Mineral Commodity Report 9 — Molybdenum

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Institute of Geological and Nuclear Sciences Ltd

Symbol	Mo
Atomic no.	42
Atomic wt	95.94
Specific gravity	10.2
Valence	0, 2, 3, 4, 5, 6
Melting point	2610˚C
Boiling point	5560˚C
Crustal abundance	1.5 ppm
Preferred analysis method	plasma atomic emission spectroscopy
Routine detection limit	1 ppm

Discovery and Origin of Names

The name molybdenum is from Latin and Greek *molybdos*, for lead, because of its lead-like appearance.

In 1778, the Swedish chemist Karl Wilhelm Scheele differentiated the mineral *molybdaina* (now molybdenite), previously thought to be a lead ore or graphite, and concluded that it contained sulphur and an unknown metal. At Scheele's suggestion, Peter Jacob Hjelm, a Swedish mineralogist, successfully isolated the metal in an impure form in 1782. Molybdenum was produced commercially from 1893, but only 10 t of the metal had been made by 1900. Large-scale use began in 1913, and it attained commercial importance in 1927.

Major Ores and Minerals

Molybdenum ranks 56th in order of abundance of the elements in the earth's crust. The native metal is not found naturally, but occurs combined with other elements in several minerals, the most important of which are molybdenite MoS_2, wulfenite $PbMoO_4$ and powellite $Ca(MoW)O_4$.

Properties

Molybdenum is a transition element of Group VIb of the periodic table and has chemical properties similar to those of chromium and tungsten. It is a silvery-grey coloured metal that is hard, ductile, and malleable, with a specific gravity of 10.2. Molybdenum has a very high melting point, high strength at high temperatures, good resistance to heat, a high modulus of elasticity, a high thermal conductivity, and a low coefficient of expansion; these properties make it useful in alloys of steel and iron.

Molybdenite is lead-grey in colour, with a metallic lustre, greasy feel, a hardness of 1 to 1.5, and a specific gravity of 4.62 to 4.73. It resembles graphite, but graphite has a much lower specific gravity (2.2).

Formation

The most important deposits of molybdenum are hydrothermal porphyries, but molybdenum is also found in some contact metamorphic deposits, hydrothermal quartz vein and breccia deposits, pegmatite and aplite deposits, and in some stratabound ores hosted in sedimentary rocks (Clark, 1989).

Porphyry Deposits

Porphyry deposits are formed from hydrothermal fluids generated by the intrusion of stocks of peralkaline granite to calc-alkaline diorite, at depths of less than about 4 km. The mineralisation is present in stockwork quartz veins, in breccias, and disseminated in the igneous and surrounding country rocks that typically exhibit zonal alteration patterns. Climax (Mo, little or no Cu), porphyry copper (Cu>Mo), and porphyry molybdenum (Mo>Cu) subtypes are distinguished on the basis of their molybdenum and copper contents, the composition of the intrusive rocks, and their tectonic setting.

Climax or stockwork type are disseminated and/or breccia pipe deposits associated with multiple intrusion of highly evolved magmas enriched in F, Rb and incompatible elements. They are found in tensional rift environments (Carter et al., 1993). The intrusive rocks are A-type, peralkaline, granodiorites to granites, rhyolites and quartz-rich porphyries, with K_2O higher than Na_2O, high F/Cl rations, trace or accessory contents of Sn and W, and low Cu contents. Molybdenite is the most important ore mineral, with grades between 0.2 and 0.5% MoS_2. Typically there have been several mineralising events, associated with intense silicification. Examples include: Climax, Urad-Henderson, and Mt Emmons in Colorado, Questa in New Mexico, and Pine Grove in Utah.

Porphyry copper deposits are associated with stocks and dikes of diorite to granodiorite, I-type composition, found in compressive continental margin subduction environments. They are mined for their copper content, although many have significant by-product molybdenum, with molybdenum concentrations ranging up to equal those of copper. Grades of worked deposits are generally low, with ranges of 0.4 to 1.1% Cu and 0.016 to 0.060% MoS_2. Some major differences from Climax type deposits include:

(a) the composition of the associated intrusive rocks;
(b) the tectonic environment;
(c) rhenium, gold and silver may be economic by-products from porphyry copper but not Climax deposits; and
(c) lower F/Cl ratios in porphyry copper deposits.

Examples of molybdenum-producing porphyry copper deposits are El Salvador and Chuquicamata in Chile, Bingham in Utah, and Panguna on Bougainville Island in Papua New Guinea.

Porphyry molybdenum deposits are end members of the porphyry copper-molybdenum family, also known as quartz monzonite type, granodiorite type, and calc-alkaline type. They have similar F/Cl ratios to porphyry copper deposits, occur in continental margin subduction zone environments associated with I-type granodiorite to quartz monzonite host rocks, and differ mainly in Cu/Mo ratio. Examples include Endako in British Columbia, Quartz Hill near Ketchikan in Alaska (1.3 billion tons of 0.10% Mo), and Thompson Creek and White Cloud in Idaho.

Contact Metamorphic/Metasomatic Deposits

Molybdenum mineralisation, generally with copper or tungsten and tin, is located at the contact of felsic intrusions and favourable host rock, usually limestone. Deposition is by replacement and tends to be erratic in distribution and concentration. Molybdenite values may be as high as a few percent, but average about 1.0% MoS_2 in economic deposits. Examples include Pine Creek in California, Helvetia in Arizona, Knaben in Norway, Tyrnay-Auz in the Greater Caucasus of Russia, and Azegour in Morocco.

Fissure-vein

Fissure-vein deposits consist of molybdenite-bearing quartz veins, in or adjacent to felsic intrusives. Pyrite is commonly present, as are small amounts of base-metal sulphides. Gangue minerals include fluorite, calcite and rhodochrosite. Ore shoots within the veins tend to be lenticular, with molybdenite values varying from 1–20%. However, the average grade of the deposits may be as low as 1–2% MoS_2. The main example is Questa, New Mexico.

Pegmatite and Aplite Deposits

Pegmatites in some batholith-sized plutons contain sporadically distributed molybdenite in crystalline aggregates with quartz, feldspar, mica and other non-metallic pegmatite minerals. Other metals may also be present, including beryllium, iron and zinc. Small quantities of molybdenite may also be found in vugs and pockets within quartzofeldspathic aplite dikes cutting granitic country rock. Molybdenite values occur erratically in pegmatite and aplite deposits. Examples include the Most Mine, Val d'Or and Preissac in Quebec.

Bedded Deposits

Molybdenum is present as an accessory mineral in many sandstone-type uranium deposits of Arizona, Utah, Colorado, New Mexico, Wyoming, South Dakota and Texas. The molybdenum content varies from a few ppm to 0.5%, and it has been recovered from a few deposits as a by-product of uranium mining. Molybdenum also occurs in several other types of sedimentary rocks such as coal, shale and phosphorite, but in subeconomic concentrations.

Uses

The main use of molybdenum is as an alloy in steels, cast iron and superalloys (alloys usable at temperatures of up to 1100˚C) to provide toughness, strength, resistance to corrosion, and tolerance to high temperatures and pressures. These alloys have applications in structural work, aircraft and missile parts, and forged automobile parts. For example, molybdenum is used in tool steels (up to 10% Mo), stainless steel and armour plate. Up to 3% Mo is added to cast iron to increase strength. Up to 30% Mo can be added to iron-, cobalt- and nickel-based alloys designed for severe heat- and corrosion-resistant applications (e.g. the Ni-based "Hastelloys"). The molybdenum alloys TZM Moly (0.5% Ti, 0.1% Zr and 99.4% Mo) and Moly-30W (70% Mo and 30% W) are used in die-casting tools, the forging and refining of various metals, and in controls for valves, mixers and pumps used at high temperatures and pressures.

Metallic molybdenum has been used for electric and electronic parts such as filament supports, anodes and grids. Molybdenum wire is used in electron tubes, and the metal also serves as electrodes in glass furnaces.

Molybdenum trioxide, molybdates, sulpho-molybdates and metallic molybdenum are components in many industrial catalysts used in the refining of petroleum, ammonia synthesis and industrial syntheses of organic compounds. Molybdenum is an essential trace element in plant nutrition; in legumes it acts as a catalyst to assist bacteria in fixing nitrogen. Molybdenum trioxide and sodium molybdate Na_2MoO_4 have been used as micronutrients. Molybdenum sulphide is used as a lubricant in high temperature environments, where oils would decompose.

Price

During the 1980s and early 1990s, the capacity to supply molybdenum far exceeded demand, and prices were pushed down to very low levels. This resulted in the closure of most primary producing mines and production was cut back at others. Demand exceeded supply in 1993 and 1994, and prices rose dramatically from around US$2.80/lb molybdenum oxide (55–57%) early in 1994, to US$3.40/lb mid 1994, and an average December 1994 price of US$13.40/lb. Prices peaked at around US$16.50/lb in January 1995, and have since declined to less than US$5.00/lb in early September 1995.

World Production and Consumption

About two-thirds of the world supply of molybdenum is obtained as a by-product of copper mining from some 40 deposits (mostly porphyry Mo and porphyry Cu), without any impetus from molybdenum demand. The primary molybdenum producers make up the difference between non-primary molybdenum supply and demand. The three primary molybdenum-producing mines which operated throughout the first half of 1995 were Cyprus Amax's Henderson, and Thompson Creek mines, and Placer Dome's Endako Mine. Henderson in Colorado produced 23 Mlb in 1993. Thompson Creek in Idaho closed during 1992–93, but was expected to produce near to its 15 Mlb/y capacity in 1994. Endako in British Columbia produced 15 Mlb in 1993. The Climax Mine in Colorado was closed in 1985 but was reopened by Cyprus Amax in April 1995. In July 1995, it was put back on standby because of the sharp decrease in molybdenum prices.

Non-primary supply to the western world was approximately 136 Mlb in 1993 (110 Mlb from by-product copper, 5 Mlb from spent catalyst and 21 Mlb imported from the east). Total western world supply was therefore 174 Mlb, compared with a total western world demand of 188 Mlb in 1993.

Tin and tungsten have been produced as by-products from molybdenum ore at the Climax mine, whereas rhenium is extracted from molybdenite concentrate produced as a by-product from some porphyry copper ores.

World resources have been estimated at about 15 Mt in some 136 deposits, of which about two-thirds are recoverable reserves. About 9.5 Mt are contained in porphyry deposits, 0.25 Mt are in contact metamorphic deposits, and 0.1 Mt are in pegmatite and aplite deposits. Approximately 87% of the world's resources occur in the Cordilleran and Andean Circum-Pacific belts, with some 50% in the USA sector, 20% in the Chilean sector and 14% in the Canadian sector.

Ore Processing, Smelting and Refining

Most commercial processing is from molybdenite-bearing ore which is concentrated up to grades as high as 90% MoS_2 by differential flotation. The concentrate is roasted in an excess of air to yield molybdenum trioxide, also called technical molybdic oxide, containing a minimum of 57% Mo. Subsequent treatment depends on the ultimate intended use of the molybdenum. Molybdenum may be added to steel in the furnace in the form of either technical oxide or ferromolybdenum. Ferromolybdenum (58–64% Mo) is produced by igniting a mixture of technical oxide and iron oxide in a conventional metallothermic process, using silicon and/or aluminium as the reductant. Molybdenum metal is produced in the form of a powder, by hydrogen reduction of purified molybdic trioxide or ammonium molybdate. The purest molybdenum powder (minimum 99.95% Mo) is produced from ammonium molybdate. Metal powder is pressed and sintered into small metal ingots which are converted into rod, wire or sheet by hot rolling, swaging or forging. Large ingots are produced by arc-casting powder under a vacuum or inert gas atmosphere.

New Zealand Occurrence and Resources

The occurrence of molybdenum in New Zealand has been reviewed by Williams (1974), Officers of the New Zealand Geological Survey (1980), and Brathwaite and Pirajno (1993). Morgan (1927), and Railton and Watters (1990) listed the occurrences of molybdenum minerals.

The main molybdenum deposits (Fig. 1) are in northwest Nelson, and consist of porphyry molybdenum deposits, notably at Copperstain Creek, Roaring Lion, Karamea Bend, Mt Radiant and Taipo. Contact-metamorphic deposits occur at Canaan, and greisen deposits are present at McConnochie Creek and Barrytown. On the Coromandel Peninsula, minor amounts of molybdenite have been found in association with porphyry copper mineralisation at Ohio Creek and in gold-silver-quartz veins at Sylvia, Neavesville and Waihi.

Porphyry Molybdenum Deposits

Exploration in the late 1960s to early 1980s discovered a number of porphyry molybdenum deposits in the Northwest Nelson area. They are genetically related to the emplacement of Late Cretaceous I-type Separation Point suite granitoids into the Paleozoic S-type granites of the Karamea suite (eg Karamea Batholith), or the nearby quartzose sedimentary rocks, mostly of the Aorere Group (Eggers and Adams, 1979). Most of the deposits are hosted by the sediments or intruding Cretaceous stocks, with a few (e.g. Taipo Spur) hosted in Paleozoic Karamea suite granitoids. The geochemistry of the molybdenum-bearing granitoids is characterised by low K_2O, Rb, and F, and high Sr and Ti, confirming the classification of the deposits as porphyry molybdenum rather than Climax type (Tulloch and Rabone, 1993).

Mineralisation typically occurs as molybdenite paint, or disseminations in joint-controlled quartz vein stockworks. Accessory minerals include minor pyrite, chalcopyrite and pyrrhotite; and rare galena, sphalerite, and bismuth sulphosalts (Rabone, 1989a).

In addition to the prospects described below, reconnaissance prospecting by Asarco, Lime & Marble, Kennecott, Otter, Cities Services, Amoco, BP and CRA has defined a number of molybdenum geochemical anomalies and showings that were reviewed by Scadden and Brathwaite (1980), Roberts (1983), and Jennings and Corner (1994).

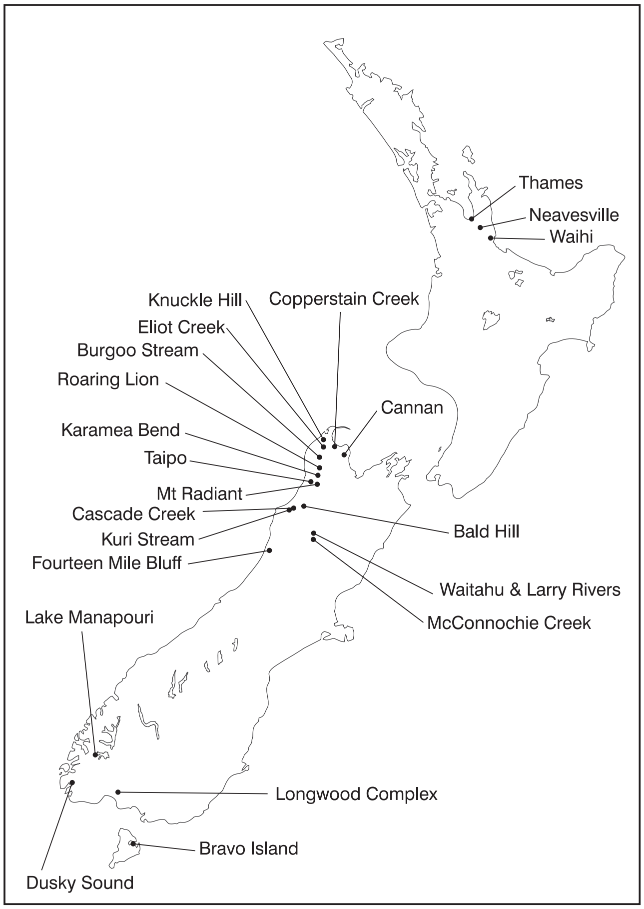

Figure 1: Location of molybdenum deposits in New Zealand.

Knuckle Hill: On the north side of the Aorere River, near Collingwood, molybdenite and pyrite mineralisation are present in a small granite stock (Ongley and MacPherson, 1923). A K-Ar age of 99 ± 2 Ma was obtained from biotite in a hornfels adjacent to the granite (Eggers and Adams, 1979).

Eliot Creek: On the west side of the Aorere Valley, 20 km southwest of Collingwood, molybdenite mineralisation is associated with several isolated granodiorite stocks that intrude phyllites and quartzites of the Aorangi Mine Formation, Aorere Group (Rabone, 1977). Biotites from the hornfels and muscovite from the greisen-granite with disseminated molybdenite were K-Ar dated at 104 to 107 Ma (Eggers and Adams, 1979). Molybdenite occurs within stockwork quartz veins and as disseminations in the intrusive and sedimentary rocks, near the contact zones. Rabone (1977, 1989a) identified two parageneses: early molybdenite-pyrite-pyrrhotite, with lesser chalcopyrite and cubanite; followed by late sphalerite-galena-pyrite-pyrrhotite-bismuth sulphosalts. An extensive propylitic alteration zone grades into intense sericitisation adjacent to mineralisation. The deposit was discovered in 1966 by H.E. Hawkes using stream sediment geochemistry (50 ppm Mo anomaly versus 1–5 ppm Mo background). Subsequent exploration work by Kennecott, Asarco and Lime & Marble, including costeans and six shallow diamond drillholes, indicated an overall grade of <0.03% Mo (Turbott, 1968; Dodds, 1969; Riley, 1973).

Copperstain Creek: Small granodiorite stocks and sills intrude lower Paleozoic Mount Arthur Marble and Onekaka Schist in Copperstain Creek, a tributary of the Pariwhakaoho River, about 11 km west of Takaka (Wodzicki, 1972a). The granodiorite porphyry is strongly altered to secondary assemblages of microcline and muscovite. Skarns are developed in the calcareous rocks and exhibit a zonal pattern from an outer tremolite-actinolite-epidote±talc zone, through an intermediate diopside zone, to an inner garnet-magnetite±hedenbergite zone. Molybdenite occurs as coatings on joint surfaces and in quartz veins within the granodiorite porphyry and calc-silicate rocks (Smale, 1970; Wodzicki, 1972a). Rock geochemical values of 100–500 ppm Mo defined a zone 450 m x 180 m (Smale, 1970); and Wodzicki (1972a) reported 91 m of 300 ppm Mo in a drillhole intersection. Wodzicki (1972a) suggested that there is a lateral metal zonation, from molybdenum in the granodiorite, out through copper, to lead-zinc in peripheral locations. Exploration, including 14 diamond drillholes, has indicated a copper resource of 10.7 Mt at 0.015% Cu (Smale, 1970; Wodzicki, 1972a).

Burgoo Stream: In the headwaters of the Aorere River, weak mineralisation of limited extent is associated with the intrusion of granodiorites and adamellites of the Burgoo granite into Roaring Lion Formation phyllite and mica schist. Quartz vein stockworks containing molybdenite and pyrite are present within both the intrusive and meta-sedimentary rocks. The deposit was discovered by Kennecott in 1968 during regional reconnaissance exploration, and was followed-up with more detailed work by Kennecott (Foster, 1971a) and later by Otter (McClelland, 1973, 1974). The best mineralisation sampled was a 30 m outcrop in Misnomer Creek which exposes a quartz stockwork from which selected grab samples assayed up to 1.6% Mo, and more representative samples assayed up to 460 ppm Mo (Foster, 1971a).

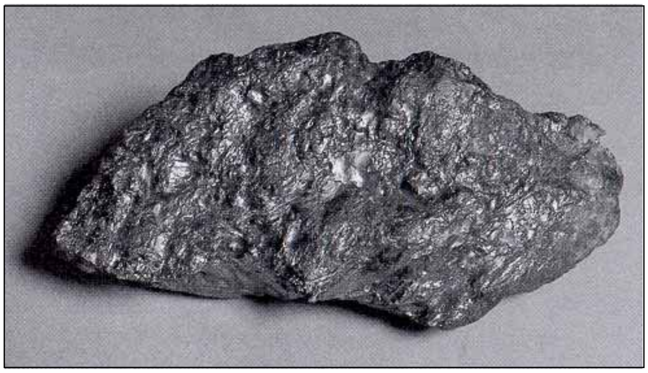

Figure 2: Molybdenite, 7 cm x 3 cm, from Mt Radiant, Westland (Photo: Wendy St George).

Roaring Lion: On the Roaring Lion River, just to the east of the Karamea Batholith, stockworks of quartz-orthoclase-molybdenite veins occur in metasedimentary rocks in three separate areas — the Discovery, Cobra and Grace prospects — discovered by Kennecott geologists in 1971 and 1972 (Foster, 1971b; Turbott, 1972a, 1972b, 1972c; Hay, 1980a, 1981). The country rocks of Ordovician sandstone, siltstone and quartzite of the Aorere Group are hornfelsed and intruded by small stocks of fine-grained granodiorite. The quartz veining is controlled by pre-mineral joint sets, probably related to regional folding.

Discovery Prospect covers an area of 1.5 km x 1 km (defined by the 10 ppm Mo in rock isopleth) within a larger area of low topography and few exposures (Walker, 1982). Molybdenum assays range from 2 to 474 ppm Mo, but there is "no obvious centre or target" (Roberts, 1989). Molybdenite and pyrite are present in quartz veins.

At **Cobra**, the 10 ppm Mo in rock isopleth defines an area of 1 km x 0.9 km. The best stockwork veining is on Cobra Face (Fig. 3), a quartzite dip slope where areas of 10% veining are common. Individual veins range up to 30 cm thick, but generally they are less than 1.25 cm thick (Foster, 1971b). Molybdenite is accompanied by minor pyrite and rare chalcopyrite, with local traces of galena, sphalerite, magnetite and pyrrhotite. Three diamond drillholes totalling 820 m were drilled by Amoco and BP into the metasediments at Cobra, but failed to intercept intrusive rocks (Hay, 1980b; Christie, 1982; Roberts, 1983). They yielded a best assay result of 790 ppm Mo over 5 m.

At **Grace** prospect, the 10 ppm Mo in rock isopleth defines an area of 1 km x 1 km in the head of Grace Creek. Chalcopyrite, molybdenite and pyrite are present in 30–70 cm thick pegmatite veins, and in a weakly developed quartz vein stockwork (Foster, 1971b). Stibnite was reported in one quartz vein. Rock samples returned assays up to 500 ppm Mo and 800 ppm Cu, but values were distributed erratically. "No centre of anomalous geochemistry or attendant hydrothermal alteration has been established" (Roberts, 1989).

Karamea Bend: Also known as Big Bend, this prospect is located on the Karamea River, and was discovered by sighting

Figure 3: Drilling on Cobra Face in 1981, by the Amoco-BP joint venture (Photo: Peter Roberts).

a large colour anomaly formed from oxidation of sulphides in slip faces (Smale 1976; cover photo). The mineralisation lies east of the main Karamea Batholith, and is related to the intrusion of stocks of fine-grained porphyritic granodiorites, monzonites, and diorites into Ordovician quartz-sericite schist and meta-argillite of the Roaring Lion Formation. Five separate stocks or dikes are known, and biotites from two of the stocks were dated by K-Ar at 100 ± 3 Ma, in contrast to a biotite K-Ar age of 290 ± 8 Ma in the main Karamea Batholith, 2 km west of Questa Creek (Smale, 1976). Within the prospect, six anomalous zones (>100 ppm Mo) occur in a 3 km by 0.5 km strip across Questa and Sunday creeks. Molybdenite occurs in quartz-orthoclase-pyrite veins forming a stockwork in metasedimentary rocks, as disseminations adjacent to quartz veins in quartz-orthoclase altered monzonite on the margin of a porphyritic granodiorite stock in Sunday Creek, and as smears in late-stage joints (Ballantyne et al., 1971; Smale, 1976; Rabone, 1977; Hay, 1979, 1980b, 1980c). Veins containing base metal assemblages — sphalerite, chalcopyrite, tennantite, galena, pyrrhotite and bismuth minerals — are peripheral to the centres of molybdenum mineralisation (Rabone, 1977, 1989a). Alteration zones are fracture and vein controlled, with peripheral chlorite alteration succeeded by biotite, and passing into the molybdenite-bearing quartz-sericite and quartz-orthoclase veins.

Kennecott drilled two diamond drillholes (539.5 m and 344.4 m) in the head of Questa Creek, and a third hole (abandoned at 112.8 m) in Sunday Creek. Assays were up to 300 ppm Mo (Ballantyne et al., 1971). Amoco drilled two shallow Winkie holes, and a 520.4 m diamond drillhole in the headwaters of Questa Creek (Hay, 1979, 1980b). The two Winkie holes assayed 162 ppm MoS_2 over 61 m and 165 ppm MoS_2 over 52 m, and the diamond hole averaged 54 ppm Mo over the 434 m of metasediments lying below 90 m of Tertiary cover.

Kakapo: This prospect is located by the Kakapo River, a southern tributary of the Karamea River, and lies on the western margin of the Karamea Batholith. The mineralisation and alteration are generally confined to a 2.5 km by 1.2 km stock of fine- to medium-grained quartz monzonite, granodiorite and quartz diorite which intrudes the medium- to coarse-grained granite of the Karamea Suite (Stevens, 1981a). The stock is intruded by pre-mineral quartz diorite and quartz latite dikes, and post-mineral lamprophyre dikes. The 10 ppm Mo in rock isopleth defines an area of 1.5 km x 1 km, whereas the strongest molybdenum mineralisation covers an area of 0.9 km by 0.4 km outlined by the 30 ppm Mo isopleth, approximately coincident with a phyllic alteration zone containing the strongest pyrite mineralisation. The phyllic alteration zone grades outward to a propylitic alteration zone extending over an area of 3 km by 1.5 km. Assays of up to 1119 ppm Mo were obtained by Amoco from quartz-veined and quartz-sericite altered granitoid rocks. Stevens (1981a) considered that the mineralising intrusive does not crop out.

Mount Radiant, Anaconda and Mt Scarlett: These prospects are located on the western side of the Karamea Batholith, 20 km to the southeast of Karamea, and south of the Little Wanganui River. Molybdenum and/or copper mineralisation is present in more than 20 separate lenticular

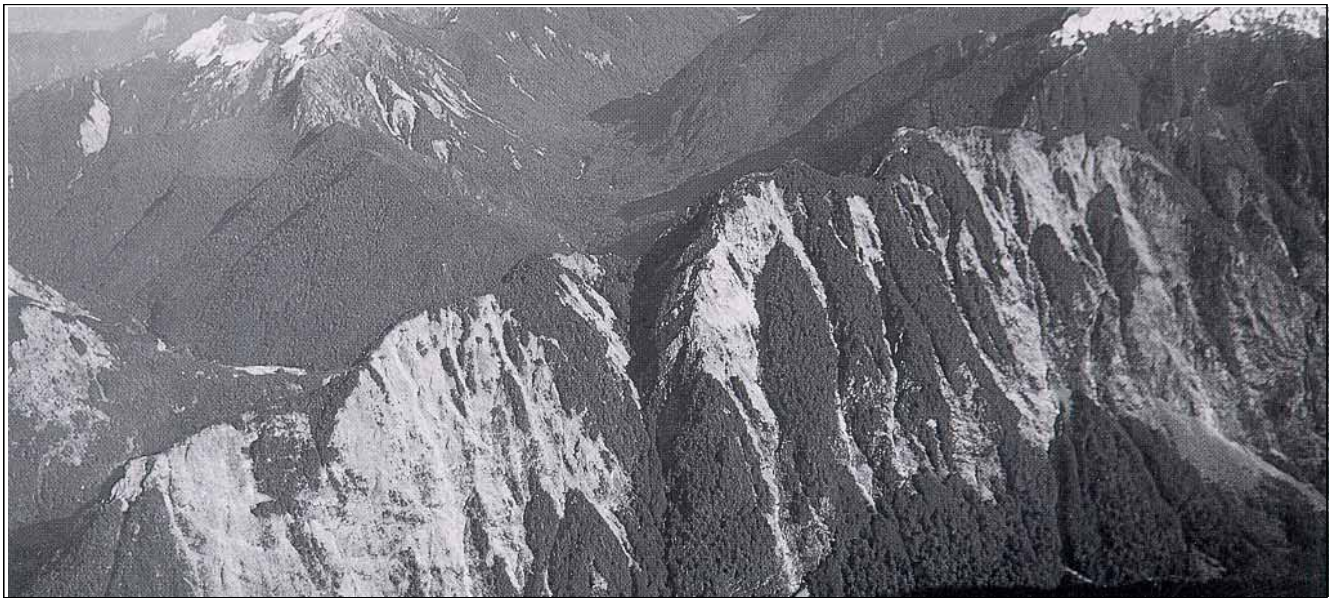

Figure 4: Taipo Spur molybdenum prospect exhibits a strong colour anomaly and has prominent topographic expression as a long ridge between Kendall Creek (foreground) and the Karamea and Taipo rivers (left mid distance) (Photo: Tony Christie).

quartz lodes and areas of quartz vein stockworks on the eastern side of Mt Radiant and north near Mt Anaconda to Mt Scarlett. Most of the lodes strike NNE, but a few strike NW. The mineralisation is associated with the intrusion of alkali porphyritic granites, granodiorites and pegmatite veins into older gneisses and coarse-grained granites of the Karamea Suite, and into a roof pendant of hornfels and schistose metasediments (Webb, 1910; Wodzicki, 1960). The main lodes are the Mt Radiant Reef, exposed in Silver Creek, and the New Anaconda Reef in Specimen Creek, each consisting of a series of parallel quartz veins with intervening country rock in lode zones 30 m and 7.6 m wide respectively. The veins contain quartz, K-feldspar, chalcopyrite, molybdenite, pyrite, tetrahedrite, bornite and bismuth minerals (Rabone, 1989a). Some lodes also contain minor gold and silver (Webb, 1910; Williams and Sanderson, 1959). Wall rock alteration to quartz, sericite and chlorite is localised along vein margins; areas of widespread hydrothermal alteration have not been recognised (Wodzicki, 1960; Maxwell, 1975a; Hay, 1980d). The Mt Radiant Reef was discovered in 1904, and most of the other quartz lodes in the area had been located by 1910. Underground workings were driven on the Mt Radiant Reef in 1914–15, but there is no record of ore production. Amoco drilled two shallow Winkie holes at Mt Radiant and obtained averages of 0.11% MoS_2 over the 16.5 m depth of one hole and 0.04% MoS_2 over the 19 m depth of the other hole (Hay, 1980d).

Taipo Spur: Stockwork molybdenum mineralisation was first recognised on the steep-sided ridge between Taipo River–Karamea River and Kendal Creek by Asarco in 1967 (Fletcher, 1968) (Fig. 4). The prospect is located on the eastern side of the Karamea Batholith, and is notable for being the only molybdenite occurrence well within the Karamea Batholith and showing no obvious relationship to the low grade metasedimentary country rocks. Also, it is one of the largest molybdenum prospects in New Zealand, with molybdenum mineralisation identified over an area of 2.7 km x 1.5 km (Maxwell, 1974; Stevens, 1981b). The 10 ppm Mo in rock isopleth covers an area of 2 km x 0.9 km. The mineralisation is hosted in Taipo granite, a porphyritic granodiorite of Cretaceous age (K-Ar dated at 102–107 Ma) which intrudes the Luna granite, a potassic granite of the Karamea Suite (Rabone, 1977, 1989b). The Taipo granite is cut by geochemically similar porphyry dikes. Hydrothermal alteration shows a poorly defined zonal pattern, with a central potassic zone consisting of a barren biotite subzone and outer epidote subzone, succeeded by an outer muscovite phyllic zone within weakly propylitised granite. The strongest molybdenum mineralisation is in shear-controlled quartz-sericite-pyrite alteration zones and quartz vein stockworks. Molybdenite is accompanied by pyrite, magnetite and minor chalcopyrite, with rare rutile, hematite, cubanite, pyrrhotite and sphalerite. The mineralisation is associated with, and enclosed by, quartz-epidote-K feldspar or quartz-sericite-albite alteration envelopes in chlorite-sericite altered granite.

The site has been the subject of considerable exploration, with programmes by Asarco (Fletcher, 1968), Kennecott (Foster, 1971c), Cities Services (Maxwell, 1974, 1975b, 1975c), Amoco (Ballantyne and Hay, 1980), and Amoco/BP (Stevens, 1981b). Four holes were drilled by Cities Services in the strongly mineralised part of this zone to a maximum downhole depth of 245 m and totalling 953.8 m. These showed average grades of 50–70 ppm Mo, with a maximum grade of 4400 ppm over 1.1 m (Maxwell, 1975b, 1975c).

Bald Hill: In the headwaters of Lyell Stream, upper Buller Gorge, high level granodiorite porphyry stocks of Lyell Porphyry intrude Greenland Group greywacke and argillite and Bald Hill granites of the western margin of the Karamea Batholith (Eggers, 1978; Bates, 1989; Eggers and Adams, 1979). The porphyry forms a series of small high-level plutons and crosscutting dikes of quartz tronhdjemite porphyry, granodiorite, quartz diorite, lamprophyre, and quartz-bearing gabbro porphyry. K-Ar ages of 112–116 Ma were obtained from Lyell Porphyry by Eggers and Adams (1979). A zone of porphyries and hornfels, approximately

2.5 km long and 0.7 km wide, contains a stockwork of quartz veins, individually up to 20 mm thick, carrying molybdenite, pyrite and chalcopyrite, with minor magnetite and bismuthinite. Significant amounts of sulphide are also related to metasomatic alteration in the sediments, and occur as disseminated mineralisation within the Lyell Porphyry. Composite rock chip samples collected over 5 m intervals yielded maximum values of 402 ppm, and selected samples gave assays of 0.01 to 0.18% Mo.

Cascade Creek: Lime & Marble Ltd located copper and molybdenum mineralisation in the Cascade Creek area of the Buller Gorge in the late 1950s (Braithwaite, 1959a). Subsequent exploration was carried out by McIntyre Mines in 1969, CRA in 1971, Otter Exploration Ltd during 1972–73, Gold Mines (NZ) Ltd in 1976, and BP in 1981 (Walker, 1981). Greywacke and argillite of the Greenland Group are intruded and locally hornfelsed by plutons of medium-coarse grained, pink quartz-feldspar porphyries of Buckland Granite, and by granodiorite and hyalodacite (chilled marginal phase) of the Berlins Porphyry. Basic dikes are also present in the area (Nathan, 1978). The mineralisation was explored as a porphyry molybdenum prospect, however Tulloch (1988; pers. comm. 1992) recently suggested that it may be related to hydrothermal fluid movement along a detachment fault (Ohika Fault).

An area of propylitic alteration, 150–200 m wide and 800–1000 m long, is present mainly in Buckland Granite, but extends into Berlins Porphyry and hornfelsed Greenland Group greywacke. Bailey (1973) identified four zones, with a quartz-orthoclase core being succeeded outwards by kaolinite-sericite-quartz, kaolinite-quartz-carbonate, and kaolinite-quartz-carbonate-sericite-albite assemblages. Pyrite is disseminated in the granitoids and metasedimentary rocks, and also occurs in quartz-sericite veins up to 2 cm thick. Sulphide phases consist of pyrite, molybdenite, and minor chalcopyrite, pyrrhotite and bornite. Pyrite is typically 1–5% by volume, but locally may reach 10% (Bates, 1978).

The Berlins Porphyry, and thus probably the mineralisation, has been dated at about 110 Ma (Eggers and Adams, 1979).

Kuri Stream (Quartz Creek): Greenland Group schistose metasedimentary rocks host quartz veins containing chalcopyrite, pyrite, and molybdenite, and accessory sphalerite, covellite, chlorite and muscovite. There are also rare fluorite veinlets. The veins are related to nearby granodiorite stocks (Braithwaite, 1959b; Leach, 1976; Walker, 1981). In upper Kehu Stream, veins (typically 6 to 20 cm thick) may form 10 to 25% of the rock volume. Stream sediment sampling by AHI Ltd (Leach, 1976) defined localised Mo (>10 ppm), Cu (>60), and F (>1500) anomalies, but results from later rock sampling by BP Minerals were not encouraging, with values of 4–7 ppm Mo, 15–75 ppm Cu and 100–480 ppm F (Walker, 1981).

Porphyry Copper-Molybdenum Deposits

Molybdenite is present as a minor constituent in some porphyry copper style occurrences in the Coromandel Peninsula, North Island.

Paritu: Near the northwestern tip of the Coromandel Peninsula, a diorite to granodiorite pluton (Paritu Plutonics) intrudes Jurassic greywacke and Miocene andesite. Minor molybdenite, with associated wolframite, pyrite, pyrrhotite, chalcopyrite, sphalerite, tourmaline and orthoclase, coat joint faces in diorite and contact hornfels rocks exposed along the coast south of Paritu (Skinner, 1976). The main copper mineralisation is further east, in Ongohi and Stony Bay streams; small quartz veins containing pyrite, chalcopyrite, sphalerite and galena are present in Sorry Mary Stream, Stony Bay Creek and Doctors Creek (Skinner, 1976).

Te Puru–Waiomu and Ohio Creek: Molybdenite is associated with several porphyry copper style occurrences in high level quartz diorite and dacite porphyry intrusives in the Waiomu–Puhoe, Te Puru, and Ohio Creek areas north of Thames (Merchant, 1986). At Ohio Creek, strong pervasive alteration occurs over an area of 8 km^2, 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 drillholes intersected a quartz vein stockwork containing bornite, tetrahedrite, covellite, enargite and lesser chalcopyrite.

Contact Metasomatic Deposits

In the area of Mt Pisgah and Mt Evans, Canaan, northwest Nelson, quartz veins containing scheelite, molybdenite, pyrite, chalcopyrite, sphalerite, and galena are present within granites and granodiorites of the Separation Point granite batholith, on its western margin and along the contact between the granites and amphibolites, diorites (Devonian Rameka Intrusives) and marbles (Williams et al., 1959; Zuckerman, 1974).

Metamorphic Related Fissure-Veins

Molybdenite was reported as an accessory mineral from some of the gold-bearing quartz lodes in the Reefton Goldfield, including the Blackwater Reef at Waiuta, the most productive hardrock gold deposit yet mined in the South Island (Williams, 1974). The lodes are located within a NNE trending belt of Greenland Group metasedimentary rocks, some 34 km long by 10 km wide. Pyrite and arsenopyrite are the main metallic minerals, but chalcopyrite and stibnite were also present locally.

Epithermal Fissure-Veins

Molybdenite has been recorded from three epithermal gold-silver-base metal deposits in the Hauraki Goldfield, Coromandel Peninsula region, North Island. The veins are all hosted in Miocene andesite and dacite of the Coromandel Group. In the **Sylvia mine**, north of Thames, molybdenite was found on the footwall of a galena-sphalerite bearing quartz reef. At **Neavesville**, southeast of Thames, a thin band of molybdenite occurs on the hanging wall side of the Ajax Reef (Barker et al., 1980). In the **Waihi Extended Mine**, molybdenite was recorded as thin irregular veins and small patches in a 0.3 m thick quartz vein on the 1360 foot level (Morgan, 1924; Brathwaite and McKay, 1989).

Pegmatite Deposits

Molybdenite occurs with chalcopyrite in pegmatite boulders in the Waitahu and Larry rivers, Victoria Range.

Granite Greisen Deposits

Bateman Creek and Kirwans Hill: Molybdenite is present as a minor phase in scheelite mineralisation of Devonian–Carboniferous age near Reefton (Pirajno and Bentley, 1985). The mineralisation occurs in sheeted quartz vein systems within major NNW striking fracture zones, and disseminated in country rocks of greisenised Karamea granite (Bateman Creek) and adjacent Greenland Group metasedimentary rocks (Bateman Creek and Kirwans Hill). Greisen minerals include quartz, albite, muscovite (some lithium-rich), sericite, tourmaline, fluorite and topaz. Metallic minerals include scheelite, pyrite, pyrrhotite, chalcopyrite, molybdenite, marcasite, arsenopyrite, cassiterite, loellingite, hematite, sphalerite, and possibly, lead sulphosalts.

McConnochie Creek: Traces of molybdenite (0.05%) are associated with copper mineralisation southeast of Reefton and 9 km south of Kirwans Hill. A small granite body has an incipient greisen mineralogy consisting of albite-quartz-muscovite with accessory quantities of tourmaline, topaz and illite (Pirajno, 1982). Both endogranite and exogranite quartz vein systems are present, and are mineralised with pyrite, chalcopyrite, marcasite, molybdenite and native bismuth, together with minor sphalerite, argentite (acanthite) and cassiterite. A single muscovite sample gave a K-Ar age of 107 Ma, but since the McConnochie granite is located within the Tobin fault zone, this may be a result of resetting by tectonic movements during the Rangitata Orogeny.

Barrytown: Molybdenite is a minor phase accompanying disseminated scheelite mineralisation in a series of quartz-tourmaline veins and adjacent 1–2 m wide greisenised zones within a small (4 km^2) S-type biotite granite pluton of mid Paleozoic Karamea Suite age and affinities (MacKenzie and Price, 1985; Tulloch, 1986). The quartz tourmaline veins are subvertical, and coincident with the NW–SE trending pluton core. The mineralisation occurs in both quartz veins and adjacent quartz-muscovite greisenised granite or greywacke. The mineralisation consists of scheelite, arsenopyrite, pyrite and marcasite, together with minor rutile, hematite and pyrrhotite, and rare chalcopyrite, cassiterite, molybdenite, galena, bismuthinite, and possibly, lead sulphosalts.

Other occurrences are noted in quartz veins in Greenland Group greywacke and argillite, between Westport and Greymouth at Punakaiki, Seventeen Mile Bluff (Banks, 1978) and Fourteen Mile Bluff (Fry, 1905; Henderson, 1917). The mineralisation at these localities probably originates from adjacent granitoids.

Miscellaneous

Longwood Complex: There is a small molybdenite-quartz vein in diorite near the western contact of the Longwood Complex in Southland (Willett, 1943; Challis and Lauder, 1977). The complex is a layered mafic intrusion with associated granite, trondhjemite, tonalite and diorite in fault contact with basaltic lavas and volcaniclastic rocks of the Takitimu Group (Challis and Lauder, 1977).

Mt Solitary Copper Lode: A copper lode at the head of Dusky Sound, Fiordland, contains “segregated crystals and nests” of molybdenite (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, 1878). Park (1888) referred to thin foliated flakes of molybdenite in gneissic schists and quartzites in this area.

Lake Manapouri: Small pods of molybdenite were found in gneiss and granite during the driving of the tailrace tunnel between Lake Manapouri and Doubtful Sound, Fiordland (Wodzicki, 1972b). The local rocks are biotite and hornblende gneiss intruded by granite and pegmatite. Wodzicki (1972b) correlated the intrusives and mineralisation with the intrusion of a large pluton of homogeneous biotite granite exposed for 14 km along the powerline road, to the southeast of West Arm.

Bravo Island: At Paterson Inlet, Stewart Island, a NW-trending quartz lode contains molybdenite, pyrite and chalcopyrite (Morgan, 1927). The host rocks are granite.

Potential and Prospectivity

Molybdenum has not been produced in New Zealand. The best known prospects are the porphyry molybdenum deposits in northwest Nelson. Deep drilling was recommended at several deposits (eg Taipo; Stevens, 1981b), but not carried out. Molybdenum exploration in New Zealand was abandoned in 1981 due to low world prices. These deposits must therefore be regarded as not fully tested. Exploration effort also waned because it was shown that the deposits were porphyry molybdenum deposits rather than the Climax type, which was in vogue as the exploration model at that time. However, several overseas porphyry molybdenum deposits, such as the Endako Mine in British Columbia, have proven sufficiently large and high grade to be economic. The main deterrent for future exploration of the deposits is their location in the Kahurangi National Park.

Future Trends

Molybdenum is an essential metal alloy for hard steels, and molybdenum steel products will continue to be imported into New Zealand. Rotondo (1994) noted “molybdenum is currently very cheap, the result of years of more-than-adequate supply and the current and future capacity to oversupply greatly exceeds demand. Easy availability and low price tend to attract greater demand.” However, new exploration for primary molybdenum deposits is unlikely in the next few years because there is substantial mothballed molybdenum-producing capacity that can be easily started up to meet the demand.

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References

Bailey, D.G. 1973: Progress report on the geology and geochemistry of the Rochfort Creek and Cascade Creek watersheds applications for MPWs 22/72 and 50/72 Westport: Otter Minerals Exploration Ltd. Unpublished open-file mining company report, Ministry of Commerce M1308.

Ballantyne, G.H.; Hay, K.R. 1980: Progress report to June 30, 1980: Taipo prospect PL 31-584, NW Nelson: Amoco Minerals NZ Ltd. Unpublished open-file mining company report, Ministry of Commerce M0942.

Ballantyne, G.H.B.; Smale, D.; Turbott, M.J. 1971: Big Bend examination: Kennecott Explorations Pty. Ltd. Unpublished open-file mining company report, Ministry of Commerce M0834.

Banks, M.J. 1978: Granite intrusion and copper-molybdenum mineralisation in the Greenland Group, Seventeen Mile Bluff, Westland. Diploma of science thesis, University of Otago.

Barker, R.G.; Brathwaite, R.L.; Torckler, L. 1980: Gold-silver mineralisation at Neavesville, Coromandel Peninsula, New Zealand. Proceedings of the New Zealand conference 1980, Australasian Institute of Mining and Metallurgy annual conference, May 1980. pp. 25–33.

Bates, T.E. 1978: Final report on mineral exploration within prospecting licence 31-253 Cascade Creek, Buller Gorge: Gold Mines of New Zealand Ltd. Unpublished open-file mining company report, Ministry of Commerce M1337.

Bates, T.E. 1989: Bald Hill molybdenum prospect. In: D. Kear ed. Mineral Deposits of New Zealand, Australasian Institute of Mining and Metallurgy monograph 13: 137–138.

Braithwaite, J.C. 1959a: Prospecting activities of Lime & Marble Ltd, Nelson. Fourth triennial mineral conference, School of Mines and Metallurgy, University of Otago. Paper 173.

Braithwaite, J.C. 1959b: Assay data and correspondence on prospecting for copper-molybdenite, Quartz Creek, Cascade area: Gold Mines of New Zealand Limited. Unpublished open-file mining company report, Ministry of Commerce M2325.

Brathwaite, R.L.; McKay, D.F. 1989: Geology and exploration of the Martha Hill gold-silver deposit, Waihi. In: D. Kear ed. Mineral Deposits of New Zealand, Australasian Institute of Mining and Metallurgy monograph 13: 83–88.

Brathwaite, R.L.; Pirajno, F. 1993: Metallogenic map of New Zealand 1:1,000,000. Institute of Geological and Nuclear Sciences monograph 3.

Carter, R.B.; White, W.H.; Stein, H.J. 1993: High-grade granite-related molybdenum systems: classification and origin. In: Kirkham, R.V.; Sinclair, W.D.; Thorpe, R.I.; Duke, J.M. eds, Mineral deposit modelling. Geological Association of Canada special paper 40: 521–554.

Challis, G.A.; Lauder, W.R. 1977: Pre-Tertiary geology of the Longwood Range. (Parts NZMS1 Sheets S167, S168, S175, and S176), 1:50 000. New Zealand Geological Survey miscellaneous map 11.

Christie, A.B. 1982: Cobra molybdenum prospect, Roaring Lion licence PL 31-437, NW Nelson: diamond drilling, November 1981 to January 1982 and subsequent geochemical work: BP Oil NZ Ltd. Unpublished open-file mining company report, Ministry of Commerce M0969.

Clark, K.F. 1989: Molybdenum resources. In: Carr, D.D. and Herz, N. eds, Concise encyclopedia of mineral resources, pp 220–222. Oxford, Pergamon Press. 426 p.

Cox, S.H. 1878: Report on the Mount Solitary copper lode, Dusky Sound. New Zealand Geological Survey reports of geological explorations 1878–1879, 11: 10–13.

Dodds, L.R. 1969: Eliot Creek molybdenum prospect, Nelson: Asarco (Aust.) Pty. Ltd. Unpublished open-file mining company report, Ministry of Commerce M0811.

Eggers, A.J. 1978: Geology and mineralisation of the Bald Hill molybdenum occurrence. Unpublished M.Sc. thesis, Victoria University of Wellington.

Eggers, A.J.; Adams, C.J. 1979: Potassium-argon ages of molybdenum mineralisation and associated granites of Bald Hill and correlation with other molybdenum occurrences in the South Island, New Zealand. Economic geology 74: 628–637.

Fletcher, D.M. 1968: Taipo molybdenum prospect, NW Nelson, New Zealand: Asarco Development (NZ) Ltd. Unpublished open-file mining company report, Ministry of Commerce M0807.

Foster, J.T. 1971a: Final report. New Zealand reconnaissance Burgoo examination: Kennecott Explorations Pty. Ltd. Unpublished open-file mining company report, Ministry of Commerce M0856.

Foster, J.T. 1971b: Progress report on New Zealand molybdenum reconnaissance: Roaring Lion Examination: Kennecott Explorations Pty. Ltd. Unpublished open-file mining company report, Ministry of Commerce M0838.

Foster, J.T. 1971c: Taipo prospect progress report: Kennecott Explorations Pty. Ltd. Unpublished open-file mining company report, Ministry of Commerce M0839.

Fry, S. 1905: Molybdenite: some notes on its occurrence in New Zealand. New Zealand mines record 8: 369–370.

Hay, K.R. 1979: The Big Bend and Cobra molybdenum prospects — a comparison. Proceedings of the New Zealand conference 1979, Australasian Institute of Mining and Metallurgy annual conference.

Hay, K.R. 1980a: Progress report to June 30 1980, Roaring Lion Area, PL 31-437: Amoco Minerals NZ Ltd. Unpublished open-file mining company report, Ministry of Commerce M0945.

Hay, K.R. 1980b: Skeleton logs and maps for Big Bend and Cobra prospect drill holes, Roaring Lion River area: Amoco Minerals NZ Ltd. Unpublished open-file mining company report, Ministry of Commerce M0944.

Hay, K.R. 1980c: Progress report to August 1980, Karamea Bend Area, PL 31-468, NW Nelson: Amoco Minerals NZ Ltd. Unpublished open-file mining company report, Ministry of Commerce M0946.

Hay, K.R. 1980d: Final report on the Mt Radiant Area, Nelson, New Zealand: Amoco Minerals NZ Ltd. Unpublished open-file mining company report, Ministry of Commerce M0947.

Hay, K.R. 1981: Progress report on the Cobra prospect PL 31-437, Nelson, New Zealand: AMOCO Minerals New Zealand Ltd. Unpublished open-file mining company report, Ministry of Commerce M0962.

Henderson, J. 1917: The geology and mineral resources of the Reefton subdivision, Westport and North Westland divisions. New Zealand Geological Survey bulletin 18.

Jennings, W.L.; Corner, N. 1994: Mineral resources of northwest South Island. Energy and Resources Division, Ministry of Commerce, Resource Information report 19.

Leach, T.M. 1976: Buller fluorite project: report on field work and data analysis: AHI. Unpublished open-file mining company report, M1328.

MacKenzie, I.F.; Price, G.D 1985: Final report on PL 31-855, Mt Ryall, Westland, New Zealand: CRA Exploration Pty Ltd. Unpublished open-file mining company report, Ministry of Commerce M1423.

Maxwell, M.G. 1974: Taipo prospect geological report, NW Nelson: Lime and Marble Ltd. Unpublished open-file mining company report, Ministry of Commerce M0900.

Maxwell, M.G. 1975a: Mt Radiant final report on exploration: NZ Cities Service Inc. Unpublished open-file mining company report, Ministry of Commerce M0910.

Maxwell, M.G. 1975b: NZ project — Taipo PL 31-355: report on drilling results and petrographic report on drill core. Unpublished open-file mining company report, Ministry of Commerce M0909.

Maxwell, M.G. 1975c: Final report exploration licences 33-015 and 33-016, Seddonville, Mt Kendall, Taipo areas, NW Nelson: NZ Cities Service. Unpublished open-file mining company report, Ministry of Commerce M0908.

McClelland, D.A. 1973: Burgoo Stream (Mo): Otter Minerals Exploration Ltd. Unpublished open-file mining company report, Ministry of Commerce M2255.

McClelland, D.A. 1974: Burgoo Target, geochemical and geological investigation May 1973, Aorere valley: Otter Minerals Exploration Pty. Ltd. Unpublished open-file mining company report, Ministry of Commerce M0893.

Merchant, R.J. 1986: Mineralisation in the Thames district — Coromandel. In: Henley, R.W.; Hedenquist, J.W.; Roberts, P.J. eds, Guide to the active epithermal (geothermal) systems and precious metal deposits of New Zealand. Monograph series on mineral deposits 26: 147–163. Berlin, Gebruder & Borntraeger.

Morgan, P.G. 1924: The geology and mines of the Waihi district, Hauraki goldfield, New Zealand. New Zealand Geological Survey bulletin 26.

Morgan, P.G. 1927: Minerals and mineral substances of New Zealand. New Zealand Geological Survey bulletin 32.

Nathan, S. 1978: Sheets S31 & S32 — Buller–Lyell (1st ed.). Geological Map of New Zealand 1:63,360. Map (1 sheet) and notes (32 p.). Department of Scientific and Industrial Research, Wellington.

Officers of the New Zealand Geological Survey 1980: Molybdenum. In: Minerals of New Zealand (part A: metallics). New Zealand Geological Survey report 38A.

Ongley, M.; MacPherson, E.O. 1923: The geology and mineral resources of the Collingwood subdivision. New Zealand Geological Survey bulletin 25.

Park, J. 1888: On mineral deposits, Dusky Sound. New Zealand Geological Survey reports of geological explorations 1888–1889, 19: 9–15.

Pirajno, F. 1982: Geology, geochemistry, mineralisation, and metal zoning of the McConnochie greisenised granite, Reefton district, Westland, New Zealand. New Zealand journal of geology and geophysics 25: 405–425.

Pirajno, F.; Bentley, P.N. 1985: Greisen-related scheelite, gold and sulphide mineralisation at Kirwins Hill and Bateman Creek, Reefton district, Westland, New Zealand. New Zealand journal of geology and geophysics 28: 97–109.

Rabone, S.D.C. 1977: Molybdenum – base metal – bismuth mineralisation at Eliot Creek, Karamea Bend, and Taipo Spur, North-west Nelson, New Zealand. Unpublished PhD thesis, University of Auckland.

Rabone, S.D.C. 1989a: Bismuth sulphosalts associated with molybdenite mineralisation in Northwest Nelson, New Zealand. In: D. Kear ed. Mineral Deposits of New Zealand, Australasian Institute of Mining and Metallurgy monograph 13: 139–142.

Rabone, S.D.C. 1989b: Molybdenum mineralisation at Taipo Spur, Karamea valley, Northwest Nelson, New Zealand. In: D. Kear ed. Mineral Deposits of New Zealand, Australasian Institute of Mining and Metallurgy monograph 13: 129–135.

Railton, G.L.; Watters, W.A. 1990: Minerals of New Zealand. New Zealand Geological Survey bulletin 104.

Riley, P. 1973: Geochemical prospecting for molybdenum at Eliot Creek, NW Nelson: Lime and Marble Ltd. Unpublished open-file mining company report, Ministry of Commerce M0886.

Roberts, P.J. 1979: PL 31-437 — Six monthly progress report to 27/8/79, Cobra prospect, Roaring Lion valley, Nelson: Amoco Minerals NZ Ltd. Unpublished open-file mining company report, Ministry of Commerce M0939.

Roberts, P.J. 1983: An assessment of the mineral resources and the mineral potential of the proposed Tasman Wilderness Area: Mines Division. Unpublished open-file mining company report, Ministry of Commerce M0974.

Roberts, P.J. 1989: Molybdenum mineralisation in the Roaring Lion area, Northwest Nelson. In: D. Kear ed. Mineral Deposits of New Zealand, Australasian Institute of Mining and Metallurgy monograph 13: 125–128.

Rotondo, M.A. 1994: Molybdenum. In: Hinde, C. et al. eds, Metals & minerals annual review — 1994: 63–64. Mining Journal Ltd.

Rowe, W.E. 1881: On Mount Solitary copper lode, Dusky Sound, Fiordland county. New Zealand Geological Survey reports of geological exploration 1880–1881, 13: 159–166.

Scadden, P.G.; Brathwaite, R.L. 1980: Geological appraisal of existing information for proposed Karamea Wilderness area, Northwest Nelson. New Zealand Geological Survey report M78.

Skinner, D.N.B. 1976: Sheet N40 and part sheets N35, N36 & N39 — northern Coromandel. Geological map of New Zealand 1:63 360. Wellington, Department of Scientific and Industrial Research.

Smale, D. 1970: Report on the examination of Copperstain Creek copper prospect, Northwest Nelson: Kennecott Explorations Pty. Ltd. Unpublished open-file mining company report, Ministry of Commerce M0825.

Smale, D. 1976: Hydrothermal alteration around younger intrusions near Karamea Bend, Northwest Nelson, New Zealand. Proceedings of the Australasian Institute of Mineralogy and Metallurgy 260: 53–58.

Stevens, M.R. 1981a: Progress report on the Kakapo Area (PL 31-812) to June 1981, Scarlett Range: Amoco Minerals NZ Ltd. Unpublished open-file mining company report, Ministry of Commerce M0956.

Stevens, M.R. 1981b: Progress report on the Taipo molybdenum prospect (PL 31-584) to 31st January, 1981: Amoco Minerals NZ Ltd. Unpublished open-file mining company report, Ministry of Commerce M0955.

Tulloch, A.J. 1986: Hydrothermal alteration and scheelite mineralisation associated with the Barrytown Pluton, north Westland, New Zealand. Mineral deposits 5: 27–36.

Tulloch, A.J. 1988: Metamorphic core complexes and detachment faults in Westland, New Zealand — implications for precious metal mineralisation. New Zealand Geological Survey report M172.

Tulloch, A.J.; Rabone, S.D.C. 1993: Mo-bearing granodiorite porphyry plutons of the Early Cretaceous Separation Point Suite, west Nelson, New Zealand. New Zealand journal of geology and geophysics 36: 401–408.

Turbott, M. 1968: Final report Eliot Creek examination: Kennecott Explorations Pty. Ltd. Unpublished open-file mining company report, Ministry of Commerce M0808.

Turbott, M. 1972a: MPW 14772 interim report, Roaring Lion area, Nelson: Kennecott Explorations Pty. Ltd. Unpublished open-file mining company report, Ministry of Commerce M0867.

Turbott, M. 1972b: MPW 14770 final report, Roaring Lion area, Nelson: Kennecott Explorations Pty. Ltd. Unpublished open-file mining company report, Ministry of Commerce M0866.

Turbott, M. 1972c: MPWs 14861 and 14862 final report: Roaring Lion River / Karamea Bend area: Kennecott Explorations Pty. Ltd. Unpublished open-file mining company report, Ministry of Commerce M0868.

Walker, M.D. 1981: A report on exploration work within the Buller licence area EL No. 33-116: BP Oil New Zealand Limited. Unpublished open-file mining company report, Ministry of Commerce M1359.

Walker, M.D. 1982: A report on field work carried out on the Discovery prospect Roaring Lion Licence, PL 31-437, Northwest Nelson: BP New Zealand Ltd. Unpublished open-file mining company report, Ministry of Commerce M0966.

Webb, E.J.H. 1910: The geology of the Mount Radiant subdivision. New Zealand Geological Survey bulletin 11.

Willett, R.W. 1943: A molybdenite-bearing quartz lode, Waiau survey district, Southland. New Zealand journal of science and technology 25B: 91.

Williams, G.J. 1974: Economic geology of New Zealand. Australasian Institute of Mining and Metallurgy monograph series 4.

Williams, G.J.; Sanderson, F.L. 1959: Molybdenite-copper prospects, Mt Radiant, western Nelson. Fourth triennial mineral conference, School of Mines and Metallurgy, University of Otago. Paper 132.

Williams, G.J., et al. 1959: Economic minerals at Canaan, Northwest Nelson. Fourth triennial mineral conference, School of Mines and Metallurgy, University of Otago. Paper 140.

Wodzicki, A. 1960: Geology and mineralisation of the Mt Radiant area, Northwest Nelson. New Zealand journal of geology and geophysics 3: 355–363.

Wodzicki, A. 1972a: Mineralogy, geochemistry and origin of hydrothermal alteration and sulphide mineralisation in the disseminated molybdenite and skarn-type copper sulphide deposit at Copperstain Creek, Takaka, New Zealand. New Zealand journal of geology and geophysics 15: 599–631.

Wodzicki, A. 1972b: Molybdenite mineralisation at the Manapouri power project, Fiordland. Unpublished New Zealand Geological Survey report, Institute of Geological and Nuclear Sciences MR1070, Ministry of Commerce M1782.

Zuckerman, M.B. 1974: Final report on the molybdenum mineralisation with MPW 54/71 “Takaka III”, NW Nelson: Carpentaria Exploration Company Pty. Ltd. Unpublished open-file mining company report, Ministry of Commerce M0902.