

Mineral Commodity Report 6 — Lead and Zinc

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Discovery and Origin of Names

The name lead is derived from the Old English *lead* and the symbol Pb is from the Latin *plumbum* meaning a lead weight; zinc is from the Greek *zink*.

Lead and zinc are among the oldest metals used. Lead figurines dating from 5800–5000 years ago have been found in Egypt and at the Dardenelles on the site of the ancient city of Abydos. The large lead (and silver) deposits of Laurion near Athens, were discovered 2600 years ago and became the main economic support of Athens. The Romans used lead extensively, particularly for water pipes, soldered with an alloy of lead and tin. Their lead was obtained from mines in Spain, Cyprus and Greece. Charlemagne established a provisional capital at Goslar in Germany because of the need to control and supervise the production of silver and lead in the nearby Rammelsberg mine. Lead craftsmen and artisans flourished during the Middle Ages of Europe, and their leaden ornaments and statues can be seen today on many buildings of the period, such as castles and cathedrals.

Zinc was known in Roman times but only in combination with copper as the alloy brass. The metallurgists of India may have isolated zinc metal as early as the 13th century, and those of China had achieved large-scale production of zinc by the 16th century. In the 16th century Philippus Aureolus Paracelsus was the first European to recognise zinc as a distinct metallic element and he named it zinckum. William Champion of England produced zinc in 1743 by reducing zinc carbonate with coke.

Major Ores and Minerals

Lead rarely occurs as a native metal in nature. The main lead ore mineral is galena (Table 1), which may contain minor amounts of silver. Galena oxidises to various secondary lead minerals, mainly cerussite, anglesite and pyromorphite $Pb_3(PO_4)_3Cl$.

The chief zinc mineral is sphalerite, which commonly contains iron up to a maximum of about 36%, and small to trace quantities of manganese and cadmium. In a few deposits, franklinite $(Zn,Mn,Fe)(Fe,Mn)_2O_4$ and willemite $ZnSiO_4$ are the principal ore minerals. The main secondary zinc minerals are smithsonite and hemimorphite $(ZnOH)_2SiO_3$.

Lead and zinc ores generally occur together, usually with silver. Most of the world production of arsenic, antimony and bismuth is as a byproduct from lead and zinc ore. The cadmium in sphalerite is the main source of this metal.

Symbol	Pb	Zn
Atomic no.	82	30
Atomic wt	207.19	65.37
Specific gravity	11.4	7.1
Valence	2, 4	2
Melting point	328°C	419°C
Boiling point	1744°C	907°C
Crustal abundance	10 ppm	50 ppm
Preferred analysis method	atomic absorption spectroscopy	plasma atomic emission spectroscopy
Routine detection limit	1 ppm	2 ppm

Ores of lead and zinc are mostly in the range of 3 to 20 wt % of either or both metals, but grades are more commonly 5–15% with averages close to 10%.

Properties

Lead, a member of Group IVa of the periodic table, is a dense, bluish-grey metal that is soft, malleable and ductile. It has low tensile strength and is a poor conductor of electricity. When freshly cut the surface oxidises to a dull grey coating made up of a mixture of lead and lead monoxide, which protects the metal from further corrosion. Lead has four stable isotopes: ^{206}Pb , ^{207}Pb and ^{208}Pb , are, respectively, the end products of the ^{238}U , ^{235}U and ^{232}Th series of radioactive decay; whereas ^{204}Pb has no natural long-lived radioactive parent. These stable isotopes and their radioactive parents are the basis for U/Pb age dating and lead isotope fingerprinting techniques used in the study of the genesis of ore deposits, and in pollution studies (Gulson, 1986).

Zinc, a transition element in Group IIb of the periodic table, is a bluish-white metal, which is extremely brittle at ordinary temperatures, but becomes malleable between 120°C and 150°C, and may be rolled into sheets between heated rollers. Zinc is unaffected by dry air but in moist air it oxidises and becomes coated with a carbonate film that protects it from further corrosion. Zinc is a good conductor of heat and electricity.

Zinc is an essential trace element in the human body but lead and many of its compounds are toxic when taken internally. Continuous exposure to even low levels of lead can be dangerous, particularly for growing children causing impairment of their mental and physical development.

Formation

Most lead and zinc production is from seven major ore deposit types:

Name, Formula	Colour	Hardness	Density	Lustre	Crystal System	Transparency	Fracture
Smithsonite ZnCO ₃	brownish-white or white	5.5	4–4.5	vitreous	hexagonal rhombohedral	subtransparent	uneven brittle
Sphalerite ZnS	yellowish-brown to black	3.5–4	3.9–4.2	adamantine	cubic tetragonal	transparent – opaque	conchoidal brittle
Anglesite PbSO ₄	white	2.5–3	6.3–6.4	adamantine	orthorhombic	transparent – opaque	conchoidal brittle
Bournonite PbCuSbS ₃	steel grey	2.5–3	5.7–5.9	metallic	orthorhombic	opaque	conchoidal or uneven brittle
Cerussite PbCO ₃	white to pale grey	3–3.5	6.6	adamantine	orthorhombic	transparent – opaque	conchoidal very brittle
Galena PbS	lead grey	2.5	7.4–7.6	metallic	cubic	opaque	flat, even or subconchoidal
Jamesonite Pb ₄ FeSb ₆ S ₁₄	dark lead grey	2–3	5.5–6	metallic	monoclinic	opaque	

Table 1: Lead and zinc minerals.

1. Volcanogenic massive sulphide (VMS) deposits are polymetallic sea floor deposits formed by hydrothermal systems which were generated by submarine volcanic activity, and are partly syngenetic and partly epigenetic in origin. They typically occur as multiple stratiform lenses within rhyolitic to basaltic submarine volcanic and associated rocks, commonly overlying, or adjacent to, discordant feeder zones containing low-grade stringer and disseminated mineralisation. The ore is composed of pyrite and/or pyrrhotite with varying amounts of sphalerite, galena and chalcopyrite. Several subclasses of VMS deposits are defined by varying composition and style of volcanism, e.g. Kuroko, Rosebery, Cyprus and Besshi. Only the Kuroko and Rosebery types are significant zinc and lead producers and are associated with rhyolitic, dacitic and andesitic volcanism in island arc environments.

Most VMS ore bodies contain between 0.1 and 10 Mt of ore, although groups of related deposits commonly aggregate more than 100 Mt. Kuroko deposits typically contain 4–5% Zn, 1–2% Cu and 1–1.5% Pb. Rosebery-type deposits are higher grade with up to 30% Zn+Pb+Cu, and up to 200 g/t Ag and 3 g/t Au. Major deposits include the Kuroko deposits of Japan; Rosebery, Hellyer and Woodlawn in Australia; and Kidd Creek in Ontario, Canada.

2. Sediment hosted stratiform (SEDEX) deposits are syngenetic deposits formed by submarine exhalations of hydrothermal fluid. The ores are concordantly interbedded within marine black shale, siltstone, sandstone, chert, dolomite and limestone. There is no apparent volcanic association. They occur in tectonically active intracratonic sedimentary basins which are commonly fault bounded. The ore consists of fine-grained pyrite and/or pyrrhotite, sphalerite, galena, sporadic barite and minor chalcopyrite.

Small local basins form the morphological traps that contain the ore-forming brine pools, and are located within larger

fault-controlled basins. The faults are synsedimentary and serve as feeders for the stratiform deposits. Discharge temperatures of the hydrothermal fluids are in the range of 150–220°C.

Deposits contain 4–550 Mt of ore (the average of 38 worldwide examples is 60 Mt), and have grades of 0.6%–18% (av. 7.3%) Zn, 0.3%–13% (av. 4%) Pb, nil–1.0% (av. 0.1%) Cu, and trace to 180 g/t Ag (av. 48 g/t). Some deposits have abundant barite associated with the sulphide ores. Typical examples include Meggen and Rammelsberg in Germany; Broken Hill, Mount Isa and McArthur River in Australia; Sullivan, Tom and Howards Pass in Canada; and Silvermines and Tynagh in Ireland.

3. Mississippi Valley (MV) type are stratabound epigenetic deposits that occur as replacement and open space fillings developed in favourable beds or horizons within thick sequences of shallow water dolomite or limestone. The ore is deposited at temperatures of 70–150°C from metal-rich brines migrating through the basin. The locus of ore deposition is frequently proximal to major fractures and/or reef facies. Dolomite, calcite, quartz and chert are common gangue minerals, and barite and fluorite may also be present in significant quantities. The main ore minerals are sphalerite, galena, pyrite and chalcopyrite, with iron sulphides much less abundant than in stratiform deposits. Precious metal values are usually low.

The ore bodies range in size from several tens of thousands of tonnes to over 20 Mt of ore. Districts containing well over 200 Mt of ore are not uncommon since MV deposits are often spatially distributed over a large area. Ore grades usually range from 3 to 10% Zn+Pb, but some deposits can contain only zinc, with grades commonly between 3–6%. Important examples are those of the Mississippi Valley and adjacent

regions in the USA, Pine Point and Newfoundland Zinc in Canada, and Silesia-Cracow in Poland.

4. Sandstone-hosted deposits are epigenetic ores, typically stratabound and commonly stratiform, in quartzitic or quartzofeldspathic sandstones and lesser conglomerates, deposited in coastal alluvial, lacustrine, deltaic, lagoonal, beach and tidal channel environments. These sediments are basal transgressive sequences that rest directly on deeply weathered basement. The ore is mainly fine- to medium-crystalline galena, with scattered smaller amounts of sphalerite, pyrite, barite, fluorite and minor chalcopyrite. These occur in multiple, thin, sheet-like ore bodies. The metals were probably leached from basement, transported by groundwater through permeable sediments and deposited by biogenically produced sulphide.

Exploitable ore bodies, or closely spaced clusters of ore bodies, generally contain 1–80 Mt of ore (most <10 Mt), with 2–5% Pb, 0.2–0.8% Zn and 1–20 g/t Ag. Examples include Laisvall in Sweden, Maubach-Mechernich in Germany, Largentiere in France, Bou-Sellam in Morocco, and Yava, Nova Scotia and George Lake, Saskatchewan in Canada.

5. Replacement deposits contain epigenetic Pb-Zn ores that were deposited by hydrothermal solutions as replacements of the host rock, typically limestone or dolomite. The form and size of the orebody is determined by structural and stratigraphic controls that localise the permeability for the ore-bearing fluids. Examples include mantos (tabular or cylindrical flat-lying layers), pipes, and irregular and branching masses. A wide variety of minerals may be present including galena, sphalerite, argentite, tetrahedrite, pyrite, enargite and chalcopyrite in a gangue assemblage of quartz, rhodochrosite, calcite, dolomite and barite. Examples are Cerro de Pasco in Peru, Parana and Sao Paulo in Brazil, Tintic in Utah, Gilman and Leadville in Colorado, and Tsumeb in Namibia.

6. Vein deposits are formed as open-space fillings in faults, fissures, joints or formational contacts and may occur in any variety of host rock. They range in width from narrow veinlets to bodies that are greater than 15 m wide. Persistent veins may follow faults or other structures for 5–15 km and extend down dip as much as 3 km. They contain a mixture of gangue minerals with local concentrations of ore in shoots of 10–15 m horizontal extent and hundreds of metres vertical extent. Ores are typically composed of coarsely crystallised aggregates of pyrite, sphalerite, galena, chalcopyrite, and numerous complex base- and precious-metal sulphide, sulphosalt, arsenide and antimonide minerals.

Individual deposits usually contain several hundred thousand to a few million tonnes of ore, with 10–30% Pb + Zn in highly varying proportions, although many districts have produced 5–50 Mt of lower-grade ore. Examples are Coeur d'Alene in Idaho, North Pennine in England, Taxco in Mexico and Freiberg in Germany.

7. Skarn deposits are epigenetic metasomatic deposits which form in carbonate rich rocks within the contact aureoles of intrusions of diorite to granite composition (mainly quartz monzonite). Skarns are associated with intrusions ranging from deep-seated batholiths to shallow dike-sill complexes

to surface volcanic extrusions. The intrusions generate the ore-forming solutions by providing magmatic fluids, or heat to drive convecting groundwater or formation water. The ore consists of assemblages of sphalerite, galena, chalcopyrite, scheelite, pyrrhotite, pyrite and arsenopyrite. The alteration assemblage is hedenbergite, andraditic garnet, diopside, hastingsite, epidote, magnetite, vesuvianite, and wollastonite, and the retrograde minerals actinolite, chlorite, epidote, ilvaite, rhodonite, fluorite, calcite and quartz.

Skarn deposits range from <1 to 30 Mt and grade 10–20% Zn + Pb and 30–300 g/t Ag. Examples are Santa Eulalia in Mexico, Yeonhua in Korea, Ban Ban in Australia and El Sapo in Columbia.

Uses

Zinc and lead are the fourth and fifth most used metals respectively, after iron, aluminium and copper.

Lead is used mainly for storage batteries, sheathing electric cables, construction (e.g. roof flashings), lining pipes and tanks in industry and in ammunition (shot and bullets). Lead sheets are used in buildings to absorb sound. Because it effectively absorbs electromagnetic radiation at short wavelengths, lead is used as a protective shielding in X-ray and radioactive applications. It is used in numerous alloys such as brass (Cu and Zn) and bronze (Cu and Sn). Alloys containing a high percentage of lead include: solder (Pb=Sn), type metal (commonly 58% Pb, 26% Sn, 15% Sb, 1% Cu), Britannia metal (Pb-Sb-Cu), pewter (Sn-Sb with historically about 25% Pb) and various bearing metals (10–90% Pb with Sn, Sb, Cu). Compounds of lead are used in antiknock additives for petrol to prevent premature detonation in internal-combustion engines (tetraethyl lead $Pb(C_2H_5)_4$), and in paints and pigments (e.g. white lead $(PbCO_3)_2.Pb(OH)_2$, litharge PbO , red lead Pb_3O_4 and chrome yellow $PbCrO_4$).

Zinc metal is used principally for galvanising iron and steel to provide a protective coating which corrodes preferentially or sacrificially because of the highly active or electropositive character of zinc. Other major uses of zinc are in various alloys, especially brass (Cu and Zn), and for die castings. The negative electrode (outside can) in a common type of electric dry cell is composed of zinc. Zinc oxide, known as zinc white or Chinese white, is used as a paint pigment, as a filler in rubber tyres, and in medicine as an antiseptic ointment. Zinc chloride is used as a wood preservative and as a soldering fluid. Zinc sulphide is useful in applications involving electroluminescence, photoconductivity, and semi-conductivity and has other electronic uses. It is employed as a phosphor for the screens of television tubes and in fluorescent coatings.

Price

Long-term fluctuations in prices of lead and zinc are generally similar as illustrated in Figure 1, with the highest prices since 1982 being in the period between 1989 and 1991. During 1995, consumption is expected to continue to be greater than production and Were J.B. & Son (1994) predicted average 1995 prices of 27 US\$/lb for lead and 52 US\$/lb for zinc.

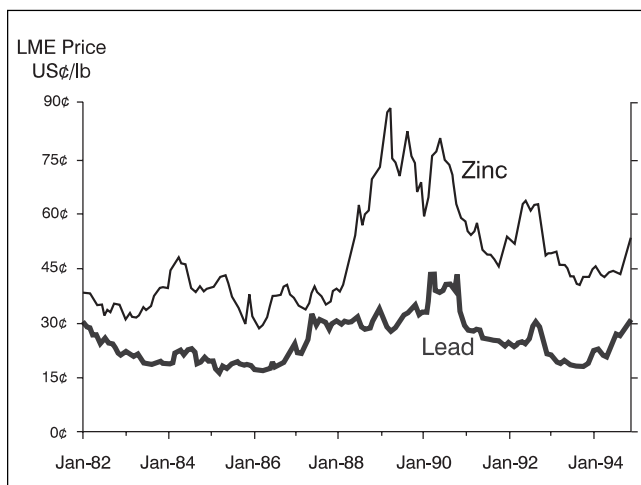


Figure 1: London Metal Exchange prices for lead and zinc (Source: Were, J.B. & Son, 1994).

World Production and Consumption

The principal lead-producing countries (with 1993 production where known) are: Australia (0.52 Mt), the United States (0.41 Mt), Peru (0.21 Mt), Canada (0.18 Mt), Mexico (0.16 Mt), South Africa (0.10 Mt), Kazakhstan and Russia. During 1993, in the Established Market Economy Countries, 2.4 Mt of lead were mined, whereas total production of refined lead, including recycled scrap, was 4.4 Mt and lead consumption was 4.5 Mt. The United States consumed 1.4 Mt of refined lead in 1993, about four times the amount used by each of the other major consumers, Japan and Germany.

The major sources of zinc (with 1993 production) are: Australia (1.01 Mt), Canada (1.01 Mt), China (0.82 Mt), Peru (0.67 Mt), USA (0.52 Mt), Mexico (0.36 Mt), Ireland (0.19 Mt), Sweden (0.17 Mt), Spain (0.16 Mt), India (0.16 Mt), Brazil (0.14 Mt), Bolivia (0.13 Mt), Japan (0.12 Mt), countries of the Commonwealth of Independent States (0.49 Mt mostly from Kazakhstan and Russia) and Poland. During 1993, world mine production of zinc was 6.90 Mt, with a total world production of refined zinc (including recycled scrap) of 7.13 Mt, and world consumption of 6.57 Mt. The United States consumed 1.14 Mt of refined zinc in 1993, compared with 0.72 Mt for Japan, 0.55 Mt for China and 0.47 Mt for Germany.

The annual consumption of lead and zinc are predominantly related to their uses in automobile batteries and galvanising respectively, and these generally follow the economic trends of the affluent nations and their demand for new automobiles and new construction.

Major new mines due to come into production between 1995 and 2000 are the Century (118 Mt grading 10.2% Zn, 1.5% Pb and 35 g/t Ag) and Cannington (47 Mt grading 10.7% Pb, 4.6% Zn and 470 g/t Ag) in Queensland, Australia; McArthur River in Northern Territory, Australia (26 Mt grading 14.0% Zn, 6.3% Pb and 63 g/t Ag); Lisheen in Ireland (22.3 Mt grading 11.9% Zn, 2.0% Pb and 27 g/t Ag); and Izok Lake in Northwest Territories, Canada (12.3 Mt grading 14.7% Zn, 2.5% Cu, 1.5% Pb, 78.4 g/t Ag and 0.1 g/t Au).

Ore Processing, Smelting and Refining

Lead and zinc sulphides are separated from their ores mainly by the process of froth flotation. The ore (2-20 wt % Pb; 2-20 wt % Zn) is crushed and ground to produce a fine suspension in water which is passed through a series of flotation cells. Air jets supply a stream of bubbles into the cells and a frothing agent is added to produce a heavy froth. Organic chemicals known as collectors are added and these cause a selective adherence of sphalerite and galena to the air bubbles. The bubbles, with their load of sulphides, are mechanically removed from the surface and the concentrate (50-64% Pb or Zn) is collected.

Lead and zinc are traditionally extracted from the sulphide mineral concentrates by roasting, sintering and then smelting. Roasting involves heating the sulphide concentrate in a furnace in the presence of air, thereby oxidising the sulphur, which is released as SO₂ gas. Sintering consists of treatment with a hot airflow and reducing agents to increase the density and particle size of the oxides and remove some impurities prior to feeding into the smelter. Smelting is the reduction of the oxides to elemental metal, usually by pyrometallurgical methods with carbon (coke or coal) and carbon monoxide in a furnace.

An alternative method commonly used for zinc is to leach the roasted zinc concentrate with sulphuric acid to form zinc sulphate, which is purified by removing contaminating elements such as Cu, Cd, Co and Ge. The solution is then pumped into electrolytic cells where the zinc is deposited on aluminium cathodes.

Lead and zinc refining is by pyrometallurgical methods (e.g. fractional distillation) or electrolytic processes. Nearly half of all refined lead and about 5% of zinc is recovered from recycled scrap.

The recovery of byproduct silver and gold from lead-zinc ores is also important.

New Zealand Occurrence and Resources

In New Zealand, most of the known lead-zinc deposits are in hydrothermal veins, commonly associated with gold and silver, as in the Coromandel Peninsula. Examples of VMS, SEDEX and skarn deposits are also known, but none of the New Zealand deposits clearly conform to the MV and replacement models, although some of the metamorphosed deposits of Fiordland could have originally been replacement deposits. The only New Zealand deposit mined primarily for lead and zinc was the Tui Mine near Te Aroha (Figure 2).

Volcanogenic Massive Sulphide Deposits (VMS)

Lead-zinc mineralisation occurs as small lenses of massive sulphide in quartz-sericite schist at Johnston's United Mine in the Aorere goldfield. Although originally mined for gold between 1866 and 1897, the style of mineralisation has attracted exploration for VMS deposits in recent years

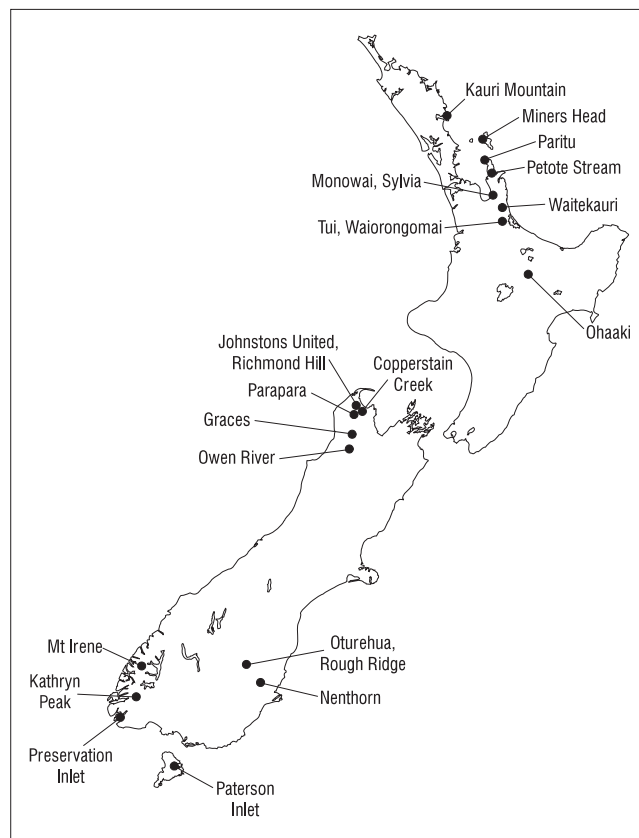


Figure 2: Location of lead and zinc deposits.

(Roberts, 1975; Canyon Resources, 1984; Brathwaite and Pirajno, 1993). Minerals present include: pyrite, arsenopyrite, pyrrhotite, galena, sphalerite, chalcopyrite and tetrahedrite (Grindley and Wodzicki, 1960). Exploration by Penzoid and Sigma Resources included geological mapping, geophysical surveys, trenching, 5 diamond drillholes and 6 reverse circulation holes (Roberts, 1975; Canyon Resources, 1984).

Recently, Westland Ilmenite Ltd carried out reconnaissance prospecting for VMS deposits associated with the volcanic rocks of the Haupiri Group in Northwest Nelson (Mathison et al., 1992; Jones and Savory, 1993). Several anomalies were identified in an airborne EM and magnetic survey, and were followed up by geochemical surveys, mapping and ground EM surveys. This work outlined a few areas of VMS style alteration and massive pyrite mineralisation with low concentrations of copper, lead and/or zinc, located in tributaries of the Anatoki and Waingarō rivers.

Sediment Hosted Stratiform Deposits (SEDEX)

Bell (1972) described the occurrence of sulphide-hornblende plagioclase fahlbands at Mt Irene, 8 km east of Charles Sound. They contain coarse pyrite and sphalerite and minor pyrrhotite and chalcopyrite. The fahlbands grade 2 to 4% Zn and 0.2 to 0.6% Cu with selected samples yielding up to 15.6% Zn. They are a few cms to 3 m thick and some can be traced for up to 400 m. The fahlbands occur erratically in a 12 to 200 m thick zone of hornblende-plagioclase schists and graphitic mica-quartz schists overlying marble (see Fig. 22-14 of Williams, 1974).

Vein Deposits

(a) Epithermal Veins

Hauraki Goldfield: Lead and zinc are present in significant quantities in several epithermal gold-silver-base metal deposits hosted in Miocene andesite and dacite of the Coromandel Group and greywacke basement of the Manaia Hill Group (Brathwaite et al., 1989). The richest base metal-bearing veins are in the Petote Stream area south of Coromandel, the Monowai, Sylvia and other gold mines between Tapu and Thames, at Waitekauri, and in the gold and base metal mines at Tui and Waiorongomai. During the late 1800s to early 1900s, minor quantities of lead and zinc were produced from some of these deposits for use as flux in the treatment of gold-silver ores. Tui Mine was operated by Norpac Mining Co. as an underground base metal mine between 1967 and 1973, producing 13,159 t of zinc concentrate and 7755 t of copper-lead concentrate, along with 3050 kg silver and 69 kg gold, from 163,000 t of ore (Bates 1989a).

A few small base metal bearing quartz veins, hosted in greywacke basement (Tokatea Hill Formation, Manaia Hill Group), crop out in streams south of Coromandel (Cadmian Stream, Aitken Stream, Hutt Creek, and Petote Stream), and were considered by Skinner (1976) to be extensions of the Tokatea Big Reef. Several dikes and stocks of Miocene andesitic and dacitic Kai-iti Porphyrites occur in the area. The quartz veins generally strike northwest and are less than 2 m thick. They contain medium-grained pyrite, sphalerite, galena, and chalcopyrite in a quartz-adularia gangue, some with late stage calcite and kaolinite (Edwards, 1979).

Gold-silver bearing base-metal sulphide veins occur in andesite around the periphery of several porphyry copper style systems north of Thames, such as the former gold-silver mines at Monowai and Sylvia (Merchant, 1986). Exploration by Spectrum Resources (Roberts, 1989) defined small resources of gold mineralisation at Monowai (high grade — 143,000 t at 14 g/t Au, 59 g/t Ag, 0.6% Cu, 0.3% Pb and 0.5% Zn; low grade — 38,000 t at 4 g/t Au, 41 g/t Ag, 0.5% Cu, 0.6% Pb and 0.8% Zn) and Sylvia (grade and tonnage not known). Earlier underground sampling, reported by Williams (1974), showed grades of up to 2.9% Pb and 4.4% Zn at Monowai and up to 5.8% Zn and 6.5% Zn at Sylvia.

The Waitekauri vein in the Jubilee low level mine (Waitekauri valley), contains minor galena and sphalerite and underground samples assayed up to 3.6% Pb and 1.5% Zn over a width of 0.2 m (Rabone, 1975).

At Tui Mine, two quartz veins, the Champion and Ruakaka, contain pyrite, marcasite, chalcopyrite, sphalerite, galena, tetrahedrite and a variety of minor primary and secondary minerals (Wodzicki and Weissberg, 1970; Courtney et al., 1990). At the time of closing (1974), the mine contained resources of 140,000 t of ore grading 4% Pb, 5.5% Zn, and 0.5% Cu above 5 level, the lowest level worked (Bates, 1989a).

Geothermal fields in Rotorua–Taupo area: Base metal mineralisation, primarily consisting of pyrite, sphalerite, chalcopyrite, and galena, has been identified in many geothermal fields (Browne, 1969, 1971; Weissberg et al.,



Figure 3: Galena and chalcopyrite from Tui Mine, Te Aroha (Photo: Eric Coppard).

1979; Hedenquist, 1983; Brown, 1986; Christenson, 1987; Krupp and Seward, 1987) and is particularly abundant at Ohaaki, where it is present at depths below 600 m as disseminations and veinlets.

(b) Lead–Zinc Veins Associated with Porphyry Copper Mineralisation

Kauri Mountain: A 1 m wide vein of mixed sulphides, mainly sphalerite and pyrite, with chalcopyrite and galena, occurs in greywacke on the shoreline near Kauri Mountain at Whangarei Heads, and may be associated with nearby andesite porphyry intrusives (Ferrari, 1925; Bell, 1976).

Miners Head: A hydrothermal breccia cemented with chalcopyrite, pyrite and minor sphalerite is associated with a diorite porphyry dike intruding greywacke at Miners Head, northwest Great Barrier Island (Rabone, 1984). The deposit was actively worked as the Otea Mine between 1857 and 1867, producing 2325 t of copper concentrate hand-picked from 50,000 t of ore (Williams, 1974). The sulphide mineralogy is predominantly chalcopyrite (containing inclusions of sphalerite, pentlandite and rare galena), with minor pyrite and pyrrhotite (Christie, 1982).

Several other minor lead-zinc showings of similar type are associated with hydrothermally altered porphyry dikes on the northern end of Great Barrier Island (Rabone, 1984).

Paritu: Copper mineralisation with minor lead and zinc is associated with a pluton (Paritu Plutonics) and dikes intruding Jurassic greywacke and Miocene andesite in the Paritu–Stony Bay area of Coromandel Peninsula. Inland, small quartz veins containing pyrite, chalcopyrite, sphalerite and galena are present in Sorry Mary Steam, Stony Bay Creek and Doctors Creek (Skinner, 1976).

Te Puru–Waiomu and Ohio Creek: Several porphyry copper style occurrences in high level quartz diorite and dacite porphyry intrusives were discovered in the Waiomu–Puhoe, Te Puru, and Ohio Creek areas, north of Thames, by Amoco in the late 1970s (Merchant, 1986).

(c) Mesothermal Quartz Veins

Northwest Nelson: Lead and zinc are recorded as associates of several gold and silver-bearing vein deposits at Laverton Creek, Richmond Hill Mine, Graces Lode and Owen River

(Bulmer Creek). Additionally, a small galena-sphalerite-pyrite lode is present in Galena Creek (tributary of Pariwhakaoho River) and was considered by Grindley (1971) to be related to the Copperstain Creek sulphide deposit. Numerous minor showings of lead and zinc identified in recent exploration of Northwest Nelson were summarised by Corner and Jennings (1994).

Laverton Creek or Parapara deposit in the headwaters of the Slate River on the Parapara Ridge, is hosted by Wangapeka Formation quartzites and sericitic schist. The mineralisation occurs in quartz veins and fractures and consists of galena, pyrite, arsenopyrite, sphalerite, pyrrhotite, chalcopyrite, chalcocite, acanthite and pyrrargyrite. It was probably deposited by hydrothermal solutions associated with a concealed intrusion of quartz porphyry (Richmond Hill Porphyry). The deposit was discovered by follow-up of a strong silver anomaly in a stream-sediment survey conducted by MacIntyre Mines in 1969. Subsequent exploration by several companies included mapping, geophysical and geochemical surveys, and seven diamond drill holes (Bates, 1989b).

Richmond Hill mine, in the Aorere goldfield, has argentiferous quartz veins cutting 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 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.

Graces Lode in the Baton River area is in structurally complex Haupiri Group rocks (Waingaro Schist Zone) adjacent to the Devil River Fault. It was included in regional exploration programmes by several companies 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 ppm Ag (Lalor and Gunn, 1971; Bates, 1974, 1976a). Mineralised samples from this prospect contain chalcopyrite, pyrite, arsenopyrite, galena, sphalerite and silver sulphide. 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 the Balloon Formation (Bates, 1976b).

Owen Goldfield, contains several base metal–silver mineralised quartz veins that have recently attracted interest mainly for gold, particularly those in Bulmer Creek (Williams, 1974; Newman, 1979; Coleman, 1981; Hawke and Jamieson, 1984; Corner, 1988). The veins of the Owen Goldfield are hosted in a strongly fractured zone within Owen Formation near its contact with Mount Arthur Marble; both formations included in the Mount Arthur Group. The veins contain pyrite, arsenopyrite, galena, chalcopyrite and sphalerite, and lesser silver and gold determined in assays.

South Westland: Hawke (1984) recorded galena mineralisation, as small veins and clots, associated with carbonatite rock float in Cowan Creek, a tributary of Burke River.

Central Otago: Galena and sphalerite occur as an accessory in many of the gold-bearing quartz lodes in the schist, particularly at Rough Ridge, Nenthorn and Barewood (Finlayson, 1908; Williamson, 1934, 1939; Williams, 1974).

Preservation Inlet, Fiordland: Layton and Associates (1971) noted small quartz veins and silicified breccias with minor base metal mineralisation in Preservation Formation greywacke and slate at several locations in Preservation Inlet.

A single 1.2 m wide quartz lode known as Bradshaw's Reef occurs in Cretaceous Kakapo Granite on the northern shore of Isthmus Sound. The lode was worked for a short time around 1900. Dodds (1968) described the lode as containing quartz, arsenopyrite, galena, chalcopyrite and possibly molybdenite. McKay (1896) additionally noted the presence of Zn, Ag and minor gold. No disseminated mineralisation occurs in the granite. Maximum assay values obtained by Asarco were 1.4 ppm Au, 360 ppm Ag, 1680 ppm Cu, 820 ppm Mo, 3600 ppm Zn, 15% Pb and 450 ppm Ni (Dodds 1968).

McKay (1896) also reported the occurrence of argentiferous galena in a lode on Coal Island in Preservation Inlet.

(d) Porphyry Molybdenum

Lead and zinc are accessory metals in several porphyry molybdenum deposits which occur in the northwestern part of the South Island. These deposits include Eliot Creek, Burgoo Stream, Karamea Bend, Mt Radiant, Taipo Spur, Bald Hill and McConnochie Creek, and they will be described in a later commodity report for molybdenum.

(e) Greisen

Barrytown: Sphalerite and rare galena and lead sulphosalts have been reported in greisen mineralisation at Barrytown. Assays of stream-sediment samples from this locality ranged from 18 to 360 ppm Zn (threshold 180) and 12 to 240 (threshold 100) ppm Pb (MacKenzie and Price, 1985).

(f) Miscellaneous Quartz Veins in Fiordland and Stewart Island

Stuart Mountains: Turnbull (1985) noted that traces of galena associated with pyrite and chalcopyrite have been found in rusty-weathering quartz boulders at the head of the Mid Burn.

Kathryn Peak: Wood (p. 173 in Williams, 1974) described an occurrence of sulphides near Kathryn Peak. They occur as disseminations and in breccias along shear zones and joints within metaquartzites and sillimanite gneiss. Analyses (up to 30% Zn quoted in Dodds, 1968) indicate the presence of sphalerite and galena in the crush- and shear-zones.

South West Arm, Paterson Inlet: Galena and silver are present in quartz veins within the Paterson Group near the entrance to South West Arm on Stewart Island, and have been explored by the driving of a small adit (Rolston, 1972).

Skarn

Motukokako Island: Zinc-lead skarn mineralisation has recently been found in Oligocene Whangarei Limestone at Motukokako (Piercy) Island (Brathwaite et al., 1990). The skarn is composed of the calc-silicate minerals hedenbergite, garnet, epidote, axinite, ilvaite and babingtonite, which are enriched to varying degrees in manganese and iron. Sphalerite and galena are disseminated in the skarn, the adjacent recrystallised limestone, and in quartz veins that cut the limestone and the unconformably underlying greywacke. The grade of the skarn mineralisation is of the order of 1–6% Zn and 0.2–1% Pb, with up to 100 ppm Ag (Brathwaite et al., 1990), which is significantly lower than average grades from economic Zn–Pb deposits (9% Zn and 6% Pb).

Copperstain Creek: At Copperstain Creek, about 11 km west of Takaka, lead and zinc are associated with copper in skarns developed by the intrusion of small granodiorite porphyry stocks and sills into Lower Paleozoic sedimentary rocks of Mount Arthur Marble and Onekaka Schist (Riley, 1967; Wodzicki, 1972). Wodzicki (1972) suggested that there is a lateral metal zonation, from molybdenum in the granodiorite, out through copper, to lead-zinc in peripheral locations.

Production

The only significant New Zealand production was from the Tui Mine, Te Aroha, from which 13,159 t of zinc concentrate and 7755 t of copper-lead concentrate were recovered from 163,000 t of ore between 1967 and 1973. The known economic resources remaining after the closure of the mine in 1973 were estimated at 140,000 t of ore grading approximately 4% Pb, 5.5% Zn and 0.5% Cu (Bates, 1989a).

Potential and Prospectivity

Small quantities of lead and zinc could be produced as byproducts of gold mining if epithermal or mesothermal deposits carrying significant quantities of these base metals were to be mined in the future. The best prospects for large lead-zinc deposits are VMS and SEDEX type deposits in Fiordland and Northwest Nelson, however access to most of these areas is severely limited by their protected land status as part of the Fiordland National Park and proposed Kahurangi National Park. A recent review of mineral exploration in Northwest Nelson by Corner and Jennings (1994) summarised a large number of lead and zinc showings and geochemical anomalies, illustrating good potential for future exploration. The skarn deposit at Motukokako Island, although not an economic deposit itself, suggests another potential target type for future exploration in northern New Zealand.

Future Trends

Although some traditional uses of lead are declining (petrol, and architectural and plumbing applications), others such as in storage batteries, and sound and vibration damping in buildings are increasing, leading to a projected increase in demand partly offset by increased recycling. The use of zinc especially for galvanising and die casting is expected to be maintained.

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