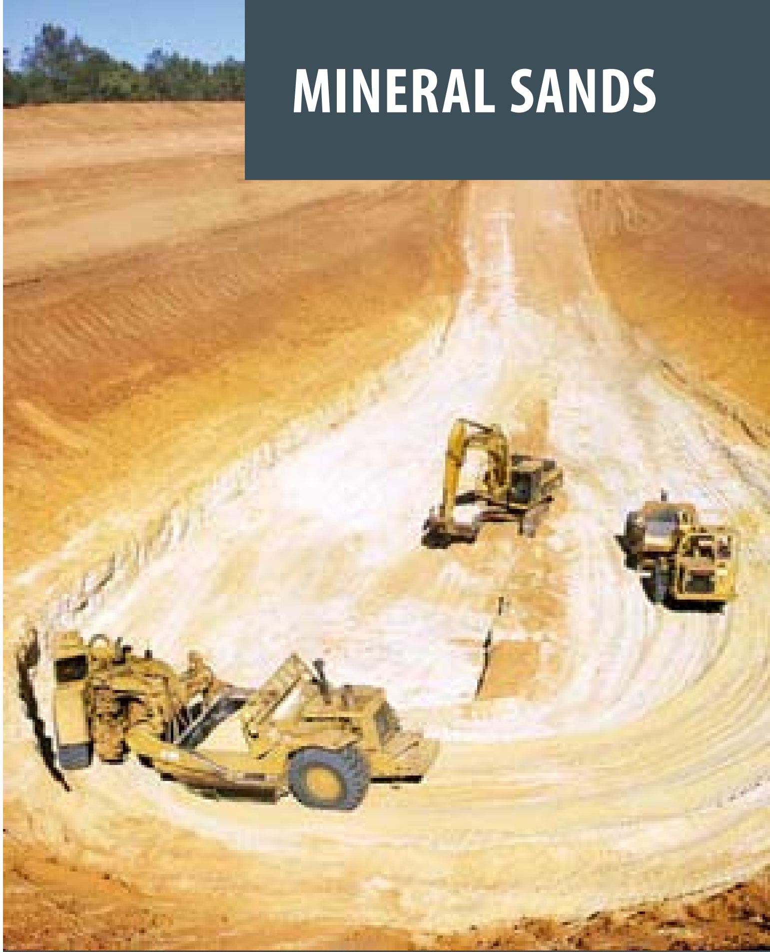

Photograph 16. Construction of a bulk sampling pit (2002) at the Ginkgo mineral sands mine, Pooncarie. The red and white sand exposed in the pit is the Pliocene Loxton-Parilla Sands, which hosts the mineral sands deposit. Construction of the Ginkgo mine was completed in late 2005. (Photography Bemax Resources N.L)

Potential and Outlook

The Murray Basin, much of which is in New South Wales, has the potential to become one of the world's major new mineral sands provinces (Figure 18). Total resources of coarse-grained heavy minerals (rutile, zircon, ilmenite and weathered ilmenite) identified in the Murray Basin exceed 100 Mt, of which over 80 Mt occurs in the New South Wales part of the basin. Development of these resources should see New South Wales regain its former position as a major world source of titanium minerals and zircon (Photograph 16).

Large resources of fine-grained heavy minerals also occur along the northwestern margin of the Murray Basin in New South Wales. Recent developments in mineral separation technology could improve the potential viability of these deposits.

Beach placers along much of the coast north of Sydney were formerly major sources of rutile, zircon and ilmenite. Mining has recently ceased and deposits are now largely depleted, uneconomic or not accessible owing to environmental constraints. Submerged barriers along the east Australian shelf, mainly near Tweed Heads and Forster–Tuncurry, north of Newcastle, where small deposits have been identified, warrant additional exploration.

Nature and Occurrence

Mineral sands are sand-sized occurrences of detrital minerals of high specific gravity (heavy minerals), including such minerals as rutile, zircon, ilmenite, magnetite, kyanite, sillimanite, monazite, xenotime, chromite, tourmaline, garnet and staurolite. These heavy minerals (Table 23) typically have a specific gravity greater than 2.9, are chemically stable, resistant to abrasion and commonly able, with the notable exception of ilmenite, to withstand diagenetic alteration (Baker 1962; Force 1991).

Table 23. Commercially important heavy minerals

Mineral	Theoretical Formula	TiO_2 Content (%)
Rutile	TiO_2	>95
Ilmenite	$FeO.TiO_2$	<70
Leucoxene	$FeO.TiO_2$	>70
Zircon	$ZrO_2.SiO_2$	Nil
Monazite	$(Ce,La,Nd,Th)PO_4$	Nil
Xenotime	YPO_4	Nil

Source: Holmes et al. (1982); Force (1991); Harben (1999)

Although heavy minerals form as accessory minerals in many igneous and metamorphic rocks, nearly all major economic deposits of these minerals, principally rutile, zircon and ilmenite, occur as detrital accumulations in young (Pliocene or younger) shoreline or beach placer deposits (Force 1991). Fluvial accumulations of these minerals are not globally significant. The potential for alluvial placer deposits of diamonds, sapphires and magnetite in New South Wales are not considered in this.

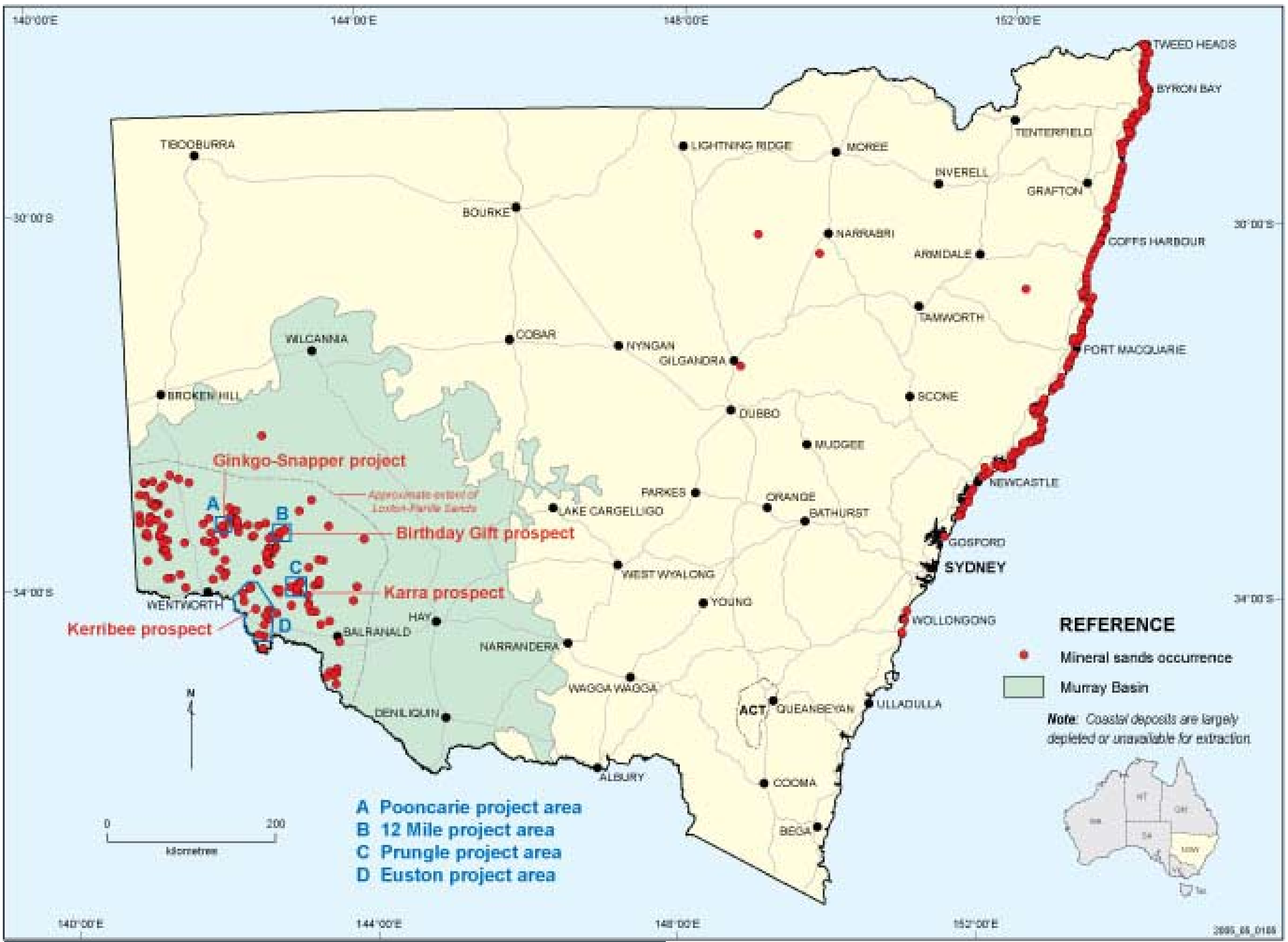

Figure 18. Mineral sands occurrences in New South Wales

Some of the main characteristics of the principal heavy minerals are as follows:

Rutile (TiO_2) has impurities, such as SiO_2, Cr_2O_5, Al_2O_3 and FeO, which invariably reduce the TiO_2 content from a theoretical value of 100% to between 94% and 98%. Rutile is the most important member of three TiO_2 polymorphs (rutile, anatase and brookite) and is the premium commercial titanium mineral. Titanium dioxide (TiO_2) has great opacity and a high refractive index — hence the demand for, and its use as, a white pigment.

Zircon (ZrO_2) is the principal zirconium mineral. Zirconite, hyacinth and jacinth are terms that are synonymous for zircon, although the last two are mostly used when referring to zircon as a coloured gem. Apart from numerous impurities, hafnium, zirconium's twin element with similar physical and chemical properties, can form small proportions (between 0.4% and 1.5%) of zircon.

Ilmenite generally contains between 35% and 45% TiO_2. Fresh ilmenite is commonly intergrown with iron or chromium oxide minerals, and thus may contain less TiO_2 than expected. However, leaching of iron from ilmenite during weathering can result in poorly crystalline mineral grains residually enriched in TiO_2. The term ilmenite commonly covers the entire range from unweathered ilmenite (TiO_2 <50%) to altered ilmenite (TiO_2 >60%). When the TiO_2 content of altered ilmenite exceeds about 70%, it is commonly referred to as leucoxene.

Monazite is the principal thorium heavy mineral in mineral sands deposits, containing up to 30% thorium and variable amounts of the rare earths (particularly cerium and lanthanum), as well as yttrium and uranium.

Xenotime is yttrium phosphate (YPO_4) — containing small amounts of cerium, erbium and thorium. Although rare in occurrence, xenotime may be recovered as a by-product during mineral sand mining.

In 2004, world production of rutile and ilmenite (all sources) was 5 200 000 tonnes, which consisted of 400 000 tonnes of rutile and 4 800 000 tonnes of ilmenite (Gambogi 2005). Australia was the leading producer of rutile and ilmenite (total of about 1 Mt), followed in importance by South Africa, Canada, Norway and India. Zircon production in 2004 was 860 000 tonnes, of which Australia was also the largest producer (about 460 000 tonnes), followed by South Africa and the Ukraine (Hedrick 2005).

Australian mineral sands production in 2006 came from deposits, in order of importance, in Western Australia and Queensland. In the Victorian part of the Murray Basin, the Wemen mine, east of Mildura, was an important source of mineral sands from 2001 to about 2004, when it closed because of declining mineral sands grades. That operation was the first mineral sands mine in the Murray Basin. Several other mineral sands projects are proposed for Victoria, with the Douglas mine in the southern margin of the basin now in production (2007).

Although New South Wales has been a major producer of minerals sands for many years, production ceased temporarily in 2003 with the closure of extraction operations near Port Stephens (near Newcastle). Mineral sands mining by Bemax Resources NL at the Ginkgo mine (near Pooncarie in western New South Wales) began in late 2005 and the first shipment of mineral sands concentrate from the mine to a mineral separation plant at Broken Hill occurred in early 2006. New South Wales is again destined to become a globally significant source of premium-quality rutile, zircon and ilmenite.

Deposit Types

The geological processes that are responsible for the development of commercially significant deposits of titanium and zircon minerals are as follows (Force 1991; Harben & Kužvart 1996; Roy 1999; Roy et al. 2000).

- The accumulation (magmatic segregations) of dense oxide-rich liquids in cooling magmas of the anorthosite–ferrodiorite suite, in alkali intrusive deposits, skarns and as relict TiO_2 in titanium-rich rocks.
- The concentration of heavy minerals in a range of coastal sedimentary environments — dominated by aeolian, wave and tidal processes. Heavy minerals also occur in fluvial placers but they are (globally) relatively insignificant. Although the concentration mechanism at the site of deposition is initially mechanical, diagenetic processes may alter the primary mineralogy and grainsize. Heavy minerals concentrations in sedimentary settings typically occur as:
  - high-grade, continuous, relatively coarse-grained beach placer (shoreline) deposits in well-sorted sandy sediments on the shoreface
  - low- to moderate-grade, irregular occurrences of fine- to relatively coarse-grained heavy minerals in clay-rich, less well-sorted sandy sediments in dune or washover deposits behind the shoreface
  - disseminated deposits of fine- to very fine-grained heavy minerals in clay-rich sandy sediments in adjacent shallow marine settings.

Beach placers supply almost all the world's heavy minerals. Ilmenite deposits in rocks of the anorthosite–ferrodiorite suite supply most of the remaining demand for titanium minerals. Some production of titanium minerals comes from fluvial placer deposits (Gbangbama, Sierra Leone) and from deeply weathered alkaline pyroxenite (Brazil).

Several other deposit types could become economic in the future:

- rutile from eclogites
- rutile from contact-metasomatic zones of alkaline anorthosites
- rutile by-products from porphyry Cu–Mo deposits.

Other possible sources of detrital titanium minerals include submerged barriers on inner continental shelves, Pleistocene glacio-lacustrine deltas, older partly indurated beaches and friable (weakly cemented) sandstones.

Extraction of mineral sands deposits is generally undertaken either by dry mining or wet mining (dredging) techniques (Force 1991). Spiral separation technologies are initially used to separate heavy minerals from their enclosing sediments. Magnetic and electrical methods are used to separate individual heavy minerals. Additional processing and/or upgrading of mineral sands products is undertaken to produce synthetic rutile, slag and 'micronised' (very fine) zircon (Harben 1999).

Main Australian Deposits

In Australia, the commercially important heavy minerals are rutile, zircon, ilmenite and monazite. They occur almost entirely as beach placer, dune and offshore deposits that range in age from older inshore deposits of Pliocene age (5–6 million years) in the Murray Basin, to deposits of Pleistocene and Holocene (<120 000 years) age along the eastern and western coasts (Roy 1999).

Intensive exploration in recent years has identified numerous deposits of heavy minerals along the Western Australian coast, the Eucla Basin in South Australia, and in the Murray Basin (Table 24), which extends across an area of about 300 000 km² in South Australia, New South Wales and Victoria.

New South Wales Occurrences

Beach placers in coastal dunes of Pleistocene and Holocene age have been the traditional source of mineral sands in New South Wales. Numerous deposits occur (or occurred) between Gosford and Tweed Heads (Figure 18). Available resources, however, are now almost entirely depleted or are not available for extraction owing to environmental restrictions. Remaining deposits are small and of variable quality. Although offshore sediments at several localities were found to contain heavy minerals, only minor deposits were defined (Whitehouse 2007). Their economic potential depends not only on their original concentration of heavy minerals, but also on those beach deposits surviving intense reworking that occurred during ensuing marine transgressions.

The Murray Basin (Figure 18) has the potential to become one of the world's major mineral sands provinces (Whitehouse et al. 1999). Intensive exploration in recent years has identified numerous coarse-grained beach placer deposits with economic potential associated with the Pliocene Loxton-Parilla Sands. Many of the deposits are associated with northeast–southwest topographic ridges — the Neckarboo and Iona Ridges are probably the most important — that appear to be structural blocks that developed in response to growth faulting (Roy & Whitehouse 2003). Those blocks intersected the coast to form 'virtual' headlands that favoured the progressive accumulation of heavy minerals. Winnowing by storm waves is believed to have formed beach placers on the uplifted fault blocks from sands derived from underlying Miocene sediments that already contained some heavy mineral concentrations.

Typically, Murray Basin heavy mineral deposits are ilmenite-rich, with 30% to 40% rutile and zircon (Roy et al. 2000). They occur as single, or multiple, deposits commonly 5 m to 10 m thick at depths ranging from near-surface to more than 50 m. They have heavy mineral grades that exceed 20% in places, are generally several hundred metres wide and 5 km to 25 km long. The Ginkgo deposit, near Pooncarie, is of unusual thickness — and contains up to 30% heavy minerals in mineralised zones with total thicknesses up to 40 m. The Ginkgo deposit is believed to represent stacked beach facies that accumulated in the early Pliocene in response to multiple sea level fluctuations with amplitudes of 30–40 m (Roy & Whitehouse 2003).

Although there are many deposits of commercial potential, they are commonly overlain by thick accumulations of younger aeolian and fluvial sediments, or are downfaulted to depths not amenable to current mining technologies. One of the major challenges facing the mineral sands industry in the Murray Basin is the development of innovative mining technologies capable of mining these deposits. The rutile and zircon assemblages are comparable in grainsize and quality to deposits traditionally mined in Australia and can be readily separated and concentrated to yield saleable products (Roy et al. 2000). The production of clean ilmenite concentrate, however, is restricted by the presence of detrital chrome-spinel, which is difficult to separate from ilmenite. The commercial potential for monazite and xenotime in these deposits is unknown.

Total resources of coarse-grained beach placer deposits of mineral sands (rutile, zircon, ilmenite and altered ilmenite) identified within the Murray Basin are about 115 Mt, much of which occurs in the New South Wales part of the basin. In New South Wales the most significant beach placer deposits identified so far include (Figure 18, Table 24) the Ginkgo and Snapper deposits west of Pooncarie (Pooncarie project area); the Castaway, Dispersion, Earl, Kerribee and Koolaman deposits northwest of Euston (Euston project area); the Birthday Gift, Western Strands and Triangle deposits east of Pooncarie (12 Mile project area); and the Karra and Cylinder deposits northwest of Balranald (Prungle project area) (Table 24).

Table 24. Selected beach placer mineral sands resources, Murray Basin, New South Wales, 2005

Project Area (cf. Figure 18)	Resource Size (Mt)	Valuable HM Content (Mt)
Pooncarie (Bemax Resources NL)	305.0	12.7
Euston (Iluka Resources Limited)	45.8	4.6
12 Mile (Bemax Resources NL)	161.0	3.4
Prungle (Bemax Resources NL)	205.0	5.5
Total	**716.8**	**26.2**

Source: Bemax Resources NL (2004); Iluka Resources Limited (2004).

The Pooncarie and the Euston project areas are the most important mineral sands resource areas. Recent work in the area north to north-east of Balranald have highlighted the potential of this region for large accumulations of heavy minerals. Although some of the deposits found so far are relatively deep, plans to exploit these resources with existing mining methods are being developed.Production at the Ginkgo deposit began in December 2005 and is likely to begin at the nearby Snapper deposit during the next few years. Between December 2005 and January 2007, about 128 000 tonnes of rutile and zircon, and almost 172 000 tonnes of ilmenite (and leucoxene) were obtained from the Ginkgo mine (Bemax Resources Ltd pers. comm. 2007).

Large deposits of fine-grained mineral sands, known as WIM-style deposits, occur in the northwestern part of the Murray Basin in New South Wales, and in the southern part of the basin in Victoria (Whitehouse et al. 1999). This style of deposit is not economic at present because conventional spiral separation techniques could not effectively recover fine-grained heavy minerals from host sand. Recent improvements in spiral separation technology and the development of new processing techniques, however, should see WIM-style deposits become economically viable.

Older sandstones may have some potential for heavy minerals in New South Wales. Heavy minerals are found in the Triassic Hawkesbury Sandstone, near Sydney, but these occurrences are generally of low grade. Heavy minerals deposits in Cretaceous sandstones in the Coonamble Embayment, Surat Basin, west of Narrabri, are also of low grade and are mainly fine-grained (Cook 2000).

Applications

About 95% of all titanium-bearing mineral sand products are used in the titanium dioxide pigment industry (Harben & Kužvart 1996). Titanium dioxide is used predominantly as an opaque white pigment to impart whiteness, brightness and opacity. Titanium dioxide pigment is the premier white pigment and is used in UV-resistant paint and plastics, high-quality paper, rubber, ceramics, fabric, toothpaste, soap, cosmetics, food and sunscreens. Other important properties of titanium dioxide include its chemical inertness, resistance to UV degradation and thermal stability over a wide range of temperatures.

Rutile, ilmenite (and leucoxene) are also used as sources of titanium metal and in flux coatings on welding rods. Titanium metal is used mainly where lightweight, strong and corrosion-resistant materials are required (Harben 1999). It is used to form surgical components, such as heart pacemakers and artificial limbs/joints, as it is the only metal not rejected by the body, or as a lightweight metal for aircraft and spacecraft components.

Zircon is generally considered a by-product or co-product in the extraction of ilmenite or rutile. About half the world's zircon production is used in the ceramic industry in glazes (to provide opacity) and to whiten ceramic bodies — including wall tiles, dinnerware, sanitary ware and decorative ceramics (Harben 1999). Zircon is widely used in TV screens and computer monitors to prevent radiation leakage. Industrial ceramics containing zircon are used in refractory applications requiring resistance to heat and abrasion. Other uses of zircon include the production of zirconium metal for use in pollution-control equipment and camera flash-bulbs; cubic zirconia crystals as a synthetic gem; rapidly rechargeable lightweight batteries; zirconium hydride in flares and fuses; and stannous hexafluorozirconate as an ingredient in toothpaste to prevent tooth decay.

Monazite is a major source of thorium and rare earth elements (including lanthanum, cerium, neodymium and yttrium). Thorium is used as a fuel in some breeder reactors and in the manufacture of welding rods, refractory moulds, ceramics, and fabricated alloys, aerospace parts and incandescent gas mantles. Rare earths have numerous applications in the manufacture of catalysts used in petroleum refining; high-strength permanent magnets; glass and ceramics; and superconductors — in addition to metallurgical and lighting applications.

Xenotime is an important source of yttrium.

Economic Factors

There is a long-term correlation between world pigment consumption and global Gross Domestic Product (GDP) growth (Force 1991). During the thirty years prior to 1999, the average annualised growth of world titanium pigment consumption has varied from 2.5% to 3.5% pa (Taylor & Moore 1999).

The market price of a titanium-oxide mineral concentrate is a function of its TiO_2 content and its suitability for a given process. Leucoxene, for example, tends to command a higher price than unweathered ilmenite. Therefore, the heavy mineral assemblage can have as much affect on the viability of an operation as the overall heavy mineral grade. Australian mineral sand deposits, which contain much higher proportions of rutile and zircon than their Indian and South African counterparts, have a distinct advantage in this regard.

Intensive exploration for mineral sands deposits is occurring in many nations, including Australia, Canada, Kenya, South Africa, Madagascar, India, Sri Lanka and the USA. Continental Africa has very large mineral sand resources. The major deposits include Richards Bay in South Africa, and the extremely large Corridor Sands Project in Mozambique, which alone has total reserves of 16.5 billion tonnes at 5.3% heavy minerals (predominantly ilmenite). However, the large African deposits tend to contain comparatively low-TiO_2 ilmenite. India also has large deposits of mineral sands, which are also dominated by ilmenite. In comparison to Africa, India and Australia, the USA has limited identified resources. Of the world's other resources of heavy minerals, the most significant appear to be in the Ukraine, though little information is available on those deposits.

Zircon is vital to the economic viability of the titaniferous feedstock industry. If present in significant quantities, it can make a significant contribution to the overall profitability of mineral sand deposits and substantially reduces the net cost of production of titanium dioxide minerals. The zircon market is relatively independent of trends in the supply of titaniferous feedstocks. Strong demand for zircon over the last few years, primarily in response to increasing ceramics consumption in China, has resulted in markedly higher prices. This may favour the development of zircon-rich deposits that have been found at several localities in the Murray Basin, and in the Eucla Basin in South Australia.

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