

# Mineral Commodity Report 4 — Copper

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## Discovery and Origin of Names

Copper was one of the earliest metals used by man, dating from about 8000 BC. Its abundance, attractive colour, ease of working, and resistance to corrosion made it an ideal material for tools, utensils and weapons. The Egyptians developed the metallurgy of copper, making casts in moulds around 4000 BC, and later extracting the metal from its ores by reduction using fire and charcoal. In about 3500 BC, copper was alloyed with tin to make bronze, for use in stronger weapons and implements, buildings, monuments and objects of art. The Egyptians obtained most of their copper from the Sinai Peninsula, until about 1500 BC, when Cyprus became the primary supply. The Romans also obtained most of their copper from Cyprus, and termed the metal aes Cyprium, “metal of Cyprus”, shortened to cyprium and later changed to cuprum; hence the symbol Cu. The name copper is derived from Kypros, the Greek name for Cyprus.

## Major Ores and Minerals

Copper occurs as native Cu and in many minerals, particularly as sulphides (chalcopyrite, bornite, chalcocite and covellite), sulphosalts (enargite), oxides (cuprite), and carbonates (malachite and azurite) (Table 1). Copper is chalcophile, and

Symbol	Cu
Atomic no.	29
Atomic wt	63.55
Specific gravity	8.89
Valence	1, 2
Melting point	1083°C
Boiling point	2595°C
Crustal abundance	55 ppm
Preferred analysis method	atomic absorption spectroscopy
Routine detection limit	1 ppm

most ores consist of sulphides, particularly chalcopyrite, usually associated with sulphides of lead and zinc.

## Properties

Copper, a member of Group 1b of the periodic table, is a reddish coloured metal that has a bright metallic lustre when polished. It is relatively heavy, tough, moderately soft, one of the most ductile and malleable of metals, resists corrosion and wear very well, is non magnetic, and is a good conductor of electricity and heat. Chalcopyrite, the main ore of copper, is brassy yellow in colour and usually occurs in massive aggregates of tetragonal crystals. Bornite, which is purple and blue, is known as “peacock” copper ore and is commonly

Name, Formula	Colour	Hardness	Density	Lustre	Crystal form	Transparency	Fracture
Azurite $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$	blue	3.5–4	3.7–3.8	vitreous –dull	monoclinic	translucent –opaque	conchoidal, uneven, brittle
Bornite $\text{Cu}_5\text{FeS}_4$	red, brown, black	3	4.9–5.3	metallic	cubic	opaque	conchoidal, uneven, brittle
Chalcopyrite $\text{CuFeS}_2$	brass yellow	3.5–4	4.1–4.3	metallic	tetragonal	opaque	conchoidal, uneven
Native copper Cu	copper–red, brown–black	2.5–3	8.5–9	metallic	cubic	opaque	hackly, ductile, malleable
Cuprite $\text{Cu}_2\text{O}$	red, red–brown	3.5–4	5.8–6.1	sub-metallic	cubic	translucent –opaque	conchoidal, brittle
Chalcocite $\text{Cu}_2\text{S}$	white –dark grey	2.5–3	5.5–5.8	metallic	hexagonal	opaque	conchoidal
Covellite CuS	blue	1.5–2	4.6–4.76	submetallic resinous	hexagonal	opaque to translucent	
Enargite $\text{Cu}_3\text{AsS}_4$	black	3	4.4	metallic	orthorhombic	opaque	uneven
Malachite $\text{Cu}_2\text{CO}_3(\text{OH})_2$	green	3.5–4	3.7–4	silky –vitreous	monoclinic	translucent –opaque	subconchoidal, uneven
Tetrahedrite $(\text{CuFeZnAg})_{12}\text{Sb}_4\text{S}_{13}$	dark grey –black	3–4.5	4.6–5.1	metallic	cubic	opaque –subtranslucent	subconchoidal, uneven, brittle

Table 1: Properties of some copper minerals.

found in massive aggregates of dodecahedral and octahedral crystals. Apart from covellite (dark blue) and malachite (green), the other main copper minerals are red, brown, grey or black in colour.

## Formation

Copper deposits can be mostly grouped into six classes (Table 2), of which three — porphyry, sediment-hosted stratabound and volcanogenic massive sulphide — account for about 80% of world production.

**Porphyry** copper deposits are associated with stocks and dikes of diorite to granodiorite composition, which crystallised at depths of about 1.5–4 km, mostly with a porphyritic texture. Hydrothermal fluids associated with the intrusion permeated a large volume of surrounding rock and developed zonal alteration and mineralisation patterns. Copper mineralisation occurs in characteristic stockwork quartz veinlets. Grades are low, with most worked deposits in the 0.4–1.1% Cu range, and therefore the deposits are generally worked as large open-pit mines. Associated metals such as gold and molybdenum may be present in sufficient quantity for byproduct mining that enhances the economic viability and profitability of the deposit. Major deposits include: Chuquicamata and Escondida (Chile); Bingham (Utah, largest open pit mine in the world); San Manuel–Kalamazoo and Sierrita–Twin Buttes (Arizona); Cananea (Mexico); Ok Tedi (Papua New Guinea); and Ertzberg (Irian Jaya).

**Sediment-hosted stratabound** copper deposits have ores concordantly bedded within marine sedimentary rocks with no apparent volcanic association. The major deposits are the Kupferschiefer (Germany, Poland, Holland and England), Zaire–Zambian copper belt, White Pine (Michigan). In these examples the sediments are typically organic-rich, calcareous shales or sandstones that were deposited during the first marine transgression over continental red beds. The deposits range in grade between 0.7 and 10% Cu although most worked deposits have grades between 1.2 and 5% Cu, and some have byproduct silver and cobalt. The currently popular genetic model suggests that the ore formed long after sedimentation of the host rocks, from heated basinal brines that sourced metals from the red beds and other underlying rocks, and which deposited the metals as they migrated through shales and sandstones.

**Volcanogenic massive sulphide (VMS)** are sea floor deposits formed by hydrothermal systems which were generated by submarine volcanic activity. Worked deposits have grades between 1.4 and 5% Cu. Several subclasses are defined by different compositions and styles of volcanism. Cyprus-type are formed in the black smoker environment of mid-oceanic ridges where hydrothermal systems are generated by basaltic pillow lava volcanism and intrusion associated with construction of the seafloor. Besshi-type are similar but they are formed along with thick sequences of continentally derived clastic sediment in epicontinental rifting environments (eg Guaymas ridge in Gulf of California). Kuroko-type are

Type	Form	Geologic Process	Typical Ore Tonnages and Grades	Coproduct or Byproduct
Porphyry	chalcopyrite in quartz veinlets in and near igneous intrusion	intrusion of granitic magma, fracturing, and flow of hot saline fluids	2–2000 Mt at 0.4–1.1% Cu	Mo, Au, Ag
Sediment hosted stratabound	beds of sandstone or shale impregnated by sulphide	flow of saline waters through reactive and/or permeable sedimentary rocks	1–1000 Mt at 0.7–10% Cu	Ag, Co
Volcanogenic massive sulphide	pods and layers of sulphide	submarine volcanism and outflow of metal-bearing saline fluids onto the sea floor	0.5–1000 Mt at 0.5–5% Cu	Zn, Pb, Au, Ag
Gabbroid-associated	layers or lenses of massive or disseminated sulphide in gabbroic rock	gravitational settling of sulphides directly from a molten rock	variable tonnage, 0.2–0.5% Cu	Ni, Co
Native copper	irregular masses and disseminations of native copper filling voids in lavas and sedimentary rock	flow of waters through fragmental, mafic-volcanic rocks and sediments	small tonnage, variable grade	Ag
Hydrothermal vein and replacement	quartz-filled fractures containing chalcopyrite and other copper sulphides and sulphosalts; deposits may replace layers of sedimentary rocks	flow of hot saline fluids through fractured and/or reactive rocks	small tonnage, variable grade	Ag, Au, Pb, Zn, As, Sb, Ba, Sn, Mn

Table 2: Classification of copper deposits (modified after Cox, 1989).

associated with rhyolitic, dacitic and andesitic volcanism in island arc environments. Primitive (or Noranda) VMS deposits, represented by the large Precambrian deposits of Canada (eg Noranda, Kidd Creek), are similar to Kuroko deposits but with some differences in host rock compositions, mineralogical content and hydrothermal alteration.

Olympic Dam hematitic granite breccia type is a major new type of deposit which was discovered at Olympic Dam, South Australia, in 1975. The mineralisation is hosted in hematitic granitic breccias of late Precambrian age that were formed by a variety of hydrothermal, magmatic, sedimentary and tectonic processes in a continental rift setting. At Olympic Dam a very large orebody of disseminated chalcopyrite-bornite-chalcocite is accompanied by gold, uranium, silver, rare earths, barium and fluorine minerals. The orebody, which contains an indicated resource of the order of 450 million tonnes at 2.5% Cu, 0.08% U, 0.6 g/t Au and 6.0 g/t Ag, is mined underground below a cover of 350 m of post-mineral sedimentary rocks.

## Uses

Copper was the most used metal before and throughout the Bronze Age, and the second most important metal from the Iron age until the 1960s, when it was surpassed by aluminium and relegated to third position. Copper is now mainly used in the electrical industry, especially in wiring, in plumbing applications, automobile parts, marine equipment, ammunition, domestic utensils, jewellery and in a variety of alloys. The important alloys in which copper is the chief constituent are brass (Cu and Zn), bronze (Cu and Sn) and nickel silver (Cu, Zn and Ni with no Ag). Other alloys include Monel (Cu and Ni) and aluminium bronze (Cu and Al). Copper is a part of nearly all coinage metals. Copper compounds are important in agriculture, particularly as fungicides (eg copper acetate), pesticides (eg copper sulphate) and wood preservatives (eg copper arsenate).

## Price

The price of copper has been at historically low levels in recent years due to worldwide recession and consequent reduced demand. In 1992 the average price of copper was US\$2293/tonne. It declined through 1993, but recovered sharply in May 1994 from levels near US\$1900 to US\$2280 in response to falling stocks and increased demand. World stocks of copper are low by historic standards, causing some volatility in the price, closely tied to short-term supply and demand.

## World Occurrence and Production

World reserves of copper were estimated at 570 million tonnes (Mt) Cu in 1987, with the main deposits located in Chile, USA, Australia, Commonwealth of Independent States, Zambia, Peru, Zaire and Canada. More than 50% of the world's known copper resources are found in porphyry copper deposits, whereas sediment-hosted stratabound deposits constitute about 30% and volcanogenic massive sulphide deposits about 7%.

Worldwide, mine production of copper concentrates is more than 7 Mt annually (7.6 Mt in 1992; Thompson, 1993), with the major producers, in order of importance, being Chile (1.9 Mt in 1992), USA (1.8 Mt), Canada (0.78 Mt), Zambia (0.43 Mt), Australia (0.37 Mt) and Peru (0.37 Mt). Many of the primary producing countries export a large portion of their concentrates which are smelted and/or refined in the country of use. For example, Japan, Germany and Belgium account for more than 20% of the world's refinery production although they have insignificant mine production. USA, although second in mine production, is the largest producer of refined copper. Secondary production of copper by recycling of scrap is significant in some countries, particularly the USA where it makes up more than 20% of total copper production. World primary and secondary production of refined copper was 8.825 Mt in 1992.

## Ore Processing, Smelting and Refining

Copper minerals are separated from ores mainly by the process of froth flotation. The ore (0.5–2% Cu) 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 the copper sulphides to the air bubbles. The bubbles, with their load of copper sulphides, float to the surface where they are mechanically removed and the concentrate (20–40% Cu) is collected. Copper is extracted from the sulphide mineral concentrates by smelting. Firstly, sulphur is removed by heating the sulphide concentrate in a furnace in the presence of air, thereby oxidising the sulphur, which is released as SO<sub>2</sub> gas, leaving a mixture called matte (30–75% Cu). The molten matte is reduced to blister copper (98% Cu) which is then cast in the form of anodes for electrolytic refining to produce cathode copper (>99.3% Cu). An alternative method of copper production from ores involves leaching the minerals from the ore and stripping the copper from the leachate by electrolysis.

## New Zealand Occurrence and Resources

New Zealand has a wide variety of copper deposits with representatives (albeit small) of most of the major types found elsewhere in the world. Past production was mainly from volcanogenic massive sulphide, serpentinite-hosted, and hydrothermal (epithermal) vein deposits. The primary origin of some deposits in Fiordland is difficult to determine because of overprinting and/or remobilisation caused by metamorphism.

Chalcopyrite is the main primary "ore" mineral, although sulphosalts such as tetrahedrite, farnatinitite, tennantite, enargite and chalcostibite have been recorded from some localities (Railton and Watters, 1990). Weathering and oxidation of the deposits have produced a variety of secondary minerals including: malachite, azurite, bornite, covellite, cuprite and native copper, and these were economically important in some deposits.

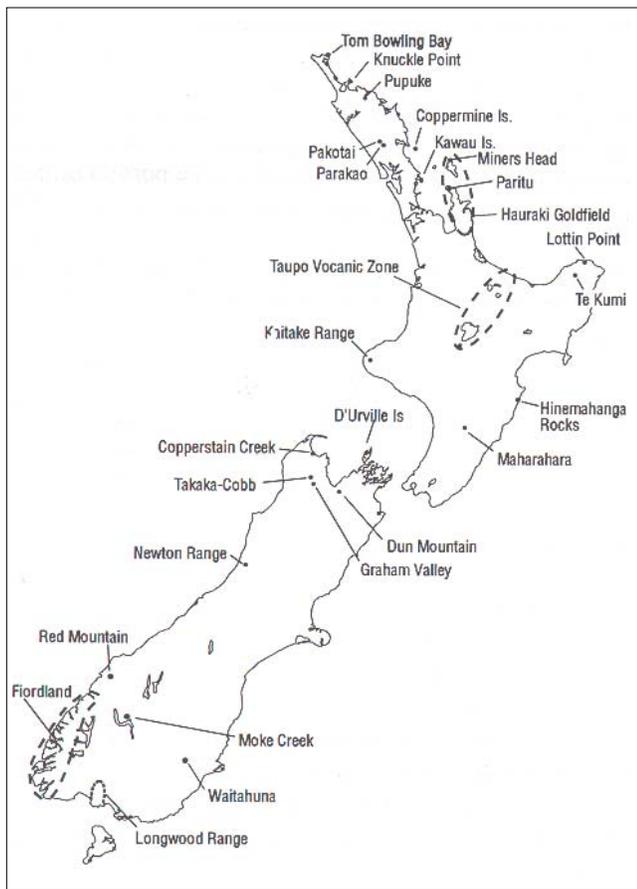


Figure 1: Location of copper deposits.

## 1. Porphyry

### (a) Porphyry copper

**Knuckle Point:** At Knuckle Point, the eastern tip of Karikari Peninsula, Doubtless Bay, Northland, disseminated chalcopyrite, pyrite and native copper occur in the carbonate cement of a breccia containing fragments of diorite wall rock, tonalite, keratophyre and basalt (Hay, 1966a, 1967). The mineralisation crops out over an area of 75 m x 75 m and was prospected as Bodies Copper Mine during 1847, 1849 and 1857. Two analyses quoted by Hay (1967) had up to 0.1% Cu, 2.1 g/t Au and 60 g/t Ag.

Similar breccias, some of which are mineralised, occur intermittently along the coast as far south as Taupo Bay and Stephenson Island (Hay, 1966b), and to the north, in an embayment just south of Pihakoa Point, a 3 m wide mineralised zone contains pyrite and chalcopyrite (Hay, 1975).

**Coppermine Island:** Copper mineralisation is associated with dioritic intrusive rocks (Miocene) in Waipapa Group greywacke basement (Permian–Jurassic) on Coppermine Island, the most easterly island of the Hen and Chicken Group (Wodzicki and Thompson, 1970). Sulphide mineralisation, mainly pyrrhotite, pyrite and chalcopyrite, occupies joints in altered diorite and interstices between fragments in dacite breccia. A four-hole diamond drilling programme by CRA Exploration Pty Ltd (M1036<sup>1</sup>) indicated

that grades were 0.03–0.11% Cu, and that grade generally decreases with depth.

**Whangarei Heads:** Discovery of minor alluvial gold at Whangarei Heads in 1887 led to the driving of a number of adits in zones of silicification in the greywacke rocks of the Waipapa Group. Limonite- and malachite-bearing quartz veins were encountered, and were reported to contain up to 720 ppm Cu (M0171). At nearby Kauri Mountain, a small hornblende andesite porphyry stock, intruding Oligocene siltstone and limestone, is hydrothermally altered and adjacent stream sediments yield copper geochemical anomalies (M0171).

**Miners Head:** A hydrothermal breccia cemented with chalcopyrite and pyrite is associated with a diorite porphyry dike intruding greywacke at Miners Head, northwest Great Barrier Island (Henderson, 1931; M0139; Rabone, 1984). The deposit was actively worked as the Otea Mine between 1857 and 1867, producing 2325 tonnes (t) of 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 copper showings of similar type are associated with hydrothermally altered porphyry dikes on the northern end of Great Barrier Island (Rabone, 1984; Moore and Kenny, 1985).

**Paritu:** Copper mineralisation is associated with a pluton (Paritu Plutonics) and dikes intruding Jurassic greywacke and Miocene andesite in the Paritu–Stony Bay area of Coromandel Peninsula. The intrusives are Miocene in age and predominantly of quartz diorite to granodiorite composition. Exploration by Southern Cross Minerals and Fletchers Ltd (M0611), and later Otter Minerals Exploration Ltd (M0392), outlined two zones of anomalous copper geochemistry in Ongohi and Stony Bay streams. In 1970, Mitsui Mining and Smelting Co Ltd drilled three diamond drillholes totalling 357 m in the Ongohi zone (M0244) and intersected disseminated chalcopyrite, magnetite and pyrite in biotite quartz diorite, averaging 0.16% Cu (M0263). Copper mineralisation is also present in diorite and contact hornfels rocks exposed along the coast south of Paritu. Inland, small quartz veins containing pyrite, chalcopyrite, sphalerite and galena are present in Sorry Mary Steam, Stony Bay Creek and Doctors Creek (Skinner, 1976; M0312).

**Manaiā:** In Kakatarahae Stream and its tributaries, 13 km south of Coromandel township, sulphide mineralised quartz veins and stockwork veins are present in a hydrothermally altered quartz diorite to dacite porphyry stock intruding basement greywacke (Stevens, 1980). The hydrothermal alteration exhibits a zonal pattern from a central core of chlorite-calcite-magnetite alteration, through clay-sericite and quartz-sericite zones, to peripheral propylitic alteration. The mineralisation consists of weak pyrite-chalcopyrite-magnetite veining.

<sup>1</sup> Relevant mining company exploration reports are referenced by the M-series file number and can be obtained from the Resource Information Unit, Energy and Resources Division, Ministry of Commerce, Wellington.

**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 (M0348, M0353). At Ohio Creek, exploration, including six diamond drillholes totalling some 2530 m, was carried out by Amoco and an Amoco–Anaconda joint venture (Merchant, 1986; M0353; M0374; M0403; M0422). Strong pervasive alteration occurs over an area of 8 km<sup>2</sup> and consists of a central quartz-sericite-pyrite altered core surrounded by concentric zones of clay-sericite and propylitic alteration. Outcrops of the “core” contain thin quartz veins with pyrite, magnetite, rutile, hematite, chalcopyrite, molybdenite and tetrahedrite, but the drillholes intersected a quartz vein stockwork containing bornite, tetrahedrite, covellite, enargite and lesser chalcopyrite, with an average grade of 0.18% Cu. Some of the mineralisation contains significant concentrations of gold, eg a 2.1 m interval of 17.3 g/t Au in drillhole DDH6.

### **(b) Porphyry molybdenum**

Copper is an associated metal 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.

## **2. Volcanogenic massive sulphide deposits**

The volcanogenic massive sulphide deposits consist of small lenses composed mainly of pyrite and chalcopyrite that are associated with (a) marine basalts of Cretaceous age in Northland and East Cape, (b) with chert and pillow lava in greywacke sequences of Permian–Jurassic age and their metamorphic equivalents and (c) with greenschists (metabasalts) and metaserpentinite of Permian–Triassic? age in Westland.

### **(a) Cyprus type deposits associated with the ophiolites in Northland and East Cape**

Previously mined copper deposits at Pupuke, Pakotai and Parakao in Northland and some copper shows at Lottin Point in East Cape are associated with Cretaceous ophiolite sequences (Tangihua Complex and Matakaoa Volcanics respectively) and are similar to Cyprus type VMS deposits (Brathwaite and Pirajno, 1993). Several other copper occurrences are associated with the ophiolite sequences near North Cape.

**North Cape:** Pyrite and chalcopyrite occur in veins and disseminations within dolerite in the Whangakea Volcanics near Kerr Point and traces of copper (0.04%) were found in green chert clasts within volcanic conglomerate at Tom Bowling Bay (Bowen, 1969a, 1969b).

**Pupuke:** Near Kaeo, small, irregular, tectonically disturbed lensoidal bodies of cupriferous sulphide, are enclosed in soft claystone and sandstone, in close proximity to dolerite and basalt. The sulphide bodies consist of pyrite, marcasite and chalcopyrite, with minor sphalerite and galena (Mason and Kobe, 1989). Secondary copper minerals include covellite,

malachite, bornite, native copper and chalcocite. Copper was first discovered in the area in 1892 and prospecting continued until 1910. The deposit was worked by the Hare–Ratjen Company, producing 133 t of ore from which 12 t of concentrate (8.2% Cu) were shipped to Sydney. Some prospecting and mining of small quantities of ore was carried out by Hazelbrook Mines from 1964–68.

**Pakotai:** Near Oputeke Road, 15 km from Pakotai township and 37 km west of Whangarei, discontinuous sulphide lenses occur in mudstone in fault contact with volcanic rocks (M0158). The lenses contain pyrite, chalcopyrite, sphalerite and marcasite (Roser, 1983). The deposit was discovered in 1944 and produced about 1400 t of copper ore between 1947 and 1951. Assays of shipped ore averaged 12.7% Cu, 57 g/t Ag and 5.8 g/t Au (Hay, 1960).

**Parakao:** A small lens of sulphides in sheared volcanic rocks and shales in the Pekapekarau Range, 32 km west of Whangarei, was worked as the Copper Queen mine. A surface limonite gossan passes down into an oxidised zone with azurite, malachite and minor native copper and cuprite. Below this at a depth of about 5 m, pyritic lode material contains secondary sulphides. The primary ore consists of pyrite and chalcopyrite with minor sphalerite (Mason and Kobe, 1989). The oxidised and secondary enriched ores were mined between 1961 and 1966 and produced about 1040 t of copper ore.

**Lottin Point:** A lens, 6.8 m long and 0.2 to 1.5 m thick, of disseminated pyrite and chalcopyrite is present in basaltic rocks of the Matakaoa Volcanics exposed on a wave-cut platform about 3.5 km southwest of Lottin Point and about 15 km east of Cape Runnaway (Pirajno, 1980b; Rutherford, 1980). Geochemical surveys by Gold Mines of New Zealand Ltd (M0696) identified two new areas with sulphide-mineralised float in the vicinity of Y14/678915 and Y14/658910. Sulphide-bearing boulders were also found in Mangatutu Stream (between Z14/721843 and Z14/732848) on the northern flank of Pukeamaru Range, southwest of Hicks Bay (Cody and Grammer, 1981).

**Hinemahanga Rocks:** Minor disseminations and veins of native copper, with cuprite and paratacamite  $\text{Cu}_2(\text{OH})_3\text{Cl}$ , are associated with calcite-zeolite alteration in pillow basalts of Early Cretaceous age at Hinemahanga Rocks (Kairakau Rocks) on the southern Hawke’s Bay Coast (Black et al., 1984).

### **(b) Massive sulphide deposits associated with chert and pillow lava in greywacke**

Several small copper deposits occur in Torlesse Supergroup and Waipapa Group greywacke and are associated with cherts and/or spilitic pillow lavas. Brathwaite and Pirajno (1993) suggested that these deposits were similar to Besshi type VMS deposits.

**Kawau Island:** En echelon lodes of massive sulphide mineralisation are associated with chert and metabasite in a mélange zone within Waipapa Group argillite and greywacke (Williams, 1959; Kear, 1966; Wood, 1976; Roser, 1983). The lodes are 2–6 m thick and concordant with the bedding of the enclosing country rock. The deposit is oxidised,

consisting downwards of: (a) gossan cap, (b) leached horizon of variable thickness, (c) 20 m thick oxidised zone, (d) more than 40 m thick secondary sulphide enrichment zone, containing up to 12% Cu and (e) primary copper ore with 1–2% Cu. The primary ore consists of massive pyrite with stringers of chalcopyrite and minor sphalerite, marcasite, pyrrhotite, bornite, tetrahedrite and hematite (Wood, 1976; Roser, 1983).

The copper mineralisation was found in 1842 adjacent to a previously discovered manganese oxide lens and a well defined lode was opened in 1846. A total of about 2500 t of ore was obtained, principally from the oxidised zone.

**Te Kumi:** Sulphide lenses with pyrite, chalcopyrite and minor sphalerite and magnetite occur in sheared/crushed greywacke at Te Kumi and in Mangahaupapa Stream, a minor tributary of Raukokore River, 32 km northwest of Ruatoria (Ongley and Macpherson, 1923; Rishworth, 1969; Pirajno, 1979). The lenses range up to 6.7 x 2.1 x 1.5 m in size and occur in an area of about 1.5 km<sup>2</sup>. Three prospecting drives totalling 55 m were excavated between 1918 and 1920. More recently, Gold Mines of New Zealand carried out geochemical surveys of the area (M0695, M0696) defining several copper anomalies in the Te Kumi prospect and Tapuaeroa Valley (M0696). Rishworth (1969) obtained values of up to 6.6% Cu from fresh samples.

**Maharahara:** In the Ruahine Ranges, 11 km north of Woodville, the Maharahara Copper Mine worked stratiform sulphide lenses hosted by red hematitic chert within greywacke (Lillie, 1953; Roser, 1983). The deposit has a strike length of up to 46 m and a variable thickness of up to 1.3 m. Primary minerals include pyrite and chalcopyrite, with minor sphalerite, pyrrhotite and barite. Underground mining during 1881–91 and 1930 produced 50 t at around 2% Cu. Exploration by Canyon Resources in 1983–85 outlined a copper geochemical anomaly associated with red chert (M0719,

M0720). Maximum values in rock chip samples were 7.8% Cu and 22 ppm Ag, with Au below detection limit.

Copper mineralisation has been reported from several other localities in the Ruahine Ranges including: Makaretu River (13 km northwest of Norsewood), Manawatu George, Mangatawainui Creek and Ruahini Tops 24 km east of Mangaweka (Lillie, 1953; NZGS, 1980).

**Makatote Stream:** Minor copper mineralisation is associated with spilitic pillow lava and chert in the Early Cretaceous Pahaoa Group near Makatote Stream, 55 km northeast of Masterton (Moore and Speden, 1984).

**Moke Creek:** Copper-rich sulphide layers occur in a greenschist band up to 3 m thick at Moke Creek, near Queenstown (Wood, 1967; Henley, 1975). The sulphides consist of chalcopyrite, with pyrite, pyrrhotite and minor sphalerite and occur as stringers and bands, a few centimetres thick, sub-parallel to foliation in the schist. Similar, but much smaller copper-bearing bands occur in Dead Horse Creek, several kilometres to the north, in Home Creek on the south side of the lake, near Lake Luna, in the Ox Burn and in several other places in the Richardson Mountains (M1793). The Moke Creek deposit has been prospected intermittently for at least 70 years, with some underground workings as recently as 1966–68. However, the only recorded production was a parcel of 3 t of ore, assaying up to 24% Cu, shipped to Australia for treatment in 1917 (Wood, 1967).

**Waitahuna:** Near Waitahuna and 13 km northeast of Lawrence, copper mineralisation occurs in a sulphide band concordant with the host greenschists (Mutch, 1967; Lowery, 1979). The band is up to 0.6 m thick and contains pyrite, marcasite, chalcopyrite, pyrrhotite and minor sphalerite. Parcels of ore shipped for trial smelting assayed 6–11% Cu (NZGS, 1980) and an assay of hand picked material contained 22% Cu, 19 g/t Ag and 0.6 g/t Au (Williams, 1974).



*Figure 2: The 20 m chimney and smelter ruins of the old copper mining operation on Kawau Island (Photo: Bruce Thompson).*

### **(c) Massive sulphide lenses in the Pounamu Ultramafics**

Small massive sulphide lenses are present in greenschist metavolcanics and metaserpentinite of the Pounamu Ultramafics on the western side of the Southern Alps in Westland. The Pounamau Ultramafics are interpreted as ophiolite (ocean crust) basement to the Torlesse terrane (Cooper and Reay, 1983). Copper-bearing sulphide lenses have been found in the Newton Range (Beck, 1965), Diedrich, Meta and Bowen ranges (M1398), Whitcombe River area (Cooper and Reay, 1983) and in the Wilberg Range (M1636, M1664). Those in the Wilberg Range appear to be the largest, with a mineralised zone 3–9 m wide and 1500 m long containing numerous pyrite-chalcopyrite lenses (30–90 cm wide) (M1622). Later exploration in the same area (M1664) identified a much more extensive zone of mineralisation comprising many small pods of massive sulphide within greenschist, with grades between 0.5 and 2.0% Cu. An analysis from the Diedrich Range returned 5.1% Cu and 3.9 ppm Ag.

### **3. Serpentine-hosted Fe–Cu**

Small shear-controlled lenses of copper mineralisation are present in serpentinised ultramafic rocks of the Dun Mountain Ophiolite Belt in the Nelson region (D'Urville Island and Dun Mountain) and in Southland (Red Mountain).

**D'Urville Island:** Copper is associated with serpentinite on a northeast-trending ridge on the southern side of D'Urville Island. Cox (1878a) described supergene mineralisation (cuprite, native copper, malachite and azurite) in several discontinuous zones traceable over a distance of some 820 m, but no defined lode was found (Cox, 1879). Several shafts and drives were opened to a depth of about 27 m, revealing primary pyrrhotite-chalcopyrite mineralisation (Johnston, 1987). In early 1879, 47 t of poorly sorted ore (averaging only 10% Cu) were shipped to Australia for smelting. A second shipment in mid 1879 was better-sorted (averaging 20% Cu), but operations ceased in 1880 due to financial problems.

An extensive low intensity copper stream sediment geochemical anomaly was detected during exploration of northwestern D'Urville Island by McIntyre Mines Ltd (M0831), but was not followed up. Minor chalcopyrite is associated with pyrite mineralisation near Punaatawehe Bay and Ohana (M0831; M0832).

Minor copper sulphide mineralisation in mafic volcanic rocks of the Dun Mountain Ophiolite Belt was prospected in 1858 at Tunnel Point across the Current Basin from D'Urville Island (Johnston, 1987).

**Dun Mountain:** The copper lodes at Dun Mountain are discontinuous and of small extent, with maximum dimensions of less than 150 m in length by 4 m in width. Primary mineralogy consisted of pyrrhotite with traces of chalcopyrite, although secondary mineral assemblages (mostly native copper and malachite with minor amounts of azurite, cuprite, chrysocolla and chalcocite) were well-developed and accounted for the best assay values (Bell et al., 1911). Primary ore was typically in the range of 1–1.5% Cu.

At the United Mine, a lens 100 m in length by 1.5 m wide, mineralised with pyrrhotite and locally dominant chalcopyrite, occurred in a zone of sheared serpentinite 8 m wide (Johnston, 1987). At the Champion Mine, mineralisation consisted of pyrrhotite with varying proportions of chalcopyrite in masses up to 4.5 m thick and blocks of native copper. At the Monster Mine, pyrrhotite with minor copper minerals are present in lenses up to 3 m across.

**Red Mountain, Otago:** Small bands of chalcopyrite, pyrrhotite and pentlandite occur as segregations in the serpentinised parts of the ophiolite belt on the west side of Little Red Hill and Red Hill Ranges (Mutch, 1965).

### **4. Gabbroid-associated Cu–Ni**

**Takaka Valley and Cobb River:** Metadiorite dikes in Devil River Volcanics, adjacent to the Cobb Igneous Complex, are associated with small lenses, veins and disseminations of gold-bearing pyrrhotite-pyrite-chalcopyrite-pentlandite mineralisation (Henderson et al., 1959; White and Whittle, 1961; M0136; M0782; M0850). Exploration by CRA (M1015; M1028) included drilling in Meter Creek, with a best intersection of 4 m of 1140 ppm Cu, 80 ppm Ni, 1.4 ppm Au and < 5 ppb Pt.

**Graham Valley:** Copper is associated with nickel mineralisation in gabbros, pyroxenites and diorites of the Riwaka Complex between the Graham and Pearce valleys (eg Prospect, Field and Price's creeks). Drilling, primarily for nickel, gave best intersections of 0.60% Cu and 2.2% Ni over 1.4 m, 0.22% Cu and 1.52% Ni over 2.5 m and 0.42% Cu and 1.42% Ni over 3.6 m (Bates, 1989). Chalcopyrite mainly occurs as interstitial blebs between the silicate minerals (Gill and Johnston, 1970; Pirajno, 1980a).

**Blue Mountain:** Copper-nickel mineralisation is associated with the Blue Mountain Igneous Complex, a central-type alkali ultrabasic-gabbro ring complex of Early Cretaceous age (Grapes, 1975) which intrudes Torlesse Supergroup rocks 15 km west of Ward, Marlborough. The complex is 1.5 km x 1 km in area and dips steeply around the margin and more gently near the centre. Exploration by Kennecott Explorations (M1576) and Gold Mines of NZ Ltd (M1590) found disseminated pyrite, chalcopyrite and pyrrhotite in layered pyroxenite at three main localities. The best rock geochemical values were 1600 ppm Cu and 1300 ppm Ni. The longest strike extension of mineralisation is 750 m.

**Darran Mountains, Fiordland:** Pirajno (1981) described mineralisation in layered gabbroic rocks in the western sector of the Darran Complex. At Camera Lake, lenses of disseminated pyrrhotite and chalcopyrite are present in anorthosite. The two largest lenses are exposed over strike lengths of 50 m and 25 m respectively and have thicknesses varying from 1 m to 8 m. At Falls Creek, disseminated sulphide-oxide mineralisation consists of pyrite-chalcopyrite-pyrrhotite and magnetite-hematite-ilmenite.

**Otama Igneous Complex:** Chalcopyrite, pyrite and minor pyrrhotite are associated with sheared and brecciated zones

in granophyre, diorite and gabbro of the Otama Intrusive Complex, Southland (M2104; M2106).

**Longwood Range:** A number of weak copper, nickel and zinc anomalies in stream sediments have been reported from the Longwood Range (Williams, 1967; M2026). Disseminated chalcopyrite, giving copper in rock values up to 0.27%, has been reported in gabbros of the Longwood Complex, Southland (Challis and Lauder, 1977; Hay, 1989; Cowden et al., 1990; M2063).

**Takitimu Mountains:** Minor copper mineralisation was recorded from a fault breccia in volcanoclastic sandstone (Hutton and McCraw, 1950; M2060).

## 5. Hydrothermal vein and replacement

### (a) Epithermal veins

**Hauraki Goldfield:** Chalcopyrite is present in significant quantities in several epithermal gold-silver-base metal deposits hosted in Miocene andesite and dacite of the Coromandel Group. The most copper-rich veins are at Petote Stream, in the gold mines between Tapu and Thames and in the gold and base metal mines at Tui and Waiorongomai. Tui Mine was operated by Norpac Mining Co. as a base metal, underground mine between 1967 and 1974, producing concentrate containing 404 t of copper (along with 7291 t Zn, 4424 t Pb, 2490 kg Ag, 60 kg Au) for export to Japan. 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).

**Taupo Volcanic Zone:** Chalcopyrite has been observed in cores and cuttings of geothermal exploration drillholes in several of the active geothermal fields. The most detailed descriptions are from the Ohaaki field, where chalcopyrite, sphalerite and galena occur associated with pyrite and pyrrhotite in quartz veins and disseminated in the hydrothermally altered wallrocks mainly below a depth of 600 m (Browne, 1971). Chalcopyrite-rich scales have been produced at depressurisation sites in wellheads at Ohaaki and Kawerau during geothermal development (Brown, 1986).

**Kaitake Range, Taranaki:** Small quantities of copper with traces of gold, silver and zinc occur in a silicified “reef” hosted by late Quaternary andesite at the Boars Head Mine (Cochrane, 1908; Morgan and Gibson, 1927; M0710).

### (b) Mesothermal quartz veins

Minor chalcopyrite occurs in many of the South Island gold-bearing quartz lodes hosted in metagreywacke and schist, particularly in the Aorere, Owen, Wangapeka, Reefton and Mt Greenland (eg Cedar Creek) goldfields (Williams, 1974).

### (c) Skarn

**Copperstain Creek:** At Copperstain Creek, about 11 km west of Takaka, copper mineralisation is associated with skarns developed by the intrusion of small granodiorite porphyry stocks and sills into Lower Paleozoic sedimentary

rocks of Mount Arthur Marble and Onekaka Schist (Wodzicki, 1972; M0825). Wodzicki (1972) suggested that there is a lateral metal zonation, from molybdenum in the granodiorite, out through copper, to lead-zinc in peripheral locations. Drilling by Lime & Marble (M0782; M0804) and Kennecott (M0825) outlined a copper-bearing zone, grading 0.06–0.6% Cu, about 60 m wide and 760 m long, dipping steeply to the west and containing an inferred resource of 10 Mt at 0.15% Cu (Wodzicki, 1972).

## 6. Mineralisation in metamorphic rocks of Fiordland

**Bligh, George and Caswell sounds:** These are minor occurrences of pyrite and chalcopyrite mineralisation generally within shear zones in metamorphic rocks. The mineralisation within George Sound occurs in dioritic gneiss. Wood (1960) noted that the ore minerals appear to be present in a local segregation concentrated close to an irregular crush zone. Exploration in 1969–70 (M1737; M1739) located minor pods/veins of quartz with chalcopyrite in a puggy fault zone where the fault cuts calc-silicate schists and hornblende-feldspar gneisses on the south shore of Caswell Sound. Bulk chip samples contained 50 to 1150 ppm Cu and 64 to 460 ppm Ni, but selected chip samples contained up to 1.3% Cu. Disseminated pyrite and pyrrhotite occur in the calc-silicate rocks.

**Brassels Point:** A 0.3 m wide sulphide band occurs in green amphibolitic gneiss on the road cutting at Brassels Point, about 1.6 km from the Deep Cove wharf (Bishop, 1967; M2051). The mineralisation consists of pyrrhotite, chalcopyrite and bornite, with considerable calcite and assays up to 1.7% Cu, 0.06% Co, 0.02% Ni and 0.035% Zn were reported (Bishop, 1967; M2051).

**Mt Luxmore:** Near the summit of Mt Luxmore, olivine gabbro of Garden Point Epidiorite contains calcite veins, a few centimetres wide, containing chalcopyrite, native copper and cuprite (M1728). Disseminated pyrrhotite and chalcopyrite are present in the host gabbro. Several 1 m zones of calcite veining assay up to 1.6% Cu, but the enclosing rocks contain less than 0.04% Cu (M1728).

**Calm Bay:** Traces of chalcopyrite occur over a 160 m section of mafic igneous rocks (Beehive Epidiorite) near the contact with Pomona Granite near Calm Bay (M1779). Three Cu–Zn geochemical anomalies were identified in the area during reconnaissance exploration by Australasian Mineral Search and Investments Ltd (M1779).

**Docherty’s Wet Jacket Mine:** Kennecott’s regional geochemical survey rediscovered a massive sulphide prospect in Wet Jacket Arm originally found by William Docherty in the 1880s or 1890s (M2051). The mineralisation, occurs in marble at the contact with underlying gneiss and consists of three bands of massive sulphide in a 6 m thick zone assaying 1.6% Cu.

**Park’s Mineral Beds:** In 1877 William Docherty discovered seven parallel bands of mineralisation over a distance of about 1.6 km between Mt Pender and Mt Hodges. They were described by Ulrich (1885) and Park (1888, 1924). The

country rock consists of hornblende-plagioclase gneiss and schist with garnet-augite- and garnet-hypersthene-gneiss, amphibolite and marble. The mineralised bands are discontinuous and strike in a northerly direction following the foliation of the host schist. The bands all contain pyrite and some contain one or more of: chalcopyrite, nickeliferous pyrrhotite, chromite and the gangue minerals orthoclase, chlorite, lepidolite, hornblende, fuchsite, zincian staurolite, gahnite, rutile, sphene and red garnet (Park, 1888, 1924; Challis, 1986; M1728). The mineralised bands occupy zones up to 12 m wide but the actual mineralised layers are 150 mm or less in width. They extend up to at least 700 m in length. Assay values up to 3750 ppm Cu and 1350 ppm Ni were obtained from the mineralised bands (Hancock, 1977).

**Mt. Solitary Copper Lode:** In 1878 William Docherty discovered a 1.5 m thick copper lode near Mt Solitary at the head of Dusky Sound (Cox, 1878b). During the following two years an exploratory adit was driven and a little mining done (Rowe, 1881). The lode is a steeply dipping shear zone containing quartz, hornblende, calcite, pyrite, chalcopyrite, pyrrhotite and pentlandite, which cross-cuts quartzose metagreywacke, gneissose granite and mafic igneous rocks (Cox, 1878b; M1728).

Layton and Associates (M2040) failed to locate the lode during their reconnaissance survey but found massive sulphide mineralisation (pyrrhotite, chalcopyrite and pentlandite) in metagabbro, ultramafic and amphibolite rocks to the east. Samples of limonitic surface material assayed up to 0.66% Cu, 0.3% Ni and 0.04% Co.

**Resolution Island:** Disseminated pyrite and pyrrhotite mineralisation occurs in hornblende-plagioclase gneiss and amphibolite and assays of up to 1350 ppm Cu, 1220 ppm Pb, 995 ppm Zn and 195 ppm Ni were obtained from float (M2035).

## Production

A little more than 7500 t of copper ore has been mined in New Zealand, since the country's first underground mine was opened on Kawau Island in 1842 — including Kawau (2500 t), Great Barrier Island (2500 t), Pakotai (1381 t) and Parakao (1026 t) in Northland and the United (700 t) at Dun Mountain in Nelson.

## Potential and Prospectivity

Because of the large number of low-cost copper mines and undeveloped deposits overseas, there is little incentive for exploration for copper in New Zealand in the immediate future unless required for strategic reasons. Nevertheless, future possible changes in the demand and price of copper and the development of new exploration models may encourage new exploration.

Although the known copper deposits in New Zealand are all small, the varied geology and number of copper shows offers some potential for future copper production, possibly as a byproduct of mining other metals. Different types of deposits,

such as the Kuroko type of VMS deposits, porphyry coppers and sediment-hosted deposits, will inevitably be sought.

## Future Trends

Substitutes are being found for some uses of copper, eg optic fibre for telephone cables, aluminium for power transmission lines and plastics for plumbing applications. The world's major copper mines are generally worked as large-scale open-pit or underground operations and many have considerable reserves. As there is no currently economically workable deposit known in New Zealand, copper will continue to be imported.

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