Mineral Commodity Report 14 — Gold

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Symbol	Au
Atomic no.	79
Atomic wt	196.97
Specific gravity	19.3
Valence	1, 3
Melting point	1064˚C
Boiling point	3080˚C
Crustal abundance	0.0034 ppm
Preferred analysis method	Fire assay
Routine detection limit	0.005 ppm

Discovery and Origin of Names

Gold was probably the first metal used by humans because of its occurrence as a free metal in placer deposits, enabling its recovery without the requirement of complex separation techniques. Earliest mining of these deposits, more than 6000 years ago, involved simple processes of washing or panning the alluvial sands and gravels. The myth of the Argonauts and the Golden Fleece probably had its origin in a raid upon miners who were using sheepskins to catch placer grains of gold. Ancient civilisations such as those in Egypt, China and India used gold for decoration and jewellery. Production was limited in extent until about 4000 years ago, when the Egyptians started producing significant quantities of gold from lode mines in the Sudan, Sinai and Egypt. Later, the Persians, Greeks and Romans learned the techniques of gold prospecting, mining and metallurgy from the Egyptians, and mined large quantities of gold from placer and lode deposits within their empires. Gold mining languished during the Middle Ages, but was revived in the 1200s, following discoveries in the Alps, Transylvania and various parts of Spain.

Gold was mined in South America and Mexico from about 4000 years ago, and was a major reason for the Spanish conquests in the early 1500s when large quantities of gold were plundered and shipped to Europe. Subsequently, the Spaniards opened many new mines and expanded previous operations. Gold mining began in the USA around 1620, as a by-product of silver mining by the Spaniards in New Mexico, Arizona and probably California. In 1848, discovery of placer gold at Sutter's sawmill in California, sparked the first major gold rush, attracting people from all parts of the world. Similar gold rushes resulted from placer gold discoveries near Bathurst, New South Wales in 1851; in the Fraser River, British Columbia in 1858; in Gabriels Gully, Otago in 1861 and on the West Coast in 1864; and in the Klondike area, Yukon in 1896. As the easily won placer gold was exhausted, attention was focused on lode deposits. For example, from the Californian diggings, the prospectors spread throughout western North America leading to a succession of new lode discoveries including the Mother Lode and Grass Valley in California in the 1850s, the Comstock lode in Nevada in 1859, the Homestake lode in South Dakota in 1876 and the gold telluride deposits of Cripple Creek in Colorado in 1892. Likewise in Australia, discovery of large lode deposits in Victoria (1854) and Western Australia (1892–93) followed on from prospecting for placer gold.

In Russia, gold mining commenced several thousand years ago, in many of Russia's rich placer deposits. In the mid 1700s, mining expanded under the control of the Czars and Catherine the Great, and by the dawn of the California gold rush, Russia was producing nearly two-thirds of the world's gold. In South Africa, gold was first discovered in 1834 on the Witwatersrand, but major mining only began in the 1890s with the development of the cyanide extraction process.

The name gold is from Anglo Saxon *gold* and was probably derived from the Sanskrit *jval*, which means to shine, or the Old Germanic root *ghel* = *gelb* for yellow or *gulth* the glowing or shining metal. The symbol Au is from the Latin *aurum* meaning shining dawn, derived from the earlier Sabine *ausum*, for glowing dawn, or the Hebrew *aor* meaning light.

Major Ores and Minerals

Gold occurs in the native state, or usually associated with varying amounts of silver, particularly as alloys such as electrum (Table 1). Gold also occurs in chemical combination with tellurium (e.g. calaverite, sylvanite and nagyagite) and mercury (gold amalgam). Pyrite, arsenopyrite, galena and many other sulphide minerals may contain traces of gold.

Properties

Gold (atomic number 79) is one of the transition elements in Group IB of the periodic table, along with copper (atomic number 29) and silver (atomic number 47). Together with silver and the platinum group metals it is one of the precious or noble metals. The mineralogical properties of gold and gold minerals are summarised in Table 1. Native gold is bright yellow and has a high lustre when in mass, but when finely divided it may be black, ruby or purple. It is a heavy, soft metal that is the most malleable and ductile of all the metals, and is a good conductor of heat and electricity, exceeded only by silver and copper. Gold is one of the least reactive metals, being unaffected by air, heat, moisture and most solvents. In nature, native gold is usually granular, threadlike (e.g. wire gold), branching (e.g. dendritic gold), in leaves or as octahedral crystals. Placer gold occurs as rounded grains or flakes, the larger ones termed nuggets (see cover). The largest nugget, the Welcome Stranger, weighing about

Name, Formula	Colour	Hardness	Density	Lustre	Crystal form	Transparency	Fracture
Calaverite $AuTe_2$	pale yellow to silver-white	2.5	9.4	metallic	monoclinic		
Electrum AuAg	yellow	2.5-3	12-19	metallic	cubic	opaque	
Gold (native) Au	yellow	2.5-3	19	metallic	cubic	opaque	hackly
Nagyagite (black tellurium) $Pb_5Au(Te,Sb)_4S_{5-8}$	dark grey	1-1.5	6.8-7.2	metallic		opaque	
Petzite $(Au,Ag)_2Te$	grey to black	2.5-3	8.7-9.0		cubic	opaque	
Polybasite $(Au,Cu)_{16}Sb_2S_{11}$	black	2-3	6-6.2	metallic	monoclinic	opaque	
Sylvanite $(Au,Ag)Te_2$	silver-white	1.5-2	8.0-8.2	metallic	monoclinic	opaque	uneven, brittle

Table 1: Properties of some gold minerals.

70.8 kg and measuring 17 x 40 x 70 cm, was found in Victoria, Australia, in 1869. New Zealand's largest nugget was the 3 kg "Honourable Roddy" found at Ross in 1909.

Formation

Gold is formed in a wide variety of hydrothermal deposits, which may be eroded and the gold concentrated by hydraulic processes in rivers and on beaches, and deposited as sedimentary placer deposits. In hydrothermal deposits, gold is most commonly associated with silver and the base metals, copper, lead and zinc. Most of these deposits are quartz veins deposited from hydrothermal fluids in fault zones at medium (mesothermal) or shallow (epithermal) depths in the crust.

Placer deposits

The high density and chemical stability of gold enables it to be mechanically concentrated in river and beach environments and preserved in placer deposits. These have accounted for more than two-thirds of the total world gold supply. They are grouped into two main classes:

Quartz pebble conglomerate or pyritic paleoplacer deposits contain gold-bearing conglomerate and sandstone that were deposited in braided streams and alluvial fans during the Precambrian. The conglomerates are clast supported with well rounded pebbles of quartz, chert and locally pyrite, in a matrix of quartz, mica, chlorite, pyrite and fuchsite. They contain native gold, pyrite, uraninite, brannerite and traces of platinum group minerals in gold-bearing "reefs" or bankets. Examples include the Witwatersrand in South Africa, the largest gold deposit in the world, Jacobina in Brazil and Tarkwa in Ghana. Ore mined from the Witwatersrand averages 10 g/t Au, 280 g/t U and 30 g/t Ag.

Young placers consist of gold-bearing gravel and sand, and their consolidated equivalents, deposited in alluvial, beach and fluvioglacial environments during the late Cenozoic. These were the deposits worked during the gold rushes. Gravity and hydraulic action concentrate gold and other heavy minerals at locations where the water velocity decreases markedly, such as on the inside of meanders, below rapids and falls, in the lee of boulders, beneath vegetation mats, along strandlines on beaches, and in "traps" such as natural riffles in the river bed formed by fractures or joints in the bedrock. Rich deposits result from several cycles of erosion, transport and deposition. In some placers, gold may be redistributed and reconcentrated by chemical migration and accretion processes. Native gold occurs along with other heavy minerals such as magnetite, ilmenite, garnet, zircon, rutile, monazite, and locally, cassiterite and platinum group elements. Examples include West Coast and Otago in New Zealand; Victoria in Australia; Sierra Nevada in California; Fairbanks and Nome districts of Alaska; Klondike in Yukon; Cariboo District in British Columbia; Choco in Columbia; and the Lena, Aldan and Amur rivers in Russia. Orris and Bliss (1986) noted that the median size of 65 young placer deposits was 1.1 Mt at 0.2 g/t Au, with most deposits between 0.022 and 50 Mt and grading between 0.084 and 0.48 g/t Au.

Mesothermal deposits

These are quartz lode deposits formed in fault and shear systems at crustal levels within and above the brittle-ductile transition zone, at depths of 3–12 km and temperatures from 200–400˚C. Deposits may have a vertical extent of up to 2 km, and lack pronounced zoning. Ribbon banded vein textures are common and were formed by "crack-seal" processes involving episodic re-opening of the veins, fluid flow and mineral deposition. The genesis of the deposits is controversial but most current workers favour a metamorphogenic-deformational origin, although some deposits may have had a magmatic influence in their genesis. Two major classes are recognised:

Greenstone lode gold deposits consist of gold-bearing quartz lodes found in Late Archean and Mesozoic greenstone belts. They are localised along or adjacent to major structural crustal breaks or suture zones, related to terrane collisional boundaries. The lodes are hosted in mafic and ultramafic volcanic rocks, banded iron formations, greywacke and conglomerate, that have been metamorphosed to greenschist and locally amphibolite facies. Wallrock alteration is characterised by quartz-pyrite-muscovite assemblages adjacent to the veins (usually within a metre) enclosed within a broader zone of carbonate alteration. The veins contain quartz, carbonate, pyrite, arsenopyrite and minor native gold and base metals. Examples of Archean age include Hollinger and Dome, in Timmins, Ontario; Mt Charlotte and Superpit on the Golden Mile in Kalgoorlie, Western Australia; Kolar in Karnataka, India; and Blanket-Vubachikwe in Zimbabwe. Phanerozoic examples include deposits in the Mother Lode and Grass Valley districts of California; Alaska-Juneau and Kensington in Alaska; and Sukhoi Log in Northern Siberia, Russia. Individual deposits average 30,000 t at 16 g/t Au (Berger, 1986). Sukhoi Log, one of the largest known gold deposits in the world, has an estimated 550 Mt at 2.6 g/t Au.

Turbidite-hosted mesothermal deposits consist of gold-bearing quartz lodes and segregations in deformed turbidite sequences of greywacke, quartzwacke, shale and carbonaceous shale, of Precambrian, Paleozoic and Mesozoic age. Metamorphic grade is generally lower greenschist. The deposits typically contain multiple quartz veins, each up to a few metres in width, that are localised along shear zones discordant or parallel to bedding in axial planes of synclines and anticlines such as the famous saddle reefs of Bendigo in Victoria. Hydrothermal alteration is generally confined to narrow zones of pervasive quartz and sericite, with disseminated carbonate, pyrite and arsenopyrite, in wallrocks adjacent to veins. The veins have a low sulphide content (<2.5%) and contain quartz, carbonates, albite, chlorite, pyrite, arsenopyrite, and minor native gold and base metals. Stibnite or scheelite are significant in some deposits. Examples of turbidite-hosted lodes are Blackwater and Globe-Progress at Reefton on the West Coast and Macraes Flat in Otago, New Zealand; Bendigo and Ballarat in Victoria; deposits in the Yellowknife district, Northwest Territories; and the Meguma district in Nova Scotia. The mines at Bendigo produced more than 373 t of gold at grades mostly between 5 g/t and more than 30 g/t, and the Meguma district produced about 35 t of gold at grades of 8 to 50 g/t (McMillan, 1996).

Banded iron formation or Homestake-type gold deposits

These deposits consist of stratabound orebodies that are confined to narrow stratigraphic intervals within thick sequences of Precambrian iron-rich metasediments, such as banded iron formation and volcaniclastics, with intercalated metavolcanics. Wallrocks are altered to quartz-siderite and ankerite-tourmaline-chlorite-magnetite assemblages. The ore consists of native gold, pyrite, arsenopyrite, pyrrhotite, and minor sphalerite and chalcopyrite in stratiform metasedimentary beds and stratabound lenses, narrow quartz veins and stockwork quartz veins. A characteristic of these deposits is the continuity of the auriferous horizons, with some deposits extending vertically over more than 3000 m. Gold mineralisation may have been syngenetic with sea floor deposition of the host iron formations and later locally redistributed during metamorphism. Examples include the Homestake Mine in South Dakota; Detour Lake in Ontario; and Morro Velho and São Bento in Brazil. The more significant deposits fall in the ranges 1 to 5 Mt and 6 to 17 g/t Au, however Homestake and Morro Velho have both been operating for more than 100 years and together have produced more than 1800 t of gold.

Epithermal gold-silver deposits

These are quartz vein, breccia and stockwork deposits formed at depths from near surface (hot-spring subtype) down to about 1500 m, at temperatures mostly between 200–300˚C, and from fluids with salinities generally less than 3 equivalent weight % NaCl. Epithermal deposits occur predominantly in subaerial, felsic to silicic volcanic terranes. Most deposits are of Tertiary age because older ones have been eroded away. Two main types are recognised:

Low sulphidation, adularia-sericite or quartz-adularia deposits are characterised by the presence of sulphide minerals with a low sulphur/metal ratio, such as pyrite, sphalerite, galena and chalcopyrite. They are associated with calcalkalic to alkalic, andesite, dacite and rhyolite. Hydrothermal alteration typically consists of quartz-adularia “silicification” adjacent to veins, grading outward to quartz-illite “sericitic”, chlorite-calcite-epidote “propylitic” and/or smectite-mixed layer clay-kaolinite “argillic” alteration. The veins commonly exhibit open-space filling textures, crustification, comb structure, colloform banding and multiple brecciation. Rarely preserved sinter terraces and hydrothermal eruption breccias represent surface outflow parts of the deposits. Gold typically occurs as electrum, and as gold-silver sulphosalt and telluride minerals, and may be accompanied by acanthite (argentite), pyrite, marcasite, arsenopyrite, sphalerite, galena, chalcopyrite and tetrahedrite. Quartz, calcite and adularia are typical gangue minerals. Examples include: Waihi, Golden Cross and Karangahake in New Zealand; Comstock and Tonopah in Nevada; Republic in Washington; El Bronce in Chile; Hishikari in Japan; Colqui in Peru; Baguio in the Philippines; Kelian in Indonesia; and Ladolam (Lihir) in Papua-New Guinea. Hot Spring examples include Broken Hills in New Zealand; Borealis and Round Mountain in Nevada; and McLaughlin in California. Gold telluride-bearing deposits that have an association with alkalic igneous rocks, e.g. Cripple Creek in Colorado and Vatakoula in Fiji, are considered a subtype of the low sulphidation type. Mosier et al. (1986) noted that the median size of 41 deposits was 0.77 Mt at 7.5 g/t Au and 110 g/t Ag. Most deposits are between 0.065 and 9.1 Mt and grade between 2 and 27 g/t Au.

High sulphidation, acid-sulphate or quartz-alunite deposits are characterised by the presence of sulphide minerals with a high sulphur/metal ratio, such as enargite/luzonite and tetrahedrite. They are associated with calcalkalic andesite, dacite and rhyodacite, and were probably formed within or below stratovolcanoes and above porphyry copper systems. Advanced argillic alteration with alunite and pyrophyllite, and acid-leached rock represented by vuggy, ‘slaggy’, residual silica are characteristic. Examples include: Goldfield in Nevada; Summitville in Colorado; Nansatsu in Japan; El Indio in Chile; Temora in New South Wales; Pueblo Viejo in Dominica; and Lepanto and Nalesbitan in the Philippines. Underground mines range in size from 2 to 25 Mt with grades from 178 g/t Au, 109 g/t Ag and 3.87% Cu (El Indio) to 2.8 g/t Au, 11.3 g/t Ag and 1.8% Cu (Lepanto), whereas open pit mines typically grade about 4 g/t Au (Panteleyev, 1996).

Sediment (carbonate) hosted (Carlin) type

In these deposits, sub-micrometre-sized gold occurs disseminated in silicified host rock and breccias, and less commonly in quartz vein stockworks. The host rocks are thin-bedded carbonaceous shales, and silty or argillaceous carbonaceous limestone or dolomite, mostly of Cambrian to Devonian age. Tertiary felsic intrusive rocks are found in, or nearby, many deposits. Hydrothermal alteration consists of decarbonatisation, silicification and formation of "jasperoid", and argillic alteration, zoned from kaolinite-dominated cores to sericite/illite-dominated margins. Ore minerals include native gold, arsenian pyrite, arsenopyrite, stibnite, realgar, orpiment and rare thallium minerals. Oxidised parts are characterised by jarosite, alunite and As and Sb oxides. Fluid inclusion and isotopic studies indicate formation from meteoric water-dominated hydrothermal fluids at depths of 2–4 km and temperatures around 225˚C (Arehart, 1996). Examples include Carlin, Cortez, Getchell, Gold Acres, Gold Quarry, Goldstrike-Post and Jerritt Canyon in Nevada; Mesel in Indonesia; Santa Rosa, El Toro and Igor in Peru; and Yata and Getang in Guizhou Province, China. Mosier et al. (1992) reported the median size of 39 US deposits as 6.6 Mt grading 2.3 g/t Au, with most deposits in the range between 1 and 50 Mt with grades from 1.0 to 6 g/t. However, two zones of the Carlin trend are significantly larger, Gold Quarry-Deep West-Maggie Creek with 464 Mt at 1.32 g/t Au, and Goldstrike-Post-Blue Star-Genesis-Bobcat-North Star with 307 Mt at 2.89 g/t Au. The presence of oxidised ores and the use of heap leaching for gold recovery are critical factors in the economics of mining low grade deposits.

Skarn deposits

These deposits are characterised by gold-bearing calc-silicate rocks, containing Ca-Mg minerals such as pyroxenes, garnets and wollastonite that are formed by metasomatic replacement of carbonate rocks or calcareous clastic rocks along contacts with high to intermediate level stocks, sills and dikes of gabbro, quartz diorite or granodiorite. Most deposits are Cenozoic and Mesozoic in age. Orebodies form veins or stratiform tabular lenses containing ore mineral assemblages of native gold, chalcopyrite, pyrrhotite, arsenopyrite and tellurides. Examples include the Nickel Plate mine at Hedley in British Columbia; Fortitude in Nevada; Thanksgiving in the Philippines; and Browns Creek in New South Wales. Skarn deposits range from 0.4 to 10 Mt and grade from 2 to 15 g/t Au. Nickel Plate has produced over 8 Mt grading 7.4 g/t Au (Ray, 1995).

Intrusion related breccia-hosted deposits

Gold mineralisation is found in magmatic-hydrothermal or phreatomagmatic pipe-like breccias associated with the intrusion of stocks, plugs, sills or dikes into a wide variety of host rocks ranging in age from Precambrian to Tertiary (Sillitoe, 1991). The composition of the intrusives includes monzonite, syenite, trachyte, latite or rhyolite. Mineralisation is associated with sericite and carbonate alteration or potassium-silicate alteration. Gold and base metals are found in sheeted or stockwork quartz veins and in disseminated pyritic zones. Examples include Kidston and Mount Leyshon in Queensland; Montana Tunnels (26.6 Mt at 0.61 g/t Au), Golden Sunlight (42.8 Mt at 1.9 g/t) and Zortman Landusky (55.7 Mt at 0.68 g/t Au) in Montana; and Colosseum in California.

By-product gold

Gold is produced as a by-product from several types of base metal deposits including volcanogenic massive sulphide, vein, porphyry copper, and Olympic Dam type deposits (see Copper and Lead-zinc commodity reports; Christie and Brathwaite, 1994, 1995a). Some porphyry copper deposits contain significant gold and are classified as porphyry copper-gold deposits, e.g. Panguna (Bouginville) and Ok Tedi in Papua New Guinea; Grasberg in Indonesia; Bajo de La Alumbrera in Argentina; Copper Mountain in British Columbia; Dos Pobres in Arizona; and Lobo in Chile (Cox and Singer, 1992; Sillitoe, 1993).

Uses

Most gold is used in jewellery, with lesser quantities for industrial purposes, bar hoarding for investment, and for coin and medallion manufacture. In jewellery and many other uses, gold is usually alloyed with small quantities of other metals to harden it and impart a specific colour, e.g. green with silver, red or pink with copper, and white with zinc and nickel, or platinum metals. The gold content of gold alloys is expressed in terms of fineness (parts of gold per 1000 parts of total metal) or in carats (parts of gold per 24 parts of total metal).

Gold is a common form of international payment and used by some nations to back their paper currencies. Approximately one third of all the gold mined to date is held by national central banks and other official agencies such as the International Monetary Fund as a support for monetary systems. Large quantities of gold are also held by private banks and institutions for investment and security. From the mid-1980s, many mine developments have been financed by gold loans, where the company borrowed gold to be later paid back from production, safeguarding the company from movements in the gold price (hedging). Gold borrowing on behalf of mines is now equivalent to about 85% of mine production.

The largest industrial use of gold is in the electric and electronic industries for plating contacts, terminals, printed circuits and semiconductor systems. Thin gold coatings are used on window glass in large office buildings as an infrared filter and for its aesthetic appearance. Gold leaf is used for gilding and lettering. Gold, generally alloyed with palladium and copper, is used in dentistry for fillings and other dental repairs.

Several gold compounds have important industrial applications. Chlorauric acid $HAuCl_4$ is used in photography for toning silver images and in gold plating, inks and enamels. Potassium gold cyanide is used in electrogilding. The radioactive isotope ^{198}Au is used in biological research and in the treatment of cancer. A number of gold complexes of phosphines and phosphites, usually also containing organic sulphur compounds, are used in treating arthritis.

Price

In 1717, the British Gold Standard was established at four pounds seventeen shillings and ten and one half pence per troy ounce. In 1792, the US Government adopted a gold standard at US$19.39 per troy ounce, at parity with the British Gold Standard. This price was raised to US$20.67 in 1879 and to US$35 in 1934. Subsequently the US$35 price effectively became the world price. This was established officially in 1944 by the Bretton Woods Agreement, making the US dollar the world's monetary standard at gold parity of US$35 per ounce. Collapse of the Bretton Woods Agreement in 1971, and abandonment of the fixed price by the US, allowed the price to rise from US$35 to over US$100 in 1973. After a slight decline in 1976, it rose to a peak of US$850 in January 1980, but dropped to US$527 at the end of 1980. From 1981 to 1989, it ranged between US$300 and US$500. In the 1990s, the price of gold has averaged around US$370. It reached a five year high of US$417 early in 1996 but soon slipped back to US$380. At the end of January 1997 it was trading at US$353.

Fluctuations in the price of gold are difficult to predict because they are related to a number of factors including:

(1) inflation, wars and other anxiety factors,

(2) cost of money and the yield on alternative assets,

(3) supply and demand outlook for gold, and

(4) price of other commodities.

However, the current weakening price is attributed to an increase in the fear of official sales by central banks prior to European monetary union, combined with a disinvestment by the private sector (GFMS, 1997).

World Production and Consumption

Gold differs from other metals in that the majority of the metal that was ever mined is still in existence. Cumulative world production to date is estimated at about 128,000 t, equivalent to a cube of gold with an edge of about 18.6 m. South Africa has been the source of about 37% of the world total, the USA and the Commonwealth of Independent States each about 10%, Australia and Canada each about 6%, and Brazil 2%. However, nearly all countries have reported at least some production.

Total world gold supply in 1995 was 3,622 t: 2,272 t from mine production, 201 t from net official sales from national stocks, 602 t from recycling gold scrap, and 548 t from forward sales and option hedging by mining companies (GFMS, 1996). South Africa is the world's leading mine producer of gold (522.4 t in 1995), mostly from mines in the Witwatersrand region. Some 70 other countries produce gold in commercial quantities, including USA (329 t in 1995), Australia (253 t), Canada (150 t), Russia (142 t), China (136 t), Indonesia (74 t), Brazil (67 t), Uzbekistan (64 t), Papua New Guinea (55 t), Ghana (52 t) and Peru (52 t) (GFMS, 1996). World gold production increased from the late 1970s until 1993, fell during 1994 and 1995, mostly because of declining output from South Africa, and increased again in 1996. Production should continue to increase as several large projects commence production in the next few years, including: Sukhoi Log in Russia (550 Mt at 2.6 g/t Au); Bajo de la Alumbrera in Argentina (694 Mt at 0.65 g/t Au) and Lihir in Papua New Guinea (104 Mt at 4.37 g/t Au).

This total gold supply of 3,622 t was used for: jewellery fabrication 2,749 t, electronic components 209 t, dentistry 66 t, official coins 92 t, medals and medallions 35 t, other fabrication 106 t, bar hoarding 299 t, private investment 44 t and gold loans 23 t (GFMS, 1996). Gold is supplied to the industrial market as metal or metal alloys in forms such as bars, sheets, foil, wire and powder. The unit of trading on the London Gold Market is a bar measuring about 178 mm x 92 mm x 41 mm, weighing approximately 12.5 kg (400 troy oz), and having a minimum fineness of 995. Quantities of gold, like those of other precious metals, are measured in Troy ounces, where 1 Troy oz = 1.097 Avoirdupois oz = 31.103 g.

Ore Processing and Refining

Placer gold is recovered by gravity methods utilising the large difference in specific gravity between gold (19.3) and commonly associated minerals such as quartz (2.7) and feldspar (2.6). The equipment ranges from a simple pan to more complex devices used in gold recovery plants and dredges, such as mats, jigs, Wilfley Tables and centrifugal concentrators.

Gold ore from lode deposits must be crushed and ground, and the gold extracted in solution. The ore is classified as either free milling or refractory. A free-milling ore generally contains gold in the native state with few associated metallic minerals. The gold is extractable from crushed ore directly by cyanide dissolution. Refractory ores have gold combined with other elements such as tellurium, or the native gold may be totally enclosed in sulphides such as pyrite and arsenopyrite. Ores may also be considered refractory if soluble minerals of base metals or carbonaceous constituents actively bind with the soluble gold cyanide complex, a process termed "preg-robbing". Refractory ores must be pretreated to break down the sulphides and/or carbonaceous material, usually by roasting, bacterial oxidation or chlorination. In bacterial oxidation, *Thiobacillus ferro-oxidans* catalyses the oxidation of gold-bearing sulphide ores at temperatures of 35–45˚C and within a pH range of 1.0–1.8. Chlorination involves the treatment of preg-robbing carbonaceous ores with chlorine under alkaline conditions at temperatures around 50˚C. Ores with a high sulphur content require pretreatment by roasting to prevent excessive chlorine consumption.

The most important historical process for recovering gold from gold and gold-silver ores was amalgamation using liquid mercury to form an amalgam with the gold. The gold is amalgamated by passing the crushed ore over copper plates coated with mercury. The amalgam is distilled in a retort to remove the mercury, leaving metallic gold. Much higher recoveries are obtained by the cyanidation process, which was developed specifically to treat South African ores, but was first used experimentally in 1889 to treat gold-silver ore at Karangahake in the Hauraki Goldfield. The ore is finely ground and treated with sodium cyanide solution which dissolves the silver and gold. In the original process, the dissolved gold is then precipitated by the addition of zinc or aluminium. The gold sludge is recovered by filtration and then melted and cast into bars. In a modern development of the cyanidation process, the carbon-in-pulp (CIP) process employs activated carbon to collect gold from the cyanide solution (pulp). Gold with accompanying silver is stripped from the carbon with a strongly alkaline cyanide-alcohol solution. The precious metals are recovered from the strip solutions by electrodeposition on a steel wool cathode. The cathode deposit is then refined into bullion or doré, a mixture of mostly gold and silver. The carbon is reused after being screen-sized and reactivated through controlled roasting.

Heap leaching has become a popular method of treating low grade oxidised ores or waste material, but is restricted to regions with dry climates and low land use. Dilute cyanide solutions are sprayed onto prepared piles of coarse gold-bearing material. The solution, after percolation through the piles, is recovered from an impervious layer beneath the ore. The gold and silver are recovered by zinc precipitation or the CIP process.

By-product gold in copper, lead, nickel, and other base metal ores is generally recovered with the other valuable minerals by flotation. The flotation concentrates are shipped to smelters, where the gold is ultimately recovered as a by-product of smelting or refining.

The gold from milling operations contains small amounts of impurities such as silver, copper and base metals. These impurities are removed from the gold by electrolysis (Wohlwill process), chlorination in the molten state (Miller process), or by direct chemical treatment, such as acid leaching.

New Zealand Occurrence and Resources

Past and present gold production has been from four main geological environments: mesothermal quartz lodes in Paleozoic metagreywacke, mesothermal quartz lodes in Mesozoic schist, epithermal quartz lodes in Cenozoic volcanic rocks, and placers in Cenozoic gravel and sand (Fig. 1). In addition, several other styles of gold mineralisation are represented including porphyry copper and other hydrothermal deposits related to igneous intrusions, and volcanogenic massive sulphide deposits.

The following description of New Zealand gold deposits is necessarily brief, and for more detailed information the reader is referred to Williams (1974), Brathwaite and Pirajno (1993) and the various reports of the Geological Resource Map of New Zealand 1:250,000 map series (e.g. Cody and Christie, 1992).

Turbidite-hosted mesothermal quartz lodes in Paleozoic metagreywacke

Turbidite-hosted mesothermal gold deposits are found in Ordovician rocks at Golden Blocks in Northwest Nelson, at Mokihinui, Lyell, Reefton, Langdons and Mt. Greenland on the West Coast, and at Preservation Inlet in Fiordland, and have accounted for about 8% of New Zealand's total gold production. They exhibit many similarities to the Bendigo-Ballarat deposits in Victoria, Australia. Most deposits are hosted in Greenland Group greywacke and argillite, except deposits at Golden Blocks and Preservation Inlet, which are hosted in graptolitic black slate-greywacke sequences. The rocks are weakly metamorphosed up to lower greenschist facies, with metamorphic mineral assemblages of quartz, albite, muscovite and chlorite.

The deposits consist of quartz veins which were formed in steeply dipping shear and fault structures. The veins contain minor native gold, pyrite and arsenopyrite, with stibnite, chalcopyrite and galena locally present. The vein quartz exhibits ribbon banded, crack-seal textures defined mainly by phyllosilicate laminae. Wallrock hydrothermal alteration consists of secondary sericite, pyrite, chlorite and carbonate in narrow zones, generally less than 1 m in width, enveloping the quartz lodes.

The deposits are metamorphogenic and were probably deposited by hydrothermal fluids released during greenschist facies metamorphism resulting from the collision and accretion of part of the New Zealand proto-continent onto the margin of Gondwanaland (Goldfarb et al., 1995).

Golden Blocks: A 2.5 km long line of discontinuous quartz lodes were worked in several mines, although most of the

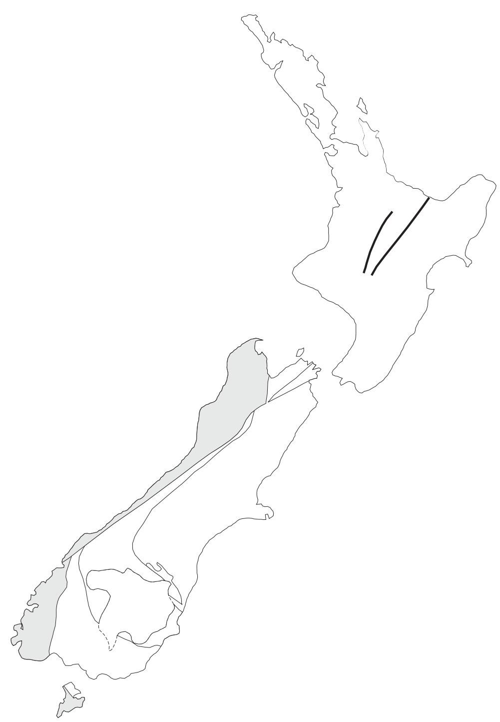

Figure 1: Location of gold deposits in New Zealand.

total 1.11 t of gold produced came from the Aorangi or Golden Blocks Mine (870 kg Au, 1897–1913). The lodes consist of sheeted lenticular quartz veins that are localised along fault-crush zones at or near the contacts of carbonaceous black shale beds with quartz sandstones (M0980[1]). The lodes lie on the flank of an overturned anticline, and the largest lodes are confined to a less than 40 m thick mudstone unit flanked by thick sandstones. Ore shoots within the lodes are lenticular and usually less than 1.5 m in width. Most of the gold produced came from a zone of near-surface enrichment, where the gold is coarse and locally rich, particularly in gently dipping parts of the lodes, and is accompanied by marcasite with minor pyrite and native copper (Bell et al., 1907).

Lyell: A number of gold-bearing quartz lodes, varying from 0.3 to 6 m in width, were worked or prospected over a 5 km long zone extending NNW from Lyell Creek to New Creek. Most of the production was from the United Alpine mine (2.504 t Au, 1874–1912), from a short but thick ore shoot mined down to 500 m (Downey, 1928; Barry, 1996). Around Lyell Creek, a phyllitic argillite unit carrying minor pyrite and arsenopyrite, hosts the quartz lodes (M1321). In the New Creek area the country rocks are intruded and hornfelsed by granite dikes (Morgan and Bartrum, 1915).

Reefton: The most important deposits are those in the Reefton area, where over 67 t of gold were produced from 84 mines between 1870 and 1951 (Barry, 1993). The gold quartz lodes are contained within a NNE trending belt of Greenland Group metasedimentary rocks, some 34 km in length by 10 km in width, which is in intrusive and/or fault contact along its eastern side by granites of Devonian and Cretaceous ages. To the south, the belt passes under Quaternary cover and to the north it is cut off by granite. Mafic dikes were reported from some of the old mines (Henderson, 1917), and in the Inglewood Mine, a mafic dike has been intruded along the hangingwall of a lode.

Gage (1948) considered that the pattern of folding in the Greenland Group strata was a major control on the localisation of the ore. He suggested that the quartz lodes were mostly subparallel to the regional NNE trending fold axes, and were located on overturned limbs of the folds. Most of the lodes are confined to a corridor about 5 km in width, which may coincide with a zone of most intense folding and shearing. However, recent structural mapping by Rattenbury and Stewart (1996) has identified a much more complex relationship between fold and shear structures at Globe Hill-Devils Creek and Waiuta than the relatively simple pattern of folding described by Gage.

The lodes consist of a series of lensoid quartz shoots within one or more shear zones. The ore shoots range in width from 0.6 to 3.2 m and have a limited horizontal extent, usually less than 150 m, but they commonly persist down-plunge to considerable depth.

The largest known deposits were worked at the Blackwater and Globe-Progress mines. In the Blackwater Mine, the Birthday Reef averaged less than one metre in width but had a strike length of 1070 m, and was mined to a depth of 830 m, to produce 23 t of gold between 1909 and 1951 (Fig. 2). The ore is bluish-grey streaky quartz, containing gold and sulphides; predominantly pyrite and arsenopyrite, locally with stibnite and trace chalcopyrite. Quartz lodes at the Globe-Progress mine produced 13 t of gold between 1879 and 1920. Exploration by CRA in the 1980s, and later by Macraes Mining, discovered gold-arsenopyrite-pyrite-(stibnite) mineralisation in a clay-rich breccia zone bordering the main quartz lode (Fig. 3). Intensive drilling on the Globe-Progress system has defined a resource of 10.68 Mt at 2.23 g/t Au, with scope for further resources along strike to the south through the Oriental, Empress and General Gordon lodes (Louthean, 1997). Macraes Mining has also been drilling for depth extensions of the lode system in the Blackwater Mine, and intersected 0.4 m at 24.6 g/t in hole WA11 on the down plunge of the Birthday Reef at 164 m below the deepest level (16 level) of the old mine (Louthean, 1997).

Mt Greenland: Steeply dipping quartz lodes follow WNW striking shears and fault crush zones in anticlinal axes of folded metagreywacke, and were traced for up to 3.2 km

Figure 2: Banded quartz of the Birthday Reef in hole WA11A at Blackwater (Waiuta), drilled by Macraes Mining in late 1996 (Photo: Tony Christie).

Figure 3: Gold-bearing quartz lode and adjacent clay-rich breccia in drillcore from the Globe-Progress prospect in Reefton (Photo: Tony Christie).

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

along strike (Morgan, 1908; Young, 1964). The main lode plunges steeply northwest, and was stoped over a width of 0.6 to 1.2 m and a length of about 60 m. Jury (1981) described a vein mineral assemblage of chalcopyrite, pyrite, arsenopyrite and sphalerite accompanied by trace amounts of galena, boulangerite, bournonite, tetrahedrite and gold, in a gangue of quartz and calcite.

Preservation Inlet: The Morning Star, Alpine and Golden Site mines produced 233 kg of gold between 1892 and 1908 from irregular stockworks of quartz veins in quartzites, siliceous greywackes and carbonaceous slates. The "lodes" occur in three distinct lines which appear to coincide with major fold axes within the Ordovician slate-quartz greywacke sequence (Benson, 1933; Williams, 1974). The ore shoot in the Morning Star mine was 0.25 to 0.4 m thick and cut out at a vertical depth of about 60 m. Gold is accompanied by minor pyrite, and galena was reported from two of the old workings.

Turbidite-hosted mesothermal quartz lodes hosted in Mesozoic schist

Turbidite-hosted mesothermal quartz lode gold deposits are found in the Haast Schist of Otago, Marlborough and Southern Alps. Although they accounted for only 2.6% of New Zealand's total pre-1980 gold production, the deposit at Macraes Flat is now New Zealand's largest known gold deposit worked by the largest operating gold mine. The lodes are typically lensoidal, less than 1 m wide and localised along single or multiple parallel shear zones that generally dip steeply, have normal dip-slip displacements, and are discordant to the schist foliation. A notable exception is Macraes Flat, where the lodes are developed in a semi-conformable, low angle thrust zone with reverse slip movement (Teagle et al., 1990; Winsor, 1991a, 1991b).

Pyrite and arsenopyrite are found in most lodes. Scheelite was mined from lodes at Wakamarina, Glenorchy, Macraes and Barewood, and is present in many others. Stibnite was mined at Endeavour Inlet and Carrick, and is also present at Macetown, Hindon, Nenthorn and Waipori. Accessory minerals include sphalerite, galena, chalcopyrite and cinnabar. Hydrothermal alteration consists predominantly of quartz and illite, and typically extends only a few centimetres away from the veins, although the Golden Bar lode at Wakamarina has an alteration envelope up to 10 m wide (Skinner and Brathwaite, 1995). Many of the lodes were only worked in the oxidised zone and became uneconomic when the finer grained, refractory gold of the primary zone was reached, typically only 20–30 m below the surface.

Fluid inclusions, stable isotopes and vein textures of the Otago veins indicate that they were deposited from low salinity hydrothermal fluids of metamorphic origin, probably generated by dehydration reactions within the sedimentary pile at the greenschist to amphibolite facies transition (Paterson, 1986; McKeag and Craw, 1989; McKeag et al., 1989; Craw, 1992a; Craw et al., 1995). A component of downward-percolating meteoric water probably mixed with the rising water at shallow depth. A genetic model for the Otago deposits involves the release of fluid during fault slip episodes (fault valving of Sibson, 1990), and mineralisation at different levels throughout the more than 100 million year uplift history of the schist belt (Craw and Norris, 1991). Arching of the schist belt along a NW-SE axis during regional uplift resulted in extension and the formation of mineralised normal faults in the upper part of the arch (e.g. Barewood, Nenthorn, Bendigo), whereas shortening and associated mineralised reverse faults occurred at deep levels (e.g. Macraes Flat) (Scott and Sibson, 1995).

Wakamarina and other deposits in Marlborough: The Wakamarina mine was the largest gold producer in the Marlborough region (556 kg Au; 390 t W). The main lode, the Golden Bar, was traced over a strike length of 1.8 km, although it was worked only over a length of 818 m. It consists of a 2 m wide lode filling a normal fault that cuts gently dipping mylonitic schist, quartzite and metabasite country rocks (Skinner and Brathwaite, 1995). The lode consists of ribbon banded quartz containing minor scheelite, pyrite and rare gold (Fig. 4). In the Wairau Valley area, quartz reefs were prospected in schist of the Waikakaho River (Mahakipawa; 4 kg Au), Top Valley (Jubilee, Wellington), Bartletts Creek (Sutherland), and at Mt Patriarch Station, but no significant production was recorded. At Endeavour Inlet, a series of en echelon quartz veins in a 300 to 350 m wide regional shear zone, carry stibnite (shallow) and arsenopyrite-pyrite-marcasite-gold (deep) mineralisation (Pirajno, 1979). The thickness of individual quartz veins ranges from 0.2 to 1.9 m wide, with strike lengths of up to 65 m, and a vertical exposure range of 400 m. At Cape Jackson, about 32 kg of gold were produced from the 0.4–0.75 m thick Ravenscliff Lode.

Macraes and other Otago lodes: In the Macraes area, quartz lodes are developed along the 25 km long Hyde-Macraes Shear Zone. The shear zone is hosted in psammitic schist, and consists of well-defined, shallow-dipping upper and lower bounding thrusts enclosing brecciated and crushed graphitic, pelitic schist, cut by steeply dipping, intrashear thrust faults (Lee et al., 1989; Teagle et al., 1990; Angus, 1992; Fig. 5). Local thickening, up to 125 m, is caused by folding and imbrication. Mineralised quartz lodes are formed preferentially in dilational jogs or on the shallow-dipping parts of intrashear thrust faults, ramp and other extensional structures, such as discordant stockwork and gash veins (Fig. 6). Gold is sited in lensoid quartz veins, quartz vein stockworks,

Figure 4: Ribbon-banded texture in the Golden Bar vein, Wakamarina, Marlborough (Photo: Bob Brathwaite).

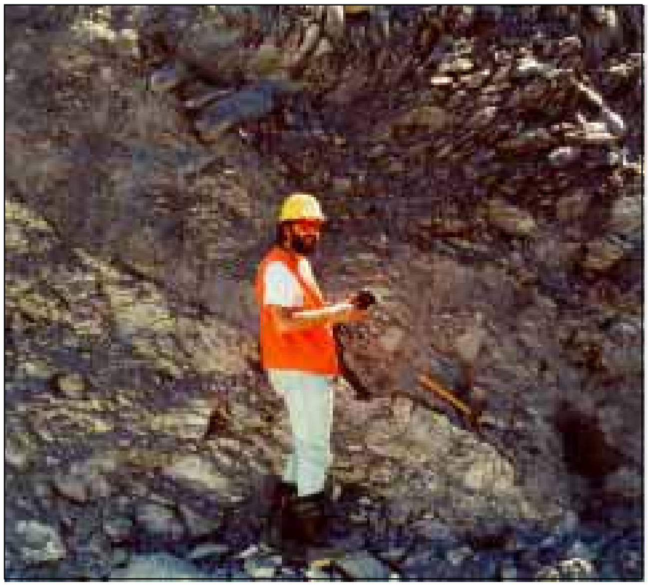

Figure 5: Sharp lower contact (immediately below hammer to right of figure) of the Hyde-Macraes Shear Zone, exposed in the Round Hill open pit, Macraes Flat Mine (Photo: Tony Christie).

Figure 6: Discordant quartz vein within the Hyde-Macraes Shear Zone, exposed in the Round Hill open pit, Macraes Flat Mine (Photo: Peter Grieve).

and with pyrite and arsenopyrite impregnated in sheared, locally graphitic schist. Calcite, scheelite and minor stibnite and chalcopyrite are also present. Wall rock alteration is confined to minor sericite and kaolinite.

Several subparallel lodes were mined intermittently between 1875–1936 for a production of about 1000 t of scheelite and 0.518 t of gold (Williamson, 1934, 1939). Exploration during the 1980s by Homestake, BHP Gold and Macraes Mining Ltd outlined low grade reserves in the Round Hill-Innes-Mills sections of the Macraes Shear Zone, and open pit mining at Round Hill commenced in late 1990 (Weston, 1991). Continued exploration has defined additional resources at Innes-Mills, Frasers, Frasers South and Golden Bar, with total resources in late 1996 of 89.9 Mt at 1.5 g/t and a reserve of 59.54 Mt at 1.58 g/t. The graphitic schist has preg-robbing characteristics reducing gold recovery during ore processing.

The only other documented mineralised low angle thrust in Otago is the Rise and Shine, which had only very small past production (M1996; M3033; Winsor, 1991a). All other known gold-bearing lodes dip at moderate to high angles. At Barewood (467 kg Au, 1890–1911; 18 t W, 1907–43), a number of small lodes are developed along a major northwest striking shear zone, the Bucklands Fault, that extends for 20 km, as well as on several other parallel, but smaller fault systems (MacKenzie and Craw, 1993). The lodes are up to 3 m thick, with thin (5–10 cm), subparallel stringers of quartz±scheelite in adjacent country rock. At Carrick (453 kg Au, 1870–early 1900s), production was mostly from near surface zones of secondary enrichment, down to depths of about 20 m (Ashley and Craw, 1995). At least 25 lodes were worked. Most strike NNW–WNW, dip steeply to the northeast, are up to 1.2 m wide, have strike lengths of tens to hundreds of metres, and consist predominantly of breccias that have been veined by quartz and carbonate. Thin, shallow-dipping gold-bearing shears are also present in the field and are brecciated and recemented where cut by the steeply dipping lodes. Recent drilling at Carrick by Summit Gold returned intersections of 55 m at 0.5 g/t Au and 71 m at 0.51 g/t Au. At Bendigo (5.039 t Au), several steeply dipping lodes are located in the hinge zone of a recumbent nappe fold (Paterson, 1986). Most of the past production came from the Cromwell Lode, which was worked to a depth of 160 m over a strike length of about 300 m. At Skippers, production was mostly from the Bullendale (1.089 t Au) and Skippers Reefs (370 kg Au), whereas recent descriptions have been of vein systems in Sawyers Creek (Craw et al., 1991) and the Nugget area (Craw et al., 1991). At Macetown (1.28 t Au), three parallel lode lines (Sunrise, Premier and Tipperary) are made up of crushed schist containing numerous veins and stringers of quartz. Some lodes have opposing dips, so that they intersect. A few lodes were payable in the primary zone and the Premier lode was worked to a depth of about 1000 m below the surface outcrop. At Oturehua (1868–1936; 121 kg gold were produced in 1930s, earlier production was not recorded), four parallel lines of lodes (Otago Central, Great Eastern, West of England and Homeward Bound) strike northwest and dip northeast at moderately steep angles (Williamson, 1934). At Nenthorn (112 kg Au, 1888–99), numerous subparallel lodes, typically spaced about 100 m apart, are 30 to 120 cm wide (average of 60 cm), strike northwest, and dip 65˚–85˚ to the northeast (Williamson, 1934). Some lodes can be traced for several kilometres along strike. Surface enrichment was important, with most mining down to a depth of only 15 m, although the Eureka Mine was worked to 60 m. The Nenthorn deposit is notable for apparently forming at shallow depths (less than 1 km) from boiling fluids at a temperature of about 200˚C (McKeag and Craw, 1989).

Gold-quartz mineralisation in the Southern Alps

In the Southern Alps, gold-bearing quartz lodes are found in Haast Schist in the Whitcombe River and Alexander Range (Poerua Mine), semi-schistose greywacke of the Taipo River area (Taipo Corner, Gold Creek, McQuilkans and others) and in low grade metagreywacke of the Wilberforce River area (Fiddes, Pfahlerts and Wilsons Reward). There was no significant production from these lodes.

Thin quartz-calcite veins with minor biotite and sulphides, and traces of scheelite and gold, have been described by Craw et al. (1987) from the Callery River area, 25 km northeast of Mount Cook. They considered that the veins were related to late Cenozoic deformation associated with rapid uplift along the Alpine Fault, allowing hot (250–320˚C) metamorphic fluids to reach relatively shallow (4–5 km) crustal levels.

Hydrothermal deposits related to igneous intrusions

Hauraki Goldfield and Northland porphyry copper: At Ohio Creek near Thames (Merchant, 1986), thin quartz veins with pyrite, magnetite, rutile, hematite, chalcopyrite, molybdenite and tetrahedrite are found in outcrops and exploration drillholes and the mineralisation has an average grade of 0.18% Cu. Best gold grades intersected were 0.26 g/t Au (and 0.22% Cu) over 298 m in DDH 5, and 4.1 g/t Au over 9.7 m in DDH 6. Other porphyry copper style deposits at Knuckle Point and on the Hen and Chicken Islands in Northland, and at Miners Head, Paritu, and Manaia in the Hauraki Goldfield may have potential for associated gold mineralisation.

Sam's Creek porphyry dike: Gold mineralisation is hosted in a quartz-feldspar-riebeckite porphyry dike emplaced in lower Paleozoic sedimentary rocks. The dike is up to 60 m wide, and has a known strike length of 7 km (M1014). Gold mineralisation occurs with arsenopyrite and pyrite in quartz vein stockworks, and is associated with a hydrothermal alteration mineral assemblage of siderite, albite, sericite, pyrite and arsenopyrite. A 600 m long zone (Main Zone) has been delineated by over 5000 m of diamond drilling in 42 holes, and a potential resource of 3.5 Mt at 2 g/t Au has been outlined (M1014). Tulloch (1992) inferred that the mineralisation was granite-related, whereas Windle & Craw (1991) have proposed a hydrothermal metamorphic origin.

Owen River and Wangapeka goldfields: At Owen River, eight 1–6 m thick gold-bearing quartz-pyrite-marcasite lodes are hosted in shales and quartzites, both underlying and overlying Mt Arthur Marble. Ferroan dolomite or calcite is a common gangue mineral and the wall rocks of the lodes are strongly sericitised (Newman, 1979). Traces of sphalerite and galena are present, and the gold is associated with a late-stage quartz-marcasite-pyrite assemblage. Mining of several lodes between 1888 and 1890 produced only 2.24 kg Au, mainly because of very low recoveries (e.g. 3 g/t from the Enterprise Mine). On the Wangapeka (Rolling River) field, three parallel, steeply dipping quartz reef zones are present in dolomitic shale, quartzite and marble of Lower Paleozoic age. They contain variable amounts of argentiferous galena, pyrite, sphalerite and chalcopyrite. No significant production resulted from mining because of low gold values and difficulties in treating the polymetallic sulphides. Newman (1979) considered that the mineralisation at both fields was deposited from hydrothermal fluids produced by dewatering of the sediment pile during intrusion of the adjacent Separation Point Granite.

Croesus Knob, Paparoa Range: Some eight quartz lodes are present in Greenland Group rocks, and most are concordant with bedding in the host greywacke. They contain pyrite, sphalerite, galena, chalcopyrite, stibnite and bournonite, and gold in coarse blebs (M1367). The Croesus Reef, the only lode found to carry economic gold values, had a strike length of 213 m, an average width of 1.5 m, and was worked to a depth of 86.6 m.

Mt Rangitoto, Westland: At Mine Creek, Mt Rangitoto, sulphide-quartz veins are in narrow shear zones in hornfelsed Greenland Group greywacke (Jury, 1981). The veins contain pyrite (dominant), sphalerite, galena, arsenopyrite and chalcopyrite with minor electrum, in a gangue of quartz and minor tourmaline and calcite. The veins assayed up to 31 g/t Au and 1400 g/t Ag, but no significant production was recorded. The mineralising fluids had a high salinity (18 wt % NaCl equiv, from fluid inclusion studies) and were possibly derived from a nearby biotite-muscovite-garnet leucogranite that has been K-Ar dated at 214 Ma on a single muscovite sample (Jury, 1981).

Southland: A gold-bearing lode (6 g/t Au) was reported from near the Otama Complex in the vicinity of Waikaia Hill (Stewart, 1906) and traces of gold were also detected in a geochemical survey of the Otama Igneous Complex (M2106). Plutonic rocks on the southern tops of the Longwood Complex locally contain disseminated gold and platinum, and assay up to 0.2 g/t Au, with 0.5 g/t Pt and 0.3 g/t Pd (Challis & Lauder, 1977; M2071). Several small gold-bearing quartz lodes occur in the Longwood Range, as at Foals Creek where quartz-sericite-pyrite altered diorite contains quartz veins assaying up to 12 g/t Au over 1.2 m (M2071). On Stewart Island, gold-bearing hydrothermal quartz veins have been prospected in the Ruggedy Granite and the Anglem Complex (Howard, 1940; M2130).

Deposits associated with detachment fault systems

A number of gold (plus silver, fluorite, barite, sulphide and uranium) occurrences in the Paparoa Range–Buller Gorge area may be related to a detachment fault system associated with the Paparoa Metamorphic Core Complex (Tulloch and Kimborough, 1989; Tulloch, 1995). Analogy with similar tectonic settings in North America suggests that the detachment fault zone may be prospective for large gold deposits of the bulk tonnage low grade type (e.g. Picacho, California).

Deposits of possible volcanogenic massive sulphide association

Aorere Goldfield, Collingwood: Gold mineralisation is localised near the gently dipping thrust fault contact of volcanogenic chloritoid schist structurally overlying graphitic schist (Grindley and Wodzicki, 1960; M0983), and was mined at Johnston's United, Phoenix, Ophir, Red Hill and Coppermine or Copper Creek. At Johnston's United, the only one of the group with significant production (583 kg Au between 1866 and 1896 from an enriched oxidised zone within 65 m of the surface), gold occurs in a 0.3–1.8 m thick, brecciated quartz-pyrite lode in sericite-quartz schist interpreted as metamorphosed tuffaceous siltstone (M0983). Also in the quartz-sericite schist, is a discontinuous massive sulphide band, 1.5–1.8 m thick, lying about 1.5 m above the gold-quartz breccia. The massive sulphide band is composed of sphalerite and galena, with lesser pyrite and marcasite, minor arsenopyrite, pyrrhotite, tetrahedrite and chalcopyrite and rare gold, and has been shown by drilling to be persistent down dip and along strike.

Low sulphidation epithermal deposits

Epithermal gold-silver deposits are found in the North Island: deposits in Northland and in the Hauraki Goldfield were formed in past geothermal systems associated with volcanism that was active in the Miocene–Pliocene, whereas gold is being deposited today in active geothermal systems such as Champagne Pool at Waiotapu in the Rotorua–Taupo area, in association with Quaternary volcanism.

Northland: Geochemically anomalous gold is reported from soil samples derived from silicified greywacke, silicified breccia and overlying sinter at Puhipuhi (White 1986; Christie and Brathwaite, 1995b, 1996). Reconnaissance drilling aimed at locating mineralised, fossil hydrothermal fluid feeder zones, has included one intersection of 10 m averaging 5.3 g/t Au and 18.5 g/t Ag in a chalcedonic quartz vein cutting an explosion breccia (BHP Gold, 1988). Elsewhere in Northland, zones of hydrothermal alteration, with disseminated pyrite and geochemically anomalous levels of As, Sb and Hg, have been found at Te Pene (M0107; Brown, 1989), Te Mata (M0107; Cameron, 1986) and Puketotara (M0106). These occurrences are associated with extensive hydrothermal argillaceous alteration which represents the near-surface zone of fossil geothermal systems, related to rhyolitic volcanism associated with the basaltic Kerikeri Volcanic Group. Reconnaissance prospecting to date has detected only traces of gold (<0.25 g/t) and silver.

Hauraki Goldfield

The Hauraki Goldfield, which extends southwards from Gt Barrier Island to Muirs Reef near Te Puke, contains about 50 known epithermal gold-silver deposits that were deposited by geothermal systems associated with volcanism that was active during the Miocene and Pliocene (Brathwaite et al., 1989). About 1,360 t of gold-silver bullion were produced between the 1860s and 1952 (about 34% of New Zealand's total gold production), mostly from deposits hosted by andesite and dacite, although a few veins in rhyolite and basement greywacke were also worked. Currently, the Martha Hill and Golden Cross mines together annually produce about 4.7 t of gold and 28 t of silver.

In the epithermal deposits, the gold occurs as electrum in quartz veins which are typically open-space fillings with quartz and calcite as the main gangue minerals. Silver, copper, lead and zinc sulphides, sulphosalts and tellurides are found in some of the veins. The veins generally dip steeply, strike in a northeasterly to northerly direction, are between 1 and 5 m wide (but exceptionally range up to 30 m wide), and up to 800 m long. They were mined over a vertical interval typically of 170 to 330 m, but up to 700 m at Karangahake and 600 m at Waihi. Individual deposits occur as vein systems occupying areas up to 3 km^2 (Waihi, Karangahake) surrounded by areas of up to 14 km^2 of hydrothermally altered rocks.

The silver-rich deposits at Te Ahumata, Tangiaro Stream and Maratoto were described in the silver commodity report (Christie and Brathwaite, 1996), and the base metal-rich deposit at Tui Mine was described in the lead-zinc report (Christie and Brathwaite, 1995a).

Coromandel and Thames: The first official gold discovery in New Zealand was of placer gold in Coromandel in 1854. Subsequent quartz lode mining began in the early 1860s from epithermal deposits at Coromandel (11.36 t Au-Ag) and Thames (67 t Au-Ag) by a large number of individuals and companies. They discovered numerous thin veins mostly with bonanza style mineralisation — isolated small pockets of very high grade ore, particularly at vein intersections. The Hauraki Block in Coromandel was unusual for the diverse strike of the veins, compared to the more northerly to northeasterly strike generally prevalent elsewhere in the goldfield. The veins at Thames have an average width of 1 m but commonly pinch and swell from a few cm to "blows" of 9 m. They contain a wide variety of minerals, predominantly pyrite, pyrargyrite and electrum, but telluride, base metal and sulphosalt minerals are also locally present (Merchant, 1986). The occurrence of enargite suggests some affinities to high sulphidation epithermal systems. Recent drilling of some prospects in Thames by Mineral Resources has defined several small zones with gold resources (e.g. M0461; M0462).

Monowai: The Monowai vein strikes northeast and dips west at 45–50˚. It crops out over a strike length of 1.5 km, varies in thickness from 5 to 18 m, and has a vertical extent of at least 500 m. The vein is hosted by andesite and contains abundant base metals and a variety of gold and silver telluride minerals (Merchant, 1986). Drilling by Central Pacific Minerals (NZ) Ltd in 1971–72 and Spectrum Resources Limited in 1983–84 defined high grade resources of 143,000 t at 14 g/t Au, 59 g/t Ag and 0.6% Cu, and low grade resources of 38,000 t at 4 g/t Au, 41 g/t Ag and 0.5% Cu (M0291; M0466; Roberts, 1989).

Golden Cross: Early mining between 1885 and 1917 produced 12 t of gold-silver bullion from the Golden Cross No. 1 Reef, at the southern end of a series of north-northeasterly striking veins in andesite and dacite. During this time, some exploration was carried out on the Taranaki section at the northern end, however the intervening Empire section was not discovered until the 1980s and mining began here in 1991. During the early phase of mining, the Golden Cross No. 1 Reef was followed for a distance of 700 m and varied in width from a thin seam to 6 m, averaging 5 m. A single ore shoot, bounded at both ends by barren primary calcite, was longest near the surface but was gradually pinched out by the calcite with depth. The Empire zone, as exposed in recent mining, consists of a steeply west-dipping deep lode system and a shallow east-dipping zone of sheeted to irregular quartz vein stockwork lying to the west (Hay et al., 1991; Caddey et al., 1995; Figs 7 and 8). The veins contain quartz, quartz pseudomorphous after calcite, calcite, pyrite, marcasite and sparse chalcopyrite, sphalerite, acanthite, polybasite, pyrargyrite, electrum, arsenopyrite and galena (Simpson, C.R.J. et al., 1995). The deep Empire Vein Zone typically consists of a steeply dipping

Figure 7: Large crustiform-banded vein exposed underground in the Golden Cross mine (Photo: Tony Christie).

vein set with sets of shallower dipping veins peeling off into the hanging wall. The veins are strongly banded, with quartz, quartz-calcite, quartz-adularia, and brecciated and cemented vein material (Fig. 7). The Empire Vein Zone and stockwork are enclosed by quartz-adularia-chlorite-illite-calcite-pyrite alteration grading outward to calcite-interlayered illite/ smectite-kaolinite (de Ronde and Blattner, 1988; Simpson, M.P. et al., 1995).

Waihi: Martha Hill is the largest producer in the Hauraki Goldfield with 1,100 t of bullion (Au:Ag ratio of about 1:6) mined from underground workings between 1878 and 1952, and beginning in 1988 an annual production from open pit mining of about 2 t of gold and 18 t of silver. Four major lodes (Martha, Welcome, Empire and Royal; Fig. 9) and numerous smaller veins (Fig. 10) strike in a northeasterly direction and form a braided vein system over 2.5 km long by 600 m wide extending to a depth of over 600 m (Brathwaite and McKay, 1989). The Martha lode dips steeply southeast, whereas the Welcome, Empire and Royal dip steeply northwest, converging with the Martha at depth.

The veins are extensively oxidised to depths of up to 200 m. In the sulphide zone, electrum, acanthite, sphalerite, galena and chalcopyrite occur in a gangue of quartz±calcite±quartz pseudomorphous after calcite±adularia±inesite (Brathwaite and McKay, 1989). Banded chalcedonic quartz is dominant

Figure 8: Stockwork quartz veins exposed in the Golden Cross open pit (Photo: Tony Christie).

in the upper part of the vein system, and although generally oxidised, pyrite, sphalerite, chalcopyrite and tetrahedrite are found as disseminations or band-specific occurrences (Panther et al., 1995). A quartz-adularia-illite-chlorite-calcite-pyrite alteration envelope surrounds the veins and passes upwards into mixed layer clay and smectite-chlorite-calcite zones (Jennings et al., 1990).

Exploration by Amoco, Cyprus and Coeur at the northeastern part of the Martha vein system, beyond the area of current mining, has identified several unmined blocks of gold-silver-base metal mineralisation (M0472; M0511; M0513; M0516; M0530). However, reconnaissance drilling 2.5 km further northeast by BP and ACM failed to locate any strike extensions of the Martha vein system (M0497; M0529; M0546; M2661). Southeast from Martha Hill, veins at Union Hill, Gladstone Hill, Winner Hill, Silverton and Favona mines produced almost 1 t of bullion between 1884 and 1905. At Gladstone Hill, drilling has defined a steeply dipping hydrothermal breccia zone containing erratic gold-silver values with some very local high concentrations (up to 63.5 g/t Au and 150 g/t Ag over 3 m in hole UW15) (Gold Resources, 1987).

Karangahake: Between 1875 and 1944, 126.7 t of bullion (Au:Ag ratio of 1:3.3) were produced from several northerly trending quartz veins hosted in andesite flow breccia and minor dacitic tuff, capped by spherulitic rhyolite. The largest veins, the Maria and Welcome/Crown have strike lengths of 1300 m and 1100 m, and average widths of 2 m and 0.5 m respectively. Gold ore extended to depths of 700 m and 300 m respectively and consisted of electrum, with acanthite-pyrite-sphalerite-galena-chalcopyrite in the lower unoxidised primary zone. Secondary enrichment may be an important factor in the development of the higher grade mineralisation in the upper and intermediate levels of the Maria Lode (Brathwaite, 1989).

Southern Cross Minerals, later New Zealand Goldfields Ltd and Southern Gold Ltd, re-opened and sampled many of the old workings in 1971–82, and later (1982–92) carried out some underground drilling and mined a small quantity of ore (M0475; M0484). In 1985–86, Freeport Australian Minerals Ltd drill tested zones of silicification and quartz stockwork veining in the altered rhyolite cap of Mt Karangahake (M0517).

Strongly silicified zones locally contain quartz vein stockworks and quartz-pyrite cemented breccias with weak mineralisation (0.02–0.6 g/t Au and 0.5–10 g/t Ag). Gold values above 1 g/t are confined to discrete, narrow quartz veins. In 1987–88, Cyprus Minerals (NZ) Ltd carried out surface and underground drilling on the Karangahake deposit and ACM carried out further drilling in 1991, but apart from a small high-grade shoot on the Maria Lode on 8 level, only narrow, low-grade gold mineralisation was intersected.

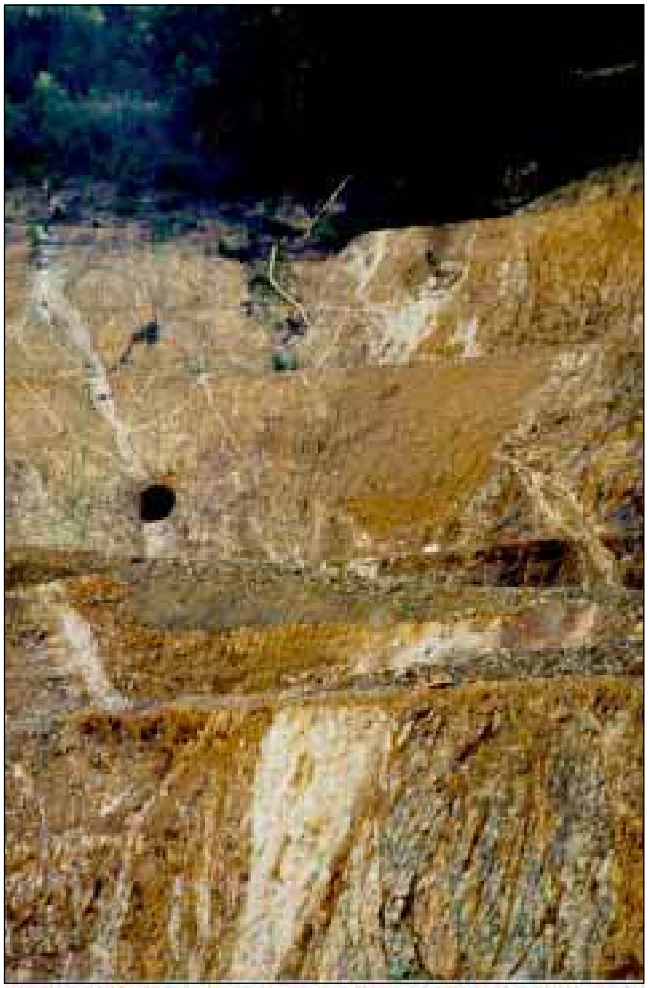

Figure 9: The Martha vein exposed in the southwestern pit wall of the Martha Hill mine. Note the large volume of stope fill replacing part of the Martha vein near the centre of the photo (Photo: Tony Christie).

Figure 10: Narrow quartz veins that lie between the Welcome and Martha veins (not shown), exposed in the southwestern pit wall of the Martha Hill mine (Photo: Tony Christie).

Deposits partly in rhyolite: Veins worked in rhyolite proved to be generally small producers, however many have been re-examined since the 1980s, mainly as potential low grade bulk tonnage prospects. At Ohui (7.3 kg Au-Ag), quartz veins are found in rhyolite (Phoenix mine) and andesite (Great Mexican and Maori Dream), and a number of "sinter" deposits are present capping rhyolite of Phoenix Hill. Drilling by Austpac Gold N.L. has encountered several high grade intersections (e.g. 1.64 m at 61.4 g/t Au and 4100 g/t Ag in DDH4) but the veins appear to lack continuity (Barker, 1994).

At Broken Hills (1.6 t Au-Ag, 1895–1913) and Golden Hills (114 kg Au-Ag), veins occur in rhyolitic rocks. In the Broken Hills Mine, mineralisation occurs in veins, breccia pipes, and zones of intense silicification but only the veins proved profitable. The veins are best developed in rhyolite and feather out into low grade stockworks on passing up into overlying pyroclastic rocks. The largest breccia pipe is 10 m in diameter on 2 level. Drilling by ICI and ACM encountered several narrow breccia and vein zones, including one with a band of acanthite-bearing quartz and assaying 35 g/t Au and 33.8 g/t Ag (M0389; M0390; M2463; M2663; M2904). At Golden Hills, drilling by Heritage tested a 200 m strike length within the 910 m long Bain Reef and intersected the reef about 50 m below the old mine workings, where it varied from 0.8 to 5.6 m wide downhole (Heritage Mining, 1995a, 1996). The best assayed section of the Bain Reef was 2 m of 3.7 g/t in GHDD-5. Several quartz veins were intersected in the hanging wall with a best intersection of 2 m at 7.26 g/t Au in GHDD-1 (Heritage Mining, 1995a).

At Neavesville (910 kg Au-Ag, 1875–1938), the Ajax Reef is hosted in andesite and overlying rhyolitic tuffs, whereas open cut workings at Birds, Golden Arrow and Graces are in rhyolitic tuffs or an intercalated silicified black shale (lacustrine silt) unit. Extensive quartz-adularia-pyrite alteration and associated gold-bearing quartz veining has been drill tested by Amoco, but average grades are < 1.0 g/t Au (Barker, 1989).

At Onemana, hydrothermal eruption breccia and siliceous sinters are present in rhyolitic tuff breccia and assay up to 1.52 g/t Au and 32 g/t Ag. Drilling by Heritage Mining has intersected 6 m of 5.7 g/t Au and 237 g/t Ag (ONDD-1) in quartz veins and hydrothermal breccia at the Breccia Knob prospect (Robson and Stevens, 1991; Heritage Mining, 1996). Mineralisation near surface consists of pyrite, acanthite and gold, whereas at deeper levels, electrum, sphalerite, chalcopyrite and galena are present (Heritage Mining, 1995b).

At Wharekirauponga, numerous northerly trending quartz veins, a few mm to over 1 m thick, are hosted in rhyolite, rhyolitic tuffs and andesite. Twenty three diamond drillholes have been drilled by Amoco, BHP and ACM and have intersected predominantly low grade mineralisation (M2621; M3021).

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

Silver-gold mineralisation is also present in fossil geothermal systems at Puhipuhi or Goldmine Hill, near Kawerau, at Ohakuri (Fig. 11), and in discoveries made during exploration in the 1980s which include the Matahina Basin, Horohoro, Wharepapa, Umukuri and Forest Road prospects (Cody and Christie, 1992; Barker, 1993). At Ohakuri, drilling by Cyprus to the north of the Waikato River outlined a large gold deposit of subeconomic grade (200 Mt at 0.6 g/t Au) in quartz-adularia altered rhyolite (Simmons and Player, 1993; Barker, 1993). Best grades are 4.05 g/t Au and 22.5 g/t Ag over 5.5 m in one hole. Drilling at Ohakuri East, 2 km to the south, by BP, intersected chalcedonic quartz veins in altered pumiceous ignimbrite, with a best intersection of 7.9 g/t over 1.2 m.

Young placer deposits

Giant placer gold fields are present in Westland and Otago-Southland, and smaller placers are found in west Nelson and Marlborough. About 600 t of gold was produced in the past, equivalent to about 54% of New Zealand's total historic production, initially during the gold rushes of the 1860s and 1870s, and later by sluicing and dredging operations. Since 1980 there have been a large number of small and medium scale gold recovery operations using hydraulic excavators and mobile gold recovery plants, with a peak exceeding 150 operations in the late 1980s (Fig. 12). The rapid throughput and relative mobility of these plants have allowed mining of ground that was not accessible or too small in volume for mining by large bucket-line dredges. The largest operations have been at Rimu, Arahura, Ross, Mikonui, Shotover Gorge, Kawarau Gorge, Island Block and Nokomai. Additionally, one bucket line dredge, the Grey River Dredge has operated near Ngahere, intermittently between 1988 and 1989 and continuously since 1993. Annual gold production from alluvial operations is currently about 2.9 t.

Figure 11: Quartz-adularia-pyrite altered tuff containing a stockwork of silver-gold-bearing quartz veinlets in dam abutment at Ohakuri, north of Taupo (Photo: Tony Christie).

Important geological factors in making economic concentrations in the Otago-Southland placers have been (1) the reworking, recycling and concentration of gold through the stratigraphic successions, and (2) authigenic growth of gold particles by chemical dissolution, transport and accretion processes, increasing the grain size of some gold particles (Craw, 1992b; Youngson and Craw, 1993, 1996).

West Nelson: In the Aorere Goldfield, near Collingwood, diggings and sluicing operations worked the late Quaternary terrace gravels and modern stream bed gravels, mainly on the east side of the Aorere Valley, but also in the Slate River and a few southern streams including Boulder River, Salisbury Creek, Buck Gully and Burgoo Stream. Several diggings in the Parapara Valley also provided rich grades of gold for a short time. Gold dredging was carried out in the Aorere, Slate and Parapara rivers but was not very successful. In the Tablelands, Mount Arthur district, workings at the Balloon Diggings, Cundy's Creek and the Caves were in Tertiary terrace gravels and in the active stream channels.

Marlborough: Most production was from the river channel deposits in the Wakamarina River and its eastern tributaries such as Deep Creek. Some gold was produced from deep leads in Cullen Creek, draining into the Mahakipawa Arm of Pelorous Sound. Gold was also found in northbank tributaries of the Wairau River. Although there were extensive workings in tributaries such as Bartletts Creek, the Onamalutu River and Waikakaho River, the total quantity of alluvial gold produced was small.

West Coast: Gold placers are found in late Pleistocene fluvioglacial and Recent alluvial gravel, and to a much lesser extent in Pliocene Old Man Group gravels, overlying the Miocene–Pliocene Blue Bottom marine siltstone and mudstone, representing basement for the auriferous sediments (Jury and Hancock, 1989; Suggate, 1996). The gold was transported and concentrated into outwash deposits close to the terminal moraine fronts of successive glaciers. A

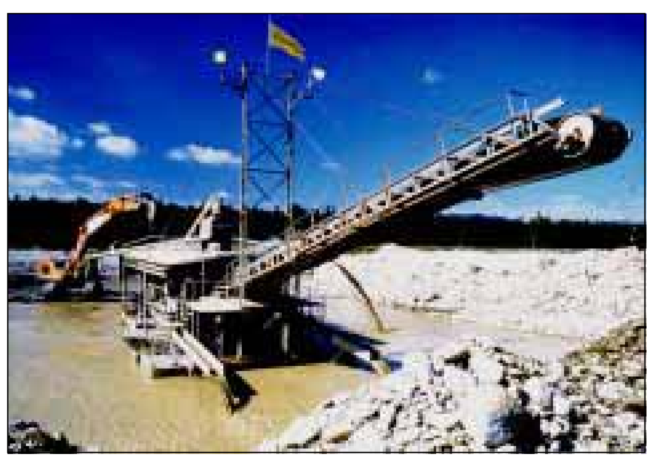

Figure 12: DML Resources alluvial gold plant, Arahura Valley, West Coast 1995 (Photo: Eoin Jury).

succession of moraines and associated outwash surfaces are present and cyclic erosion and redeposition of previously deposited till and outwash gravels increased the concentration of gold. An especially favourable situation was where a sequence of ice advances terminated in the same area, with the ice or meltwater outflow from a younger advance breaking through the terminal moraine and proximal outwash of a previous advance, as at Kaniere and Rimu in the lower Hokitika Valley (Suggate, 1996). The largest Pleistocene placers were worked at Reefton, Dunganville, Marsden, Greenstone, Kumara, Goldsborough, Callaghans, Humphreys Gully, Kaniere, Rimu and Ross. Between Hokitika and Ross, and south of Ross, the glaciers advanced to a position west of the present day shoreline, and outwash gravels deposited during past lower sea levels would now be offshore.

The present day river beds and floodplains have been extensively dredged and sluiced, especially in proximity to auriferous outwash deposits or downstream from lode-bearing Paleozoic rocks. The most extensive river bed placers are found along the Grey River and its tributaries, and in the lower valleys of the Taramakau, Arahura and Hokitika rivers.

Otago and Southland: Gold placers were formed by erosion of the Haast Schist and deposition of auriferous conglomerates during several major fluvial depositional phases related to regional tectonic episodes and marine transgression and regression cycles during the Late Cretaceous to the present. The younger deposits were the richest, because of erosion, recycling and concentration of the gold from older deposits. The main placers occur in:

(a) Late Cretaceous and early Tertiary terrestrial fanglomerates and breccias of the Blue Spur Conglomerate deposited in fault-angle depressions in the schist basement, e.g. Blue Spur, Wetherstons, Forsyth, Waitahuna Gully, Glenore and Adams Flat gold placers. Gabriels Read's famous discovery in Gabriels Gully was in Blue Spur Conglomerate.

(b) Quartz gravels of the Eocene Hogburn Formation and Miocene Wedderburn Formation in the Manuherikia Basin (Surface Hill, St Bathans, Vinegar Hill and Cambrians diggings), Idaburn Basin (Armitage, Blackstone Hill, Woolshed and German Hill diggings), Maniototo Basin (Kyeburn, Naseby, Gimmerburn, Garibaldi, Shepherds Hut, Hamiltons, Sowburn and Patearoa) and in the Waikaka Valley.

(c) Quartz gravels of the Miocene Gore Lignite Measures (Waikaka and Waimumu fields).

(d) Greywacke-schist gravels of the Pliocene Maori Bottom Formation (Naseby diggings).

(e) Quaternary alluvial fan gravels (Bannockburn; Fig. 13).

(f) Late Quaternary terrace gravels and riverbed gravels (Clutha-Kawarau river systems).

At Orepuki and Round Hill in Southland, Pleistocene terrace placers contained gold and platinum group metals derived from the Longwood Complex. Sluicing operations at Round Hill, from 1885 to the early 1950s, yielded more than 2.5 t Au and 0.047 t of platinum concentrate. On Stewart Island, in the Port Pegasus area, gold and cassiterite placers were worked intermittently between 1888 and 1914 in small stream and eluvial gravel deposits on the flanks of the Tin Range.

Beach gold

Beach placers are found on the west and south coasts of the South Island in present day beaches, older postglacial beach deposits, and the raised beach deposits of successive marine interglacials which underlie the remnants of coastal terraces (Fig. 14). Gold, along with ilmenite, magnetite, garnet, zircon and other heavy minerals (Minehan, 1989) is concentrated into lenticular beach placers known as 'blacksand leads'. Some leads contain gold-bearing sand layers with up to 10 g/m^3 in grade, although the gold is always very fine, in the size range of 0.01 to 0.1 mm (Douch, 1988). The largest deposits on the West Coast were leads in Addisons Flat and adjacent terraces near Westport, in terraces near Charleston and Barrytown, the Hou Hou Lead and associated leads west of Kumara, the Lamplough Lead north of Hokitika, and leads near Okarito Lagoon and on Gillespies Beach. The older leads near Westport and Charleston were cemented and the material required crushing before processing. Dredges were

Figure 13: Gold placer in Quaternary quartz-schist gravels, Bannockburn near Carrick, Otago (Photo: Bob Brathwaite).

Figure 14: Gold placer in Quaternary cross bedded dune sand (terrace deposits), Mitchells Gully near Charleston, West Coast (Photo: Bob Brathwaite).

used to work the Barrytown, Okarito Lagoon and Gillespies beach deposits during the 1930s–40s. Recently, Westland Ilmenite (1991) estimated resources at Barrytown of 50 Mt of potentially mineable sand at an average grade of 100 mg/m^3 gold, 13.8% ilmenite, 0.2% zircon and less than 0.1% each of monazite and rutile.

In Southland, gold and platinum were produced from beach placers at Round Hill and Orepuki, and gold was also mined from a Pleistocene marine terrace west of the Waiau River mouth at the Tunnel Claim. On the southeast Catlins Coast, Holocene beach placers were worked at Porpoise Bay, Wallace Beach and Progress Valley Beach. In addition, dredges worked the beach placers for gold (and platinum) at Haldane Bay and Waipapa Beach (M2118).

Offshore placer gold

Hauraki: Sedimentary deposits of gold, resulting from the erosion of the epithermal deposits and discharge of mine tailings, occur offshore of Thames and at some other localities. Some reconnaissance drilling has been carried out in Kennedy Bay, in Coromandel and Whangapoua harbours and at Thames foreshore and offshore mudflats.

West Coast: Sampling by CRA Pty Ltd defined the Harvester prospect, a 67 km^2 area, 8–14 km offshore from Hokitika, in water depths of 70–100 m, where surface gravel, less than 1 m thick, returned an average grade of 189 mg/m^3 (M2514; Lew and Corner, 1990).

Production, Reserves and Potential

New Zealand's officially recorded production of gold up to December 1995 was 958 t, but there was probably a large additional quantity undeclared, particularly during the early gold rushes. Current annual production is some 11 t and comes from the hard rock mines at Macraes Flat, Golden Cross and Waihi, several medium sized alluvial operations, including the Grey River Dredge, and a large number of small alluvial mines.

Exploration in recent years has identified significant gold resources in the Hauraki, West Coast and Otago goldfields. At Martha Hill, Waihi, a resource of about 23 t Au was defined by drilling, and an open-pit mine started up in 1988 at a production rate of about 2.5 t Au per year. At the Golden Cross deposit, northwest of Waihi, mining of a resource of about 19 t Au began in 1991. The largest identified resource in New Zealand is at Macraes in east Otago, which has been mined since 1991 and has a current (1996) resource of 94 t Au. Additionally, resources have been identified at Globe-Progress in Reefton (23 t Au), Sams Creek in Northwest Nelson, Monowai, Thames, and in the Waitekauri Valley in the Hauraki Goldfield. Total in-ground placer gold resources have been roughly estimated at more than 300 t for West Coast and more than 90 t for Otago (Douch, 1988). Nelson and Southland contain largely untested resources.

Continuing exploration at Macraes Flat and Reefton is expected to expand known resources in these areas. Elsewhere, exploration is expected to continue for new epithermal gold deposits in Hauraki Goldfield, Northland and the Taupo Volcanic Zone, and for turbidite-hosted mesothermal deposits and placer deposits in Westland and Otago. The discovery of intrusive-related gold at Sams Creek and the recognition of detachment fault related mineralisation in Westland, illustrates the potential for the discovery of new types of gold deposits. In relation to many geologically similar gold mineral provinces in the world, New Zealand is comparatively under-explored (e.g. White et al, 1995) and there is ample justification for further drill testing of currently known prospects, and regional geophysical and geochemical surveys to find new deposits.

Future Trends

Worldwide gold demand for jewellery, industrial and investment purposes is expected to continue. There is a move from heavy investment jewellery to modern and lightweight adornment jewellery. A decrease in bar hoarding is expected, partially offset by the use of various forms of gold savings accounts in countries where gold is still the most trusted store of wealth. However, the trend towards trading blocks and potential new currency areas such as the Common European Currency due in 1999 will reduce the requirement for gold in official reserves. Shedding of large quantities of gold from central banks and other official holders could cause a significant decrease in the price of gold.

Declining mine output from South Africa and Russia is currently being partially offset by increases in production in South America and Asia. Increased costs, legislative constraints and/or threats of royalties in South Africa, USA, Australia and other major developed nation producers are encouraging many multinational mining and exploration companies to invest in the western Pacific, Southeast Asia, South America, Eastern Europe, the Commonwealth of Independent States and East Africa.

In New Zealand, production of gold is likely to increase over the next few years with expansion at the Macraes Mine and the likely development of the Globe-Progress and Blackwater mines. Production may decline after the year 2000 unless new deposits are found to replace mined-out reserves at Waihi and Golden Cross. Increasing costs of exploration, development and production, and new royalties are deterrents to exploration and development of new deposits.

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