

# Bismuth

By Gill Burke

**Intense competition and rivalry between the leading industrial nations and major TNCs has made bismuth a new strategic mineral.**

**One example is superconductors, where Japan and Japanese TNCs are concentrating R & D on superconductors with bismuth.**

## Uses

The exceptional physical absorption of bismuth and its compounds has led to a wide and growing range of uses. These fall into three main groups:

- Chemicals
- Metallurgical additives
- Electronics/electrochemistry.

The bismuth uses relevant to this Report fall into the latter category, together with metallurgical use as fusible alloys. As bismuth is non-toxic it is increasingly being substituted in industrial use for toxic materials especially tellurium.

## Metallurgical additives

*Fusible alloys* have unique properties: low melting points and unusual expansion and contraction characteristics. Bismuth forms a number of binary, tertiary quaternary and quinary alloys, commonly with tin, lead and cadmium which melt in the range 47C° to 262C°. Indium is included for even lower melting points. Many of these alloys are eutectic, that is they melt/solidify totally at a certain point rather than melting gradually as temperature increases.

Bismuth itself melts at 271C° and is unusual in that its volume increases by approximately 3.3% in changing from molten to solid state. This characteristic remains present in bismuth alloys to varying degrees depending upon bismuth content. Generally, alloys containing more than 55% Bi expand upon solidification and those containing less than 48% Bi contract. Those in the 48-55% range are generally dimensionally stable.

Fusible alloys can be used in temperature indication and safety devices, for example the thermal fuse which can protect electrical installations against excessive electrical currents. Another use is as a support to delicate structures that have to be machined. A good example of this application is the machining

of turbine blades for jet engines. The blades themselves are forged of high temperature alloy and the ends by which they must be secured to the turbine must be fluted and bear a precise angular relationship to the rest of the blade. For machining, the blade is put into the cavity of a steel block and the hole filled with fusible alloy. The block is easily held in a chuck for machining and afterwards the alloy is simply melted away with hot water.

## Electronics/electrochemistry

The uses of this group also cover a wide range. These include:

- Thermoelectric generators

These are for use in satellite and space vehicles, underwater cable systems, the refrigeration systems for submarines or in observations posts in remote areas with extreme weather conditions. A thermonuclear pacemaker using a bismuth/telluride thermocouple was developed by the UK Atomic Energy Authority in the late 1970s.

- Bubble memories

These are a type of computer memory device which do not lose stored information when the power is switched off. Initially developed for computers that had to be used in dirty or rugged environments, bubble memories are now of increasing importance in the development of 'fifth generation' computers. Early bubble memories used a bismuth/garnet substrate, however this has largely been superseded by the gadolinium-gallium-garnet substrate, which although more expensive is much faster.

- Electroceramics

Bismuth stannate is used as an additive to barium titanate ceramic capacitors to produce bodies with an intermediate level of dielectric constant. These show remarkably little variation with temperature. Bismuth also improves the mag-

netic and ceramic properties of ferrites (ceramic permanent magnets).

• Radiation detectors

In the early 1980s several germanium producers were interested in the development of applications using the oxide compound bismuth germanate (BGO). The compound's importance lies in its use in electromagnetic calorimetry for radiation detection and measurement. It is being researched by the *Centre Européenne pour la Recherche Nucléaire* (CERN) using crystals supplied by the Shanghai Institute of Ceramics, China.

• Superconductors

Research over the past three years has shown major advances in superconductors. In 1986 the discovery of a high temperature conductor based on the rare earth lanthanum (see below) combined with barium, copper and oxygen initiated a revolution in physics. The material had a maximum superconducting temperature of 28 degrees Kelvin (0K = 270C°). In 1988 a material was identified which defines another class of superconductors – one that does not contain rare earths. The new superconductor was composed of bismuth, strontium, calcium, copper and oxygen. It is thus much cheaper.

**Production and reserves**

Bismuth is one of the earth's rarer metals in terms of crustal abundance, occurring in an estimated one part in ten million- similar to cadmium or silver. Concentrations of bismuth are reported to be highest in deep sea nodules. Bismuth occurs as native bismuth and as ores, but because of uneconomic concentration there are very few deposits that can be mined. Almost all available bismuth is produced as a by-product of the processing of copper, lead or zinc and to a lesser extent of gold, tungsten and other metals.

Table 1 gives world bismuth mine production, reserves and reserve base as estimated by the United States Bureau of Mines. Although, for a variety of reasons, little reliance can be placed on the detail of these estimates they are nonetheless broadly indicative of the distribution of bismuth resources throughout the world.

The Bureau of Mines estimates for world mine production of bismuth are considerably higher than other sources; even so there are sufficient reserves for all foreseeable requirements in both the short and medium term.

Estimates are given in thousand pounds of bismuth content because almost all mine production data is for by-product bismuth. Only Bolivia produces bismuth as a primary metal.

The fact that most bismuth mine production is as a by-product also effects the long term calculation of reserves,

since these are often re-evaluated in the light of changing base metal prices. This has been the case for example in Australia, where reassessment of recoverable economic tonnage of copper at Peko Wallsend's Warrego mine has dramatically curtailed the company's future as a mine producer of bismuth.

Furthermore, mine production data provides only part of the picture since many important bismuth producing countries have little or no mine production. For bismuth, as with many other of the new strategic minerals, the role of the refiners is a crucial one. Few producing countries export bismuth concentrates, most export either refined bismuth or bismuth bullion. Data for world production of refined bismuth is given in Table 2.

The importance of refiners is clearly shown in Table 2 where Belgium, the world's largest producer of refined bis-

**Table 1**  
**Bismuth: World mine production, reserves and reserve base \***

	Mine production		Reserves	Reserve base
	1987	1988		
Australia	2 400	2 600	40 000	60 000
Bolivia	1	5	10 000	12 000
Canada	490	500	12 000	20 000
Japan	1 200	1 300	50 000	127 000
Korea, Rep of	220	200	8 000	10 000
Mexico	2 150	2 200	12 000	30 000
Peru	1 400	1 000	24 000	92 000
USA	W	W	20 000	30 000
Other Market Economies	—	—	8 000	22 000
Cent Planned Economies	1 091	1 200	16 000	47 000
<b>World total</b>	<b>8 952</b>	<b>9 005</b>	<b>200 000</b>	<b>450 000</b>

\* Data in thousand pounds of bismuth content

W = withheld for proprietary reasons

Source:

US Bureau of Mines, Mineral Commodity Summaries 1989

muth has no mine production at all. Mexico and China are both of growing importance both as mine producers and refiners. Peru remains one of the world's major bismuth producers, but output has been severely affected by industrial unrest over recent years and by the Sendero Luminosa guerillas.

The 'others' category includes two other important refining nations with no mine production - the German Federal Republic and the UK, although both are less important than they were. Exports of refined bismuth from the GFR have declined from 380 t in 1984 to 130 t in 1988, whilst UK exports have declined from 430 t in 1984 to only 60 t in 1988. This latter decline reflects the decline of the Peko-Wallsend stockpile (discussed under Australia below) and the diversification activities of Mining and Chemical Products of the UK.

World production of bismuth reached a peak of 5 365 t in 1974. The following year, the French Health Authorities banned bismuth in pharmaceutical products in the wake of a series of deaths through overdosing. Subsequently prices and demand both fell and many smaller operations closed. By 1979

prices had recovered, only to fall again as a consequence of the recession. Recovery was spasmodic, but by 1987 had reached an estimated 4 196 t.

## PRODUCING COMPANIES

### AUSTRALIA

Australia is probably still the world's largest producer of bismuth, although no figures are available after 1986. In that year around 1 400 t was produced which accounted for over one-third of world production. This production came almost solely from the Tennant Creek operations of Pasminco Ltd in the Northern Territory. There was some past production in Queensland as by-product of magnetite mining. Bismuth is also produced as by-product by two smelting companies. The amounts, which are believed to be small, are stockpiled and are not included in official Australian production figures.

#### Pasminco Ltd

Pasminco was formed in 1988 from a merger of Peko-Wallsend Ltd with North Broken Hill Pty Ltd and with

CRA's lead/zinc/silver interests. The recent nature of the merger coupled with the fact that the operations discussed here and under "heavy minerals" below were undertaken solely by Peko-Wallsend make it sensible to refer to them under that name.

Peko-Wallsend had/has a wide range of activities, mainly within Australia. Principal operations include:- mining of copper, gold, silver, bismuth, scheelite, rutile, zircon and iron ore; investment in uranium mining; mining and trading in coal; minerals exploration; processing ferrous and non-ferrous metals; metals and minerals marketing; direct participation and investment in oil and gas exploration development and production; the manufacture of industrial pumps and mineral dressing equipment.

The bismuth is contained in gold-copper ores at the Warrego, Juno, Peko and Geko mines near Tennant Creek, Northern Territory.

These ores are processed to produce gold bullion, copper concentrates and cement copper. 1987 a total of 95 877 t of ore yielded 11 798 oz gold bullion, and 7 267 t of copper-bismuth concentrate.

In the past Peko exported its copper concentrates to Japan. The contained bismuth was considered to be a "refiner's prize" and thus not included in Australian production figures. The gold/bismuth concentrates were originally shipped to Norddeutsche Affinerie AG in West Germany for gold recovery and extraction of bismuth metal. The bismuth was then sent to *Mining and Chemical Products Ltd (MCP)*, UK, for further refining.

In 1972, Peko-Wallsend and MCP formed a joint company, MCP Peko Ltd, based in the UK, for marketing Peko's bismuth worldwide. After 1980 no further shipments were made to West Germany. Also in 1980 Peko began to stockpile its bismuth.

Peko-Wallsend employed a variety of processing methods at Tennant

**Table 2**

### Bismuth: World production of refined bismuth 1984/1989 (t)

	1984	1985	1986	1987	1988*
Belgium	400	600	980	860	950
China	50	60	90	225	460
Japan	590	610	600	530	500
Mexico	380	400	500	590	620
Peru	680	750	600	400	320
USA & Canada	600	390	300	280	300
Others	500	790	850	1 550	1 290

\* = Estimated

#### Source:

Industria Penoles SA

Creek. These suffered from poor equipment performance and commissioning problems with a new Pierce Smith copper converter, but most of all from falls in the price of copper and rises in the cost of energy.

In 1984 a reassessment of proven ore reserves at Warrego was undertaken. As a result, production was cut to 250 kt/year high grade gold ore. This did not yield sufficient copper to keep Peko's Mount Morgan smelter open. A small bismuth oxychloride plant and a small smelter to convert bismuth oxychloride to bullion were commissioned at Warrego in 1985 and 1986.

The high grade zones of ore at Warrego were expected to be fully extracted by 1988. There does not appear to have been a further reassessment of reserves in the light of higher copper prices and it thus appears that Peko/Passminco will cease to be a force in mine bismuth production. The company remains a force in the world bismuth market however, on account of its stockpile - although this too is rumoured to be near depletion.

#### **Other Australian bismuth developments**

A variety of companies were involved in exploration but most seem to have succumbed to the 1987 stock market crash. None are currently producing.

#### **BELGIUM**

All Belgium bismuth production comes from imported ores, concentrates and intermediate smelter products. Belgium is, however, the largest single producer of refined bismuth in the world. All this production comes from two companies.

#### **Metallurgie Hoboken-Overpelt SA (MHO)**

MHO operate, among other plants a lead smelter and refinery at their metallurgical complex at Hoboken near Antwerp. The complex also recovers anti-

mony, indium, selenium and tellurium. MHO obtain part of their raw material on a smelter toll basis.

Until recently MHO produced bismuth in 10 kg bars of 99.99% purity. These were marketed by Société Générale des Minerais SA (20.77% MHO owned). MHO also produced 9.999% (3 nines) and 9.9999% (4 nines) purity bismuth which it marketed itself. For the past few years MHO has only been producing bismuth concentrates in crystal form. These are sent to Sidech (see below) for refining into bismuth metal.

#### **Société Industrielle d'Etudes et d'Explorations Chimiques SA (Sidech)**

Sidech is one of the largest bismuth producers in Europe. The company operates a refinery and chemical plant at Tilly processing ores, concentrates, residues, scrap and waste catalysts containing bismuth, cobalt, lead, molybdenum, nickel and tellurium. The Tilly plant has a capacity of 1 250 t/year refined bismuth metal minimum 2 nines purity and higher grades.

Sidech have been closely associated with the Bolivian bismuth interests. The company co-operated with COMIBOL, the Bolivian State mining corporation, in building a bismuth smelter at Tellamayú in 1972 and a refinery in 1976. Previous to that considerable quantities of Bolivian bismuth had been refined at Tilly.

#### **BOLIVIA**

Bolivia is rare in that it produces bismuth as a primary metal as well as a by-product from lead, zinc and copper mining. The content of some sulphide ores can be as high as 40% bismuth. Bolivia was one of the world's largest mine producers of bismuth until the late 1970s when it largely succumbed to falling prices.

Mine production was 651 t in 1977 but fell to 307 t in 1978 and collapsed

to 10 t in 1980. Around 80 t was estimated for 1986 but only around 20 t for 1988.

The break even price for Bolivian bismuth operations is estimated to be around 5.00 USD/lb. The price on the European Free Market on November 24, 1989 (in ton lots in warehouse, minimum 2 nines purity) stood at 4.20 USD - 4.65 USD/lb per lb.

Bismuth mining (indeed all mining) in Bolivia is dominated by the State owned *Corporacion Minera de Bolivia* (COMIBOL). Since restructuring in 1985, the principle bismuth mine - Seccion Tasna mine at Tasna, Potosi - has been under a COMIBOL subsidiary. COMIBOL is joint owner of the Telamayú smelter which has 650 t/year full capacity which has never so far been reached.

Other bismuth producers are Empresa Nacional Unificada SA and Fabulosa Mines Consolidated. Empresa operates ten mines whose main product is antimony. The Mina Boliva mine opened in 1975, produces complex bismuth-silver, copper and lead ores with a capacity of 150 t per day of ore. Fabulosa Mines produce tin with bismuth by-product, but no details are available.

#### **CANADA**

Bismuth is produced in Canada as a by-product from the processing of lead-zinc, lead-zinc-copper and copper ores. Canadian bismuth production figures are given below. The major sources are the lead-zinc-copper mines of New Brunswick and the lead-zinc mines of southeast British Columbia. Until 1972, the molybdenite mines of northwestern Québec were the main source of Canadian bismuth, but economic difficulties then closed the mines. Minor amounts of bismuth have been recovered from the silver-cobalt ores of northern Ontario and the silver ores of Great Bear Lake, Northwest Territories

### **Cominco Ltd**

Cominco is one of the world's largest producers of lead and zinc. The corporation also produces and sells other base and precious metals, compound semiconductor materials and components for the electronics and other high technology industries. The corporation's operations are divided into two segments: *Cominco Metals* and *Cominco Fertilisers*. The metals division is responsible for mining, processing, smelting and marketing of metals.

Cominco's majority shareholder (29.5%) is Nunachiaq Inc, a holding company representing *Teck Corporation*, Vancouver (50%), *MIM Holdings Ltd* Australia (25%), and *Metallgesellschaft AG*, West Germany (25%).

Much of Cominco's bismuth production derives from lead concentrates produced at their Sullivan mine at Kimberley, BC. Other sources include lead concentrates from Pine Point mine, Northwest Territories, and domestic shippers. A significant amount of bismuth producing lead concentrates originates from foreign shippers. The Red Dog mine - a big zinc-lead-silver surface deposit in Alaska is expected to come into production in 1990 to offset exhaustion at Pine Point and other zinc mines around the world. Whether the Red Dog ores will contain bismuth is not yet clear.

Cominco produces primary bismuth metal as a by-product of lead-zinc smelting and refining at their integrated complex at Trail, British Columbia. Annual production capacity is 272 kt/year refined zinc, 136 kt/year refined lead. Bismuth is contained in lead bullion at a level of approximately 0.5% and is recovered as 99.99+% metal following treatment of the anode slime from the lead refinery. Some bismuth is processed further at the Cominco Electronic Materials Inc. high purity plant to a purity of 99.9999%. This bismuth metal is used in research and the electronics industry.

During 1985, Cominco reached an agreement with the Canadian government on its participation - through 69 M CAD equity financing - in the construction of a new lead smelter at Trail. The existing facility, which has been operative since 1899, does not meet environmental guidelines and is considered to be among the highest cost lead smelters in the world to run.

The new plant is expected to become operational by 1991, have a 160 kt/year facility and cost a total of 281 MCAD. The new smelter will have two Kivcet process flash smelter units. These will use domestically produced coal enabling Cominco to achieve a 50% saving of energy costs. The smelter will be automated and will meet environmental regulations.

### **Brunswick Mining and Smelting Corporation Ltd (BM&S)**

BM&S conducts mining and metallurgical operations in the province of New Brunswick. The company is a 63% owned subsidiary of *Noranda Minerals Inc* a segment of *Noranda Inc* of Ontario. Bismuth production is derived from ores mined in the company's Number 12 mine, Gloucester City/Bathurst area. The mine produced 51 kt lead concentrates in 1987. The orebody was worked by open pit until 1971 but is now worked by underground mining. BM&S proven reserves all told, in 1986 were: 86.613 Mt - 0.31% copper, 8.95% zinc, 3.64% lead, 2.81% silver; with a further probable 25.167 Mt.

The smelting division of BM&S at Belledune, Bathurst, can produce bismuth metal and alloys. Recovery is from desilverised lead bullion by Kroll-Betterton process as a bismuth-lead-calcium dross. The dross is refined pyrometallurgically with chlorine to produce bismuth metal and alloys, although since 1974, only bismuth-lead alloys have been produced. These contain either 8% Bi or 50% Bi. A bismuth crystal plant was completed in 1980.

This produces a crystal alloy containing 45% Bi, 45% Pb and 10% Mg/Ca which is exported for recovery of bismuth and lead.

### **Mines Gaspe**

Like BM&S, Mines Gaspe is a division of Noranda Minerals Inc. but in its copper group, whereas BM&S is in its zinc group. Copper-molybdenum concentrates are obtained from the Needle Mountain mine which in 1986 had reserves of 2.581 Mt grade 2.11% copper and 0.029% molybdenum. A new underground copper mine in the E Zone at Mines Gaspe began production in 1986, but operations were suspended following a severe underground fire in 1987.

Bismuth is recovered from flue dusts at the company's copper smelter at Murdochville, Québec. The dusts are then shipped to BM&S in New Brunswick for refining at a rate of around 4 kt/year.

The dust contains between 0.5% and 1.0% Bi. Up to the end of 1975 the Mines Gaspe smelter was estimated to have recovered 210 t of bismuth from over 69 Mt of ore. Production of bismuth in Québec has not been reported since 1976 and is probably included in figures for New Brunswick.

### **Other Canadian bismuth developments**

*Nova Pb Inc* (which was formerly part of Preussag Metal Inc) operates a secondary lead plant in Toronto. During 1986 the company began taking in dust scrap from Noranda's Toronto smelter operations. A complex 4-phase metals extraction process is used to recover lead together with copper, bismuth, arsenic, zinc and cadmium. 1984 lead production amounted to 25 kt. This is well below the plant's 60 kt/year capacity. No figures for bismuth production appear to be available.

The remaining developments are all non-operational, waiting either for im-

improvements in prices of other minerals or due to exhaustion of reserves:

*Terra Mines Ltd* operated three silver mines in the Camsell River area, near Port Radium, Northwestern Territories. The Silver Bear mine produced silver-copper-bismuth which was treated on-site at a 140 t per day concentrator. Individual concentrates were produced by flotation and jigging. The Smallwood Mine produced silver. The Norex mine produced silver-bismuth ore by shrinkage stoping. This ore, grading 0.04% - 6.5% bismuth was treated at the Silver Bear concentrator. In 1984, due to low silver prices, the Norex and Smallwood mines were closed and allowed to flood. Continuing low prices led to the closure and subsequent flooding in 1985 of Silver Bear Mine. The company claim exploration work is continuing and all three mines will resume operations when silver prices improve. The costs of de-watering however seem likely to be substantial.

*Sullivan Mines Inc* (formally the Sullivan group) was acquired in 1987 by *Cambior Inc* of Québec. Most of Sullivan's bismuth interests - the Cupra and D'Estrie lead-zinc-copper mines in Ontario and Nigadoo River Mines in New Brunswick - had ceased operation in the 1970s. The former due to low copper prices and escalating production costs, the later due to exhaustion.

There is a further molybdenum-tungsten prospect in New Brunswick. This, - the St George mine and mill - was operated by the Mount Pleasant Joint Venture, a 50/50 partnership between Sullivan Mines and *Billiton Canada* ( a subsidiary of *Billiton BV*). It is estimated to contain 7 Mt ore grading 0.39% tungsten, 0.22% molybdenum and 0.11% bismuth ; a further 19 Mt grading 0.2% tungsten, 0.14% molybdenum and 0.08% bismuth; plus 2.6 Mt grading 0.42% tin, 0.77% tungsten, 0.05% molybdenum and 0.06% bismuth. Production started April 1984 with the mill operating at 650 kt/year

but production rate was reduced by October to 325 kt/year due to low prices and poor demand for tungsten. The mine closed in 1985.

In that same year, *Lac Minerals* acquired an option to gain 50% interest in the venture. Lac's main interest was a tin prospect to the north of the mine. The company began a drilling and development programme on an underground exploration ramp in order to evaluate reserves of some 6.5 Mt grading 0.8% tin established by Billiton. By end of 1985 this work had indicated significant new zones of tin mineralisation and a 3.4 MCAD exploration programme was planned for 1986. The decline of tin prices set this back, although Lac indicated interest in the recovery of other minerals - bismuth, copper, lead, indium and zinc - from the prospect.

## CHINA

According to available figures, China has changed from being a net exporter of bismuth to a net importer. In 1983 China imported an estimated 200 t bismuth metal. Imports increased to 300 t in 1984 to between 322 t and 332 t in 1985. Imports fell to 250 t in 1986 only to rise even higher to around 463 t in 1988. Throughout this period, China has offered bismuth metal for sale. Feed material is bought in Hong Kong to be refined in China and exported. The main sources of Chinese bismuth metal imports are Peru, Mexico and Japan. Chinese exports are destined for the USA, Eastern and Western Europe.

Bismuth recovery from ores is considered to be low. The tin operations at Gejiu, Yunnan Province, process complex ores containing 0.5% tin, 0.4% copper, 0.1% tungsten, 0.05% bismuth and 9% sulphur. The plant produces a tungsten concentrate containing 65% tungsten oxide with a high level of tin and bismuth impurities. Deposits of bismuth are known in the Miyun Mountain

area northeast of Beijing. The area also contains deposits of silver, lead, zinc, and cadmium

Base metal processing plants such as the Guangzhou smelter in Guangdong and the Shenyang copper-lead-zinc smelter and refinery in Liaoning are reported to recover bismuth, selenium and tellurium as by-products. The Shanghai smelter, which is China's biggest producer of electrolytic copper also produces by-product bismuth, cobalt and manganese together with germanium, indium, gold, platinum, palladium, selenium and tellurium. Bismuth metal grading over 99.99% is produced for alloying and chemical applications. In addition, the Shanghai Institute of Ceramics produces highly specialised crystals of bismuth germanate.

Bismuth is also believed to be recovered from ores processed at the Zhuzhou zinc-lead-copper smelting complex in Hunan province. Estimated output is believed to be around 20 t per month, equivalent to 240 t/year. The complex was reported as closing for some months in 1987 with subsequent loss of some 100 t bismuth production which had to be met by increased imports.

Export business from the smelters is largely handled by the China National Metals Imports and Exports Corporation. However, in January 1988 *China Industrial Resources* (CIR) began trading and is now an important player. CIR's parent company, CIR Holdings is based and capitalised in Zug, Switzerland. The two principal shareholders are Sasso Corporation, and the Chinese owned but Hong Kong based Guangdong Enterprise Holdings. CIR exports and imports metals and minerals from and into China. The company is particularly active in vanadium, tungsten and molybdenum. CIR has a two-way trading business in bismuth, whereby it sells pharmaceutical material to China in substantial quantities and buys metallurgical bismuth in return.

## CZECHOSLOVAKIA

In late 1982 it was reported that a new cyclone reactor had been commissioned at Vajskova in the lower Tatra region of central Slovakia for the production of around 1 kt/year antimony metal. The new facility was to process concentrates mainly produced as a by-product of mercury. These concentrates are reported to also contain bismuth and copper. No other details are obtainable.

## FRANCE

Small amounts of bismuth were recovered as a by-product of gold bearing ores in the South of France. According to the USBM, France terminated metallic bismuth production in 1977. One mine continues to operate but without apparently producing any bismuth.

### Société des Mines et Produits Chimiques de Salsigne SA

Sté des Mines et Produits Chimiques de Salsigne account for all mined production of bismuth in recent years. The company is 45.27% owned by *Cheni SA* who are in turn a 100% subsidiary of the *Bureau de Recherches Géologiques et Minières* (BRGM) - the French Geological Survey and mining investment arm.

Salsigne operates underground and open-pit mines at Salsigne-Aude in south central France, and a smelter at Combe-du-Saut north of Carcassonne. In 1987 the mine produced 2 053 kg gold, 4 258 kg silver and 984 t copper. Possible reserves of 2.045 Mt grade 10.8g/t and probable reserves of 270 kt/year grade 12.5g/t. About 150 kt/year gold-silver-copper ore is produced, milled and smelted at the company's facilities. The mineralisation is pyrite and arsenopyrite grading an average of 12g/t gold, 30g/t silver, 0.10% bismuth, 0.15% copper and 7% arsenic. In addition, antimony, arsenic and bismuth were produced as by-products from the smelter flue dusts. In 1977 a new electrofiller

from Lurgi of West Germany was installed to improve bismuth and arsenic recovery.

However, the impact of the French health authorities ban on bismuth-based pharmaceuticals coupled with concomitant falling prices led to the refinery operations closing in 1979. From 1979-1984 there were reports of bismuth production and sales from Salsigne. *The British Geological Survey* (BGS) record between 64 t/year and 97 kt/year bismuth mine production. It is thought at the time that in fact Salsigne was slowly selling off its stockpile and that the BGS figures do not reflect actual mine production, but this now does not seem to be the case. In fact Salsigne had continued mining operations but had stockpiled the bismuth dusts and residues at Aude.

Since 1984 Salsigne has spent an estimated 149 MFRF on modernising its mining and processing facilities. Bismuth metal production is believed to have recommenced in 1988 at a reported rate of 150 t/year.

### Société Minière et Métallurgique de Peñarroya SA

Peñarroya, the world's largest lead producer, was formerly part of the *IMETAL* group with worldwide interests in non-ferrous mining and smelting. In 1988 it was announced that Peñarroya and Preussag AG Metall of West Germany would merge (by Preussag taking a 45% share in Peñarroya) to form a new company *Metaleurop AG*. This would be the world's largest lead and second largest zinc producer. *Imetal* still retain a 14% share.

The announcement of *Metaleurop's* first half-year results at end September 1989 gives group profits of 273 MFRF a sum greater than the 251 MFRF profits for the whole of 1988.

The new company has taken over all Preussag's smelting and metal processing operations. These include the lead/zinc smelting activities at Goslar-

Oker and Nordenham and a high purity minor metals production in Langelsheim. On the metals processing side, five hot-dip galvanizing lines and two pressure die casting operations have been transferred. The mines at and Bad Grund, West Germany remain with Preussag and are to close.

Bismuth is recovered as a by-product of Peñarroya's lead and zinc refining. The Largentiere lead mine in France was closed in 1982, following exhaustion of reserves and the Laurium refinery in Greece was also closed. However, mining, smelting and refining is still carried on in Italy, Spain and Morocco.

In 1986 the group produced 218 kt zinc metal, 287 kt lead, 491 t silver, 512 t cadmium and 338 kt sulphuric acid. The last reported production of bismuth was 12 t in 1972. However, *Minemet*, another member of the *IMETAL* group (and formally known as *Société Française de Minerais et Métaux*), sells bismuth.

Reports of the formation of *Metaleurop* make no reference to the future production of bismuth by the new company. However the new merger will certainly involve minor metals and it can be assumed that bismuth will continue to be produced. Both participants are already significant producers of cadmium, but it is in indium and germanium they stand to benefit most. Preussag has developed downstream and high purity production to a large degree where Peñarroya has concentrated on shipping concentrates and basic grade metal. It is estimated that the combination of their activities could have a substantial impact on minor metal trade patterns. In germanium the two together account for production of 20 t/year from total world output of 150 - 160 t/year and in indium Peñarroya produces some 20 t/year metal whilst Preussag has capacity to refine some 15 t/year.

#### Other French bismuth producers.

*Metauxblancs* produce bismuth alloys, but have no mine production of bismuth. No other details seem available.

### GERMAN FEDERAL REPUBLIC

West Germany was a major producer of bismuth metal until 1979. Although domestic mine production was small (10 t/year), most bismuth metal was recovered from Australian gold-copper-bismuth concentrates shipped for refining. Production of bismuth metal was largely halted when imports of concentrates from Peko-Wallsend/Pasminco, Australia ended in 1979/80. These concentrates were treated by *Norddeutsche Affinerie AG* at the copper, lead, and precious metals smelting and refinery complex at Hamburg. The bismuth metal was then shipped for further refining to MCP of the UK.

*Norddeutsche* is 40% owned by *Degussa AG*. In addition, a subsidiary of *Degussa*, *Dr LC Marquart GmbH*, also produced bismuth as a by-product at their Bonn-Benel cadmium refinery. In 1981 however *Marquart* were integrated into *Degussa's* Inorganic Chemical Products Division and bismuth production stopped. *Norddeutsche* is still believed to be producing small amounts of bismuth metal at Hamburg, but no production figures are available.

In 1987, *Degussa* acquired *Leybold AG*, a leading producer of high technology manufacturing equipment for the electronics industry. Most of the 18% increase in sales of *Degussa's* metals division in 1988 came from *Leybold*. *Degussa's* own activity in the electronics field centre round the supply of high purity minerals and semi-finished parts for the production of chips and computer hardware. *Leybold's* activities complement these.

In addition, *Preussag Pure Metals GmbH*, a subsidiary of *Preussag AG Metall*, and *Lurgi AG* are believed to

produce bismuth metal, but no production figures are available. *Preussag* has bought into *Peñarroya* of France to form a new company *Metaleurop* which will have a substantial impact upon the minor metals market and, by implication, upon bismuth production.

### GREECE

The lead mining and processing operations at *Lavrion* closed in 1982 after nearly a century of operation. For the final period operations had been conducted by a subsidiary of the French *Peñarroya* group who used the, then named *Laurium*, smelter to process feed from mines in France.

In 1983 the processing works were taken over by the *Greek Mining and Metallurgical Company of Lavrion SA*, a consortium of the local municipal authority, former employees, and some state-owned investment banks. The new co-operative run the plant at 32 kt/year of lead concentrates to produce 19 kt/year refined lead and lead alloys, 55 t silver and some bismuth. Feed for the plant consists of lead concentrates from the state-owned *Olympus* and *Statonian* mines in the *Chalkidiki* Peninsular. Bismuth is produced in the form of lead alloy at a rate of 300 t/year alloy.

In addition, in 1982, the *Greek Bank of Industrial Development (ETVA)*, through their subsidiary *Aegean Metallurgical Industries SA*, submitted new plans for a long-proposed lead-zinc smelter. This would also be in *Chalkidiki* close to the *Kassandra* mines, including *Olympus* mine, which would provide the feed. The *Kassandra* mines are operated by the *Hellenic Chemical Products and Fertilizers Co*, a subsidiary of the *Bodossakis* group who are in turn 80% owned by the Greek government. The programme includes expanding mining production at the *Olympus* mine from 300 kt/year to 800 kt/year of ore; capacity at the other two

*Kassandra* mines to remain at 550 kt/year.

The proposed plant would be an integrated sulphide smelter. Capacity would be 40 kt/year each of lead and zinc, 180 kt/year of sulphuric acid as well as 96 500 troy ounces of gold, 860 000 troy ounces of silver, 200 t cadmium and other by-products including arsenic and bismuth. No completion or start-up date has yet been announced.

### ITALY

There is no recorded mine production of bismuth in Italy, but *Sameton SpA* produces a small amount at its 80 kt/year total capacity *San Gavino* lead refinery, *Cagliari*. *Sameton* was formed in 1984 and the *San Gavino* plant is one of nine smelters and refineries operated by the company. *Sameton* itself is jointly owned by *Tonolli Semilavorati* and *Samin SpA* (a member of the state-controlled oil agency, the *ENI* group).

The *San Gavino* refinery employs both electrolytic and pyrometallurgical refining techniques and has a capacity of 70 t/year of by-product bismuth. 1986 production was 66 t. The metal is of 99.99% purity and is produced in 10 kg bars. The main end use for this bismuth is in pharmaceuticals and the iron and steel industry. In 1986, 35% of production was exported to the UK 1.5% to West Germany and 1.5% to Switzerland. No other companies in Italy are known to produce bismuth.

### JAPAN

Japan was the leading producer of bismuth metal during the late 1960s and early 1970s with production reaching a peak of 895 t in 1972. Much of this production was recovered from imported copper and lead concentrates. An important source until 1973 was the Australian company *Peko-Wallsend*. There are no published figures for Japanese mine production. The US Bureau of



Mines have estimated that about 30% of total metal production in 1982 was derived from domestic ores and estimate some 1 400 t mine production for 1987. The Bureau admits however, that it's data for Japan is in need of revision and it is expected that a new study of the country will be completed this year. Today Japan is the world's third largest bismuth producer.

Bismuth is recovered in Japan principally as a by-product of processing lead, and to a lesser extent copper, concentrates. Of the total quantity of lead concentrates consumed by Japanese smelters in 1983 only about 25% was from domestic mines. The rest was imported mainly from Peru, Canada and Australia. Over 50% of bismuth metal produced is used domestically, principally by the electronics industry, the rest is exported mainly to Europe, the USA and India.

In the past Japan has been a net exporter of bismuth. However, there have been a number of occasions when the situation has reversed and Japan has emerged as a net importer. In 1984, for example, increased domestic demand left little metal available for export. As a result, exports dropped and shortfalls in demand had to be met by imports. During 1985, bismuth producers were operating at 70% capacity, due largely to lower bismuth content in their feed ores.

Despite this low level of production, domestic consumption was down, which meant that stocks of bismuth and exports both increased. In 1986, bismuth consumption in Japan increased while production remained level. The shortfall in demand was met by stocks which were severely depleted during 1986. This low level of stocks - 60 t in December 1986 as compared to 136 t in December 1985 - meant that early 1987 exports fell sharply. Production also fell and as a result Japan reappeared as an importer of bismuth.

There appear to be seven companies producing bismuth metal in Japan. The production capacity of these companies is given in Table 3 and their operations detailed below.

#### **Dowa Mining Co Ltd**

Dowa operate two lead-zinc-copper mines, Kosaka mine and Hanaoka mine in Akita Prefecture and a copper-lead smelter/refining complex at Kosaka. The complex processes both domestic and imported copper ores and domestic lead ores. Electrolytic copper and lead; gold, silver, selenium, bismuth and antimony are recovered. The complex has a capacity to produce 240 t/year of bismuth metal grading 99.995% Bi upwards. Production totalled 89 t in 1982, and 61 t in the first half of 1983. During 1985 the rate of bismuth production was 15 t per month.

#### **Furukawa Co Ltd**

Furukawa operate a 42 kt/year capacity copper smelter at Ashio, Tochigi Prefecture, where they also produce bismuth

from lead slimes. The company also jointly own a 7 kt/year electrolytic copper smelter at Hibi, Okayama Province, with Mitsui Mining and Smelting and Nittetsu Mining Co Ltd. In 1974 and 1975, 19 t/year of bismuth were produced but this subsequently dropped to 10 t in 1980 and 6 t/year over the period 1981 - 1985. In mid-1984, Furukawa reported that their capacity was 12 t/year of 99.9% pure bismuth, with production running at 5 t/year. The company report that their bismuth is used in the electronics industry.

#### **Mitsubishi Metal Corporation**

Mitsubishi Metal Corp. is responsible for the non-ferrous metal business of the Mitsubishi group, both in Japan and worldwide. The corporation has a number of mines in Japan that supply concentrates from which by-product bismuth is derived. These include the Furutobe and Matsuki copper-lead-zinc mines in Akita Prefecture.

In 1986, Mitsubishi closed its 30 kt/month lead-zinc mine at Hosokura

**Table 3**

#### **Japan: Bismuth production capacity, 1985**

<b>Company</b>	<b>Plant/Location</b>	<b>Capacity (t/year)</b>
Mitsui Metal & Mining	Kamioka, Gifu Prefecture	164
Mitsubishi Metal	Hosokura, Miyagi Pref	<sup>1</sup> 50
Nippon Mining Co Ltd	Sagonoseki, Oita Pref	180
Sumitomo Metal Mining	Kunito, Hokkaido Pref	<sup>2</sup> 60
Toho Zinc	Chigirishima, Hiroshima Pref	180
Dowa Mining	Kosaka, Akita Pref	240
Furukawa	Ashio, Tochigi Pref	12
		<b>Total 886</b>

<sup>1</sup> = possibly closed 1986

<sup>2</sup> = possibly being run down

Source:  
Metal Bulletin

and possibly also its electrolytic lead refinery there. The Hosokura refinery, when operative, had capacity to produce 50 t/year bismuth metal.

Bismuth is possibly also produced from the other Mitsubishi refineries, although no details are available. The Corporation owns a copper smelter and refinery at Naoshima, and a smelter and electrolytic zinc refinery at Akita, together with other metal fabrication plants. In addition, Mitsubishi has a 55% share in a 40 kt/year lead smelter-refinery also at Naoshima, in co-operation with Cominco Ltd.

#### **Mitsui Mining and Smelting Co Ltd**

The company and its subsidiaries form an integrated enterprise with operations in Japan and elsewhere in the world. Operations include mining, smelting and refining of zinc, lead, copper, gold and silver and also of by-product cadmium, bismuth, selenium and various rare earths. In 1983 the company bought a 3% share in Cominco.

The company's principal properties in Japan are the Kamioka zinc-lead mine and smelter in Gifu Prefecture, the Hikoshima zinc smelter in Yamaguchi, the Hibi copper smelter in Okayama Prefecture and the Takehara electrolytic copper, lead and by-products refinery in Hiroshima Prefecture. In 1986, the Kamioka mine and the Hikoshima smelter became independent subsidiaries. Lead concentrates from Kamioka are processed in the adjacent electrolytic lead refinery. The plant has capacity to produce 290 t/year bismuth metal. Recent production has been around 165 t/year.

#### **Nippon Mining Co Ltd**

Nippon is Japan's largest integrated non-ferrous metal producer. The company is also a major petroleum refiner and petrochemical producer, a metals fabricator and an electronic and speciality metals producer. Nippon now only operates two mines in Japan itself. Both are sub-

sidary companies. Toyoha mine in Hokkaido produces lead/zinc concentrates and Kasuga mine has siliceous gold bearing ores.

Nippon Mining was Japan's second largest bismuth producer during the early to mid 1980s. Most of this came from operations at the smelting/refining complex at Saganoseki, Oita Prefecture. By products from there include bismuth, gold, selenium and tellurium. Bismuth is also produced at the Hitachi refinery in Ibraki prefecture, which has refining capacity of 10 kt/month per month electrolytic copper and has also by-product and speciality metals products plants.

#### **Rasa Industries Ltd**

This company has not produced any bismuth since 1979. Previously, Rasa Industries operated a smelting plant at Miyako where products included blister copper, cadmium, tellurium and bismuth. 75% of bismuth was recovered from drosses and residues from ores mined in Furukawa Prefecture. These ores contained 0.45% Bi. Bismuth production was 119 t in 1977 but only 37 t in 1979.

#### **Sumitomo Metal Mining Co Ltd**

Like many of the other Japanese companies mentioned above Sumitomo Metal Mining is part of a transnational group whose activities stretch far beyond mining and metals. Like many of the above mentioned companies, Sumitomo's bismuth production has declined; in part because of the cessation of supplies of copper concentrates from Peko-Wallsend/Pasminco, in part because of the decline of lead and copper mining in Japan itself. Sumitomo now only has one mining operation in Japan – the *Hishikari* gold-silver mine at Kagoshima – which began production in 1985.

The *Toyo* copper smelter in Ehime Prefecture has been increased in capacity from 1.05 kt t to 1.5 kt copper per

day and the refinery from 4.5 kt to 6 kt per month. It is not clear whether this expansion has been paralleled by the running down of the Kunito copper smelter in Hakkaido prefecture from which most of Sumitomo's bismuth production had previously come. Kunito had capacity to produce 60 t/year bismuth metal and production was between 30 t/year and 40 t/year in the early 1980s.

In 1986 a plant for the production of rhenium powder as a by-product was built at the *Toyo* smelter, with capacity of 1.2 t/year per year. In 1986 the company signed an agreement with *Rhône Poulenc Minerale Fine* for the establishment of a joint venture – *Nippon Rare Earths KK* – for the manufacture and sale of rare earths in Japan.

#### **Toho Zinc Co Ltd**

The company operates a 72 kt/year capacity electrolytic lead refinery at *Chigirishima* in Hiroshima prefecture. Most of the concentrates treated at the plant are imported. Bismuth metal is produced as by-product. Following capacity expansion to 180 t/year bismuth metal in 1983, production rose to around 90 t/year in 1985. The bismuth metal is 99.999% bi and main uses are as metallurgical additives, in low melting point alloys and in medicines.

Toho Zinc also has a 5% share in the *Hachinohe Smelting Co*. This is a joint venture between Mitsui Mining and Smelting Co Ltd (50.2%), Dowa Mining Co Ltd (20%), Nippon Mining Co Ltd (10%), Mitsubishi Metal Corp (9.8%) and Nisso Smelting Co Ltd (5%). Hachinohe treats zinc and lead for the joint venturers and on a toll basis. In addition, Toho has a 70% interest in *Gran Bretana SMRL*, who operate a lead-zinc mine in Peru.

#### **REPUBLIC OF KOREA**

There are two main producers of bismuth in South Korea: *Korea Tungsten*

*Mining Co Ltd. and Korea Mining and Smelting Co Ltd* Nearly all Korea's refined bismuth is exported, mainly to Western Europe and the USA. Mine production of bismuth in Korea was estimated to be 1 785 t.

#### **Korea Tungsten Mining Co Ltd (KTMC)**

KTMC is the principal producer of bismuth in South Korea and one of the largest tungsten miners in the world.

The company's main scheelite mine is situated at *Sangdong*, Gwangwon-do. Crude ore is processed into natural scheelite, ammonia paratungstate and tungstic oxide. Bismuthinite concentrate containing molybdenite is produced as by-product. There is a refinery and plant complex at *Daegu* which produces pharmaceutical grade bismuth metal, tungsten metal powder, tungsten carbide powder, molybdc trioxide and ferro-molybdenum. Nominal bismuth refining capacity is 136 t/year and full capacity was reached in 1986. 95% of KTMC bismuth metal is exported.

#### **Korea Mining and Smelting Co. Ltd (KMSC)**

KMSC is Korea's leading non-ferrous metal refiner. The company is a member of the *Lucky-Goldstar* group. The major raw material is copper which accounted for 64% of 1987 production. Bismuth is produced as by-product from lead smelting.

The smelter is located at *Changhang* and has capacity of some 136 kt/year lead and 40 t/year bismuth metal. Production of bismuth metal has been below capacity in recent years. An estimated 25 t was produced in 1986. This was exported, primarily to the Netherlands, together with a further 9 t from stocks. Roughly the same amount was produced and sold in 1987. Bismuth metal stocks in 1987 were +/-9 t.

#### **Young Poong**

Young Poong is affiliated to *Korea Zinc* and is Korea's second largest producer of zinc ingots. No details of bismuth production are available. In 1987, 84.7% of production was zinc ingots; 6.3% was sulphuric acid and 1.0% cadmium ingots.

#### **MAURITANIA**

Mauritania has only recently begun to figure in world bismuth production and very few details are available. It is possible that the country may turn out to be an important producer. Mauritanian bismuth is a by-product of copper production.

The *Akjoujit* copper deposits, located northeast of Nouakchott, the Mauritanian capital, were worked by two state-held companies - *Société Cuivre de Mauritanie* and *Société des Mines du Cuivre de Mauritanie*. The complete mining operation closed in 1978 due to high fuel prices, low copper prices and problems with the refractory copper ore process. The deposit is 75% sulphide ore occurring as pyrrhotite, chalcopyrite and cubanite. Prior to closure the operation had produced over 98 kt of copper metal.

In 1983, the Mauritanian government received 100 MUSD from a group of Arab countries to modernize and reopen the mine. Production is believed to have recommenced and possibly +100 t refined bismuth was produced in 1987.

#### **MEXICO**

Mexico is the world's second largest producer of bismuth. This position has been retrieved over the past two years after declining in the early 1980s. Production of bismuth peaked in 1978 at 978 t but subsequently declined to around 450 t in 1984.

Mexico is a major metals producer in world terms. In 1987 she was the world's first in silver (75.0 M troy

ounces), fourth in zinc (304 kt) and fifth in lead (177 kt). Mexican bismuth is primarily a by-product of lead refining. There are hundreds of active mining companies in the country, but most are small and four companies only produce the bulk of the nation's non-ferrous metals. Only two of the four are major bismuth producers:- *Industrial Minera Mexico SA* (IMMSA) and *Industrias Peñoles SA de CV*. Of these, Peñoles is the most significant as, since 1986, IMMSA has only produced bismuth bullion.

#### **Industrial Minera Mexico SA (IMMSA)**

IMMSA is a member of the *Grupo Industrial Minera Mexico SA de CV*. The group as a whole engage in mining copper, lead, zinc, gold silver and coal and operating refineries for non-ferrous metals and by-products. Another member of the group, *Mexico Desarrollo Industrial Minero* (Medimsa), is 34% owned by *Asarco Inc* of USA. Medimsa operates 11 mines and 5 smelters in Mexico for coal, coke and silver-lead-zinc.

IMMSA operate six underground mines each incorporating a flotation concentration plant. The company also operates three smelters (copper, lead and zinc) and two refineries (lead and zinc); it is the lead smelter and refinery that produce bismuth.

The lead smelter is situated at Chihuahua in Chihuahua State; it produces lead bullion, zinc fume and cadmium dust. The plant includes blast and reveratory furnaces with total feed capacity of 120 kt/year. The lead refinery is at Monterrey, NL; it produces refined lead, silver, gold, antimony and impure bismuth. The bismuth-lead bullion, with approximately 300 t/year bismuth content is exported to Belgium for refining.

#### **Industrias Peñoles SA de CV**

The Peñoles mine-exploration group operates 23 mines, 19 of which produce

lead-silver-zinc. The group also has a lead smelter and a zinc refinery. The company, which celebrated its centenary in 1987, claims to be the largest zinc, cadmium and gold producer in Mexico. 1988 production included: 4 954 kg gold, 1 436.415 kg silver, 116 326 t lead, 106 014 t zinc, 6 869 t copper, 764 t cadmium and 618 t bismuth.

Ores are treated at the *Torreón* metallurgical complex in Coahuila State. The zinc plant came on stream in 1973 and features fluid bed roasters, leaching facilities and electrolytic refining. The lead-silver refinery started up in 1976, replacing a plant in Monterrey which had operated since 1887. Lead bullion from the smelter is de-bismuthised in the refinery. Some technical problems were experienced with the refinery in 1984, and in 1986 an industrial dispute briefly disrupted supplies. As a consequence Peñoles accumulated some 1.5 kt unrefined lead-bismuth ore containing about 6% bismuth, - equivalent to some 90 t bismuth metal. This was issued for tender in 1987 and eventually shipped to the USSR.

Increased demand for bismuth from the USA together with rising prices in 1987, caused Peñoles to announce plans to increase production by 10 t/month. Production capacity at Torreón is 500 t/year depending on bismuth content of the lead concentrates so capacity working was presumably reached in 1987. Production has subsequently increased by around 5 t per month.

Peñoles supplies the domestic market for bismuth metal. This is very small, only about 45 t per year. Some 92% of its output is exported - in 1988, 71% went to the USA, 20% to Europe, 7% to Latin America and 2% to Asia. No details are available on grade of purity, but 60% of output is used for pharmaceuticals, 23% for machinery parts and the remainder for other industrial uses.

## NETHERLANDS

Although there are no production figures published by the US Bureau of Mines or other sources; nonetheless in the past it has been reported that *Hollands Metallurgische Industrie Billiton BV*, a subsidiary of *Billiton Nederland BV*, produced bismuth at their Arnhem works.

The works consist of a chemical plant, producing lead and tin chlorides plus a tin-lead smelter refinery plant with rotary furnaces and refining kettles. The refinery produces refined lead, battery lead, refined tin and tin alloys; also, reputedly, refined bismuth granules and tin-lead bismuth alloy ingots. This reputed bismuth production was also reputed to be small.

## PERU

Peru accounts for about 25% of Western world bismuth consumption. The country's share of the world bismuth market increased steadily from 1980 - 1985 and in that year Peru was the world's largest exporter of refined bismuth. Since then a variety of factors, discussed below, have hindered growth.

### **Empresa Minera del Centro del Perú SA (Centromin)**

Centromin now produces all Peru's bismuth. The company was formed in 1974 following nationalisation. It is a wholly owned subsidiary of *Minero Perú SA* another state-owned corporation.

Centromin owns and operates six mines, seven concentrators, two smelters and four refining installations. The mines are polymetallic producing mainly copper, lead and zinc concentrates together with gold and silver.

The principal smelter-refinery at *La Oraya* processes concentrates both from the Centromin mines and from small local producers. Until the opening of COMIBOL's *Telamaya* smelter in Bolivia in 1972, Bolivian concentrates

were also treated. The *La Oraya* complex consists of a pyrometallurgical copper and lead smelter, a hydrometallurgical zinc refinery and an electrometallurgical refinery for the production of copper, lead, bismuth, cadmium and silver.

In addition, in 1983 a new 61 MUSD lead sinter plant came into production. This plant is highly automated and is equipped with pollution control devices. The sinter plant has 95 kt/year capacity. Production difficulties at the lead smelter in 1987 almost halved bismuth production and by early 1988 was still only working at 65 per cent capacity, mainly due to problems with a conveyor.

Bismuth is recovered from the lead bullion in the lead electro-refining stage. Anode slimes from the Betts process are melted in a reverberatory furnace then transferred to a converter. The molten slimes are blown twice, first removing antimony as slag and second producing a bismuth slag. The slag is reduced to metal containing about 30% Bi with coke fines in the converter then charged into a cupellation furnace where a further bismuth slag is formed then reduced. Bismuth from the reduction furnace is fire refined to 99.9994% purity.

There have been a variety of difficulties affecting Centromin's production over recent years. Strikes by miners and the action of the Sendero Luminosa guerrillas affect the mine-to-smelter and smelter-to-port links regularly. In 1987 for example, industrial disputes cut around 30 days off the mining year, while road or rail links were disrupted for a total of about eight weeks.

In 1984, *Minero Perú Comercial (Minpeco)*, the sales agent for Centromin declared force majeure on all metal shipments except bismuth ingots, silver and tellurium because of transport problems due to landslides and heavy rains. In 1985, industrial disputes led to Minpeco again declaring force majeure,

this time on cadmium and bismuth shipments. As a consequence Centromin embarked on a 22 MUSD emergency cost cutting plan to minimise projected losses of 50 MUSD. In 1988 force majeure was again declared and strikes and consequent supply disruptions drove bismuth prices very high over December 88/January 89. The US highest January price was 6.95 USD/lb and the European price 6.80 USD/lb.

In 1986, Peruvian sales of bismuth were some 200 t below actual production. This was mainly due to lower demand but also to the high prices then set by Minpeco. As a result, Peru lost a lot of sales to Mexico. Subsequently, greater Peruvian price flexibility has had the effect of depleting stocks. By late 1987 stocks were believed to be as low as 150-200 t. The main destinations for Peruvian bismuth are China, Europe, the USA and the USSR.

An important development in late 1987, was the opening by Minpeco of warehousing space in Barcelona, Spain. The intention being to deliver direct to consumers and thus by-pass traders. Almost all Centromin's copper lead and zinc are already sold direct in this way. Barcelona was attractive to Minpeco because it is the home of pharmaceutical buyer *Omicron* - a significant buyer of bismuth.

Since an important feature of the bismuth market is the large number of small consumers; holding stocks in the Barcelona warehouse enables Minpeco to provide a quick and flexible response to demand for small consignments. The impetus behind Minpeco's move was past action by traders. The company believed that trader-to-trader business had adversely affected the market and pushed price downward.

#### **Past Peruvian bismuth producers**

Two other companies were reported to have produced bismuth in the past:-

*Compania de Minas Buenaventura SA*, 33.6% owned by the *Cerro Corpo-*

*ration* of the USA, operates mines at Orcopmapa, Uchucchacua, Julcani and Huachocolpa. The Julcani mine at Huancavelica produces silver, lead and copper concentrates plus quantities of bismuth. In 1975 the company produced 93/t of bismuth, mostly in lead concentrates.

*Compania Minera Atacocha*, who operate the Atacocha lead-zinc-silver-gold-copper mine at Cerro de Pasco, are also reported to have produced 22 t bismuth in 1975.

Although these mines are believed to still be in operation, there have been no reports of any bismuth production in recent years. The lead-zinc mine operated by *Gran Bretana SMRL* mentioned above has no details available regarding bismuth.

#### **ROMANIA**

The US Bureau of Mines estimate that about 80 t of bismuth is produced per year.

The only known producer is the state-owned *Intreprinderea Metalurgica de Metale Neferoase*. This company operates a lead-zinc smelter at Copsa-Mica. Their products include antimony metal and trioxide, bismuth, cadmium, gold, lead bullion, high grade zinc, gold and debased zinc.

It is not known in what form the bismuth is produced nor whether it is consumed domestically or exported.

#### **THE UNITED KINGDOM**

Like Belgium, the UK produces no mine bismuth and all its production comes from imported concentrates. Exports of refined bismuth have declined markedly over recent years after peaking in 1984 at about 420 t. Under 50 t were exported in 1987, rising to just over 50 t (estimated) in 1988. How much bismuth is domestically consumed is unclear; thus it cannot be concluded that the decline in exports after

1984 is due to declining domestic demand. In all probability export figures are reasonable reliable indicators of UK production.

#### **Mining and Chemical Products Ltd (MCP)**

MCP is the principal importer and refiner of UK bismuth and a major influence on the world bismuth market. Until November 1985, MCP-Peko (See above) were the only bismuth producer to quote a price for the metal. Following problems in metals trading after the collapse of the ITC the bismuth quote was suspended. The producer price had reportedly been already under review, as long-term customers had increasingly varied needs which were no longer adequately met by a blanket producer price system. The suspension of the MCP-Peko price however led to individual trading firms having far greater influence on the market.

MCP has two main centres of operation at Wembley in Middlesex and at Wellingborough, Northamptonshire. The Rosemont Road Works, Alperton, Wembley, include smelting and refining facilities: pyrometallurgical (furnaces and melting pots), hydrometallurgy, electro-refining and electro-winning (electrolytic tanks and pressure vessels). The plant products include bismuth in both metallurgical and pharmaceutical ingots, needles, granules, pellet, powder and shot and compounds; gallium metal and compounds; and a range of fusible alloys plus annealing equipment for use with these alloys.

In 1986 MCP acquired the business and assets of *Minwood Metals*, Wellingborough. Production of copper alloys, tellurium and selenium has been transferred there from MCP's subsidiary *Rhonda Metals*. Minwood is to become the centre for pyrometallurgical products and the plant at Alperton will specialise and develop operations in hydrometallurgy.

As mentioned above bismuth metal from Peko-Wallsend, Australia, was sent to MCP for refining until 1980. It is believed that MCP had then (and maintains) considerable stocks since there have been no reports of their being unable to meet demand. Whether some of Peko's stockpile has come on to the market this way is unclear. MCP, of course, refine concentrates from other sources and the company also maintains stocks in the USA, Europe and Australia.

#### Other UK producers

*Copper Pass Ltd*, a subsidiary of RTZ, operate a smelting and refining plant at North Ferriby on Humberside. A new electric-arc furnace was commissioned in 1986 to increase refined tin capacity to 20 kt/year. New dust and fume equipment was also installed in the smelter.

Copper Pass products include bismuth (capacity 250 t/year), electrolytic copper (4 kt/year), indium (3 t/year), refined lead and alloys (15 kt/year), silver (100 t/year) and refined tin (15 kt/year). The company produces low grade and complex ores, residues, ashes, drosses and flue dust. Copper Pass are believed to have their bismuth refined by MCP.

In addition, *Johnson Matthey Chemicals Ltd* of Royston, Hertfordshire, produce high purity metals and chemicals for laboratories and research and development. Production of bismuth is believed to be on a small scale although a wide range of bismuth products are available.

## THE UNITED STATES OF AMERICA

There are no official figures for USA production of bismuth. Primary production is limited to one company - *Asarco Inc*--and refinery production figures are withheld to avoid disclosing company proprietary data. *Arsarco* announced in September 1989 they were ceasing bis-

mut production but it is not clear how final this is.

#### *Arsarco Inc*

*Arsarco* is a transnational corporation operating in primary metals, recycling, asbestos and coal. Primary metals operations involve mining smelting refining and selling of copper, silver, lead, zinc and related by-products.

*Arsarco* was the only primary bismuth producer in the USA until the announcement this year that production would cease. No bismuth production figures were published but bismuth was believed to originate from the lead-zinc-silver mines at Leadville, Colorado, *Sweetwater* in Missouri and West Fork also in Missouri. *Sweetwater* was purchased in 1986 and has capacity for 100 kt/year lead and 8 kt/year zinc. Since start-up in December 1987 1 000oz silver and 300 t lead have been produced.

In addition to USA production, bismuth bearing lead concentrates were believed to be imported from *Asarco's* Quiruvilca mine in Peru and Quioma mine in Bolivia.

Bismuth is recovered from the pyrometallurgical refinery at Omaha, Nebraska. The refinery has a capacity of 142 kt/year refined lead, antimonial lead and refined bismuth.

The announcement that *Asarco* was 'bowing out' of bismuth production (reported in *Metal Bulletin*, September 1989), made no reference to any of the above mines or plant. Instead, it referred solely to *Asarco's* copper with bismuth by-product operations. Copper concentrates had previously been imported from Latin America to feed another *Asarco* smelter at El Paso, Texas. Lead smelting had been suspended at El Paso in 1985, but the company still had facilities to leach antimony from the copper-antimony-silver concentrates produced by their Coeur mine in Idaho and the adjacent Galena mine in which

*Asarco* has a 75% of net profits after royalties stake.

Expansion of *Asarco's* copper mining activities within the USA, especially at the Ray mine in Arizona is expected to provide all the feed for the El Paso smelter and remove the necessity to import copper concentrates. In 1986, *Asarco* had purchased the Ray mines from *Kennecott Corporation*, a subsidiary of *Standard Oil Co.*

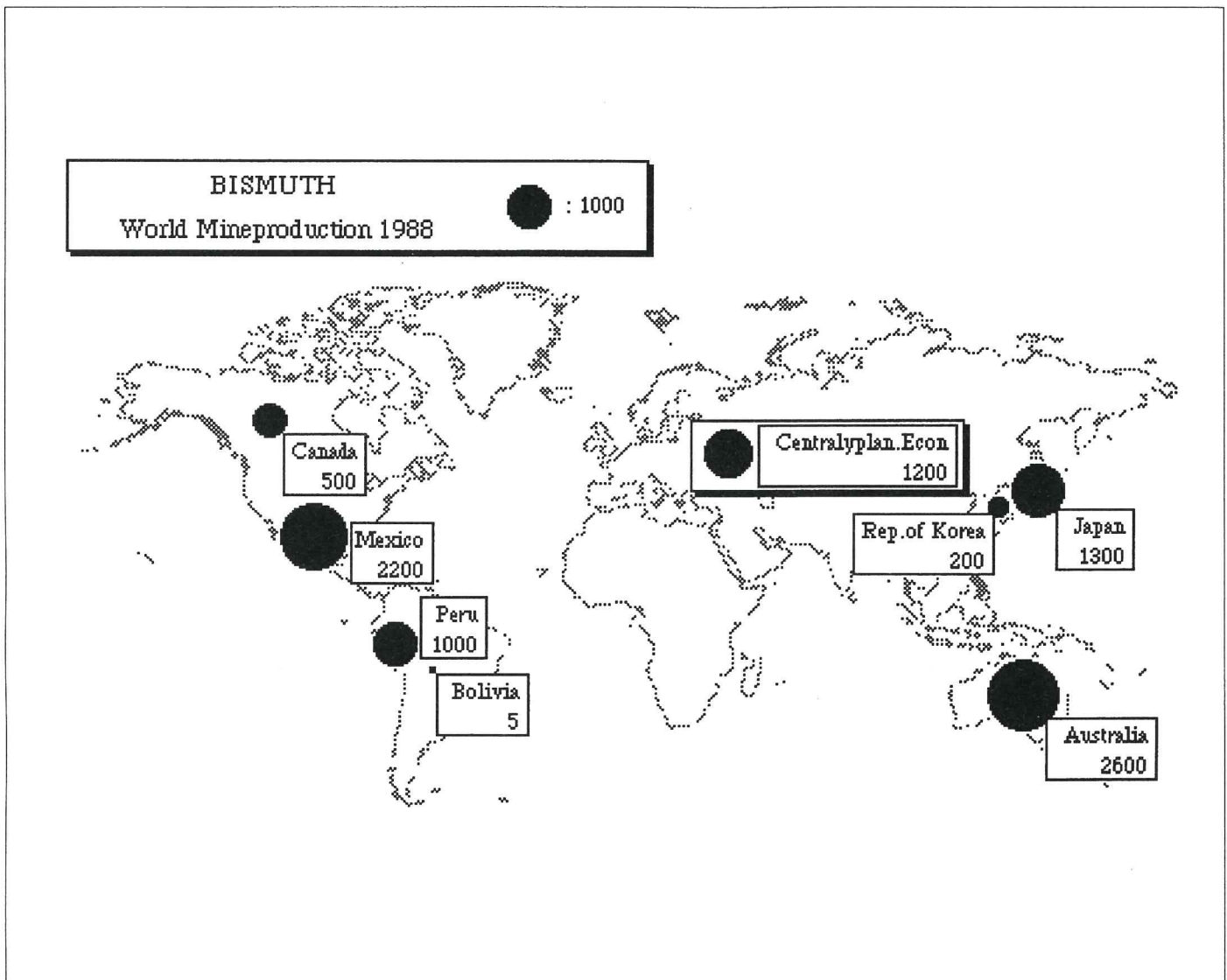
The Ray smelter, which had formed part of the operations, had closed and since 1983 Ray concentrates had been processed at yet another *Asarco* smelter at Hayden, Arizona.

Subsequently, Ray mines output significantly increased - in 1987 Ray produced 378 000 oz silver (1986: 37 000) and 107.7 kt copper (1986: 10.6). Smelting is now to shift to El Paso and mining and milling capacity at Ray is to expand to meet smelter capacity of 290 kt/year copper.

Thus it would seem that *Asarco* is only partially 'bowing out' of bismuth production, and that lead/bismuth refining will still continue.

#### Other possible US bismuth producers

*Minproc Ltd* of Australia was reported to be recovering precious and minor metals from flue dust at the Anaconda Copper Reduction facility. An estimated 360 kt of flue dust, containing arsenic and substantial quantities of copper, gold, silver, lead, zinc, mercury and bismuth is located at the Anaconda complex, Montana. A joint venture company, - *Artech Ventures* - between *Artech Recovery* and *CSS Management Corporation* was formed to exploit the arsenic bearing dust. In 1987 *Minproc* became a substantial shareholder in *Artech* and explored ways to widen the scope of exploitation. The extraction process, known as the Cashman process, was developed in collaboration with the US Bureau of Mines. Operations commenced in 1988 with initial capacity of 100 t per day, rising to 400



t per day. No details are available on the success of the venture.

The *United Refining and Smelting Company* are believed to produce limited quantities of bismuth from secondary sources, particularly bismuth-cadmium alloys. Most of the output is used to make 'Unibrand' fusible alloys. These are available in nine grades.

*Atomergic Chemetals Corporation* operate an electrolysis and zone-refining plant at San Diego, California, where they produce high purity metals such as arsenic, beryllium, bismuth, ce-

rium mischmetal, cobalt, gallium, germanium, indium, manganese, mercury, molybdenum, niobium, selenium, tantalum metal and oxide, tellurium, titanium sponge, tungsten, vanadium and zirconium. Their bismuth production is between 90 t/year and 180 t/year. This is limited to high purity grades (99.995%, 99.999% and 99.9999%) of single crystals, powder, custom fabrications, alloys and bismuth chemicals. The main end use is pharmaceuticals or as chemical reagents. Scrap is mainly used as raw material.

*Metalspecialities Inc* have a remelting plant at Fairfield, Connecticut, which treats scrap and residues. Their products include bismuth, cadmium, gallium, germanium, indium, refined lead and alloys, remelted lead and alloys, lead semis, platinum, palladium, selenium, tellurium, refined tin and alloys, and rare high purity elements. The company have agency agreements with MCP of UK for minor metals and bismuth alloys, and with MCP-Peko Ltd. of UK for metallurgical and pharmaceutical grades of bismuth. *Metalspecialit-*

ies produce low melting point bismuth alloys under their own trade name "METSPEC".

*Ney Smelting and Refining* operate a smelting/alloying plant at Brooklyn, New York. Their products include antimony metal and trioxide, bismuth, cadmium, secondary copper ingot, remelted lead and alloys, refined tin and alloys and special high grade zinc. Their bismuth capacity is reported to be around 10 t/year. Ney also produce fusible alloys under the trade name "Neylo".

*Precise Alloys Inc.* have a smelting-refining plant at Westbury, New York. They produce mainly remelted lead including alloys, and some antimony metal and trioxide, bismuth and indium. Their bismuth capacity is unknown.

Other producers include *Niagara Falls Metals and Minerals Inc.*; and the *Pesses Co* of Solon, Ohio. Furthermore, in 1992, the *Mitsubishi Copper Co*, a subsidiary of *Mitsubishi Mining* will commence smelting operations at Texas City, Texas. The new smelter will depend upon imported Latin American copper concentrates (possibly those which previously went to El Paso). Bismuth will be produced as part of the smelting process and will be shipped to a refinery along with the copper anodes. The company has stated it has no plans to become a seller of bismuth metal.

### The USSR

Bismuth production in the Soviet Union is estimated to have risen steadily over the past thirty years, rising from 30 t in 1963 to 84 t in 1986. In 1982, the USSR was reported to be planning to increase recovery of bismuth from tin and tungsten.

Bismuth is recovered from a variety of sources including as by-product of lead and zinc smelting in *Kazakhstan* and other regions; from dust and crude metal at the *Balkhash*, *Kirovgrad* and *Mednogorsk* complexes; and from tungsten and molybdenum ores in the *North*

*Caucasus*. The *Ustarassy* mine in the Chatkal mountains is the only known bismuth mine in the USSR. Concentrates from the mine are sent to the *Chimkent* lead smelter in Kazakhstan for processing. Bismuth is also produced at the Ust'-Kamengorsk lead-zinc complex in east Kazakhstan (also known as the Altai complex).

There are no detailed statistics available for trade in bismuth but the Soviet Union is known to be a major importer. In 1980 some 600 t - 700 t of bismuth metal was purchased from Bolivia (see above). Some 200 - 300 t was purchased from various sources in 1982; a further 200 t from Minpeco, Peru in 1984 plus some reported imports from Romania. Total imports for 1987 were believed to be around 500 t.

### YUGOSLAVIA

Yugoslavia has plans to expand its non-ferrous metals industry over the years to 2000, with greater emphasis placed upon polymetallic ores and secondary lead production. This will involve the introduction of new technology and more efficient use of lead and zinc concentrates particularly for recovery of antimony, bismuth, indium and cadmium.

Bismuth is known to be produced by the state-owned *Rudarsko-Metalursko-Hemijski Kombinat Trepca* at their lead and zinc mining, smelting and refining complex at Trepca, Zvecan. Annual capacity is 30 kt and lead concentrates are obtained from eight mines operated by the company. During 1984 and 1985, Rudarsko invested about 320 MUSD in modernising its facilities and in optimising production from its Ajvalija and Kisnica mines. Priority has been given to geological exploration, modernisation of ore production and the opening up of new mines. A 20 MUSD budget had been allocated for exploration up to 1990 but this had been pruned to 5.7 MUSD by mid 1989.

### OTHER POSSIBLE MINOR BISMUTH PRODUCERS

The US Bureau of Mines records the following data (none of it recent) on minor bismuth producers:

Small quantities of bismuth are recovered from mining operations in *Argentina*. The main source is the *San Juan* province where production is reported to have been 360 kg in 1975, In the same year a further 14 kg of bismuth minerals were produced in Catamarca province, probably as a by-product from manganese, gold and silver operations of *Yacimientos Mineros de Agua de Dionisio* at Farallon Negro.

In *Spain*, *Industrias Arsenicales Reunidas* were reported in 1972 to be the only producers of bismuth. Capacity was believed to be 40 t/year. An expansion programme had been proposed to raise capacity to 100 t/year but presumably was set back by the French Health Authority ban in 1974.

In *Sweden*, *Boliden Metall AB*, have in the past produced bismuth by-product at their lead and copper smelting-refining complex at *Skelleftehamn*. However, no production has been reported since 1965.

In *Uganda*, some 30 t of bismuth was produced between 1971 and 1979 in small amounts that did not exceed 5 t/year. No other details are available on source or type of production.

In addition, the USBM believe that *Brazil*, *Bulgaria*, *East Germany*, *Namibia* and *Mozambique* produce bismuth but available information is inadequate for reliable estimates.

The Bureau also claims that large, unmeasured, quantities of bismuth are present in *Australia*, *Bolivia*, *China*, *Mexico*, *North Korea*, *Peru* and the *Republic of Korea*. These resources do not as yet appear on any development schedule. ■