

Mineral Commodity Report 7 — Manganese

by Tony Christie

Institute of Geological and Nuclear Sciences Ltd

Discovery and Origin of Names

The name manganese is of Italian origin and is a corruption of magnesia, from the Latin *magnes* meaning magnet, a reference to the magnetic properties of the ore mineral pyrolusite.

The manganese oxide pyrolusite has been used in glass-making since the time of the pharaohs in Egypt. Manganese was first distinguished as an element in 1774 by the Swedish chemist Carl Wilhelm Scheele while working with pyrolusite. It was isolated the same year by Scheele's associate, Johan Gottlieb Gahn, by burning pyrolusite with charcoal. Manganese had no practical uses until 1839, when it was introduced as an additive in the manufacture of crucible steel. From 1856, the use of ferromanganese in the Bessemer method of steel-making made this process very successful.

Major Ores and Minerals

Manganese is the twelfth most abundant element in the earth's crust and is present in more than 300 minerals, but the only known natural occurrences of manganese metal are in meteorites. The economically important manganese minerals include: the oxides pyrolusite, psilomelane, braunite, and manganite; the silicate piemontite; and the carbonate rhodochrosite (Table 1). The most important ores consist of

Symbol	Mn
Atomic no.	25
Atomic wt	54.94
Specific gravity	7.21–7.44
Valence	2, 3, 4, 6, 7
Melting point	1245°C
Boiling point	1962°C
Crustal abundance	0.1%
Preferred analysis method	plasma atomic emission spectroscopy
Routine detection limit	5 ppm

manganese dioxide in the form of pyrolusite, psilomelane and wad, usually with variable amounts of iron oxides. Ores containing 5–10% Mn are called manganiferous iron ores, those containing 10–35% Mn are ferruginous manganese ores, whereas those with more than 35% Mn are manganese ores. Manganiferous iron ores and ferruginous manganese ores are also referred to as manganiferous ores. The major production is from sources with about 15% Mn to more than 50% Mn.

Properties

Manganese is a transition metal in Group VIIB of the periodic table, between chromium and iron. It is a hard, brittle, silvery-white metal with a high specific gravity of 7.21 to

Name, Formula	Colour	Hardness	Density	Lustre	Crystal System	Transparency	Fracture
Braunite $3(\text{Mn,Fe})_2\text{O}_3\cdot\text{MnSiO}_3$	brownish-black	6–6.5	4.8	submetallic	tetragonal	opaque	uneven brittle
Manganite $\text{Mn}_2\text{O}_3\cdot\text{H}_2\text{O}$	steel grey to black	4	4.3	submetallic	orthorhombic	opaque	uneven
Psilomelane $\text{BaMn}_9\text{O}_{16}(\text{OH})_4$	dark steel grey to black	5–6	3.7–4.7	submetallic	orthorhombic	opaque	
Pyrolusite MnO_2	dark steel grey to black	2–2.5	4.75	metallic	tetragonal	opaque	rather brittle
Piemontite $\text{Ca}_2(\text{Mn,Fe}^{3+},\text{Al})_2\text{AlO}_3\cdot\text{OH}(\text{Si}_2\text{O}_7)(\text{SiO}_4)$	reddish brown	6.5	3.4	vitreous	monoclinic	semi-transparent	uneven
Rhodochrosite MnCO_3	red-brown	3.5–4.5	3.45–3.6	vitreous	rhombohedral	semi-transparent	uneven brittle
Wad oxides of manganese with variable composition	dull black, bluish, lead grey, brownish black	5–6	3.4–4.3	dull	amorphous	opaque	

Table 1: Manganese minerals.

7.44 (depending on the allotropic form), and somewhat resembles iron in appearance and properties.

Pyrolusite is a soft, iron-grey mineral with a metallic lustre and specific gravity of 4.75. It occurs as a pseudomorph of manganite or other manganese minerals, usually massive or reniform, in some examples with a fibrous and radiate structure. Psilomelane is similar to pyrolusite in colour and specific gravity, but it has a submetallic lustre and is much harder (5 to 6). It is amorphous and can be massive, botryoidal, reniform or stalactitic.

Formation

The formation of manganese deposits and classification of different deposit types was described in detail by Roy (1981). A five-fold classification scheme is used here:

Sedimentary deposits are formed by chemical processes that segregated manganese during the deposition of marine sediments. The deposits are stratiform and lenticular. Two subclasses are defined based on their mineralogy: carbonate and oxide. Carbonate deposits are associated with carbonaceous or graphitic rocks, often clayey, that were formed in a reducing environment, probably in enclosed basins. In contrast, oxide deposits are most commonly associated with coarser clastic sediments, with little or no free or organic carbon, produced under strongly oxidising conditions with free water circulation. Oxide deposits generally have higher grades and are more extensive than carbonate deposits. In many of the mined oxide and carbonate deposits, the grade has been increased by residual concentration. The world's largest manganese deposits are sedimentary deposits, including those of the Nikopol district in Ukraine, Chiatura district in Georgia and Kalahari district of South Africa. These are mainly oxide deposits, although some have associated carbonate facies. This lateral zonation from oxide to carbonate facies is probably related to the proximity to the ancient shoreline, with the oxide facies being formed close to the basin margin, whereas the carbonate facies formed more distally. Other oxide deposits include Groote Eylandt in Australia and the Imini deposit in Morocco. The Molango deposit in Hidalgo State, Mexico is an example of a large carbonate deposit.

Seafloor nodules are a special type of sedimentary manganese deposit that represent a large unmined resource of manganese, iron, copper, nickel and cobalt. They are abundant in sediment-starved areas of the deep ocean basins, mainly in the Pacific Ocean. They occur in irregular, single-layer fields at or within a metre of the sediment-water interface. Individual nodules are potato-sized earthy brown to bluish black lumps with a dull lustre. They consist of one or more nuclei (shark teeth, whale ear bones, rock fragments or other nodules) surrounded by discontinuous concentric layers of metal oxides and clay.

Hydrothermal manganese deposits are typically found as epithermal and mesothermal veins, and rarely as stratabound deposits. The manganese minerals may form ore-grade concentrations, or may be present as gangue in association with ore minerals of other metals, commonly with Pb-Zn-Ag

vein mineralisation. Examples include Butte in the USA (mesothermal-epithermal Pb-Zn-Cu-Ag-Au veins), Navidad in Chile (epithermal Mn veins) and Dzhezda in Kazakhstan (Mn mantos and veins).

Volcanogenic sedimentary manganese oxide deposits are associated with chert and basaltic volcanics in oceanic basins. These deposits are of minor importance in terms of world manganese production, but are the main type found in New Zealand. Worldwide, these deposits are mainly silicate ores, with less common carbonate ores, and rare oxide ores. In contrast, the New Zealand deposits contain mainly oxide ore. The deposits in Olympic Peninsula in the USA and Noda Tamagawa in Japan are examples related to mafic volcanic rocks, whereas Langban in Sweden and Karadzhal in Kazakhstan are examples related to felsic volcanic rocks.

Residual accumulations and laterites (supergene deposits) are found in humid tropical regions where intense weathering has leached many elements from the rocks, usually sedimentary manganese proto-ores, forming a residual concentration of manganiferous material. Deposits of this type are mined extensively in Brazil (Serra do Navio deposit in Amapa district and Morro da Mina deposit in Minas Gerais district), India (Orissa, Karnataka, Maharashtra and Madhya Pradesh) and Gabon (Moanda deposit). Other examples include Nsuta in Ghana, Tambao in Burkina Faso and Kisenge in Zaire.

Uses

Manganese is the fourth most widely consumed metal after iron, aluminium and copper. More than 90% of manganese is used by the iron and steel industry, both in the production of iron and steel, and in alloys of steel. The remainder is used in a variety of industrial, chemical and pharmaceutical applications.

The various end-uses of manganese have different ore requirements giving rise to the classification of manganese ore into metallurgical, chemical, and battery grades. Metallurgical grade material has about 38–55% Mn and may differ from chemical grade ore only in physical form. Chemical and battery grade ores are often categorised by their MnO₂ content, which is typically in the range of 70% to 85% (44% to 54% Mn).

Manganese is an essential ingredient in the process of converting iron ore to steel, with about 7 kg of manganese used in the production of one tonne of steel. It is added in the form of alloys such as ferromanganese (about 80% Mn, 15–18% Fe) and spiegeleisen (12–33% Mn, the remainder Fe). The manganese serves as a desulphurising, deoxidising and conditioning agent during the smelting of iron ore. As an alloying element in steel, manganese increases toughness, strength and hardness. Most steels generally contain less than 1% Mn. Manganese steel, or Hadfield steel, contains 12–14% Mn and is used for very rugged service where hardness and toughness are required (e.g. armour plate, projectiles, safes, crushers, and cutting and grinding machinery). Nonferrous manganese alloys include manganese

bronze (Mn, Cu, Sn, and Zn) and manganin (Mn, Cu, and Ni). Manganese bronze resists corrosion from seawater and is used for propeller blades on boats and torpedoes. Manganin is used in the form of wire for accurate electrical measurements, because its electrical conductivity does not vary appreciably with temperature.

Manganese dioxide is used in dry-cell batteries, most commonly in the carbon-zinc type, where it acts as a depolarizer by suppressing the formation of hydrogen gas at the carbon (positive) electrode. It is also used in paint and varnish oils, in glass-manufacture (e.g. for decolouring glass by removing iron-impurities), bricks and ceramics, and in preparing oxygen, chlorine and iodine. Manganese sulphate is used as a fertilizer, in dyeing cotton, and in paint and varnish oils. Sodium and potassium permanganate (NaMnO_4 and KMnO_4) are used as oxidizers and disinfectants.

Manganese is essential in trace quantities for plants and animals, but excess quantities are toxic. A manganese deficiency in humans disrupts growth and results in various disorders of the bones and the central nervous system.

Price

Manganese prices increased dramatically from 1987 to 1990 but have since declined to 1988 levels. In May 1995, manganese ore (48–50% Mn and maximum of 0.1% P) was US\$1.95/t, and manganese metal (99.7%) was US\$1700–1780/t.

World Production and Consumption

The annual world production of manganese ore is about 20 Mt (19.5 Mt in 1993; Dancoisne, 1994). High-grade manganese ores are mostly supplied by the Commonwealth of Independent States (Ukraine, 6 Mt in 1993; Georgia, formerly 200 000 t but no production in 1993; Kazakhstan 150 000 t in 1993), China (4.2 Mt in 1993), South Africa, Brazil, India, Australia and Gabon. The CIS has very large deposits totalling 3000 Mt in two principal districts, Nikopol (Ukraine) and Chiatura (Georgia), but although some material is high grade, much is of low grade and otherwise poor quality, and mining costs are high.

Most of the manganese production is used for steel-making and therefore demand for manganese is closely tied to the fortunes of the steel industry and the industrialised nations.

Ore Processing, Smelting and Refining

Raw manganese ore may be upgraded by flotation, heavy medium or high-intensity magnetic separation. Manganese ores and concentrates are purified by several methods. The predominant method used is electrothermy in which manganese oxide ore is reduced to manganese ferroalloys in an electric arc furnace with aluminium and silicon. Blast furnace-type operations are still used in some countries to make high-carbon ferro-manganese. Higher grades of manganese, including manganese metal, are commonly

produced by the electrolysis of sulphate solutions of manganese. In this method, manganese ores are converted to manganese oxides by heating. The oxides are mixed with sulphuric acid to form manganous sulphate and this solution is purified and subjected to electrolysis.

Manganese processing usually also recovers iron in the form of ferro-manganese alloys. Recovery of other by-product metals is rare.

Some manganese is recycled as by-product recovery from steel scrap, steel slag and nonferrous scrap. Scrap recovery specifically for manganese is insignificant.

New Zealand Occurrence and Resources

The occurrence of manganese in New Zealand (Figure 1) has been reviewed by Reed (1959, 1960), Officers of New Zealand Geological Survey (1970), Williams (1974), Roser et al. (1980) and Brathwaite and Pirajno (1993). Morgan (1927) and Railton and Watters (1990) listed the occurrences of manganese minerals.

A. Volcanogenic Sedimentary Deposits

Permian–Jurassic deposits

Stratabound deposits of manganese oxides are associated with the spilitic red-rock suite of rocks in the Permian–Jurassic greywacke and argillite of the North Island (Waipapa Group and Torlesse Supergroup), and their metamorphosed equivalents in the South Island (Haast Schist). The red rocks consist of mafic lava, chert, jasperite, and volcaniclastic

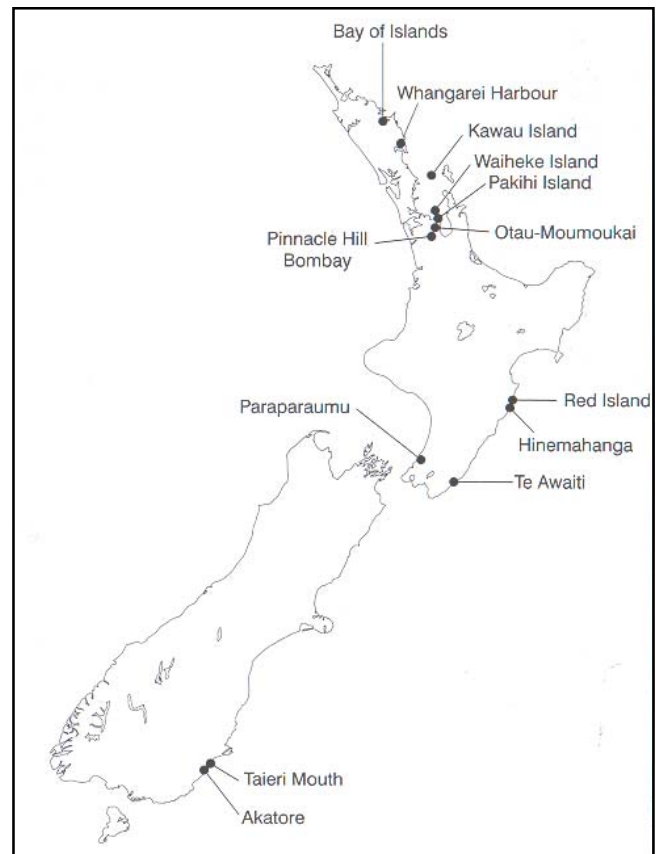


Figure 1: Location of manganese deposits in New Zealand.

argillite. The manganese deposits are usually hosted by red argillite and chert. Deposits are most common in Northland and South Auckland, where the main localities are Bay of Islands, Whangarei Harbour, Waiheke Island, Bombay, and Otau and Moumoukai in the Hunua Ranges. In the South Island, the main occurrences are with metamorphosed chert and spilite in the form of lenses of manganese oxides at Taieri Mouth in Otago, and as disseminations of piemontite in schist near Arrowtown and elsewhere in Otago, Westland and Marlborough.

The association of the manganese deposits with spilitic volcanic rocks indicates that their formation was related to submarine volcanism (Reed, 1960; Stanaway et al., 1978; Roser, 1983). The manganese and chert were probably chemically precipitated from low temperature hydrothermal solutions, and accumulated on the sea floor along with other sediments. In many deposits, the manganese was further concentrated by diagenesis and secondary processes (Stanaway et al., 1978; Roser, 1983).

The ore occurs as disseminated and massive mineralisation, in pods, lenses, laminae, lumps, nodules and veins. Primary mineralisation, formed during sedimentary (syngenetic) and diagenetic stages, is characterised by oolitic ore textures. Secondary (supergene) mineralisation has rhythmic colloform structures, abundant cross-cutting veinlets of secondary minerals, and structureless masses of replacement minerals (Stanaway et al., 1978; Roser, 1983). The mineralogy consists of quartz, hematite, and a complex variety of manganese oxides. Syngenetic minerals include braunite, bementite $\text{Mn}_8\text{Si}_6\text{O}_{15}(\text{OH})_{10}$, manganite and hausmannite Mn_3O_4 , and some assemblages may be altered to cryptomelane $\text{KMn}_8\text{O}_{16}$ and psilomelane during burial and diagenesis. Secondary minerals include psilomelane, cryptomelane and goethite, with lesser quantities of pyrolusite, lithiophorite $(\text{Al},\text{Li})\text{MnO}_2(\text{OH})_2$, todorokite $(\text{Mn},\text{Ca},\text{Ba})_2\text{Mn}_{12}\text{O}_{33}\cdot 8\text{H}_2\text{O}$, nsutite $\text{MnO}_2\cdot x\text{H}_2\text{O}$, jakobsite MnFe_2O_4 , birnessite $\text{Na}_4\text{Mn}_{14}\text{O}_{27}\cdot 9\text{H}_2\text{O}$, and secondary manganite.

Bay of Islands: At Tikitikioure (Tikiora Hill), 4 km south-east of Russell, stratabound lenticular lenses of manganese mineralisation, 1–10 m long and less than 1 m thick, are present in coloured argillite, and pink and white chert within the greywacke–argillite rocks of the Waipapa Group (Sekula, 1972; Roser, 1983). The mineralisation consists of braunite, cryptomelane, nsutite (bementite), psilomelane, pyrolusite and lithiophorite. Between 1864 and 1885, several hundred tonnes of ore were mined from small pockets in “quartzose or jasperoid greywacke.” Exploration by Winstone Mineral Exploration Ltd (Carlson, 1974a) recorded manganese values of 50.8% and 28.2% (with low Fe) on selected ore samples.

At Frenchman’s Hill, small quantities of ore were recovered in the 1800s from numerous quarries and trenches. The mineralisation is associated with a bedded chert in Waipapa Group greywacke.

A number of other small deposits are present in the northeast Northland area and many were worked in the 1800s. They include deposits at: Kaiwauwaru Bay, Puketi, Purerua

Peninsula (Mt Pocock), Kiripaka Hill, Manganese Hill, Hukerenui, Ruapekapeka, and Otonga (Bell and Clark, 1909; Ferrar, 1925, 1934; Sekula, 1972; Stanaway et al., 1978). Analyses for single samples have been reported for material at Kiripaka — 49.4% Mn (Ferrar, 1925), Otonga — 63.4% (Ferrar, 1925) and Mt Pocock — 50.0% Mn (Carlson, 1974b). Bell (1976) reported that the deposit at Hukerenui (between Kawakawa and Whangarei) contains about 150 000 t of mineralisation with assays up to 79% MnO_2 .

Whangarei Harbour: At Parua Bay, manganese mineralisation is present in a thin sequence of red argillite, chert, and red and green spilites (Roser, 1983). Over 2000 t of ore containing jacobsite and psilomelane was extracted between 1884 and 1894. Ferrar (1925) reported a single analysis of 41.16% Mn.

At Manganese Point, a complex sequence of interbedded spilites, cherts, and coloured argillites are intercalated in the Waipapa Group greywacke–argillite. Stratabound pods less than 30 cm in length and conformable lamellae less than 5 cm thick are present in red and pink cherts and red argillites, and contain cryptomelane, psilomelane, minor pyrolusite and braunite (Roser, 1983).

At Stockyard Cove, a sequence of spilite, coloured argillite and chert is terminated by a fault and followed by sandstone and manganese-bearing bedded chert (Roser, 1983). Psilomelane and pyrolusite are present as 1 cm-wide secondary joint fillings in cream and red cherts. The deposit was prospected by several adits but no production was recorded.

Kawau Island: Manganese mineralisation is found at several locations on the island, associated with jaspilite, chert and spilite sequences in Waipapa Group greywacke. Three locations were mined intermittently from 1842: Manganese Point on the northwest coast, Beaumont Point on the west coast, and near South Cove on the southwest coast (Ferrar, 1934). The last is known more for its copper production than for manganese. It was opened as a manganese mine in 1842, but copper was discovered later in that year and became the main focus of mining for the next 27 years, until the closure of the mine.

Waiheke Island: Nests, stringers and discontinuous lenses of manganese mineralisation are found within lenses of bedded chert and jaspilite of the Kiripaka, Rocky Bay and Waikorariki formations in the Waiheke Group greywacke and argillite sequences (Halcrow, 1956; Schofield, 1979). The chert and jaspilite lenses are usually less than 150 m thick and some are associated with lavas. The main occurrences of manganese are on the west side of Maunganui (the highest point on the island), where the manganese lenses range from 0.6 to 4.8 m in width, and at Te Matuka Bay and Rocky Bay. Mining between 1878 and 1884 produced 11 600 t of ore. Pickering (1971) reported analyses of 34.0% and 11.7% Mn.

Pakihi Island: Manganese is associated with a more than 85 m-thick section of bedded jaspilite and chert of the Kiripaka Formation (Hutton, 1869; Schofield, 1979).

Mineralisation of predominantly psilomelane occurs in numerous bands, about 2.5 cm thick.

Otau: Manganese occurs within a northerly trending band of Kiripaka Formation of Waiheke Group (Schofield, 1976). At the Otau mine, this formation is a 25 m-thick sequence of red-brown, red and green argillites with included dislocated blocks of iron-chert, confined by sharp contacts to weathered greywacke (Roser, 1983). Manganese mineralisation crops out over a distance of 103 m and was worked in several adits and trenches (Healy, 1937; Macpherson, 1941). The mineralisation strikes north and dips 65° to 80°W, and averages about 4 m thick. The manganese minerals are bementite, braunite, cryptomelane and nsutite (Roser, 1983). The deposit was worked by Mirandite Products Ltd and produced 3838 t of ore up to its closure about 1960.

Moumoukai: The band of Kiripaka Formation at Otau continues southward and contains another concentration of manganese at Moumoukai (Schofield, 1976). Here, the mineralisation was traced over a strike distance of 52 m with signs of continuation for a further 46 m to the northeast (Macpherson, 1941). The mineralisation is exposed in a 4 m wide pit and consists of lenticles, laminae and nodules of primary iron-manganese mineralisation in red argillite with secondary mineralisation in veins and joints (Roser, 1983). The manganese minerals are psilomelane and cryptomelane with minor hausmannite and manganite, and secondary pyrolusite. The deposit was worked as the Piggotts and Cloude-slay claims and produced 1934 t of ore.

Bombay: At Pinnacle Hill (Figure 2), massive and disseminated mineralisation is present in bedded hematitic chert and argillite, of Kiripaka Formation (Fyfe, 1933; Macpherson, 1941; Schofield, 1976). The orebody was small as illustrated by the size of the open pit developed during its extraction, which was 60 m long by 3 m wide and varying from 4.5 m to 7.5 m deep. The orebody had a dip of 60° to 70°, tapered at both ends and narrowed to a width of

0.6 m in the deepest part of the pit. Weak banding in the ore was considered a remnant of primary sedimentary structure by Stanaway (1972), probably as laminae in shale interbeds or coloured argillite. The mineralisation contains braunite, psilomelane-cryptomelane, pyrolusite and nsutite. Production was 494 t of mostly high-grade secondary ore.

Skinner and Chin (1983) carried out a stream-sediment geochemical survey to detect manganese deposits in the Bombay-Hunua area. In addition to detecting the previously known deposits, anomalous manganese values suggested the presence of a significant undiscovered manganese concentration west of Pinnacle Hill.

Paraparaumu: This deposit is hosted in Torlesse Supergroup rocks and is notable because the mineralisation occurs as the carbonate rhodochrosite. According to McKay (1899), the manganese horizon ranged from 1–3 m in width, and was traceable for 100–140 m along a ridge. The mineralisation is present as nests and veins in white chert, which is underlain by a chloritic argillite. Pillow basalts also outcrop in the immediate vicinity (Roser, 1983).

Taieri Mouth–Akatore: About 100 t of manganese ore were mined south of Taieri Mouth (Hector, 1892). The mineralisation occurs within a 3.7 m-thick band in a brown argillite/chert sequence in Haast Schist. The band contains massive manganese oxide mineralisation as pods, up to 15 cm thick, and more commonly as small pockets and veins. Manganese minerals include pyrolusite, manganite and ramsdellite (Coombs, in Reed 1959). Hector (1892) gave analyses between 17.0% and 58.1% manganese.

Manganese mineralisation is also found a few kilometres to the south, on the coast, south of Akatore Creek (Read and Reay, 1971). Felsic metatuff within Haast Schist contains metachert-carbonate lenses up to 3 m thick, with pink-coloured pods of manganese mineralisation up to a metre thick. Associated metavolcanic rocks developed from basic

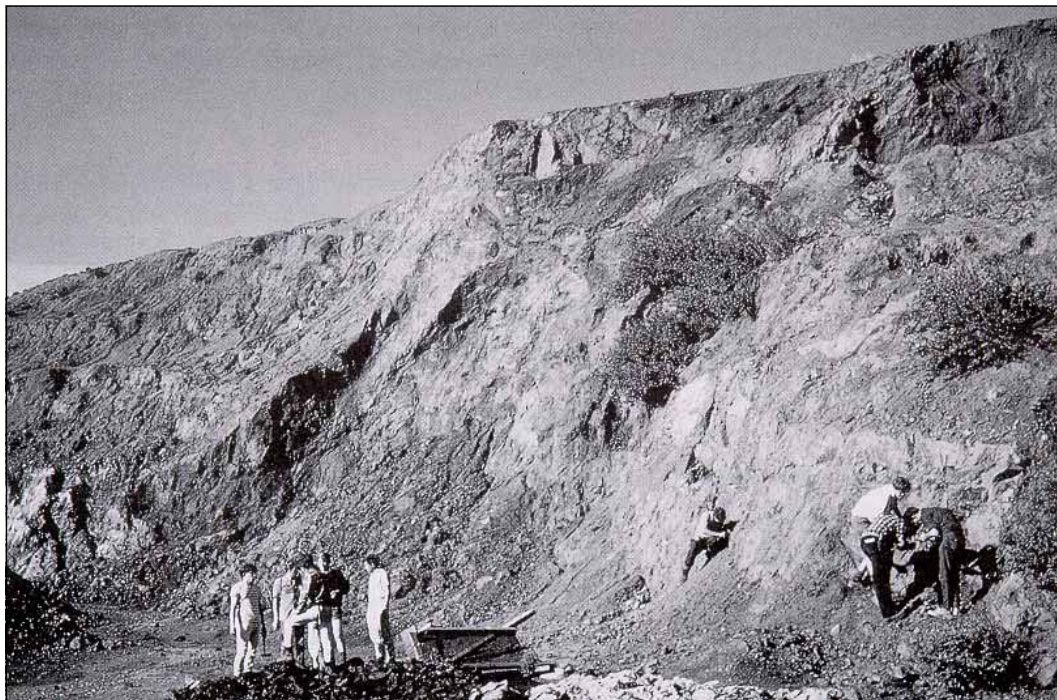


Figure 2: Manganese mine in chert and argillite at Pinnacle Hill, Bombay, South Auckland (Photo: Bruce Thompson).

tuffs, breccias and flows. Rhodochrosite and akatereite are the main manganese minerals, along with rhodonite, spessartine, pyroxmangite and tizenite (Read and Reay, 1971). Secondary wad, psilomelane, pyrolusite and todorokite fill veinlets and blacken outcrops.

Miscellaneous occurrences in schist: Small lenses of manganese mineralisation up to 2 m thick are present in schist at several locations in Otago and Westland (Hutton, 1940, 1942; Turner, 1946; Mason, 1955; Reed, 1960; Turnbull, 1975). They are usually represented by rhodonite-spessartine-rhodochrosite schist, spessartine-magnetite schist, or piemontite schist. Watters and Challis (1985) described a manganese-bearing metachert within schist of the Onamalutu valley, Marlborough. The metachert contained up to 7% Mn, mainly as piemontite and spessartine-rich garnet. Meta-quartzite in the Marlborough schist of Wakamarina valley also contains probable spessartine garnet (Skinner and Brathwaite, 1994).

Cretaceous deposits

Manganese deposits occur associated with Cretaceous sedimentary and volcanic rocks at Red Island and nearby Hinemahanga Rocks in Hawke's Bay, and at Te Awaitei in southern Wairarapa. Their similar geologic setting to the Permian–Jurassic deposits suggests a similar volcanogenic origin.

Red Island: Stratiform manganese oxide horizons are interbedded between basalt and limestones (Roser, 1983; Kobe, 1976; Kobe and Pettinga, 1984). Manganite, psilomelane group minerals, pyrolusite, hematite and limonite are present but ore-grade material is of very small volume.

Hinemahanga (Kairakau) Rocks: The rocks consist of basalt pillow lava interbedded with limestone and mudstone. Manganese nodules occur in the limestone, whereas copper mineralisation is present in the basalt (Black et al., 1984; Kobe and Pettinga, 1984).

Te Awaitei: Fyfe and Reed (1959) described an occurrence of high-grade manganese mineralisation about 7 km southwest of Pahaoa River mouth. Manganese minerals form coatings and pockets throughout a 20 m wide band of basaltic lava (spilite) and chert within Early Cretaceous Pahaoa Group greywacke, argillite and conglomerate. The mineralised pockets are 1–2 m long and up to 45 cm thick, and in places are associated with hematite layers. The main mineral is braunite, and minor psilomelane is also present. Two analyses gave values of 86.9 and 90.7% MnO₂.

B. Hydrothermal Deposits

Rhodochrosite, rhodonite and manganiferous calcite, and secondary pyrolusite and wad are present in some of the epithermal gold-silver-bearing quartz veins in the Hauraki Goldfield (Fraser and Adams, 1907; Morgan, 1924). Inesite, a pink manganese silicate, is present at Waihi (Hutton, 1941). Rhodonite was reported from the mesothermal gold-bearing quartz veins of Nenthorn and Waipori in Otago (McKay, 1892; Marshall, 1918). Brathwaite et al. (1990) noted several

manganese minerals in zinc-lead skarn mineralisation on Motukokako Island, near Cape Brett.

C. Seafloor Nodules

Manganese nodules are present on the sea floor below 1000 m of water depth within New Zealand's 200-mile (322 km) offshore economic management zone, particularly on the Campbell Plateau (Summerhayes, 1967; Roser et al., 1980; Glasby and Wright, 1990). The nodules are concretionary crusts of ferromanganese oxides around a nucleus such as pumice, coral, glacial pebbles or phosphorite nodules. Manganese nodules from the Southwest Pacific have relatively low contents of nickel, cobalt and copper compared with those in the North Pacific.

Production

The total recorded production of manganese ore in New Zealand is 26 102 t. New Zealand's first metal-mining operation was the extraction of manganese from an adit on Kawau Island in 1842. The export ore, because of its heavy nature, was sought after as ballast cargo for sailing ships journeying from New Zealand. The development of a mine shaft on the Kawau Island deposit led to the discovery of a copper lode which proved much more profitable than the manganese. A larger manganese operation was carried out on Waiheke Island, producing 11 600 t between 1878–84. Mining was also carried out in the Bay of Islands and near Whangarei in Northland, and at Taieri Mouth, Otago. The total recorded production for manganese mining in New Zealand, between 1878 and 1911 was 19 674 t at a grade of 40–50% Mn.

After a long period of virtual cessation of manganese production, three deposits were worked in South Auckland between 1937 and 1960: Pinnacle Hill at Bombay, 494 t; Piggotts-Cloudeslay claims Moumoukai, 1934 t; and Mirandite Co. Ottau, 3838 t (Reed, 1960). The ore contained between 19 and 56% metallic manganese.

During both periods of mining, the ore had to be hand picked after extraction to maintain reasonable grade. In addition, the patchiness and small size of the deposits required selective mining techniques by small parties.

Imports

New Zealand imported 281 t of manganese metal and oxides worth NZ\$458 123 during 1994, compared with 1088 t worth NZ\$1 632 169 in the year July 1983–June 1984 (Rabone, 1984; Statistics New Zealand).

Potential and Prospectivity

Reed (1960, p. 353), in his review of manganese deposits in New Zealand, concluded that "All the deposits are small and patchy and do not lend themselves to large scale mining." There is potential for discovery of new manganese deposits of the "red rocks"-greywacke association, however they are unlikely to be substantially larger than those worked in the past and would be uneconomic under today's conditions. Nevertheless, small quantities of manganese could be

selectively mined from a number of deposits if required for strategic reasons.

The offshore seafloor nodule deposits represent a vast resource that could be utilised in the 21st century if suitable technology for inexpensive seafloor mining is developed.

Future Trends

Manganese will continue to be in demand, particularly for making iron, steel alloys and batteries. There is potential for the increased use of manganese in special steels as new applications develop, and increases associated with a general rise in steel production and use of steel in developing countries such as China.

Cannon (1989) noted that although the known world reserves of manganese are very large, there is a limited supply of known high-grade ores (>35% Mn) required for steel production. Future production may be dominated by South Africa. Improvements in world manganese supply could result from:

- a. Discoveries of new high-grade ore deposits.
- b. Development of cost-effective techniques to upgrade low-grade deposits to make synthetic high-grade ore.
- c. Changes in steel and ferromanganese making technology to use ores of lower grade than those now used.
- d. Initiation of manganese recovery from seafloor nodules.

Acknowledgements

Hugh Cargill, Bruce Thompson and David Skinner provided constructive reviews and comments on the manuscript and Michelle Fraei drafted the location map. The Publicity Unit of Crown Minerals Operations Group provided partial funding, and Roger Gregg and Annemarie Crampton are thanked for their support of the project.

References

Bell, A.B. 1976: Reconnaissance exploration at Kauri Mountain, Northland, New Zealand: for Aotea Minerals Ltd in association with Strategic Exploration Ltd. Unpublished company report, Ministry of Commerce M0171.

Bell, J.M.; Clarke, E. de C. 1909: The geology of the Whangaroa subdivision. New Zealand Geological Survey bulletin 8.

Black, R.D.; Brathwaite, R.L.; Moore, P.R. 1984: Pillow lava and associated copper minerals at Kairakau Rocks, southern Hawke's Bay. New Zealand Geological Survey record 3: 92–97.

Brathwaite, R.L.; Isaac, M.J.; Challis, G.A.; Brook, F.J. 1990: Tertiary limestone and Zn-Pb mineralised skarn at Motukokako, Cape Brett, northern New Zealand. New Zealand journal of geology and geophysics 20: 427–438.

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

Cannon, W.F. 1989: Manganese resources. In: Carr, D.D. and Herz, N. eds, Concise encyclopedia of mineral resources, pp 196–197. Oxford, Pergamon Press. 426 p.

Carlson, J.R. 1974a: Geological report on Mt Tikitikioure, Russell MPW 462: Winstone Minerals Ltd. Unpublished company report, Ministry of Commerce M0168.

Carlson, J.R. 1974b: Preliminary report on Mt Pocock MPW 476: Winstone Minerals Ltd. Unpublished company report, Ministry of Commerce M0167.

Dancoisne, P.L. 1994: Manganese. In: Hinde, C. et al. eds, Metals & minerals annual review — 1994: 59–60. Mining Journal Ltd.

Ferrar, H.T. 1925: The geology of the Whangarei-Bay of Islands subdivision. New Zealand Geological Survey bulletin 27.

Ferrar, H.T. 1934: The geology of the Dargaville-Rodney subdivision. New Zealand Geological Survey bulletin 34.

Fraser, C.; Adams, J.H. 1907: The geology of the Coromandel subdivision, Hauraki, Auckland. New Zealand Geological Survey bulletin 4.

Fyfe, H.E. 1933: Manganese Deposit, Bombay. New Zealand journal of science and technology 15: 203–207.

Fyfe, H.E.; Reed, J.J. 1959: Note on the occurrence of manganese in southeastern Wairarapa. New Zealand journal of geology and geophysics 2: 262–264.

Glasby, G.P.; Wright, I.C. 1990: Marine mineral potential in New Zealand's exclusive economic zone. Marine mining 9: 403–427.

Halcrow, H.M. 1956: The geology of Waiheke Island. Transactions of the Royal Society of New Zealand 84: 51–69.

Healy, J. 1937: Manganese deposit at Otatau, block XIV, Wairoa survey district. New Zealand Geological Survey 31st annual report p. 22.

Hector, J. 1892: Progress report by the Director. New Zealand Geological Survey reports of geological explorations 1890–1891, 21: LIX–LXII.

Hutton, C.O. 1940: Metamorphism in the Lake Wakatipu region, western Otago, New Zealand. New Zealand Geological Survey memoir 5.

Hutton, C.O. 1941: Inesite from Waihi Mine, North Island, New Zealand. Transactions of the Royal Society of New Zealand 71: 99–102.

Hutton, C.O. 1942: Piedmontite-bearing quartz schists from Black Peak, northwestern Otago. New Zealand journal of science and technology 23: 231–232.

- Hutton, F.W. 1869: On the geology of the island of Pakihi. *Transactions of the New Zealand Institute* 1: 167–168.
- Kobe, H.W. 1976: Petrology and mineralisation of Karamea (Red Island) southern Hawke's Bay. *Tane* 22.
- Kobe, H.W.; Pettinga, J.R. 1984: Red Island (New Zealand) and its submarine-exhalative Mn-Fe mineralization. In: Wauschkuhn, A. et al. eds., *Syngeneses and epigenesis in the formation of mineral deposits*. Berlin, Heidelberg, Springer-Verlag. Pp. 562–572.
- Macpherson, E.O. 1941: Manganese deposits in Manukau and Franklin counties. *New Zealand journal of science and technology* B22: 185–192.
- Marshall, P. 1918: The geology of the Tuapeka district, Central Otago division. *New Zealand Geological Survey bulletin* 19.
- Mason, B. 1955: Notes on some New Zealand minerals. *New Zealand journal of science and technology* 36: 557–560.
- McKay, A. 1892: On the quartz reefs of the Nenthorn district, Otago. *New Zealand Geological Survey reports of geological explorations 1890–1981* 21: 50–54.
- McKay, A. 1899: Report on a deposit of rhodochrosite at Paraparaumu. *Mines statement*. Parliamentary paper C9: 2–3.
- Morgan, P.G. 1924: The geology of the mines of the Waihi district, Hauraki Goldfield. *New Zealand Geological Survey bulletin* 26.
- Morgan, P.G. 1927: Minerals and mineral substances in New Zealand. *New Zealand Geological Survey bulletin* 32.
- Officers of New Zealand Geological Survey 1970: Minerals of New Zealand (Part A: metallics). *New Zealand Geological Survey report* 38A.
- Pickering, R. 1971: Report on reconnaissance investigation of manganese deposits, MPW applications 77/70, 83/70, 84/70, 92/70, Auckland district: Geotechnics (Aust) Pty Ltd. Unpublished company report, Ministry of Commerce M0257.
- Rabone, S.D.C. 1984: New Zealand metallic and non-metallic mineral commodity imports and exports 1982–83 and 1983–84. *New Zealand Geological Survey report* M142.
- Railton, G.T.; Watters, W.A. 1990: Minerals of New Zealand. *New Zealand Geological Survey bulletin* 104.
- Read, P.B.; Reay, A. 1971: Akatoreite, a new manganese silicate from eastern Otago, New Zealand. *American mineralogist* 56: 416–426.
- Reed, J.J. 1959: Manganese ore in New Zealand. *Proceedings of the mineral conference, School of Mines and Metallurgy, University of Otago*, paper 181.
- Reed, J.J. 1960: Manganese ore in New Zealand. *New Zealand journal of geology and geophysics* 3: 344–354.
- Roser, B.P. 1983: Comparative studies of copper and manganese mineralisation in the Torlesse, Waipapa and Haast Schist Terranes, New Zealand. Unpublished PhD thesis, Victoria University of Wellington.
- Roser, B.P.; Glasby, G.P.; Childs, C.W. 1980: Manganese in New Zealand. In: *Geology and geochemistry of manganese* 2: 183–196. *Reviews of the Hungarian Academy of Sciences*. Stuttgart, Schweizerbart'sche Verlagsbuchhandlung.
- Roy, S. 1981: *Manganese deposits*. London, Academic Press. 458 p.
- Schofield, J.C. 1976: Sheet N48—Mangatawhiri. Geological map of New Zealand 1:63,360. Wellington, Department of Scientific and Industrial Research
- Schofield, J.C. 1979: Part sheets N38, N39, N42, & N43—Waiheke. Geological map of New Zealand 1:63,360. Wellington, Department of Scientific and Industrial Research.
- Sekula, J. 1972: Manganese deposits and associated rocks of Northland, New Zealand. Unpublished MSc thesis, University of Auckland.
- Skinner, D.N.B.; Brathwaite, R.L. 1994: The Wakamarina quartz-gold-scheelite lodes, Marlborough. *Proceedings of the 28th annual conference 1994, New Zealand Branch of the Australasian Institute of Mining and Metallurgy*, pp 15–32.
- Skinner, D.N.B.; Chin, H. 1983: Manganese at Bombay and Hunua: a geochemical prospecting test programme. *Industrial minerals and rocks* 8: 13–20.
- Stanaway, K.J. 1972: Manganese deposits and associated cherts and argillites of Auckland area. Unpublished MSc thesis, University of Auckland.
- Stanaway, K.J.; Kobe, H.W.; Sekula, J. 1978: Manganese deposits and the associated rocks of Northland and Auckland, New Zealand. *New Zealand journal of geology and geophysics* 21: 21–32.
- Summerhayes, C.P. 1967: Manganese nodules from the southwestern Pacific. *New Zealand journal of geology and geophysics* 10: 1372–1381.
- Turnbull, I.M. 1975: New manganese mineral localities in Otago. *Industrial minerals and rocks* 1972. Department of Scientific and Industrial Research information series 108: 41–49.
- Turner, F.J. 1946: Origin of piedmontite-bearing quartz-muscovite-schists of Northwest Otago. *Transactions of the Royal Society of New Zealand* 76: 246–249.
- Watters, W.A.; Challis, G.A. 1985: Manganese and iron-bearing metachert in the Onamalutu Valley, Marlborough. *New Zealand Geological Survey record* 8: 59–63.
- Williams, G.J. 1974: *Economic geology of New Zealand*. The Australasian Institute of Mining and Metallurgy monograph 4.