O_3				15 ppm
P_2O_5	<0.20			0.159
CaO				0.01
MgO				
Moisture (@ 105 °C)				
LOI (@ 950 °C)				0.16
U				508 ppm
Th				244 ppm
Parent activity U+Th				

Mineralogical composition (DERA Analysis):
Sample: 97.92 % zircon, 0.57 % various Al-silicates, 0.05 % rutile, 0.97 % quartz

Grain size distribution µm	**Guaranteed**	**Typical**	**Sample**	
			Sheng Sheng Analysis	**DERA Analysis**
>420				
355				<0.01
300				0.01
250				0.04
212				0.07
180				0.15
150				1.13
125				8.02
106				17.55
90				27.84
75				28.94
63				12.33
53				3.16
45				0.55
<45				0.20
Mean (µm)				94.3
D50 (µm)				99.5

Name: **Wenchang Sheng Sheng Prime Zircon 66 %**

Deposit: Kalimantan Island, Indonesial

Producer: Wenchang Sheng Sheng Mining Co., Ltd.

Chemical composition wt.-%	Guaranteed	Typical	Sample	
			Sheng Sheng Analysis	DERA Analysis
ZrO_2+HfO_2	>66.0			66.7
ZrO_2				65.3
HfO_2				1.35
SiO_2				32.8
TiO_2				0.07
Al_2O_3				0.19
Fe_2O_3				0.06
Cr_2O_3				15 ppm
P_2O_5				0.140
CaO				0.01
LOI (@ 950 °C)				0.12
U				250 ppm
Th				251 ppm

Mineralogical composition (DERA Analysis):
Sample: 98.74 % zircon, 0.16 % various Al-silicates, 0.15 % monazite, 0.05 % apatite, 0.46 % quartz

Grain size distribution µm	Guaranteed	Typical	Sample	
			Sheng Sheng Analysis	DERA Analysis
>600				>0.01
500				<0.01
420				<0.01
355				0.08
300				1.74
250				8.96
212				19.50
180				16.61
150				20.24
125				14.55
106				7.51
90				5.02
75				3.76
63				1.47
53				0.46
45				0.07
<45				0.02
Mean (µm)				177.6
D50 (µm)				188.1

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Front cover: Wet concentration plant at Moma, Mozambique
Zircon bags at KZN Sands, Republic of South Africa

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