

# Mineral Commodity Report 13 — Silver

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## Discovery and Origin of Names

Silver has been known and valued as an ornamental and decorative metal since ancient times. Silver articles have been found on the site of the Great Chaldean temple at Ur on the Euphrates, and in the tombs of Pharaohs dating back as far as 6000 years ago. About 5600 years ago, silver was mentioned in the books of the Egyptian Pharaoh Menes, who set its value at two-fifths that of gold. The Phoenicians used and traded silver obtained from mines in Armenia, Siphnos, Crete, Sardinia and Spain. Silver was used along with gold as money about 2800 years ago in countries between the Indus and the Nile.

Ancient silver mines are known in China, India, Iran, Sudan (Nubia) and Ethiopia. Rich mines of Laurium in Greece and Rio Tinto in Spain, provided the monetary base for the Greek Empire and later, the Roman Empire, and exhaustion of many of the Roman mines may have contributed to the decline of the Roman Empire. Rich silver deposits were later discovered in central Europe, allowing its important economic role to continue. Within the European silver belt, silver mining began at Freiberg in Saxony in the 1100s, at Příbram, Czechoslovakia in the 1300s, and at Jáchymov, Czechoslovakia in 1516. In the early 1500s, large quantities of silver, along with gold, were taken by the Spanish conquistadors from the Incas of Peru and Bolivia, and the Aztecs of Mexico, and shipped to Europe. Subsequently, the Spaniards opened many silver mines or expanded previous operations in Mexico (e.g. Taxco, Zacatecas, Sultepec and Pachuca between 1521 and 1524), Peru (e.g. Charcas, 1535) and Bolivia (e.g. Potosi, 1544). From the early 1600s, the Spaniards also operated mines in New Mexico, Arizona and probably California. Discoveries of silver in North America, such as the Comstock Lode (Nevada) in 1859 and Cobalt (Ontario) in 1850, helped develop the economies of USA and Canada.

The name silver is from the Anglo-Saxon *seolfor*, whereas the chemical symbol Ag is from the Latin *argentum*, both names for the native metal.

## Major Ores and Minerals

Silver ranks about 66th among elements in natural abundance in crustal rocks. It most commonly occurs in sulphide and sulphosalt minerals and alloyed with gold as electrum. The main silver bearing minerals are acanthite and its higher temperature form argentite, and electrum, tetrahedrite, pyrargyrite and native silver (Table 1). Because it substitutes or combines with many elements, silver occurs as an essential element in over 100 minerals, and it is a minor constituent in many more. Galena is commonly an important carrier of silver, mainly as very small inclusions of tetrahedrite (Gasparrini, 1993).

Symbol	Ag
Atomic no.	47
Atomic wt	107.88
Specific gravity	10.55
Valence	1, 2
Melting point	961°C
Boiling point	2212°C
Crustal abundance	0.07 ppm
Preferred analysis method	Atomic absorption spectroscopy
Routine detection limit	0.2 ppm

## Properties

Silver is one of the transition elements in Group 1B of the periodic table, along with copper (atomic number 29) and gold (atomic number 79). Together with gold and the platinum group metals it is one of the precious or noble metals. In pure form it has a brilliant white metallic lustre, a high specific gravity and the highest electrical and thermal conductivity of all the metals. With the exception of gold and perhaps palladium, silver is the most malleable and ductile of all metals. It has a hardness between 2.5 and 3, harder than gold but softer than copper.

Silver is a chalcophile element and combines with sulphur, selenium, tellurium, chlorine, bromine and iodine, rather than forming silicate minerals. Although silver is the most active chemically of the precious metals, it is not very active in comparison to most other elements. It is stable in pure air and water, but it tarnishes on exposure to hydrogen sulphide or air containing sulphur, resulting in a coating of silver sulphide  $\text{Ag}_2\text{S}$ , which is the black tarnish commonly seen on silverware. Gold and silver may be mixed to form solid solutions (alloys) in any proportions. The silver content of silver alloys is expressed in terms of "fineness" or parts of silver per 1000 parts of total metal. Commercial silver is usually 999 fine. Quantities of silver, like those of other precious metals, are measured in troy ounces, where 1 troy oz = 1.097 avoirdupois oz = 31.103 g. There are 12 troy oz to the troy pound (0.3732 kg) and 1 troy oz = 20 pennyweights = 480 grains.

The properties of the main silver minerals are summarised in Table 1.

## Formation

Silver is formed in a wide variety of hydrothermal deposits and is most commonly associated with gold and the base metals, copper, lead and zinc. Most deposits in which silver is the main economic mineral are epithermal quartz veins or five element (Ni-Co-As-Ag-Bi) veins. Silver occurs as a by-

Name, Formula	Colour	Hardness	Density	Lustre	Crystal form	Transparency	Fracture
Acanthite/argentite Ag <sub>2</sub> S	greyish black	2–2.5	7.19– 7.36	metallic	cubic	opaque	subconchoidal uneven
Cerargyrite (horn silver), AgCl	white or pale grey	2–3	5.8	resinous to adamantine	cubic	transparent to subtranslucent	conchoidal
Electrum, AuAg	yellow	2.5–3	12–19	metallic	cubic	opaque	
Hessite, Ag <sub>2</sub> Te	grey	2.5	8.4	metallic	cubic	opaque	
Miargyrite, AgSbS <sub>2</sub>	black	2.5	5.2–5.3		monoclinic	opaque	
Petzite, (Au,Ag) <sub>2</sub> Te	grey to black	2.5–3	8.7–9.0		cubic	opaque	
Polybasite (Ag,Cu) <sub>16</sub> Sb <sub>2</sub> S <sub>11</sub>	black	2–3	6–6.2	metallic	monoclinic	opaque	
Proustite (light ruby silver), Ag <sub>3</sub> AsS <sub>3</sub>	ruby red	2–2.5	5.55– 5.64	adamantine	hexagonal	subtransparent to subtranslucent	conchoidal or uneven
Pyrargyrite (ruby silver), Ag <sub>3</sub> SbS <sub>4</sub>	deep red to black	2–3	5.7–5.9	metallic to adamantine	hexagonal	translucent to opaque	conchoidal
Silver (native) Ag	silver–white	2.5–3	10.1– 11.1	metallic	cubic	opaque	hackly
Stephanite Ag <sub>5</sub> SbS <sub>4</sub>	black	2–2.5	6.26		orthorhombic	opaque	uneven, brittle
Sylvanite (Au,Ag)Te <sub>2</sub>	silver–white	1.5–2	8.0–8.2	metallic	monoclinic	opaque	uneven, brittle
Tetrahedrite (Cu,Fe,Zn,Ag) <sub>12</sub> Sb <sub>4</sub> S <sub>13</sub>	dark grey to black	3–4.5	4.6–5.1	metallic	cubic	opaque – subtranslucent	subconchoidal, uneven, brittle

Table 1: Properties of some silver minerals.

product or accessory metal in epithermal and mesothermal gold deposits and most base metal deposits.

**Epithermal silver-gold:** These are quartz vein, breccia and stockwork deposits formed at depths between 100 and 1500 m, predominantly in volcanic rocks and mostly in the Tertiary. Silver typically occurs as acanthite, electrum, and as sulphosalt and telluride minerals. The deposits were formed at temperatures mostly between 200–300°C, from fluids with salinities generally less than 3 equivalent weight % NaCl, although some deposits with abundant base metals were formed from fluids with salinities up to 13 %. The base metal rich deposits merge into the “veins” class of base metal deposits listed below. In most silver-gold deposits, silver is produced as a by-product of gold mining, e.g. Waihi and Golden Cross in New Zealand, Comstock Lode and Tonopah in Nevada, Republic in Washington, and Vatukoula in Fiji. In contrast, most of the deposits in Mexico are particularly silver rich and collectively have produced about 150,000 t of silver. Simmons and Albinson (1995) recognised two groups of deposits in Mexico: silver-gold deposit (e.g. Tayoltita, Guanajuato, Pachuca and El Oro) hosted in Eocene, intermediate composition volcanic and intrusive rocks, and silver-lead-zinc deposits (e.g. Naica, Fresnillo, Providencia, Taxco) associated with Oligocene-Miocene volcanic rocks and intrusions of felsic composition, but commonly hosted within underlying Paleozoic-Mesozoic sedimentary rocks. The silver-lead-zinc deposits were formed at higher temperatures and from fluids with higher salinities ( $\geq 10$  versus  $\leq 3$  eq. wt. % NaCl) than the silver-gold deposits.

The world’s largest silver deposit is Cerro Rico de Potosi in southern Bolivia, mined since 1544 with an estimated production of 30,000 to 60,000 t of silver, and resources in 1988 of 828 Mt grading 150–250 g/t Ag and 0.3–0.4% Sn (Suttill, 1988). The mineralisation occurs in a Miocene dacite dome, and underlying tuff ring and heterolithic breccia, all overlying Ordovician shales. A large number of epithermal quartz veins containing silver and tin minerals crosscut earlier porphyry alteration and stockwork tin mineralisation. The epithermal veins have a complex mineralogy that includes pyrargyrite, sphalerite, galena, tetrahedrite, jamesonite, boulangerite and stannite.

**Five element (Ni-Co-As-Ag-Bi) veins:** These are veins of open-space fillings that occur in diabase (dolerite) and sequences of sediments (slate-greywacke-quartzite) and pyroclastic rocks. The mineralogy consists of native silver, acanthite, freibergite, and other argentiferous sulphosalts, along with pyrite, Ni-Co sulphides and arsenides, native bismuth, bismuthinite and native arsenic. Some deposits also contain uraninite. The gangue is calcite or dolomite with some barite and quartz. Fluid inclusions indicate that the early stages of mineral deposition occurred from highly saline solutions at temperatures up to 450°C, which decreased in temperature and became more reducing throughout the depositional sequence. In a review of the deposits, Kissin (1992) noted that there is considerably controversy on their origin, but that isotopic characteristics were generally suggestive of a non-magmatic origin and derivation of components from diverse sources. Examples are Cobalt and Gowanda in Ontario, Echo Bay and Camsell River by Great

Bear Lake in North West Territory, Erzgebirge in Germany, Konigsberg in Norway, and Jachymov in Czechoslovakia.

**Base metal deposits:** Most of the silver mined (68% in 1995) is produced as a by-product of the extraction of lead, copper and zinc, the silver helping to make many of these deposits profitable. The different types of deposits are described in the "Formation" sections of the copper (Christie and Brathwaite, 1994) and lead and zinc (Christie and Brathwaite, 1995) commodity reports, and include:

- Volcanogenic massive sulphide deposits (VMS), e.g. Kuroko deposits of Japan, Rosebery in Tasmania, Rio Tinto in Spain, and Kidd Creek in Ontario. Average silver grades are in the range of 12–200 g/t.
- Sediment hosted stratiform deposits (SEDEX), e.g. Rammelsberg in Germany, Broken Hill, Mount Isa, McArthur River and Century in Australia, and Sullivan and Izok Lake in Canada. Trace to 470 g/t Ag (average 48 g/t).
- Sediment-hosted stratabound deposits, e.g. Kupferschiefer in Germany, Poland, Holland and England, the Zaire-Zambian copper belt, and White Pine in Michigan.
- Sandstone-hosted deposits, e.g. Laisvall in Sweden, Maubach-Mechernich in Germany, Largentiere in France, Bou-Sellam in Morocco, and Yava, Nova Scotia and George Lake, Saskatchewan in Canada. Average silver grades are 1–20 g/t.
- Replacement deposits, e.g. Cerro de Pasco in Peru, Parana and Sao Paulo in Brazil, Tintic in Utah, Gilman and Leadville in Colorado, and Tsumeb in Namibia.
- Vein deposits, e.g. Coeur d'Alene in Idaho, Butte in Montana, North Pennine in England, and Freiberg in Germany.
- Skarn deposits, e.g. Santa Eulalia in Mexico, Yeonhua in Korea, Ban Ban in Australia and El Sapo in Columbia. Average grades 30–200 g/t Ag.
- Porphyry copper deposits, e.g. Chuquicamata in Chile, Bingham in Utah, and Ok Tedi in Papua New Guinea.
- Hematitic granite breccia copper deposits, e.g. Olympic Dam, South Australia. Average silver grade 6 g/t.

## Uses

About 30% of silver supply is used for photographic materials, 30% in silverware and jewellery, and the remainder is used in various industrial uses such as in electrical and electronic contacts and components, electroplating, brazing alloys and solders, dental alloys, batteries, coatings for mirrors and glass, catalysts, water purification and bearings. A large quantity of silver is used for monetary purposes, as reserves of silver bullion and coins. However, the use of silver in coins has decreased dramatically since the mid 1900s because the value of the silver contained in many of the coins rose above their face value. Its use is now generally restricted to limited circulation or commemorative coins and medallions, which account for about 3% of total silver consumption.

In many of its uses, silver is alloyed with small amounts of other metals to make it harder, more durable, and resistant to tarnish. For example, sterling silver for tableware is 92.5% silver and 7.5% copper or other metal. Jewellery silver is 80% silver and 20% copper. Yellow gold in jewellery is usually about 53% gold, 25% silver and 22% copper. Gold dental alloys contain about 10% silver, and pre-1965 coin silver in the USA was 90% silver and 10% copper. Silver is one of the most commonly used metals for electroplating either metallic on non-metallic materials, for decorative purposes or to increase their reflectivity as in the case of its use in mirrors. Several silver compounds have important uses. Silver bromide, silver chloride and silver iodide darken on exposure to light, and are used in emulsions for photographic plates, film and paper. Silver iodide is also used in cloud seeding for artificial rainmaking. Colloidal silver, dilute solutions of silver nitrate, and some other silver compounds are used in medicine as antiseptics and bactericides. Silver carbonate and silver chromate are used as catalysts in the synthesis of organic compounds.

## Price

The price of silver is quoted for a troy ounce and has been around US\$5/oz in the 1990s, with a highest price of US\$6.16/oz in May 1995, an average price in 1995 of US\$5.20/oz and a price of US\$5.07/oz in early August 1996.

## World Production and Consumption

Total world silver production from mining was 469 M oz in 1995 (The Silver Institute, 1996). Mexico has the highest production (75 M oz in 1995), followed by Peru (61 M oz), USA (50 M oz), Commonwealth of Independent States (45 M oz), Canada (39 M oz), Chile (33 M oz), Poland (32 M oz), Australia (30 M oz) and China (27 M oz). In 1995, only 16% of the silver mined was produced from primary silver mines, whereas 68% was produced as a by-product of lead, zinc and copper mining, and the remaining 16% mostly as a by-product of gold mining. Recent increases in world production have been related to the start-up of new gold-silver mines, e.g. Eskay Creek in Canada. During 1996 and 1997, production will also be increased by the recommissioning of several former operations that have been held on standby. For example, the Green's Creek base metal mine in Alaska restarted in July 1996 with a planned production of 10 M oz Ag/year, and the Coeur and Galena mines in Coeur d'Alene are expected to recommence operations at about 3 M oz Ag/year.

In addition to primary supplies from mines, demand is also met from inventories and recycling of silver, particularly from photographic materials, electrical components and jewellery. Total world silver supply from mine production and scrap silver was 610 M oz in 1995, whereas consumption was 764 M oz in 1995 giving a significant shortfall in supply that was made up from inventories. Worldwide silver inventories (including silver held in bullion coins) were estimated at under 700 M oz for 1995, sufficient to meet the current supply/demand gap for only another four or five years.

## Ore Processing, Smelting and Refining

Several metallurgical processes are used to extract silver from silver ores and ores of other metals. The most important historical process for recovering silver from silver and silver-gold ores was amalgamation. In this process, liquid mercury is added to the crushed ore and forms an amalgam with the silver. The amalgam is washed out of the ore and distilled in a retort to remove the mercury, leaving metallic silver. Much higher recoveries are obtained by the cyanidation process, which was first used commercially in 1889, to treat gold-silver ore at Karangahake in the Hauraki Goldfield. It subsequently replaced amalgamation at most other gold-silver and silver mines. The ore is finely ground and treated with sodium cyanide solution which dissolves the silver and gold. Different strengths of solution and exposure times may be required for silver and gold ores. The dissolved silver is then precipitated by the addition of zinc or aluminium and an alkali to the solution.

Most of the world's silver is extracted from copper and lead ores. Silver minerals are recovered along with lead or copper sulphides by the process of froth floatation (see copper and lead-zinc commodity reports, Christie and Brathwaite, 1994, 1995). The lead and copper concentrates are then smelted, during which the silver is adsorbed by either the lead or the copper. Silver is extracted from copper by the Betts process, in which copper is electrolytically refined. In this process silver is obtained from the sludge, or anode slime, deposited in the baths. Silver is dissolved out of the sludge with nitric acid and is then obtained in pure form by electrolytic refining, and is smelted to produce silver bullion.

Silver is extracted from lead by the Parkes process, in which slab zinc is added to the molten crude lead. The zinc reacts with silver to form alloys with higher melting points and lower densities than the lead bath. These alloys float to the surface and are skimmed off. Zinc is removed from the alloys by distillation. Any lead remaining with the silver is removed by cupellation, a process in which the molten metal is heated in a blast of air on a cupel, or hearth, made of bone ash. The lead is converted to litharge,  $PbO$ , which flows over the edge of the cupel, leaving pure silver.

Silver is made available commercially as sterling silver and in ingots, plate, moss, sheets, wire, castings, tubes and powder. Ingots produced at refineries generally weigh about 31 kg and are about 305 mm long by 127 mm wide and 102 mm thick.

## New Zealand Occurrence and Resources

The occurrence of silver in New Zealand has been reviewed by Officers of the New Zealand Geological Survey (1970), Williams (1974), and Brathwaite and Pirajno (1993). The most significant occurrences are associated with gold in the epithermal gold-silver-quartz veins of the Hauraki Goldfield (Fig. 1). In these and other New Zealand deposits, silver occurs mostly in acanthite, electrum and pyrargyrite. However, Raiton and Watters (1990) listed more than 20 silver minerals recorded in New Zealand.

## Epithermal deposits

**Puhipuhi:** Silver mineralisation was discovered at Puhipuhi in 1888, and mining from 1888–1900 produced 38 kg of silver (Ferrar, 1925). The largest known silver occurrence is in quartz veins and silicified zones in greywacke and argillite on the northwestern and southeastern flanks of the basalt-capped Puhipuhi Plateau. Argentinian tetrahedrite is the main silver mineral present. Siliceous sinter, silicified breccia and quartz veins containing cinnabar and stibnite occur nearby at Rising Sun, Puhipuhi, Plum Duff and Mount Mitchell (Williams, 1974; White, 1983, 1986). Recent exploration for gold-silver deposits has focused on this area of mercury-antimony deposits, searching for deep fluid feeder zones with gold-silver mineralisation. Reconnaissance drilling has included an intersection of 10 m averaging 18.5 g/t Ag and 5.3 g/t Au in a chalcedonic quartz vein cutting a hydrothermal explosion breccia (BHP Gold, 1988).

**Hauraki Goldfield:** Silver has been an important by-product of gold mining in the Hauraki Goldfield and is currently produced during gold mining at the Martha Hill and Golden Cross mines. About 47 separate deposits are known in the region (Brathwaite, 1981) and collectively have produced more than 1000 t of Ag and 300 t of gold. Most are hosted by Miocene andesite and dacite although some deposits, of a similar Miocene or Pliocene age, are hosted by Jurassic greywacke or by Late Miocene to Early Pliocene rhyolite and ignimbrite (Brathwaite et al., 1989). The mineralisation occurs predominantly in quartz veins, typically subvertical to steeply dipping, and generally striking in a northeasterly to

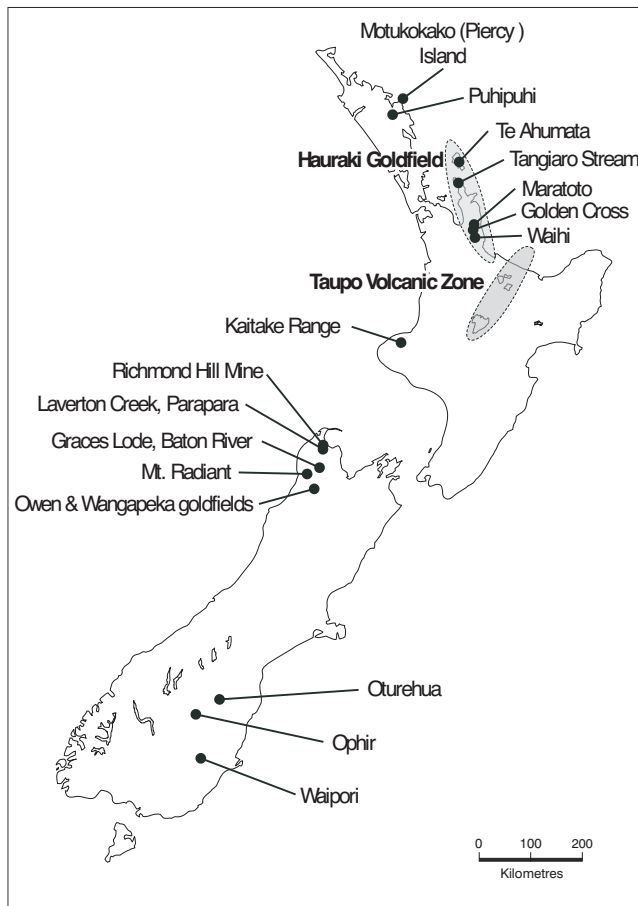


Figure 1: Location of silver deposits in New Zealand.

northerly direction. Vein widths are typically between 1 and 5 m but exceptionally range up to 30 m (Martha vein zone, Waihi). Vein lengths are typically up to about 800 m long. The veins were mined over vertical intervals typically of 170 to 330 m, but up to 700 m at Karangahake.

The main ore minerals are electrum and acanthite which occur along with other metallic sulphide minerals such as pyrite, marcasite, arsenopyrite, sphalerite, galena and chalcopyrite in a gangue of quartz, carbonates and adularia. Gold-silver telluride (particularly hessite) and selenide minerals characterise a few deposits, for example tellurides in the Tapu-Thames area (Merchant, 1986), selenides at Te Ahumata (Ramsay and Kobe, 1974), and tellurides and selenides at Maratoto (Main, 1971, 1979).

Fluid inclusion and stable isotope studies on some of the deposits suggest that the mineralisation formed from low salinity fluids at temperatures predominantly between 200 and 320°C, in environments similar to many modern geothermal systems (Brathwaite et al., 1989). These fluids have hydrothermally altered the rocks surrounding the veins to propylitic (secondary chlorite, calcite, quartz, interlayered illite-smectite, illite and pyrite), sericitic (quartz, illite and pyrite), K-feldspar (quartz, adularia, illite and pyrite) and argillic (kaolinite, smectite, interlayered illite-smectite and pyrite) mineral assemblages.

Descriptions for Te Ahumata, Tangiaro Stream and Maratoto are included here because they are essentially silver deposits, with Ag: Au ratios of about 25:1, 130:1 and 100:1 respectively, whereas descriptions for the major gold-silver deposits will be given in the forthcoming commodity report for gold.

**Te Ahumata:** Mineralised quartz veins occur in hydrothermally altered Miocene andesites (Coromandel Group) capped by silicified late Miocene–Pliocene rhyolitic pyroclastic rocks and volcanoclastic sediments (Whitianga Group). The veins were worked in three geographically separate areas, Barrier Reefs, Iona and Sunbeam, with a total production of 1300 kg of gold-silver bullion, mostly between 1892 and 1908 from Lees Reef in the Iona area. In 1971, Consolidated Silver Mining Company quarried 900 tonnes of quartz from the Iona quarry and recovered 210 g/t Ag and 8.8 g/t Au from the processing of the quartz in their plant at Maratoto, near Paeroa. In 1978–83, AMOCO prospected the area and drilled 10 diamond drillholes totalling 1670 m. Six vertical holes tested the possibility of large tonnage, low grade mineralisation beneath the plateau, and three angled holes targeted on Iona Reef intersected mineralisation in rhyolitic rocks in the hanging wall of the reef. The best grades were 190 g/t Ag and 0.58 g/t Au over 11.3 m in hole DDH2, including a 0.5 m section grading 1150 g/t Ag, 0.48 g/t Au and 9.5% Sb.

The mineralogy of the veins is complex with base metals, sulphosalts, seleniferous and selenide minerals, and stibnite (Ramsay and Kobe, 1974; Erceg, 1981). Erceg (1981) described the hydrothermal alteration as an early zoned system later overprinted by “acid oxidative leaching” producing quartz and kaolinite. The early alteration was proximal adularia-illite, followed outwardly by interlayered illite-smectite, and distal Ca-smectite alteration.

**Tangiaro Stream:** Silver, as tetrahedrite, occurs in a 1 m wide quartz vein hosted in Coromandel Group andesite (Skinner, 1967). Other minerals present include marcasite, pyrite, arsenopyrite, galena, chalcopyrite, sphalerite and electrum. McKay (1897) and Fraser and Adams (1907) reported assays ranging from 580 to 3370 g/t Ag.

**Maratoto:** Seventeen quartz-carbonate veins were worked in the Maratoto area, the most important being the Payrock, Maratoto, Silver Queen and Camoola. The Payrock and Maratoto are traceable for 3 and 2.8 km respectively. The veins have a NNE strike and most average less than 3 m thick, although the Camoola averages 6.1 m and attains a maximum thickness of 24.4 m (Fig. 2; Main, 1979). In the Camoola and Silver Queen veins, the ore occurs in bonanza shoots within dilation zones, fan shaped and widening upwards in longitudinal section (Main, 1979). Fine grained mineralisation, consisting of assemblages of pyrite, marcasite, acanthite, electrum, hessite, aguilarite, chalcopyrite, sphalerite and galena occurs in a gangue assemblage of quartz, quartz pseudomorphous after calcite, calcite, manganiferous calcite, siderite and rhodochrosite (Fig. 3; Main, 1979; Christie, 1982).

The veins are hosted in Coromandel Group andesite and dacite flows and breccias, hydrothermally altered to quartz-kaolinite-pyrite adjacent to the veins and passing outward to propylitic alteration assemblages of chlorite, epidote, carbonate, illite, quartz, adularia, heulandite, pyrite and minor clay (Main, 1971).

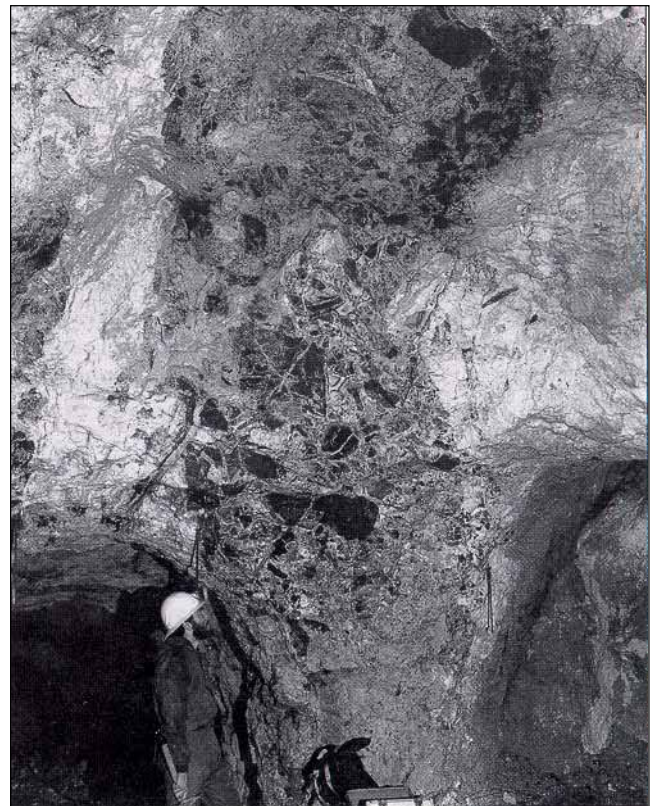


Figure 2: Epithermal silver-bearing vein, Maratoto Mine, Hauraki Goldfield, containing a band of wall rock breccia cemented by calcite and quartz (centre), flanked by bands of calcite with minor quartz (left and right) (Photo: Lloyd Homer).

Early mining produced 680 kg of silver-gold bullion (Downey, 1935), whereas between 1968 and 1973, mining on the Camoola and Silver Queen veins by Consolidated Silver Mining Company produced 3000 kg of silver and 23 kg of gold.

**Geothermal systems of the Taupo Volcanic Zone:** Small quantities of ore-grade silver-gold mineralisation have been deposited by geothermal fluids in several active geothermal fields of the Taupo Volcanic Zone, including Ohaaki (Broadlands), Rotokawa, Waiotapu and Kawerau. The mineralisation is found in surface siliceous sinters, subsurface quartz veinlets, quartz infilling cavities and silicified hydrothermal breccias, and disseminated in wallrock (Weissberg, 1969; Weissberg et al., 1979; Hedenquist and Henley, 1985). Highly mineralised precipitates have also been found in pipes, weir boxes, and drillhole discharges associated with geothermal exploration and development (Weissberg, 1969; Brown, 1986).

Silver-gold mineralisation is also present in fossil geothermal systems at Puhipuhi or Goldmine Hill, near Kawerau, at Ohakuri, and in discoveries made during exploration in the 1980s which included the Matahina Basin, Horohoro, Wharepapa, Ohakuri, Umukuri and Forest Road prospects (Cody and Christie, 1992; Barker, 1993).

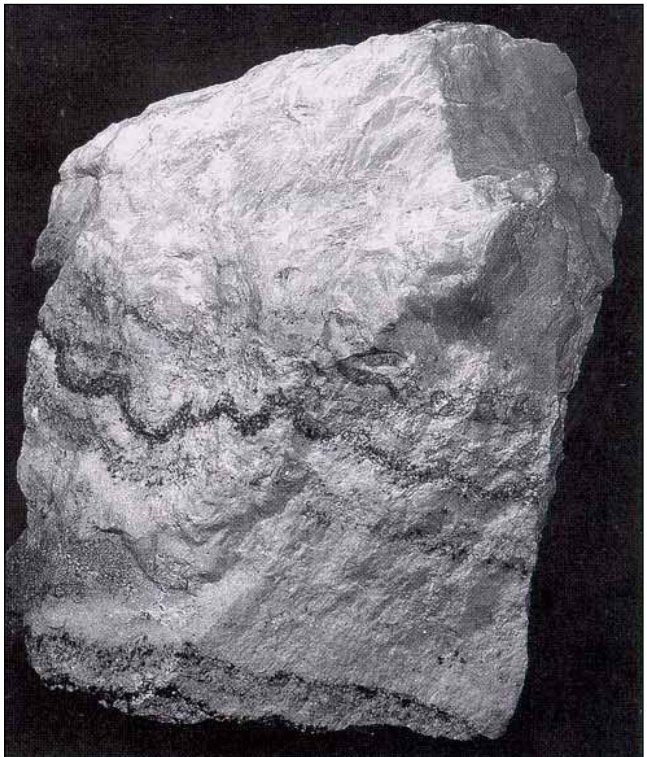
**Kaitake Range, Taranaki:** Silver is present along with copper, gold and zinc in a silicified “reef” hosted by late Quaternary andesite at the Boars Head Mine, where assays up to 62 g/t Ag and 0.3 g/t Au were reported (Cochrane, 1908; Morgan and Gibson, 1927; Geotechnics, 1973).

### Mesothermal veins of possible granite affiliation

**Laverton Creek or Parapara:** Exploration in 1969–80s discovered silver and base metal mineralisation in Wangapeka Formation quartzites and sericite schists, intruded by small dikes of quartz-feldspar porphyry. Quartz veins and fractures contain galena, pyrite, arsenopyrite, sphalerite, pyrrhotite, chalcopyrite, acanthite and pyrargyrite. Rock chip sampling returned values of up to 890 g/t Ag, whereas seven diamond drillholes gave best silver intersections of 51.7 g/t over 39.08 m and 19.7 g/t over 35.19 m (Bates, 1989).

**Richmond Hill Mine:** Cox (1877a, 1877b, 1882) described three quartz veins, up to 60 cm thick, and with silver values ranging from 69 to 58 000 g/t, from Richmond Hill in the Aorere Goldfield. The veins cut granitoids and Haupiri Group amphibolites near the thrust contact of the Haupiri and Golden Bay (Bay Schist Formation) groups (Grindley and Wodzicki, 1960). Riley (1972) considered the mineralisation to be hosted in blocks of schist included within diorite of the Richmond Hill Porphyry. The veins contain pyrite, chalcopyrite, argentiferous galena and tetrahedrite. Attempts at mining the deposit during the 1880s were abandoned without production. Later prospecting by Lime & Marble (Riley, 1972) included sampling of the workings and costeans, and stream sediment, rock chip, and soil geochemical sampling of the surrounding area.

**Baton River prospect or Graces Lode:** This prospect is found in structurally complex Haupiri Group rocks (Waingarō



*Figure 3: Thin black bands of silver minerals in calcite, 15 x 11 cm, from the Camoola vein, Maratoto Mine, Hauraki Goldfield (Photo: Brian Robinson).*

Schist Zone) adjacent to the Devil River Fault, and was included in several regional exploration programmes from 1971–88. McIntyre, Kaiser and Otter Minerals outlined a 1.5 x 0.7 km lead-zinc-(copper) anomaly, and reported float mineralisation values up to 19% Zn, 12% Pb, 7% Cu, and 200 g/t Ag (Lalor and Gunn, 1971; Bates, 1974, 1976a). Mineralised samples contain chalcopyrite, pyrite, arsenopyrite, galena, sphalerite and acanthite. Two holes were drilled by Western Compass and two were drilled by Otter Minerals. The most significant mineralisation encountered (up to 5600 ppm Zn, 1100 ppm Pb, 1200 ppm Cu and 10 ppm Ag) was associated with quartz and quartz-carbonate veins in chert and phyllite (Bates, 1976b).

**Owen and Wangapeka goldfields:** Veins containing pyrite, galena, chalcopyrite and sphalerite carry some silver and gold, and are hosted by dolomitic shale, quartzite and marble of early Paleozoic age. The veins have recently attracted interest, mainly for gold, particularly those in Bulmer Creek, where CRA (Hawke and Jamieson, 1984) found isolated high values for silver in samples from prospecting adit dumps (88.6 g/t) and float (12.1 g/t). The nearby Beilby’s Reef was also prospected at the turn of the century (Williams, 1974), and showed good silver values.

### Miscellaneous occurrences

Silver occurs in trace levels in most of the mesothermal gold-bearing quartz lodes in the Mesozoic Haast Schist of Otago, however significant concentrations were reported from lodes at Oturehua, Ophir, and the Cosmopolitan lode at Waipori (Williams, 1974; Officers of New Zealand Geological Survey, 1970).

Low levels of silver have been found associated with most base metal sulphide occurrences. Two notable examples are

lead-zinc skarn mineralisation, containing 6–120 g/t Ag, in Oligocene Whangarei Limestone at Motukokako (Piercy) Island (Brathwaite et al., 1990), and molybdenite-chalcopyrite veins at Mt Radiant which contain minor silver (Williams and Sanderson, 1959).

## Production and Resources

The main production of silver has been as a by-product of mining of gold from the Hauraki Goldfield, where the total amount of silver recovered from 1862 to the end of 1995 is estimated at 1256 t. The Martha Hill and Golden Cross mines produced 17.7 t and 11.1 t respectively in 1995. Pre-mining resource estimates for silver in these mines were 244 t at Martha Hill and 61 t at Golden Cross.

## Future Trends

Currently, demand for silver is increasing and has exceeded supply for the last 7 years, causing a gradual decline in stocks. The consumption of silver in photographic materials has received a temporary boost with the introduction of the new Advanced Photo System (APS) launched in April 1996, but may decline in the long term as new electronic image processing systems are developed. Aluminium has largely substituted for the use of silver in mirrors, but otherwise there is an increasing use of silver in other industrial applications, particularly in electronic devices such as personal computers, cellular phones and electronic systems in the automotive industry. Therefore, there is an overall trend of increasing demand which will need to be supplied by increased production. However, most silver is produced as a by-product of other metals and increases in production from these sources is dependent on the prices for copper, lead, zinc or gold. In the short term, increases in production from silver mines could partly be met by recommissioning former operations that are currently mothballed.

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