
# Beryllium

*By Gill Burke*

**In the second article in our series on strategic minerals Gill Burke analyzes beryllium, columbium/niobium, gallium, germanium, the "heavy minerals" and indium.**

## Uses

Beryllium is mostly used as an alloy with copper for electronic components: connectors, switches and relays. Continued emphasis on miniaturisation and faster processing speeds in computer equipment has led to steadily increased demand for beryllium/copper alloys in aerospace and defence uses as well as in automobiles. Beryllium metal has structural uses in aircraft frames, satellites and space vehicles. Beryllium oxide is also used in electronic components.

Relatively high price of beryllium limits its use to applications requiring light weight, high strength and high thermal conductivity. Substitutes are available: steel, titanium or graphite composites for beryllium metal, phosphor bronze for beryllium copper alloys and graphite for beryllium's nuclear applications. With all these however there is substantial loss of performance. In most cases substitution is an unattractive option; Japan, for example, imports all its beryllium supplies, but all the substitutes must be imported also. The USA, although the world's largest producer, also imported 140 short tons contained beryllium in 1987.

## Production and reserves

The USA has estimated deposits of 59.8 kt contained beryllium.

The Spoor Mountain area of Utah contains a proved reserve of 5.4 Mt bertrandite. This is currently mined and grades 0.23% beryllium. The US stockpile in 1988 contained 16.2 kt beryl ore; 6.7 kt beryllium copper master alloy and 263 t beryllium metal. A further 27.2 t of vacuum hot pressed beryllium billets were purchased on a 19 MUSD contract in July 1988 for delivery from September through to 1989. Domestic USA production was 254+ t.

Reliable quantitative information on other world reserves is unavailable, although the largest deposits are probably in Brazil, China and the USSR.

**Table 4**
**Beryllium: world mine production (t)**

| | 1986 | 1987 | 1988[1] |
|---|---|---|---|
| USA | 237 | 219 | 254 |
| Argentina | 1 | 1 | 1 |
| Brazil | 38 | 40 | 41 |
| Madagascar | 1.9 | 1.9 | 1.9 |
| Portugal | 1 | 1 | na |
| Rwanda | 1 | 1 | na |
| Zimbabwe | 1.9 | 4.5 | 4.5 |
| Other market econs | 1 | 1 | 1 |
| China | na | 54 | 54 |
| USSR | 76 | 77 | 77 |
| **World total** | **358** | **400** | **433** |

[1]1988 figures estimates, na = not available.

**Source:**
US Bureau of Mines

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The tables in our series on strategic minerals are numbered consecutively, starting with the first article in Vol 7 No 2.

***"Beryllium's thermal and optical properties are essential to fire control and forward-looking infrared optical systems. The LANTIRN system, compatible with the F-15E and other tactical military aircraft, also benefits from from beryllium' s light weight, low mass and high stiffness characteristics. This unique, new military electro-optical system will enable pilots to fly beneath enemy radar in total darkness and attack at speeds exceeding 500 mph."***
***Brush Wellman 1986 Annual Report.***

Other current producers are believed to have limited reserves. Egypt has appreciable amounts of unexploited beryllium in the quartz veins of its tin/tungsten deposits although gemstone quality beryl has long been exhausted. Morocco also has beryl occurring at about 6% in coarse pegmatite in the Zenaga region and at Ifni in the Anti-Atlas Mountains. These deposits were mined from 1948-1952 and produced about 550 t of beryl. In addition, large reserves, said to be enough to cover western Europe's needs for the next decade, were found in northern Norway in 1988.

## Producing companies

### NORTH AMERICA

With the bulk of world beryllium production located in the USA, monopoly control lies with *Brush Wellman Inc*, both as producer and supplier. The company is fully integrated; owns extensive mineral rights; operates the bertrandite mine in Utah; and owns and operates an extraction plant processing bertrandite and beryl ore into beryllium hydroxide.

The other USA beryllium producer is *Cyprus Minerals Co.* Formed in 1969 Cyprus Minerals was the mining subsidiary of *Amoco Corp*, but was spun-off in 1985.

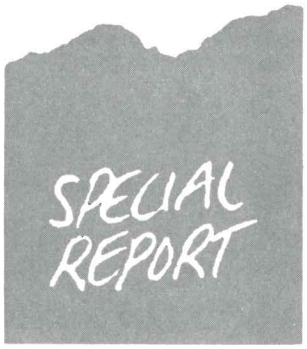
Cyprus is involved in beryllium mining in Brazil together with a Brazilian corporation. Its USA beryllium operation is near El Paso,Texas. This started out as a joint exploration venture with *Cabot Corp*, but in 1986 Cyprus entered into an agreement with Cabot to acquire the orebody. This indicated to be 11.34 Mt of BeO at a cut off grade of 2%. Cyprus also holds an option to purchase a Brazilian prospect from Cabot. In July 1988, Cyprus declared the company's first quarterly dividend, 10 US cents per share. This appeared to establish its staying power as a stand alone company.

### AFRICA

The principle beryllium producer is *Bikita Minerals (Pvt) Ltd*, incorporated in 1952 in Harare, Zimbabwe. The company mines the Bikita and Al Hayat quarries by open cast methods for a variety of minerals: lepidolite, caesium (pollucite), petalite, spodumene and beryl. Handsorting results in clean minerals of glass grade quality (less than 0.005% $Fe_2O_3$). There is a dry-grinding and a flotation plant. Major expansion in 1986 has extended the life of the operations to 30 years at nominal output of 30 t/year. Plant capacity is double that. Bikita Minerals is 50% owned by *RTZ Corp*. A further 25% is each held by *Amax Inc* and *Kerr McGee Chemical Corp.*

### EUROPE

There are two major European suppliers of beryllium. These are *Eli Mamane* of Portugal and *Industrias Polo Congregado SA* of Spain. The former is a small company, founded in 1985 and owning four mines at Belmont, Guarda and at Viseu producing quartz, feldspar, tantalite, mica and beryllium. Industrias Polo Congregado (also founded in 1985) is larger. It is not a primary producer but engages in marketing and processing. The company owns a processing plant at Paterna, Valencia. Its mineral products are zircon, rutile, ulexite, colemanite, chromite, bauxite and borax as well as beryllium. ■




# Columbium/ niobium

## Uses

Columbium and niobium are different names for the same mineral. Columbium is the name generally used in the USA and will be used herewith. The mineral is often discussed together with tantalum (see below) because they normally appear in the same orebodies. Columbium is chiefly extracted from the mineral pyrochlore or from mixed columbite/tantalite ores. It is used mainly as ferrocolumbium by the steel industry, and as columbium alloys and metal by the aerospace industry. It is important in the manufacture of specialized types of *high strength low alloy* (HSLA) steels and can also be used in nickel, iron and cobalt based superalloys. US usage in 1987 was 44% construction, 24% transportation, 13% oil and gas industries, 11% machinery and 8% others.

Substitutes for columbium are vanadium and molybdenum in HSLA steels; tantalum and titanium in stainless and highstrength steel and in superalloys; molybdenum, tantalum, tungsten or ceramics in high temperature applications. In each case there may be a performance or cost penalty.

## Production and reserves

There are an estimated 3.4 Gt of columbium, sufficient for over 300 years consumption at current levels. Resources are unevenly distributed, with 77% of world reserves found in Brazil. Output is dominated by Brazil and Canada with 96% of total production between them, of which the bulk is from Brazil. Both Japan and the USA import all their columbium. The USA has about 360 Mt of resources in identified deposits, but these are considered uneconomic at current prices and no significant mining has taken place since 1959. The USA stockpile of columbium at 30th September 1988 was 916 t of concentrate and 422 t of ferrocolumbium.

## Producing companies

### BRAZIL

The chief Brazilian and world producer of columbium is *Companhia Brasileira de Metalurgia e Mineração (CBMM)* whose head office is in Rio de Janeiro. The company is the major world producer of pyrochlore concentrates and ferro-columbium from its mine and smelter at Araxa in the Minas Gerais.

**Table 5**
**Columbium: world mine production**
**(t columbium content)**

| | 1986 | 1987 | 1988[1] |
|---|---|---|---|
| Brazil | 13.0 | 7.7 | 15.2 |
| Canada | 2.1 | 1.8 | 2.4 |
| Malaysia | 0.1 | 0.1 | 0.1 |
| Other market economies* | 0.2 | 0.2 | 0.1 |
| **Rounded world total **** | **15.4** | **9.8** | **17.8** |

[1] 1988 figures estimates, all figures rounded.

* Australia, Nigeria, Rwanda, Thailand and Zaire.

** Not including centrally planned economies

**Source:**
British Geological Survey, World Mineral Statistics 1984-1988

No production figures are presently available.

The shares in CBMM are privately held. The stockholders are:

*Moreira Salles 55%; Molycorp Inc* (a wholly owned subsidiary of *Unocal Corp*, Los Angeles) 45%.

Another important Brazilian presence is the *Anglo American Corp do Brasil Ltda* (Ambras), a subsidiary of *Anglo American Corp of South Africa Ltd.*, one of the largest corporate mining organisations in the world. Anglo American holds 45% 'A' shares and 100% 'B' shares in Ambras through *Benham Holdings Ltd*, which acts also as holding company for *Anglo American Corporation of South America SA*, Anglo's other Latin American subsidiary.

Ambras' produces ferrocolumbium at its 32% subsidiary *Mineração Catalao*. The company's other Brazilian interests are in gold, nickel, banking, agriculture and steel.

## CANADA

The only columbium mine in Canada is *Niobec* at Chicotimi, Québec.

Niobec was seriously affected by the slump in US steel production in 1984, leading to a period of closure. In 1986, *SOQUEM* (Société Québecoise d'Exploration Minière, wholly owned by the Québec government) reorganized its operations and set up a new company *Cambior Inc*, to which it transferred its interest in Niobec plus its 50% share of the Doyon open-pit gold mine. Niobec is a joint venture between *Teck Corporation* of Vancouver and Cambior Inc.

Teck Corp operates seven mines in various parts of Canada producing gold, columbium, zinc, copper, molybdenum and coal. In 1986 a group led by Teck formed a holding company *Nunachiaq Inc* to purchase a 31% interest (later increased to 41%) in *Cominco*, the integrated natural resource company with major activities in mining, smelting, refining, mineral exploration, fertilizer production and metals marketing. The group was formed by *MIM Holdings* (25%), *Metallgesellschaft AG* (25%) and Teck (50%). Teck's links with MIM and Metall go back some years. The corporation has been termed one of Canada's most dynamic diversified resource companies.

SOQUEM engages, directly or with others in mineral exploration and mining development ventures. In addition to Cambior the company holds a 37.78% share in *Sté Minière Louvem* Inc. It has interests in 46 mining properties, investments in *Sullivan Mines Inc, Aiguebelle Resources Inc, Muscocho Explorations Ltd* and *Sunburst Exploration Ltd*, plus other assets. A bank loan of 10 MCAD was conditional on the public offering of its shares in Cambior. After a consistent loss of earnings, rising to 78 MCAD in 1986, the company was reorganized. Net income then rose to 24.9 MCAD in 1987 and 6.9 MCAD in 88.

## Other companies

*Greenbushes Ltd* of Victoria, Australia, produces columbium as a by-product by way of tantalum out of tin. Thus some is also recovered from tin slags during processing for tantalum, as is the case in Thailand. These companies will be examined in more detail under the tantalum heading below.

*Fansteel* and *Teck Corp* have recently opened a columbium refining plant in Japan, since Japan has no domestic columbium resources. However, the decline in Japanese steel production brought a concomitant decline in ferrocolumbium output.

The major European supplier of columbium is *Hermann C Starck* of Berlin. The company is not a primary producer. The Starck group also supplies tantalum and fused alumina. Sales in 1985 totalled about 400 MUSD. A 90% interest in the Starck group was purchased in 1986 by *Bayer*, the West German chemical and metallurgical manufacturer. ■

**Table 6**
**Columbium: reserves and reserve base 1988** [1]
**(t columbium content)**

| | Reserves | Reserve base |
|---|---|---|
| Brazil | 3 220 000 | 3 630 000 |
| Canada | 122 000 | 315 000 |
| Nigeria | 63 500 | 90 000 |
| Zaire | 31 500 | 90 000 |
| Other market economies | 6 000 | 8 000 |
| **World total** | **3 443 000** | **4 130 000** |

[1] 1988 figures estimates

**Source:**
US Bureau of Mines


# Gallium

## Uses

Gallium occurs in very small concentrations in many rocks and ores of other metals. Most of it is produced as a by-product of treating bauxite and the remainder from residues of zinc processing. Its principal use is as gallium arsenide. About 95% of gallium consumed in the USA was as gallium compounds to produce semiconductors, light emitting diodes (LEDs), laser diodes and other electronic devices. Theses devices were incorporated into computers, fibre optics, communications systems and satellites. It is also used for the manufacture of gadolinium-gallium-garnet (GGG) for production of bubble memories. A recent development has been Al-GaAs, aluminium-gallium-arsenide.

Gallium-arsenide have high priority with the US military. Indeed it is estimated that one quarter of demand for new generation computer chips made from GaAs crystals will come from the *Strategic Defense Initiative* (SDI or 'Star Wars'). Some 172 MUSD has already been committed to SDI work on GaAs in *monolithic microwave integrated circuits* (MMIC) through 1991. So far, the high cost and difficulty of producing high-purity gallium crystals has hindered commercial application despite the race to build the 'fifth generation super computer.' GaAs chips cost 175 USD for a 3 inch wafer in 1987. However, *Vitesse Electronics,* of Camarillo, California and *Sumitomo Electric* of Japan both claim to be beginning mass production of GaAs chips.

Substitutes for gallium in LEDs are liquid crystals made from organic compounds. Silicon and indium phosphide are alternatives for gallium in many semiconductor applications.

## Production and reserves

1987 world primary production of gallium was estimated to be about 50 t with Japan, France, and West Germany as largest producing countries. Japanese consumption of gallium was 70% of world total in 1984 and is growing at annual rate of 36%. Countries with smaller output were China, Czechoslovakia, Hungary and the USA. In 1987 there was no gallium or GaAs in the US stockpile.

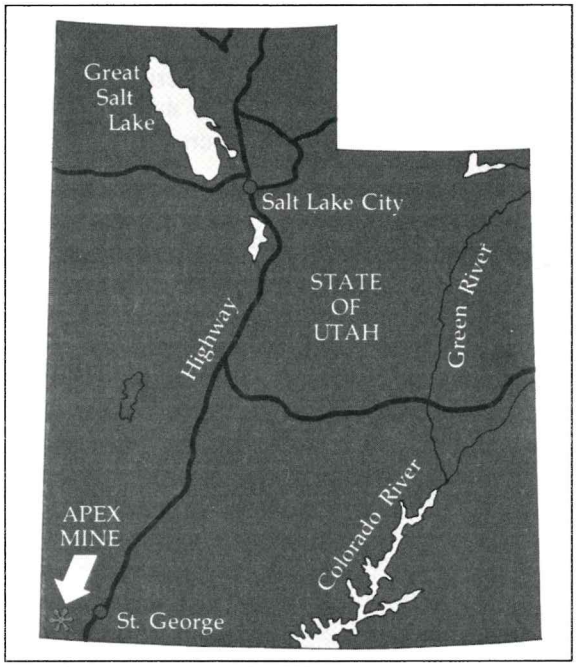
Despite its growing and specialized use, the price of gallium has remained stable and relatively low over the past five years. Prices are related to purity of metal. In 1987 prices went historically low at 285 USD/kg for 4N metal. 1988 prices were in a range 300 – 400 USD for 4N metal and 6N metal around 460 – 470 USD/kg. Earlier cutbacks in aluminium smelting did not firm price as much as might have been expected. Despite this, there has been considerable expansion in gallium recovery and refinery capacities over recent years in preparation for an expected increased demand and tightening price by the 1990s.

Supply of gallium is linked closely to the world bauxite market. Thus on the one hand there can be no possible shortage since world bauxite reserves are so large, whilst on the other, any cut back in aluminium smelting decreases supply. Thus meaningful estimates of current reserves cannot be made. Only part of the gallium present in bauxite is recoverable and its concentration is low, averaging 0.005%.

## Producing companies

Only one company appears to actually be a primary producer This is *Musto Explorations Ltd* whose head office is at Vancover, Canada. The company operates the Apex mine, mill and processing plant in St George, Utah, USA, through its subsidiary company *St George Mining Corp (USA).* Unique because specifically built to produce two metals usually derived from by-products, output was rated at 10 t of gallium and 19 t of germanium per year. First sales of gallium and germanium products were made in 1986. The venture has not been successful and in September 1987 went

***Location of St George Mining's Apex mine in Utah, USA. The mine, controlled by Musto Exploration, is the only primary gallium producer in the world.***




into the hands of the bankruptcy receiver.

Total sales from St George Mining were 1 MUSD, compared with total cash operating cost of 4.7 MUSD. Output was 746 kg gallium, 2.5 t germanium and 1.2 t copper. Reserves at end of 1986 were 271 890 t grade 0.034% gallium, and 0.093% germanium.

In 1987 throughput was doubled over the 1986 average of 856 t/month and it was hoped that a positive cash flow would be generated. This did not prove to be the case largely because of technical difficulties connected with the plant itself.

However as the markets both for gallium and germanium remain strong, various other mining companies have subsequently considered St George Mining, not least because of its potentially strong position to supply the USA stockpile. In July 1988, *Hecla Mining* signed an option agreement of four months thus gaining a closer look at the mine and plant workings. Hecla itself is a successful gold and silver producer not previously known for involvement with other strategic minerals.

Considerable new capacity for gallium production has appeared worldwide over the past year or two especially the expansion of recovery and refinery plant capacity. In Czechoslovakia extraction capacity by *Zavod*, the state enterprise at their Ziar plant was planned to double to 2 t/year by 1990. Similarly, the primary gallium plant of the *Hungarian Aluminium Corp* at Ajka aimed to double extraction to 8 t per year by 1988. *Ingal's* Schwandorf plant in West Germany increased its annual capacity to 15 t per year in 1987, although the extraction plant at Lünen closed. New plants that came on stream late 1987/early 1988 were Alcan's 4 t/year unit at Jonquire in Canada and a 4-5 t/year recycling plant at Kingston Jamaica; *Elkem* at Bremanger, Norway set up a new 5 t/year plant.

The major player in the expansion of gallium production is the French TNC *Rhône Poulenc* (RP). Already a leader in gallium production, Rhône Poulenc has spent 150 MAUD on building a gallium plant at Pinjara, Western Australia with a capacity of 50 t/year. This is expected to commence production in 1989. Rhône Poulenc has also constructed a purification plant at Freeport, Texas, USA. This should also have 45 kt/year capacity. The aim of the Freeport plant is to produce high purity metal of 6N - 8N gallium. These moves will effectively double worldwide gallium capacity. In addition, the company is also offering to recycle GaAs waste generated in producing pure gallium crystals at its plant at Salindres, France.

Rhône Poulenc supplied a consortium of European scientists with the 30 t of gallium they required late 1989 for an experiment with neutrinos. Originally the Swiss firm *Sulzer* had hoped to produce and supply the necessary gallium at a plant it was building in Louisiana, USA. This was to be fed by *Kaiser's* alumina refinery at Gramercy. However, conflict of interests over the patents on the plant has led to RP now supplying Sulzer.

These moves pose a big threat for the major Japanese gallium producers. *Dowa Mining*, whose head office is in Tokyo is the only primary producer in Japan. Dowa recovers an estimated 6 t/year of gallium from zinc blende (sphalerite) ore as a by-product of zinc at its *Akita Zinc Co* Iijima refinery. In 1986 Dowa decided to make some of its mines independent. This involved capitalization and rationalization of two mines, Uchinotai and Hanaoka, with 30% reduction of output. Conversely, Dowa stated that it intended to place more emphasis on the recovery of rare metals with hopes for 7 t/year of gallium, 1.5 t/year of germanium and 4 t/year indium.

*Sumitomo Chemical*, a member of the Sumitomo Group, is even more directly affected by Rhône Poulenc's threatened output increase of gallium since it produces four to five Nines purity gallium at its works at Ehime, Shikoku Island. The works, which have been operating for three years cost 13.3 MUSD. Its operating capacity is 50 t/year but this has not been regularly achieved.

Competition with Sumitomo Chemical has not, however, prevented another division of Rhône Poulenc from establishing a joint venture with another division of the Sumitomo Group for the manufacture and sale of rare earths in Japan. This company *Nippon Rare Earths KK* will be discussed more fully below. Nor do ventures that exclude Japanese interests in Western Australia prevent RP from adopting an aggressive stance towards other Australian competitors. ■


# Germanium

## Uses

Germanium is usually derived as a by-product from copper or zinc. It has many special applications in electronics, chemotherapy, polymer chemistry and optical instrumentation. Germanium is incorporated into solid state devices, including LEDs for lasers. It has both civil and military use in infra-red detection devices and in fibre optics. These latter uses are increasing whilst electronic use of germanium shows a downward trend. The Japanese are having success in the full scale development of optical fibre telecommunications systems, using germanium oxide cored fibres as a transmission medium.

Less expensive silicon has increasingly been substituted for germanium in certain electronic applications. Bimetallic compounds of tellurium, selenium, indium and gallium can also be substituted. However germanium is more reliable in some high- frequency and high powered applications and is more economical as a substrate for LEDs. Zinc selenide or germanium glass can be substituted for germanium metal in infra-red guidance systems, but at the expense of performance.

More than 50% of the metal used in manufacture of electronic and optical devices is routinely recycled as new scrap. As a result of dispersal of microelectronic devices, very little germanium is returned as old scrap. Thus high purity optical devices may ultimately constitute a large source of recyclable material.

## Production and reserves

World mined production is centered on Zaire, the USSR, Namibia and the USA. Europe is the major producer of refined germanium utilizing concentrates from Zaire, Namibia and (less pure) from China. Germanium output is ultimately dependent on current rates of base metal production and the availability of germanium bearing residues. Production of germanium rich zinc concentrates from Zaire ceased in 1981 but subsequently resumed. Only approximate estimates of most output is available. 1981 ore production was estimated at 22.5 t for Zaire and 7.3 t for Namibia. No figures are available for the USSR, but the USA imports about 1-2% of its germanium from there. Total USA germanium imports were 30 t in 1987.

The price of germanium has shown considerable volatility. In 1980-82 there were peak prices of 1 250 USD/ kg for the metal and 850 USD/kg for the oxide. The rise was caused by an influx of speculators enthusiastic about

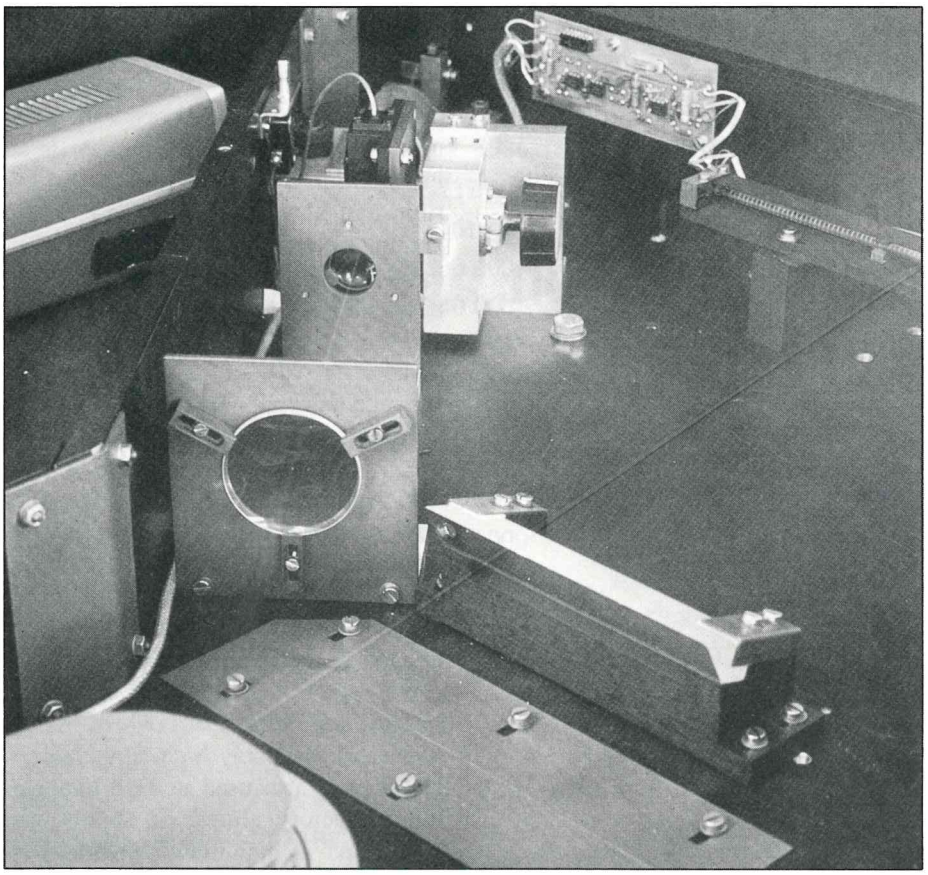
**Table 7**
**Germanium: world refinery production 1986-1988 (t)**

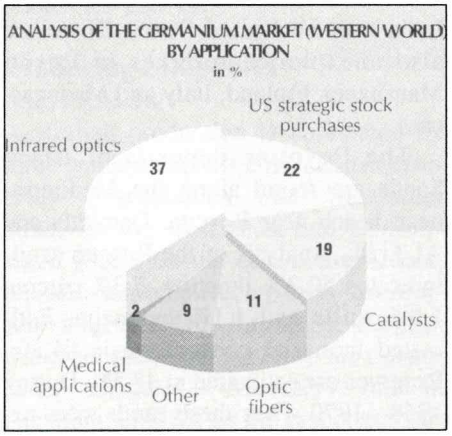
| | 1986 | 1987 | 1988[1] |
|---|---|---|---|
| USA | 22 | 25 | 21 |
| Zaire | na | na | na |
| Other market economies | 41 | 40 | 45 |
| Centrally planned economies | 17 | 17 | 18 |
| **World total (excl Zaire)** | **80** | **82** | **84** |

[1] 1988 figures estimated, na= not available

**Source:**
US Bureau of Mines

***Germanium is used to monitor a laser beam in a high powered laser writer (right).***
***The germanium market by application in 1989 (below).***






germanium's prospects in electronics and optic fibres. Prices fell from 1985 due to expectations of Musto Explorations' increased production. Lowest point was 350 USD/kg. Notice of Musto's suspension in 1987 brought prices up to 460 USD/kg The price on the USA free market on 6th June 1989 was 590 - 610 USD/kg.

Nonetheless despite price sensitivity, available resources in zinc and lead-zinc-copper sulfide ores are fairly readily available. If germanium were to be recovered from ash and flue dusts resulting from burning certain coals for power generation, worldwide germanium resources would become several thousand tons.

Germanium is classified as strategic by the United States. There was 11.7 t in its stockpile at end September 1988, but the goal was for 146 t. The *General Services Administration* (GSA) of the USA planned to meet this goal at the rate of 30 t/year. The GSA contracted to purchase some 30 t of zone refined germanium in late 1987 from contractors in USA, France, Israel and Belgium. Delivery times were stretched to August 1989 so as not to disrupt the market. Despite this, the potential tightening of supply caused price increases.

## Producing companies

Many of the gallium producing companies mentioned above, also produce germanium.

An important additional source is Zaire. Zairean germanium concentrates are produced by the state owned *Générale des Carrières et des Mines* (Gecamines) This organization is engaged in mining and processing of cobalt, copper, gold, silver, zinc and cadmium in Zaire, principally in Shaba province. Zaire is the world's largest producer of cobalt. The strategic importance of this was dramatically highlighted in 1978, when Shaba separatism was crushed by the use of French paratroops.

Gecamines has two hydrometallurgical plants for copper cathodes, at Shituru and Luilu; one pyrometallurgical plant for blister at Lubumashi; and one hydrometallurgical plant for zinc at Uzk (Kolwezi). The company currently has the capacity to refine only about half the copper it produces. The rest is refined by *Metallurgie Hoboken-Overpelt SA* of Belgium. In the past the company has exported germanium as magnetic copper-germanium concentrate and as a filter cake containing about 12% germanium obtained from smelter fumes. ■


# "Heavy minerals": ilmenite/rutile, monazite/zircon, hafnium

These minerals are taken together due to their common characteristics, and to their frequently being mined together either as mineral sands or as by-products of tin. Monazite concentrate is an important source of the rare earth Thorium and also of uranium and zircon. Hafnium is recovered as a by-product of hafnium free, nuclear grade, zirconium based alloys.

## Uses

Ilmenite and rutile are the chief sources of titanium and titanium oxide, - see below. Ilmenite contains roughly 95% $TiO_2$ and rutile 53%. Ilmenite supplies 90% of world demand for titaniferous material. It is also used in welding rod coatings and for manufacturing metal, alloys, carbide and chemicals. Monazite is used in the electronics industry. Zircon is used for high accuracy optics, ceramics and refractories where it can withstand extremely high temperatures. Hafnium is also used in high temperature refractory alloys, as an alloying agent, and in hafnium-columbium carbide for cutting tools.

Ilmenite and rutile are substitutes for each other, and synthetic rutile substitutes for both. Zirconium can be susbstituted with oxides of titanium and tin in ceramic uses and by stainless, steel, aluminium, columbium and vanadium in nuclear reactors. There are no substitutes for hafnium in its major applications: nuclear reactors and refractory metal alloys, but zirconium oxide can substituted in selected refractories and ceramics.

## Production and reserves

Australia is the world's largest producer of mineral sands and dominates world markets. The Australian industry exploits marine placer deposits on the east coast of New South Wales and Queensland; on the west coast south of Perth and the Eneabba district on the coastal plain. Fueled by strong European, Japanese and US demand for ilmenite,monozite, rutile and zircon Australian mineral sand prices have doubled over 1985–87. In 1986, the value of ilmenite exports increased to 46 MAUD a 24% increase over 1985; rutile jumped by 32% to 111 MAUD and zircon 20% to 67 MAUD Strong demand for $TiO_2$ brought prices from 425 AUD/t in mid 1985 to 600 AUD by late 1986. Ilmenite rose from 40 AUD/t to 60 AUD/t in the same period; zircon from 130 AUD/t to 170 AUD/t and monazite from 550 AUD/t to 850 AUD/t

Other major sources are Canada, India and the United States. There are also unexploited reserves in Egypt, Mauritania, Finland, Italy and Madagascar.

The Egyptian deposits of Black Sands are found along the Mediterranean beach near Rosetta, Damietta and Al Arish. Analysis of the Rosetta sands indicates 50.7% ilmenite, 7.3% zircon, 1.0% rutile and 1.1% monazite. Estimated monazite concentrate is 84.3%. Reserves are estimated at 47 Mt. During 1958 - 1970 when these sands were exploited 20 kt/year were produced. It seems surprising that no development is now being undertaken.

Mauritania also has Black Sands containing ilmenite, garnet, zircon and monazite along the shore at Ras Argwen, Ras Gyroom, Ras Mino, Tshilese etc, with reserves estimated at several million tons of sands containing 2.5 – 5.0% $TiO_2$.

Brazil has considerable reserves of rutile and smaller reserves of ilmenite, but output so far has been small and as a by-product of tin. The more substantial Malaysian output is also linked to tin mining. Indeed, during the early days of the tin crisis when many mines were suspended, one Malaysian company had to actually import ilmenite to meet contractual obligations to Japan.

Ilmenite is not defined as a strategic mineral by the USA, although its titaniferous end products most certainly are. Rutile is held in the stockpile, 39 kt

at end September 1988, with a goal of 106 kt. Monozite is not distinguished from other rare earths in the USA stockpile. Zirconium is not stockpiled by the USA but is by Japan.

Hafnium is not stockpiled and primary production details of hafnium are not available. USA reserves of hafnium associated with zircon amount to about 72.5 kt. The USA reserve base is about 145 kt.

Details of world mine production of ilmenite, rutile and zircon are given in Tables 8,9 and 10.

## Producing companies

### AUSTRALIA

Australian production is dominated by three major companies: *Associated Minerals Consolidated* and *Westralian Sands* on the west coast and *Consolidated Rutile* on the east coast. Lesser, but still important companies are *Mineral Deposits Ltd, Pasminco, Pioneer Concrete* and *Strategic Minerals Corporation*. Of the 13+ Mt reserve base in Australia, 2.72 Mt on the east coast cannot be mined because of environmental legislation.

### Associated Minerals Consolidated

Associated Minerals Consolidated was incorporated in New South Wales in 1953. It operates mines at Eneabba and Capel in Western Australia and at Green Cove Springs in Florida USA. The company has a synthetic rutile plant at Capel and another at Narngulu, W Australia. Ore reserves as of June 1986 were 1.2 Mt rutile, 2.8 Mt zircon, and 7.4 Mt ilmenite. Probable reserves included a further 1.116 Mt rutile, 2.044 Mt zircon and 6.2 Mt ilmenite.

Authorized capital is 50 MAUD in 100 000 000 shares of which 32.979 MAUD has been issued as 65 957 933 shares. The company is a wholly owned subsidiary of *RCG Pty Ltd*, itself a wholly owned subsidiary of *Renison Goldfields Consolidated*. The Chairman, Managing Director and Deputy

**Table 8**
**Ilmenite: world mine production (t)**[1]

| | 1986 | 1987 | 1988 |
|---|---|---|---|
| Australia | 1 237 694 | 1 498 087 | 1 442 894 |
| Brazil | 61 414 | 169 303 | na |
| Canada (a) | 2 500 000* | 2 400 000* | 2 500 000* |
| India | 140 000* | 140 000* | 140 000* |
| Malaysia | 414 941 | 509 202 | 486 305 |
| Norway | 802 426 | 852 323 | 898 035 |
| South African Rep | 255 000 | 317 000 | 350 000* |
| Sri Lanka | 133 873 | 128 500 | 97 085 |
| China | 145 000* | 145 000* | 150 000* |
| USA | 290 000 | 290 000 | 290 000 |
| USSR | 450 000* | 450 000* | 450 000* |
| Other market economies | 13 721 | 16 330 | 18 140 |
| **World total** | **6 900 000** | **7 600 000** | **7 800 000** |

[1] For figures of Ti content see map on page 25.

**Table 9**
**Rutile: world mine production**

| | 1986 | 1987 | 1988 |
|---|---|---|---|
| Australia | 215 744 | 246 263 | 246 204 |
| Brazil | 311 | 392 | na |
| India | 7 000* | 7 000* | 7 000* |
| Sierra Leone | 97 101 | 113 252 | 126 358 |
| South African Republic | 58 060 | 51 710 | 54 430 |
| Sri Lanka | 7 260 | 7 260 | 8 160 |
| USA | W | W | W |
| Centrally planned economies | 9 980 | 9 980 | 9 980 |
| **World total** | **395 000** | **435 000** | **460 000** |

* = Figures estimated

a) Processed into slag. Canada produces some ilmenite which is sold as such and not processed into slag, but tonnages are small. In 1988, Canada produced 950 000 t (80% $TiO_2$)

b) Ti content of titanium minerals and slag

W = witheld

na = not available

**Sources:**

British Geological Survey, World Mineral Statistics 1984 –1988, US Bureau of Mines

MD of Renison are also those of Associated Minerals. RCG itself is of course an associate company of *Consolidated Goldfields Plc*, itself now part of the Hanson Group.

The output of Associated Minerals Consolidated, together with that of another subsidiary, *Allied Eneabba Ltd*, make Renison the largest producer in Australia. Allied Eneabba, incorporated in Western Australia in 1972, has been mining and processing mineral sands at Eneabba, north of Perth, since then. The nominal plant capacity is 250 kt ilmenite, 50 kt rutile, 120 kt zircon and 10 kt monazite. In addition, there is a kyanite separation unit attached in 1985. At end 1985 Renison bought the 50% stake in Allied previously owned by *E I Du Pont de Nemours and Co* for 4.61 MAUD.

Renison subsequently acquired all remaining shares and since 1 January 1986 Allied has been a wholly owned subsidiary of RCG. Its Chairman, C Anderson is Managing Director of Renison and another of its Directors, WP Murphy, is on the Renison Board.

In 1986, the Western Australian government, in an effort to stem the flow of unprocessed monazite from companies like Allied Eneabba, encouraged a project to build a rare-earth extraction plant at Geraldton. In April, the WA Minister for Mines and Energy made a statement accusing the French TNC *Rhône Poulenc* (RP, see gallium above) of threatening to cut WA out of the world monazite market, and of using 'quite thuggish' tactics. Western Australia is the world's largest monozite exporter and producer. Exports of 15 224 t in 1984-85 were valued at 6.8 MAUD. Of this France, ie Rhône Poulenc, took almost 63%, 9 579 t; followed by the USA with 4 530 t and Malaysia with 1 115 t.

The Minister accused RP of world wide lobbying, including the board of *Asahi Chemical Industries Ltd* of Japan who were to have been technical partner in the proposed 80 MAUD plant

**Table 10**
**Zircon: world mine production (t)**

| | 1986 | 1987 | 1988 |
|---|---|---|---|
| Australia | 451 824 | 456 590 | 505 888 |
| Brazil | 15 116 | 18 140 | 28 029 |
| China | 15 000* | 15 000* | 15 000* |
| India | 16 000* | 16 000* | 16 000* |
| South African Republic (a) | 160 000* | 160 000* | 160 000* |
| Other market economies (b) | 15 248 | 21 860 | 31 569 |
| USA | 85 000 | 90 000 | 114 651 |
| USSR | 85 000* | 90 000* | 115 000* |
| World total | **843 000** | **863 000** | **959 000** |

* = estimates

(a) Including baddeleyite; (b) Malaysia, Sri Lanka, Thailand

**Source:**

British Geological Survey, World Mineral Statistics 1984 – 1988

**Table 11**
**Australian mineral sands**

| | 1986 | 1987 |
|---|---|---|
| Production of rutile (t) | 215 774 | 246 263 |
| Exports of rutile(t) | 229 665 | 250 000 |
| Value (MAUD) | 116.4 | 147.1 |
| Production of ilmenite | 1 237 694 | 1 498 097 |
| Exports of ilmenite | 1 034 209 | 1 043 000 |
| Value (AUD) | 48.5 | 54.9 |
| Production of zircon (t) | 451 824 | 456 590 |
| Exports of zircon (t) | 445 690 | 456 000 |
| Value (AUD) | 74.5 | 96.1 |
| Production of monazite (t) | 14 822 | 12 700 |
| Exports of monazite (t) | 14 100 | 11 400 |
| Value (AUD) | 9.2 | 8.4 |

**Source:**

Australian Bureau of Mineral Resources; British Geological Survey, World Mineral Statistic

planned with Allied Eneabba. There was talk that the sale of Du Pont's shares to Renison was connected with RP's wishes. This seemed to have at least some foundation when in early 1987 Associated Minerals Consolidated signed a long-term agreement for the whole of its monazite production to go to Rhône Poulenc and no plant was built.

Instead, Rhône Poulenc itself proposed to build a monazite processing plant at Pinjarra, Western Australia. The 150 MAUD project was to process about 15 kt monazite per year. Export earnings were projected at 100 MAUD per year.

In 1988 however, the Western Australia State Government's Environmental Protection Authority made known it's opposition to the proposal. The first stage, of 'cracking' the mineral sand into intermediate product, was approved by the authority; but the second stage was refused. This stage would have produced ammonium nitrate, radium and thorium as by-products and the authority feared that the ammonium nitrate tailings ponds would be contaminated by the radio-active radium. In January 1990, after two years of discussion, Rhône Poulenc announced indefinite postponement of the project.

**Westralian Sands**

Westralian Sands was incorporated in 1954 in Perth as an oil exploration company. The subsequent discovery of substantial ilmenite deposits in the Capel district however led to this becoming the company's major activity. Mining operations are at Yoganup. The North Capel mine having achieved above budget performance was mined out and decommissioned in 1987. A new mine was opened at Yoganup North the same year. The separation plant is also at Capel.

In March 1987, a 65 MAUD plant at North Capel to produce 100 kt/year synthetic rutile was opened. This effectively doubled Westralian's output and ensured its position as the world's leading synrutile producer. When production is complete, almost waste-free synrutile for titanium dioxide pigment should be produced. This represents an important downstream development for the WA mineral sands industry.

*Tioxide Australia Pty* is a 39% shareholder in Westralian and the major proportion of output is sold to the *Tioxide Group* under long term contracts. Another shareholder (16%) *Ishihara Sangyo Kaisha Ltd* also buys synthetic rutile under contract.

**Consolidated Rutile**

*Consolidated Rutile*, incorporated 1963 in Queensland, is a subsidiary (50.14%) of *Cudgen RZ Ltd* of New South Wales. Cudgen is not quite yet a subsidiary of anyone, although *Minasco Resources Pty Ltd* (a 100% subsidiary of *Gencor*, South Africa) holds 49.94% of its shares and *CTB Nominees Ltd Sydney* holds 14%.

The company mines rutile and zircon at North Stradbroke Island, Queensland and mills at Brisbane. An ilmenite upgrading plant commenced operations early 1987 with the capacity to produce 175 kt/year of low chrome ilmenite. Proven and probable reserves are 1.457 Mt. rutile and 1.317 Mt zircon. Production in 1986 was 99.201 kt rutile and 79.714 kt zircon.

The company is reported to have long term contracts with *Kerr McGee Chemical Corp* of the USA.

**Other Australian producers**

Of the less dominant companies *Mineral Deposits Ltd* (MDL) is a subsidiary of *Broken Hill Proprietary* (BHP), which has only recently emerged as a mineral sands producer of note.

The breakthrough for BHP came with the environmentally sensitive state of New South Wales approving a potential 20 MAUD/year project at Viney Creek on the central coast. MDL currently operates at Hawks Nest, north of Newcastle, NSW. Production is running at 30 kt/year rutile, 20 kt/year zircon, 10 kt/year ilmenite and 2 kt/year monazite. In addition, MDL has a dominant position in the extraction equipment market.

Other companies operating in New South Wales are *Pioneer Concrete Services Ltd* and *Pasminco Ltd.*.

The later operates in NSW through a 50% joint interest with *Coffs Harbour Rutile NL*. Coffs Harbour is, in its turn a 85.9% subsidiary of Pioneer Concrete.

Pioneer Concrete as its name suggests started out quarrying aggregates and manufacturing and distributing premixed concrete. Incorporated in 1954, the company has since diversified into oil and gas exploration and production; refining, shipping, distributing and marketing petroleum products as well as exploring, evaluating and developing uranium, base metals and mineral sands.

Pioneer's modus operandi is mainly by joint ventures. These ally it to many important TNCs such as *Amax Iron Ore Corp* and *Mitsui Coal Development (Australia)* (coal prospecting); *Electric Power Development Corp. of Japan* and *Mitsui Mining and Smelting Co Ltd* (coal mine development); *Pechiney* (silicon manufacture),and *Poseidon* (gold exploration).

The mineral sands mines are located at Newcastle, New South Wales, and near Bunbury, Western Australia. Output projections suggest that the mines are expected to supply about 6 per cent of world annual requirements for zirconium and 10 per cent of titanium.

In December 1989 the Japanese trading house *Nissho IWAI* purchased Pioneer's mineral sands operation for 240 MAUD, outbidding the Australian CRA and RCG and the Finnish mining company Outokumpu.

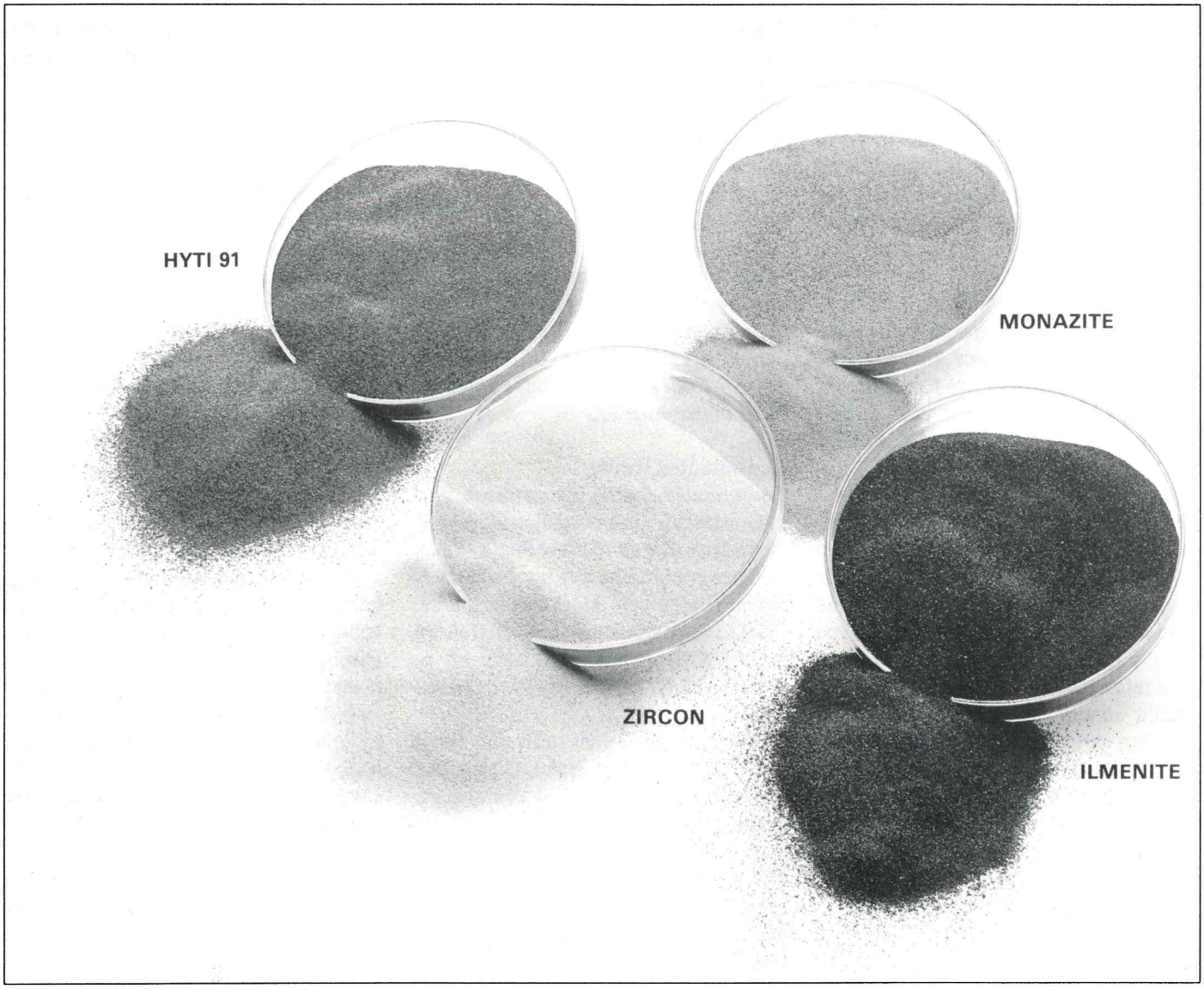
*Pasminco* (see under bismuth RMR Vol 7 No 2) has two heavy minerals

*Hyti 91 is a product containing rutile and leucoxene. The latter is an alteration product of ilmenite.) Both ilmenite and Hyti 91 can be used as feedstocks in two chemical processes that yield titanium dioxide pigments. these pigments have very high opacity and are used extensivelyin paints, paper and plastics. Hyti 91 is also used in welding electrode formulations.*

*Zircon is zirconium silicate with physical properties which make it especially suitable as a foundry sand and as an opacifier in ceramic glazes. Large tonnages of zircon based refractories are used in steel- and glassmaking.*

*Monazite is a mixture of rare earth phosphates. The rare earths can be separated by solvent extraction to produce a wide range of metals, oxides and other compounds. Among the many uses of rare earths are polishing powders for optical lenses, glass compositions (eg cameras, microiscopes), magnets for miniature earphones and red phosphors for colour television sets.*

*Ilmenite is an iron titanate from which the iron can be readily removed to produce titanium.*
*Photo and text from Westralian Sands, Annual Report 1982.*




joint ventures, one with *Australian Anglo American Gold Pty Ltd* (Peko 60%) to treat tailings at Mt Morgan mine and the other with *Coffs Harbour Rutile* mentioned above. The mineral sands operation is at two mining plants at Tomago in the Newcastle area. Output in fiscal 1986 was 33.5 kt rutile, 46.2 kt zircon and 63 t monazite.

The remaining Australian companies are in Queensland and in Perth, Western Australia. They are *Currumbin Minerals Pty Ltd.*; and *Strategic Minerals Corp* NL.

Currumbin is a wholly owned subsidiary of *Neumann Associate Cos Pty Ltd* and all its directors are members of the Neumann family. The head office is in Currumbin, Queensland and its mining operations at Kirra in Queensland and Kingscliff, NSW. It has a treatment plant and grinding mill at Currumbin. In 1984 the company produced 5 kt of rutile sand and 6 kt of zircon sand. Reserves are estimated to be good for twenty years mining.

Strategic Minerals Corp is still at the exploration stage for mineral sands. It was incorporated in 1979 as an energy mineral exploration company, but now focuses on gold, strategic and other precious minerals and has prospects in NSW, Queensland and W. Australia.

Joint exploration ventures are with Shell Co of Australia Ltd; RZM (Newcastle) Ltd; Hawk Investments Ltd; Homestake Australia Ltd and Hunter Resources Ltd. The company also has a 25% interest in the Golden Spec/Blue Spec gold antimony mine in W Australia, due to start producing gold 1988.

## Other producers

These are loosely grouped by region/country.

### SOUTHERN/WEST AFRICA

Amongst the proliferation of mining operations in Africa few are notable for heavy mineral production. Those that are already subsidiaries of major TNCs. Of these, the South African *Palabora Mining Co Ltd* is probably the most important. The company was formed in 1956 by *Rio Tinto of South Africa Ltd* and a group of companies headed by *Newmont Mining Corp* to develop a low grade copper deposit in Northern Transvaal. RTZ has a 38.9% beneficial interest. By-products of the copper process include uranium oxide, magnetite, zirconium products, nickel sulphate, sulphuric acid and small quantities of gold, silver and platinum group minerals. Magnetite concentrates in 1986 were 110 kt with 1.18% $TiO_2$. There are concentrating, smelting and refining plants at the Palabora complex, thus moving some way downstream before selling.

The other South African companies, *Tisand (Pty) Ltd* and *Richards Bay Iron and Titanium (Pty) Ltd,* have mining and smelting facilities. Their operations will be discussed below under *QIT* of Canada.

On the other hand *Sierra Rutile Ltd,* in Freetown, Sierra Leone, whilst a significant producer has no processing facilities. Incorporated in 1971 it dredge mines in the Bonthe and Bamba/Belebu districts of Southern Province. A tailings plant augmented production by 8 kt/year from 1986-1988. Output in 1986 was 97.1 kt rutile.

In 1983, Sierra Rutile became a wholly owned subsidiary of *Nord Resources Corp,* of Delaware USA. Nord engages in the mining and processing of rutile and perlite and in the exploration for strategic and precious minerals. Joint ventures with Highlands Energy Corp, San Francisco, USA, explore for gold, precious metals and strategic minerals in Australia, Papua New Guinea and western USA.

In November 1989, *Kenmare Resources*, a Dublin based mining company announced plans to go ahead with a 100 MUSD mineral sands project at Congolone near Angoche on the northern coast of Mozambique. The ten years proven mineable reserves are expected to yield two thirds ilmenite and one third zircon. Kenmare will have a 71.25 per cent equity interest in the project, the Mozambique government 25 per cent and the *Geological Survey of Yugoslavia* (which identified the reserve) 3.75 per cent.

### INDIA/SRI LANKA

The State owned *India Rare Earths Ltd* process mineral sands in Kerala, Tamil Nadu and Orissa states. A synrutile plant was commissioned at Orissa in 1986. The company has two divisions. The mineral sands division produces, manufactures and exports ilmenite, rutile and zircon; the rare earth division produces rare earth chemicals and will be referred to below. In 1984 135 kt of ilmenite was produced, 5.5 kt rutile and 8.4 kt zircon.

In Sri Lanka, the *Ceylon Mineral Sands Corp.* mines, processes and exports ilmenite, rutile, zircon, monazite and high-titanium ilmenite. Incorporated in 1957 in Colombo, the company is a wholly local operation. All its Directors are Sri Lankan and there seems to be no connection with any overseas company or TNC although no details are available after 1985. Output in that year was 11.5 kt ilmenite, 8.6 kt rutile and 4 kt zircon.

The third company, *New India Mining Corp Pvt Ltd,* is only marginally a heavy minerals producer. Its principal activity is open cast iron ore mining and export. These operations are at Redi. The company also operates the Dongarpal manganese mines and the Ventura silica sand mines. No details are available later than 1984. The company appears to have no major non-Indian shareholders, nor links with any TNCs.

### MALAYSIA

The four Malaysian companies are all tin producers. Three are close to each other in Selangor state. One of the four is a private company, one a Malaysian subsidiary of an American corporation; the other two are associate companies of *Malaysia Mining Corporation.*

In the price debacle that followed the collapse of the ITC the production of ilmenite, zircon and monazite helped keep many operations going, although all companies laid up many of their dredges.

*Berjuntai Tin Dredging Berhad,* in Selangor, and *Tronoh Mines Malaysia Berhad,* in Perak, are both Associated Companies in the MMC group. Of these Berjuntai is by far the most significant mine, indeed is one of the most important in Malaysia. MMC holds 37.4% but as the two other principle shareholders, *London Tin (Malaysia) Bhd* (27.49%) and *Anglo Oriental (Malaya) Sdn Bhd* (9.83%) are both wholly owned subsidiaries of MMC, the group share is virtually total.

There are nine dredges at Berjuntai, although only four were in operation in 1986. Rough concentrates yield ilmenite, silica, zircon, monazite and pyrite as well as tin ore. No separate recovery figures are published for the tin by-products, but the proportion of ilmenite, zircon and monazite is believed to be high.

The impact of the tin crisis can be seen in that for the year ending 30th April 1986 the company made a profit before taxation of 0.934 million *Malaysian ringit* (MYR) compared to 13.947 MMYR the previous year. For the six months ending October 1986 low tin prices contributed to a loss before taxation of 1.839 MMYR.

Tronoh is a smaller undertaking with only two dredges, one of which

was laid up over 1986. Operations also include mining and dry-stripping. In addition to ilmenite and zircon, gold is an important by-product, 5 107 grammes were produced in 1985. The revenue from this was 86 683 MYR. In 1985 11 297 t of ilmenite and 270 t of zircon were also produced. These, together with other, unspecified, heavy minerals realized 133 373 MYR.

The MMC Group Chief Executive is Chairman of both Berjuntai and Tronoh mines. MMC has exploration and development projects in several countries outside Malaysia as well downstream activities of smelting, tin plate manufacture, marketing and engineering services. An important associate company is the Australian diamond mining operation *Ashton Mining Ltd*, in which MMC holds 46%.

MMC is a publicly quoted group not a state corporation; nevertheless the Malaysian government holds the majority of shares through its various trust companies. At 20th March 1989 the principal shareholders were *Pemegang Amanah Raya, Malaysia Sekim Amanah Saham Nasional* (44.16%) and *Pemodalan Nasional Berhad*, the government finance trust company, (11.29%).

There are not very many dredge mining companies outside the MMC group in Malaysia. One that is, is *Selangor Dredging Bhd.* incorporated in 1962. The company operates two dredges at Kuala Langat, Selangor, one of which was shut down 1985-1986. No separate details are available for by-product production, but 7.3 t of tin was mined in 1986 from which ilmenite and other minerals were derived. Whilst it is a local operation, all the Directors are Malaysian Chinese, in 1987 *Kammer Corp NV* agreed to subscribe 50% equity amounting to a maximum of 1.875 MUSD.

The remaining company *Perangsang Pasifik Sdn Bhd* is a 70% subsidiary company of *Zemex Corp* whose head office is in New York. Originally incorporated in 1907 in the USA as Yukon Gold Co, the corporation had, since 1939 operated under the name of *Pacific Tin Consolidated.* Its present name was adopted in June 1986, in no small part because of restructuring of its Malaysian operations.

Having mined as Pacific Tin in the Berjuntai area for many years, Zemex now holds 70% in a reformed joint venture company with *Kumpulan Perangsang Selangor Bhd (KPS)* which is wholly owned by the Selangor State government. Selangor, like other state governments within Malaysia, seeks increased benefit from its natural resources. In return for its 30%, KPS granted new mining subleases subject to a 5% royalty on tin sales. No details of production are available, but sales of industrial minerals increased by 6% or 1.3 MUSD in 1985.

Zemex holds 49% in the *Sierra Mining Co Ltd (Thailand).* This will be discussed in Vol 7 No 4 under tantalum/titanium. The major line of business for the corporation is now industrial minerals and powder metallurgy; tin accounts for less than 12% of sales revenue. Presumably the tin obtained by Perangsang Pasifik has necessary by-products, otherwise the restructuring has little purpose. At 1st February 1985, *Denison Mines Ltd* held 40% and *Madame Lim Siew Kim* of Kuala Lumpur held 9.18% of the outstanding A stock.

## CANADA

*QIT Fer et Titane Inc* was incorporated to exploit massive ilmenite deposits in the Allard Lake region of Québec, Canada. Originally incorporated in Delaware USA, it was reincorporated in Canada in 1957 and adopted its present name in 1978. The company is a wholly owned subsidiary of *Standard Oil Co (Sohio)*, itself a subsidiary of *RTZ Corp* of UK. No details of capital or accounts are available. Operations are the mining and smelting of ilmenite to produce upgraded titanium oxide. High purity iron and high grade ferrous powders are also produced. Other products include rutile and zircon. The mine plant and related facilities are at Havre St Pierre. In 1983 proved ore reserves were 84 Mt, grade 65%. Ore is shipped some 600 miles to Sorel where it is smelted to produce titanium bearing slag and pig iron. In 1987 capacity at Sorel was expanded from 850 kt/year to 1.150 Mt/year.

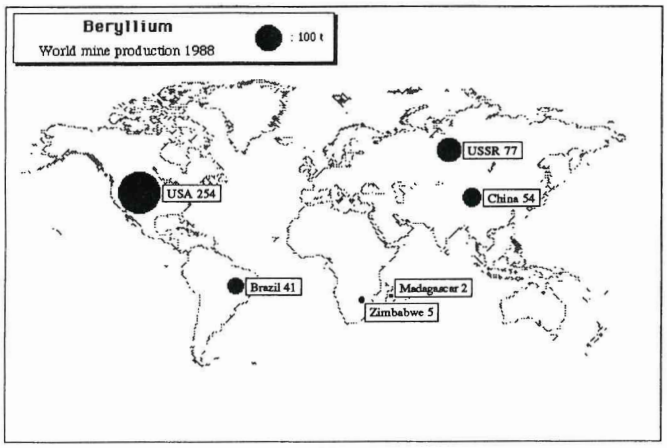
A wholly owned subsidiary, *Québec Metal Powders Ltd*, operates an iron powder plant at Tracy, Québec, which utilizes iron from QIT's smelter. Another wholly owned subsidiary, *GLC Canada Ltd* is a major producer of carbon electrodes. No details on output are available.

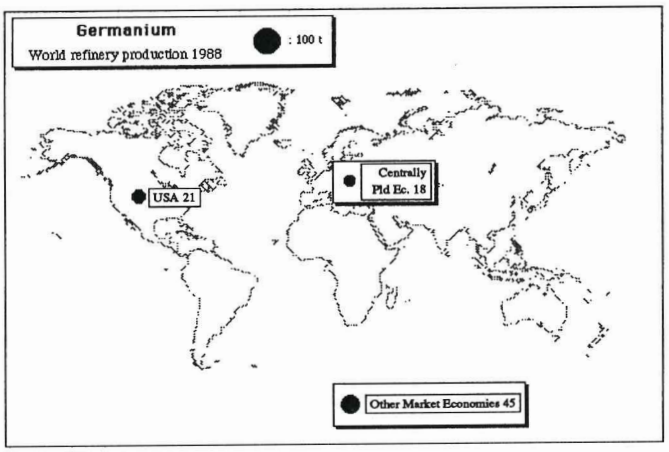
In addition to its Canadian operations, QIT holds an interest in major iron and titanium deposits located at Richards Bay, Natal, South Africa (see also above). Ilmenite, rutile and zircon are produced and a smelter converts the ilmenite to a high grade titania slag and low manganese pig iron. Annual production at full capacity is approximately 56 kt rutile, 115 kt zircon, 400 kt titania slag and 217 kt low manganese pig iron. Mining is by suction dredge. The operating companies are *Tisand (Pty) Ltd* (31.8%) and *Richards Bay Iron and Titanium (Pty) Ltd* (42.5%).

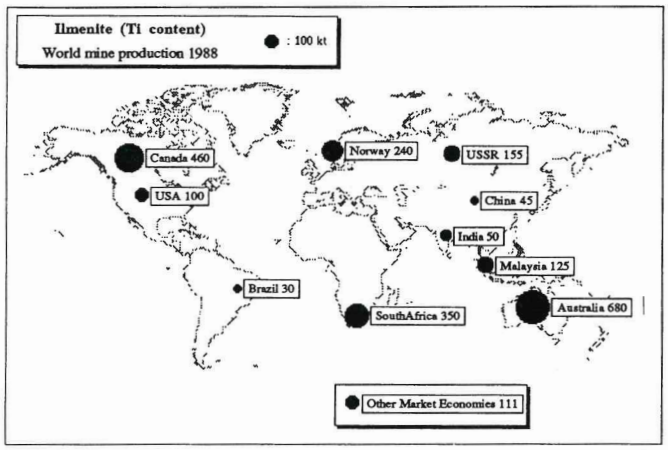
In mid 1986 QIT entered into a joint venture with the *Malgache Government* to develope the country's beach sand deposits. QIT has a 49% interest. The operation is envisaged to have an output of 300 kt/year ilmenite.

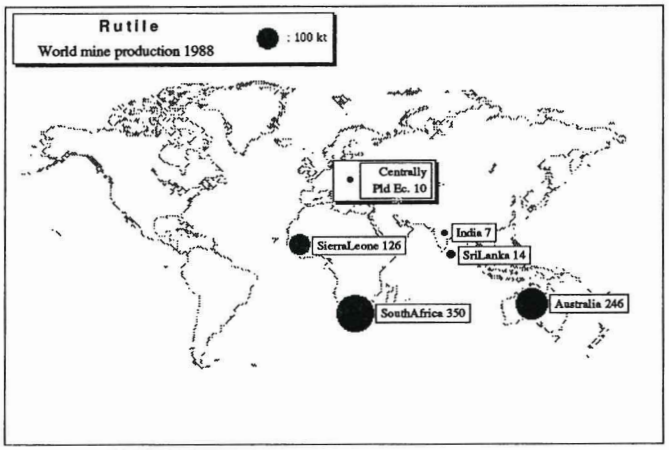
## NORWAY

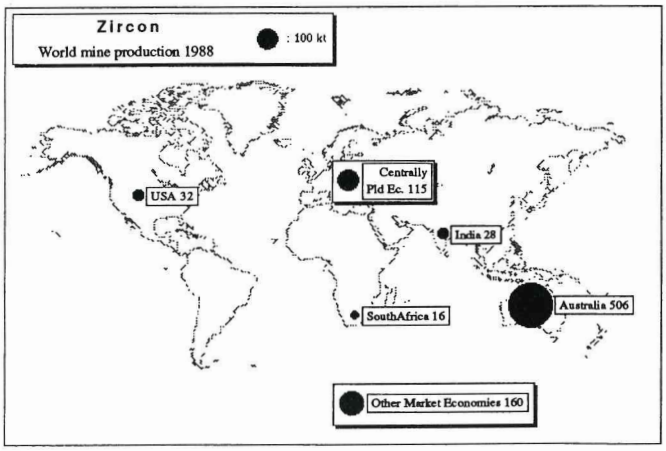
Ilmenite and magnetite are produced by *NL Industries Inc (Titania AS)* whose Head office is at Hauge Dalane, Norway. Mining operations are at Tellnes. The feed capacity of the concentrator is 4 500 t/day. No other data at present available. ■

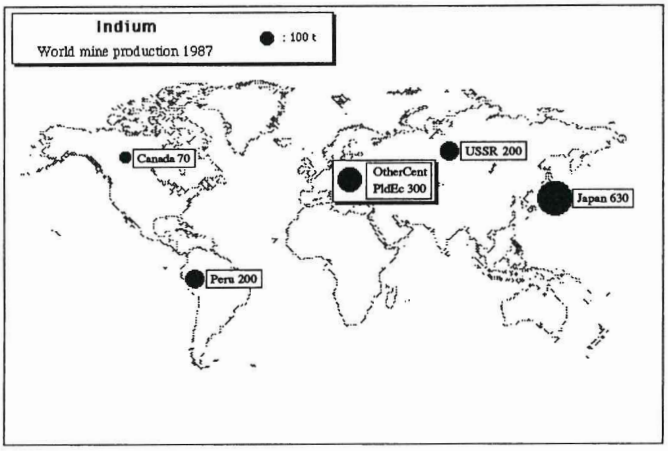

Beryllium
World mine production 1988
: 100 t
USA 254
USSR 77
China 54
Brazil 41
Madagascar 2
Zimbabwe 5

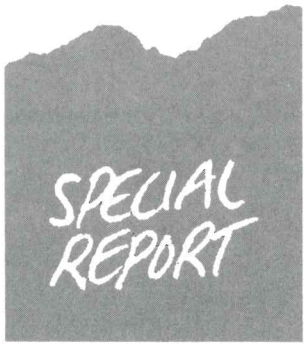

Germanium
World refinery production 1988
: 100 t
USA 21
Centrally Pld Ec. 18
Other Market Economies 45


Ilmenite (Ti content)
World mine production 1988
: 100 kt
Canada 460
USA 100
Norway 240
USSR 155
China 45
India 50
Malaysia 125
Brazil 30
SouthAfrica 350
Australia 680
Other Market Economies 111


Rutile
World mine production 1988
: 100 kt
Centrally Pld Ec. 10
India 7
SierraLeone 126
SriLanka 14
SouthAfrica 350
Australia 246


Zircon
World mine production 1988
: 100 kt
USA 32
Centrally Pld Ec. 115
India 28
SouthAfrica 16
Australia 506
Other Market Economies 160


Indium
World mine production 1987
: 100 t
Canada 70
USSR 200
OtherCent PldEc 300
Japan 630
Peru 200




# Indium

Established uses of indium include, infrared detectors, aircraft windshield coatings, nuclear reactor control rods, plating on electronic components, low melting alloys, solders, coating on electrical contacts and dental alloys. A growing use is as a transparent electrically conductive coating on glass, such as is used for liquid crystal displays on computer touch screens, calculators and wristwatches.

Research is continuing on indium in semiconductors and indium/indium tin oxide coatings for solar cells and windows. In 1987 estimated USA indium usage was: electrical and electronic components, 40%; solders alloys and coatings, 45%; research and other, 15%.

There are alternative materials available for most uses of indium. In transistors silicon has generally replaced the more expensive germanium/indium. For some alloys gallium can be used,- if cost not important. Boron carbide and hafnium can replace indium in nuclear reactor control rods.

## Production and reserves

Indium occurs primarily in zinc sulphide ores. These are found in many parts of the world, although the indium content is not the same in all zinc ores. Zinc with high grades indium is concentrated in Canada, Peru, Japan, the USA, the USSR and China. USA domestic production is derived from residues generated in zinc and other base metal refining. The mineral is extracted from flue dusts at lead and zinc smelters and also from the cadmium bearing residues during the purification of zinc sulphate. It is then electrolyzed to required purity.

Indium is a specialized market due to high unit cost and small market volume. Different grades of metal are required for various applications. Metal for electronic applications has to be 4N purity. The closure of particular zinc mines can sharply tighten availability leading to considerable price volatility.

There was no indium in the USA stockpile as of end 1987. However it had been selected for further study as a possible candidate for inclusion by a panel of representatives from US indus-

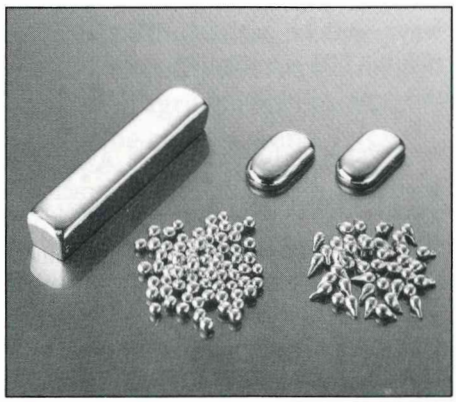
**Table 12**
**Indium: world mine production and reserves**
**(thousand troy ounces metal)**

| | Refinery production | | Reserves | Reserve base |
|---|---|---|---|---|
| | 1986 | 1987 | | |
| Japan | 540 | 630 | 2 000 | 4 000 |
| Canada | 180 | 70 | 8 000 | 18 000 |
| Peru | 100 | 200 | 3 000 | 4 000 |
| USA | NA | NA | 7 000 | 17 000 |
| Other market econs | NA | NA | 24 000 | 37 000 |
| USSR | 200 | 200 | 6 000 | 8 000 |
| Other centr pld econs | 300 | 300 | 4 000 | 8 000 |
| **World total** | **1 320** | **1 400** | **54 000** | **96 000** |

**Source:**
US Bureau of Mines

*Manufacturing equipment for high purity indium att Nippon Mining's Isohara plant (right).*

*High purity indium (below).*



try and government. Agencies represented included the Departments of Commerce, Defence, the GSA, the Bureau of Mines, and the Federal Emergency Management Agency. The estimated value of US consumption in 1987, based on the average price, was 5.8 MUSD. Prices are quoted in USD/troy oz for 1 000 troy oz lots in the USA and in USD/kg for 100 kilo lots in Europe and Japan.

## Producing companies

For indium, as with almost all the metals discussed here, (certainly with all those that are produced as by-products), it is the refiners and processors who play the dominant part and who occupy the controlling production positions.

Refined indium is produced by: *Metallurgie Hoboken-Overpelt* of Belgium; *Mitsui Mining and Smelting, Nippon Mining* of Japan; *Indium Corporation* of America; *Preussag AG* of West Germany; *Cominco* of Canada and the State owned operations of China and the USSR. Of these Nippon Mining and Cominco have integrated mining and processing facilities, although Cominco's mine output is probably channeled via *Metallgesellschaft Ag* (see Teck Corp under Columbium above).

Nippon Mining (or *Nihon Kogyo KK*) is Japan's largest integrated nonferrous metal producer. It is also a major petroleum refiner and petrochemical producer, a metal fabricator and an electronic and speciality metal producer. It has numerous subsidiary and associate companies. The company has some domestic mines and is engaged in exploration in Japan and overseas.

Nippon stopped its indium output in 1981, but other producers did not follow suit. Prices subsequently fell by almost half over 1981-82. Subsequently prices rose due to increased Asian demand for electronic applications and Nippon resumed production.

Indium is produced by *Nikko Zinc Co Ltd* (a wholly owned subsidiary) at its Mikkaichi smelter in Toyama Prefecture. This has a production capacity of 12 kt/month distilled zinc produced by electrothermic process. Overall, Nippon produced 101 338 t zinc metal in 1986. No separate details are available for Nikko Zinc. ■