

Mineral Commodity Report 5 — Platinum Group Metals

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Discovery and Names

The six platinum group metals (PGM) are platinum Pt, palladium Pd, rhodium Rh, iridium Ir, ruthenium Ru and osmium Os.

The first recorded use of PGM, as natural alloys, was about 2700 years ago by the Egyptians in artwork along with silver, for which it may have been mistaken (McDonald and Hunt, 1982). The presence of PGM in placers mined for gold appears to have led to their accidental inclusion in gold jewellery from Egyptian, Roman and Byzantine times. The Indians of Ecuador and Colombia made articles of PGM and gold-PGM alloys, demonstrating that they had developed sophisticated metallurgical skills. PGM first came to the attention of Europeans in the early 1700s when they were described from gold placer deposits in the Pinto River, Colombia by Spanish scientist Antonio de Ulloa. Pure platinum, palladium, and rhodium were first isolated in 1803–04, by the English chemist William Wollaston, and, in 1803, pure iridium was discovered by Smithson Tennant in England, and by N.Z. Vauquelin and A.F. de Fourcroy in France. Tennant also identified osmium in 1803 or 1804. Ruthenium, the last PGM to be isolated, was discovered in 1844 by the Russian chemist K.K. Klaus.

Platinum was named from the Spanish word platina (silver) on account of its appearance. Palladium was named from the asteroid pallas, both discovered at about the same time. Rhodium is from the Greek rhodon for rose, after the colour of aqueous acidic solutions of the metal salts. Iridium was named from the Greek iris, meaning rainbow, because of the many colours seen in solutions of iridium salts

in aqueous acid solution. Ruthenium is from Ruthenia, the Latin for Russia, and osmium is from the Greek osme, a smell, because of the characteristic odour of its volatile tetraoxide.

Major Ores and Minerals

Platinum and palladium are the most abundant of the PGM, with rhodium a distant third. In nature, the PGM nearly always occur as native metal alloys, eg platinum with iron as isoferroplatinum Pt₃Fe, or as minerals such as the sulphides braggite (Pt,Pd,Ni)S and cooperite (Pt,Pd)S, the arsenide sperrylite PtAs₂, the bismuthide monchelite (Pt,Pd)(Te,Bi)₂ and the antimonides geversite PtSb₂ and stabio-palladinite Pd₃Sb. Worldwide, the principal minerals are sperrylite, cooperite, braggite, platinum-iron alloy, osmiridium IrOs, iridosmine OsIr and laurite RuS₂. The most common forms in New Zealand are platinum-iron, and osmium-iridium-ruthenium alloys (eg osmiridium and rutheniridosmine RuOsIr). PGM typically occur as small grains and inclusions in nickel-copper sulphide minerals and chromite, and as flattened, rounded detrital grains in placer deposits (Figure 1).

Properties

PGM are second and third row transition elements of Group 8B of the periodic table (Figure 2). Together with gold and silver, which lie adjacent to platinum and palladium respectively in the periodic table, they are known as precious or noble metals. The PGM have a close geological association with three other adjacent elements in the periodic table: iron, cobalt and nickel.

PGM are silver to dark steel-grey in colour and have specific gravities ranging from 12.0 (palladium) to 22.7 (iridium); pure platinum has a specific gravity of 21.5. The PGM are generally refractory, chemically inert over a wide temperature

Symbol	Pt	Pd	Rh	Ir	Ru	Os
Atomic no.	78	46	45	77	44	76
Atomic wt	195.09	106.40	102.91	192.22	101.07	190.20
Specific gravity	21.5	12.0	12.4	22.7	12.4	22.6
Valence	2, 4	2, 4	2, 3, 4	2, 3, 4, 6	2, 3, 4, 6, 8	2, 3, 4, 6, 8
Melting point (°C)	1772	1554	1963	2443	2310	3050
Boiling point (°C)	3827	2900	3700	4500	4080	5500
Crustal abundance (ppm)	0.01	0.01	0.005	0.001	0.005	0.005
Preferred analysis method ¹	Fire assay	Fire assay				
Routine detection limit (ppm)	0.005	0.002	0.0001	0.0001	0.005	0.005

¹ Nickel sulphide fire assay with instrumental neutron activation analysis (INAA) or inductively coupled plasma emission (ICP) finish are preferred over conventional lead fire assay.



Figure 1: Detrital grains of platinum group metals, probably osmiridium and iridosmine, from the Lee Valley, Nelson. The largest grain is 2 mm x 1 mm (Photo: Eric Coppard).

range, have good electrical conductivity and are excellent catalysts. Platinum and palladium have a hardness of 4–5 on the Moh scale and are malleable and ductile, allowing them to be easily wrought into different forms. Rhodium has particularly good catalytic characteristics and provides superior properties at high temperatures when alloyed with platinum. Ruthenium is hard and brittle, making it difficult to work. It imparts hardness when alloyed with platinum and palladium. Iridium has a hardness of 6–7 and retains its strength and corrosion resistance at high temperatures. Osmium is the hardest (7) and has the highest melting point of the PGM, but remains brittle and difficult to work, even at high temperature, limiting its applications in industry. Native platinum always contains some iron, and when it contains more than about 5% Fe it is distinctly magnetic.

Formation

The PGM are found in three types of deposits, which in order of importance of past and present production are: magmatic, placer and hydrothermal (including metamorphic).

Magmatic type deposits consist of segregations in large bodies of layered, gravitationally differentiated, gabbroic and ultramafic rocks. As a consequence of the high density of the PGM, they tend to settle out of the silicate melt, along with other heavy minerals such as copper-nickel sulphides and chromite, and accumulate in thin layers which can sometimes be traced for considerable distances. The magmatic deposits can be grouped into three major classes:

1. Stratiform or Merensky-type deposits which are formed in large intrusions of ultramafic-gabbroic rocks, such as the Bushveld Complex in South Africa and the Stillwater Complex in Montana. Layering is prominent, with PGMs restricted to layers 10–200 cm thick containing minor Fe-Ni-Cu sulphides (eg Merensky Reef in the Bushveld Complex grading about 8 g/t PGM). The Longwood and Riwaka complexes are considered to be New Zealand representatives of this class (Challis, 1989; Cowden et al., 1990).

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac [^]															
* Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu																	
^ Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lw																	

Figure 2: Periodic table.

2. Ophiolite or Alpine-type deposits which occur in dismembered portions of ophiolite ultramafic sequences formed as part of the oceanic crust. They are commonly associated with podiform chromitites, as in the Dun Mountain Ophiolite Belt in New Zealand.
3. Ni-Cu and Ni magmatic sulphide type deposits with PGM mined as a by-product of nickel and copper ores. The most important are the Noril'sk deposits in Russia and the Sudbury deposits in Canada which grade about 4 g/t and 1 g/t PGM respectively.

Challis (1989) noted that differences in mineralogy between the stratiform and ophiolite types of deposits — characterised by Pt-Pd alloys, sulphides, and arsenides versus Os-Ir-Ru alloys respectively — was a distinguishing feature between PGM in the Longwood and Riwaka Complexes, and those shed from the Dun Mountain Ophiolite Belt.

Placer deposits, formed by the erosion of the PGM-bearing ultramafic rocks, are found in Alaska (Goodnews Bay), Columbia (Choco District) and Russia (Ural Mountains). This type of deposit was the first exploited source of PGM, initially in Columbia and then in the Ural Mountains, before attention switched to the magmatic deposits. Significant by-product PGM was obtained from placer gold mining in Alaska, Oregon and California.

Hydrothermal origins for some PGM deposits are receiving growing recognition (Stumpfl and Ballhaus, 1986). PGM found with gold in quartz veins in Tertiary andesite near Thames were deposited in the epithermal (near surface) environment by a former geothermal system. Remobilisation of PGM in Pounamu ultramafic rocks under conditions of high grade metamorphism possibly accounts for PGM found in quartz veins with gold, silver and copper-nickel sulphides in north Westland, New Zealand (Craw et al., 1987; Challis, 1989).

Anomalously high concentrations of iridium are associated with the Cretaceous–Tertiary boundary, coincident with mass extinctions of animals and plants, and popularly ascribed to the impact of an asteroid.

Uses

PGM have wide use because of their unique catalytic properties, chemical inertness, relative thermal stability, hardness, high melting points, electrical conductivity and aesthetic appearance. A large proportion of the platinum and

Demand	Pt	Pd	Rh	Ir	Ru	Os
Total demand (oz)	4.04 M	4.26 M	360,000	33,000	182,000	5,000
End Uses						
Autocatalyst	35%	15%	90%			
Jewellery & dental	39%	34%				
Electrical	4%	46%	2%		68%	
Chemical	5%	4%	3%	68%	30%	Most
Investment	8%					
Glass	3%		1%			
Petrol refining	2%					
Other	4%	1%	4%	32%	2%	

Table 1: Demand and end use patterns of PGM in the Western World during 1993.

palladium and almost all of the rhodium produced is used for catalysts in automobile exhaust anti-pollution devices, known as catalytic converters (Table 1), in which carbon monoxide and unburnt hydrocarbon pollutants are converted to less harmful gases. Other catalytic uses are in the production of a wide variety of chemicals (eg nitric acid) and in petrol refining. Platinum and palladium are also used in jewellery and dentistry as a substitute for gold. In the glass industry, platinum is used at high temperatures to contain, stir and convey molten glass, and to 'spin' glass fibre. Several of the PGM are used in scientific and industrial apparatus such as crucibles, thermocouples (eg Pt-Ir, Pt-Rh, Ir-Rh) and electrodes. Palladium and ruthenium are mainly used in the electronics industry, particularly as alloys (eg with silver) for electrical contacts or in pastes in miniature solid-state devices, and in integrated circuits. The hardness of ruthenium and osmium is utilised in applications such as jewellery, fountain pen nibs, medical and dental tools, and mechanical bearings and parts. Osmium is additionally used as a tissue stain in microscopy. The International Temperature Scale over the range of 630.5–1063 °C is defined by a thermocouple using a 10% rhodium-platinum alloy. The international prototype standard kilogram of mass and the standard metre are made of an alloy containing 90% platinum and 10% iridium. Platinum has been used in coinage since 1828 and platinum alloy coins released recently in Australia and Canada have become a popular, although small-scale, investment commodity.

Price

The price of platinum in 1993 varied between \$US350 and \$US419 per oz, averaging \$US374 (Johnson Matthey, 1994), and was \$US411 in late August 1994. Palladium varied between \$US106 and \$US146 per oz during 1993 and was \$US153 in late August 1994. Rhodium, the most valuable of the PGM, declined from \$US1850 in January to \$US980 per oz in December 1993 and was \$US860 in late August 1994. Prices of iridium and ruthenium also dropped during 1993 from \$US260 to \$US80 per oz for iridium, and \$US25 to \$US18 per oz for ruthenium. They were \$US70 and \$US18 respectively in late August 1994. Osmium sold for between \$US400 and \$US450 per oz during 1993 and 1994.

World Occurrence and Production

South Africa, Russia and North America account for over 98% of the world's production of PGM. South Africa is the largest producer of platinum and rhodium, mainly from six companies operating both underground and opencut mines on the Merensky reef and UG2 chromitite layer in the Bushveld Complex. The ore has a high platinum:palladium ratio and contains a significant amount of rhodium. Copper and nickel are present in minor amounts but the ores are primarily mined for their platinum content. In 1992, South Africa produced 72% of total world supply of 3.82 million oz of platinum, and 74% of the supply of rhodium (world total 0.38 million oz). The second largest producer of platinum is Russia (20%), followed by North America (5%). The Russian PGM production is mainly from the Noril'sk region in Siberia, and the Pechenga deposit in the Kola Peninsula. In both regions, the PGM are magmatic segregations associated with copper-nickel sulphides in gabbroic lopoliths. The ore tends to have a high palladium:platinum ratio, and in 1992 Russia produced about 55% of the world supply of palladium. North American production of platinum, palladium and rhodium is mainly as a by-product of mining for copper-nickel sulphides in the Sudbury lopolith, Canada. More recently, there has been mining of PGM from the Stillwater layered ultramafic-gabbroic complex in Montana, USA, although the high (3.5) palladium:platinum ratio of the ore, the depressed price of palladium, and the high mining costs have so far made this a marginal operation. PGM deposits of the Great Dike in Zimbabwe are currently being investigated for development at the Hartley Complex, where PGM are concentrated in a 2 m thick sulphide enriched layer (Main Sulphide Zone) within a sequence of gabbro, pyroxenite and peridotite layers, over a 100 km long by 10 km wide section of the 450 km long dike (Delta Gold, 1993).

Rhodium is produced mainly from platinum ores in South Africa, Canada and Russia, and from gold ores in Columbia and Brazil. Iridium and osmium are produced mainly from the Witwatersrand paleoplacer gold deposits in South Africa, which yield small amounts of osmiridium (35% Os and 30% Ir), and iridosmine (40% Ir), although another important

source of osmium is from osmiridium in the placer deposits at Goodnews Bay in Alaska.

There is no routine metallurgical method for the processing of PGM ores and extraction of the metals. The method used is dependent upon the starting material, which may be various types of refractory ore, slimes resulting from nickel or copper processing, crude platinum, scrap or used catalyst. Gravity methods are used for concentrating placer PGM, whereas PGM are recovered from magmatic deposit ores by crushing and grinding, followed by gravity separation or flotation, with later upgrading using additional physical, hydro-metallurgical or pyrometallurgical techniques. In deposits with associated nickel and copper, the PGM are recovered from residual products mainly by dissolution and reprecipitation as insoluble salts, complexes or metals. Scrap is separated and re-refined using ion exchange resins.

World production of the major PGM during 1993 was 4.38 million oz of platinum, 4.135 million oz of palladium, 375,000 oz of rhodium, and smaller quantities of iridium, ruthenium and osmium.

New Zealand Occurrence and Resources

Magmatic

Platinum-palladium alloys are associated with magmatic nickel-copper sulphides in the Riwaka Complex at Graham Valley (Northwest Nelson). The complex is a 30 km long layered basic-to-ultrabasic intrusion occupying the axis of the Riwaka syncline. Cowden et al. (1988) noted that the richest sulphide mineralisation is associated with a marginal zone of hornblende-poor pyroxenites and gabbros within an intrusion otherwise dominated by hornblende-bearing ultramafic and mafic lithologies. Sulphide mineralisation is present disseminated in layers up to 5 m thick, within which there are high-grade layers up to 3 m thick. Pyrrhotite, pentlandite, and chalcopyrite form up to 35% of the rock. Sigma Resources NL investigated the PGM potential of the deposit and estimated grades of 0.8% to 1% Ni, 0.4 to 0.7% Cu, 0.05–0.3 ppm Pt, 0.1 ppm Pd and 0.07% Co with an inferred potential resource of 2 Mt (Cowden et al., 1988).

Exploration of Cobb Igneous Complex serpentinites and peridotites in the Takaka valley area for Au-Ag-Cu-Ni mineralisation was carried out by CRA in the late 1980s. At the Asbestos Creek prospect, platinum-palladium mineralised chromitite veins in pyroxenite consistently returned positive platinum assays (up to 1100 ppb Pt, but generally in the range 200–600 Pt) and low palladium levels (15–40 ppb Pd) (Stegman, 1987). Six samples of gold-copper mineralisation from the neighbouring Meter Creek grid (Stegman, 1988) returned values of up to 480 ppb Pt, 460 ppb Pd and 162 ppb Ru-Rh-Ir-Os. The above results and isolated higher values for grab samples (one talc magnesite at 1.7 ppm Pd; Stegman, 1987), coupled with occurrence of detrital material, indicate that the Cobb Igneous Complex has PGM potential.

PGM have been reported from the Longwood Complex in Southland (Challis and Lauder, 1977; Cowden et al., 1990). The complex is a layered intrusion containing gabbro, norite, anorthosite and pyroxenite. Disseminated PGM, with associated gold, are present in coarse-grained troctolite and anorthosite of the southern tops area and are located within a 1 km x 10 km area of anomalous Pt and Pd values identified in stream sediments by Sigma Resources NL. Reconnaissance soil sampling by Sigma obtained values up to 0.47 ppm Pt, and the best rock assay was 3.0 ppm Pt and 3.3 ppm Pd from a float sample (Cowden et al., 1990). Minerals identified included cooperite, cooperite-braggite, sperrylite, isoferroplatinum, iridosmine and osmiridium.

During the late 1980s, reconnaissance geochemical surveys specifically for PGM were carried out in several regions by Platinum Group Metals NL and Sigma Resources NL. Regions surveyed included Red Hill in southeast Nelson (Sigma, 1988a), Matakitaki River area near Murchison (Cowden, 1988), Blue Mountain – Mt Tapuaenuku area in Marlborough (Sigma, 1988b), Livingston Mountains near Te Anau (Bawden, 1987a) and West Dome near Lumsden, Southland (Bawden, 1987b; Rossiter, 1990). Further work was recommended on the Rotoroa Complex rocks near Murchison (Cowden, 1988) and an area immediately north of West Dome (Rossiter, 1990). No follow-up work appears to have been carried out. CRA Exploration Pty Ltd encountered geochemically anomalous PGM in chromitite samples from the Cascade Massif during reconnaissance exploration surveys of the Olivine Range in south Westland (Mackenzie, 1984).

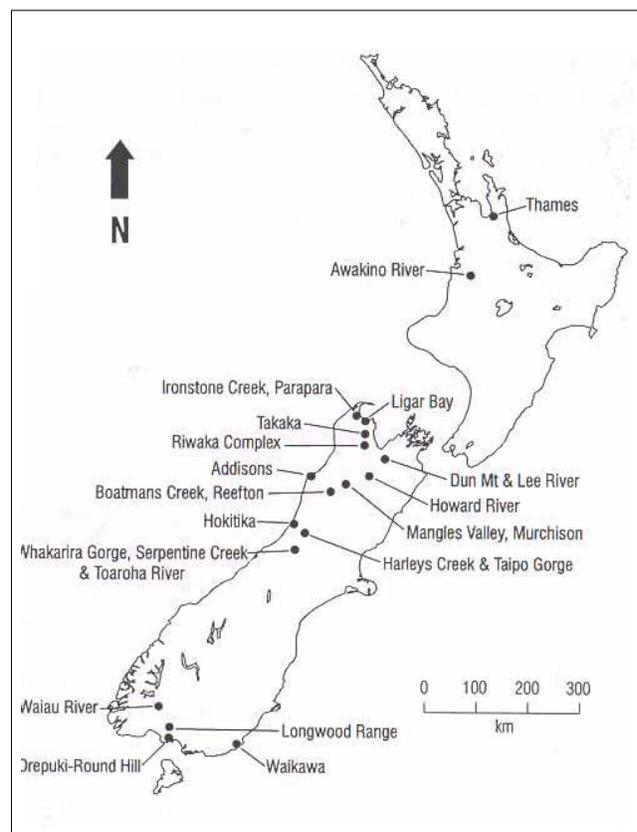


Figure 3: Location of platinum group metal occurrences.

Placer

In the North Island, detrital PGM were reported in the headwaters of the Awakino River (Henderson and Ongley, 1923). The locality is uncertain and no assay was given, but the source of the PGM is possibly a small lens of serpentinite at Piopio.

In the South Island, at least eight placer sources of PGM have been recorded (Challis, 1989; Figure 3). PGM have been reported from several localities from the west Nelson region since alluvial gold mining began, but with one exception few details are available. Detrital PGM from Ironstone Creek, Parapara, were examined by electron microprobe (Challis, 1989). Five of six analysed grains consisted mainly of rutheniridosmine with included platinum blebs, and the remaining grain consisted of osmiridium, rimmed by iridosmine. The relative abundance of Ru-Os-Ir compared with Pt-Pd suggests that the grains were derived from chromite-bearing ultramafic rocks. Detrital osmiridium has also been reported from Ligar Bay in the Collingwood area, and from alluvial gold workings around Takaka (Officers of New Zealand Geological Survey, 1970). A dredging operation at Appo's Flat, south of Collingwood, during 1905 recovered concentrates that assayed 141 g/t Au, 22 g/t Ag, 16 g/t Pt and 1 g/t Ir/Os, whereas concentrates from coarse conglomerates south of Appo's Flat assayed 62 g/t Au, 160 g/t Pt and 650 g/t Ir (Douch, 1987). Platinum and isoferroplatinum are associated with gold in Pleistocene alluvial gravels in the Howard River area in south Nelson (Challis and Palmer, 1987). The coarse grain size of the PGM suggests that they are derived from a nearby source, possibly the gabbroic rocks of the Rotoroa Complex.

According to Worley (1923), reports of detrital platinum in the Lee River (Dun Mountain Ophiolite Belt) date back to the 1860s. Panned material was associated with abundant chromite. Spectrographic analysis of samples suggested that Ir, Os and Ru were the main PGM (Williams, 1974), consistent with the observations of Challis (1989). The source of the PGM is a chromite-rich part of the Dun Mountain Ophiolite Belt, typified by that section exposed in Long Gully.

Morgan and Bartrum (1915) reported PGM in the raised marine blacksand deposits worked for gold at Addisons and elsewhere both north and south of the Buller River. Henderson (1917) noted PGM in gold-dredge concentrates in the Boatmans Creek area near Reefton and in alluvial gravel in Ten Mile Creek north of Greymouth. Morgan (1927) referred to PGM in a beach claim at Hokitika and Hutton (1950) noted rutheniridosmine in concentrates of the Kanieri gold-dredge.

Detrital platinum deposits on the south coast near Orepuki have been the object of past and present mining activity. At the Tunnel Claim, Orepuki, and at Round Hill, the platinum is associated with gold and occurs in Pleistocene to Recent beach and alluvial placers (Wood, 1969; Hay, 1989). Concentrate samples from the Orepuki area contain isoferroplatinum, sperrylite, and small amounts of various

platinum-palladium alloys and sulphides that were probably derived from the nearby Longwood Range (Challis, 1989). Platinum has also been obtained from beach placers on the southeast Catlins coast. At Waikawa, two distinct populations of PGM are found, dominated by isoferroplatinum and osmiridium respectively suggesting derivation from both gabbroic and ultramafic sources (Challis, 1989).

Hydrothermal

In the Queen of Beauty mine near Thames, platinum, containing a small amount of iridium, was found in quartz veins in hydrothermally altered Tertiary andesite in association with gold and silver. Assays reported between 39 and 311 g/t PGM (Pond, 1882), but the occurrence was sporadic and no PGM were reported from other mines in the area.

At Maungaparerua, near Kerikeri, Consolidated Brick and Pipe Investments Ltd reported platinum associated with hydrothermal clay alteration and cinnabar and pyrite-marcasite mineralisation of a rhyolite dome, but the platinum was subsequently determined to be a result of sample contamination (Weissberg et al., 1982).

PGM, together with gold, silver, pyrite and chalcopyrite have been reported from quartz veins in schist of north Westland: Harleys Creek, Taipo Gorge, Whakarira Gorge on the Kokatahi River, Serpentine Creek and Toaroha River (Bell and Fraser, 1906; Morgan, 1908). Samples assayed up to 5.1 g/t PGM. The veins are located near occurrences of Pounamu Ultramafics and Challis (1989) suggested that the PGM were derived from the ultramafic rocks during metamorphism.

Production and Imports

PGM were produced as a by-product of placer gold mining at several locations in the South Island from the 1870s, however, until the advent of the electrical industry in the 1880s, they were commonly discarded (Douch, 1987). The only recorded production is from Southland where 47 kg were produced by the Round Hill Mining Company near Orepuki between 1897 and 1907, and 13 kg of PGM concentrate from various gold claims between 1907 and 1916 (Brathwaite and Pirajno, 1993). Over the last ten years, imports of platinum have been less than about 40 kg per year: 9.54 kg of platinum were imported during 1993.

Potential and Prospectivity

The PGM occurrences in the Riwaka and Longwood complexes bear similarities to the layered mineralisation in the Bushveld and Stillwater complexes (Challis, 1989; Cowden et al., 1990) and suggest potential for the presence of a stratiform PGM deposit. Similar rock types in the Rotoroa and Darran complexes, and the occurrence of detrital PGM sourced from the Rotoroa Complex (Challis, 1989) and Cobb Igneous Complex, indicate that these rocks should also be considered as prospective targets for future exploration.

Future Trends

The special chemical and physical properties of PGM and absence of suitable substitutes, are responsible for a continuing growing demand in industrial applications, particularly associated with the increasing environmental awareness and the importance of PGM in devices for reducing automobile exhaust emissions. South African producers are able to increase production, but the principle producers in Russia and Canada are reliant on the nickel (and copper) demand. Recycled scrap represents only a minor source (about 10% in the USA), although spent nuclear fuels could become a significant source of ruthenium, rhodium and palladium in the future. Development of BHP Minerals and Delta Gold's Hartley platinum project in the Great Dike, Zimbabwe, could have a major impact on PGM supply and price. The high value of PGM, their expanding industrial consumption, and current dependence on supply from a small number of countries, continue to make PGM an attractive exploration target.

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