JOM World Nonferrous Smelter Survey, Part II: Platinum Group Metals

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The platinum group metals (PGMs) are a family of six grayish to silver-white metals with close chemical and physical affinities. The three heavier metals, platinum (Pt), iridium (Ir), and osmium (Os), have densities of about 22 g/cm^3. The three somewhat lighter metals, palladium (Pd), rhodium (Rh), and ruthenium (Ru), have densities of about 12 g/cm^3. The PGMs belong to the transition metals of Group VIII in the periodic table, as do iron (Fe), nickel (Ni), and cobalt (Co). These metals have similar geochemical behavior and tend to be concentrated together geologically. The PGMs, along with gold (Au) and silver (Ag), are classified as noble metals because of their high resistance to oxidation and corrosion.

Their great scarcity classifies them as precious metals. Only about 1/13 as much platinum is produced as gold, itself a very rare metal. (By contrast, about 5 million times as much iron as platinum is produced in the world.) As precious and noble metals, PGMs are chemically more versatile than gold, and have found numerous industrial applications. They are also the only competitors for gold

Table I. PGM Production in 2003

	Pt Supply		Pd Supply		Rh Supply	
	Moz.*	Tonnes	Moz.*	Tonnes	Moz.*	Tonnes
South Africa	4.670	145.2	2.310	71.8	0.545	17.0
Russia	1.050	32.7	2.950	91.8	0.140	4.4
North America	0.295	9.2	0.940	29.2	0.020	0.6
Other	0.225	7.0	0.250	7.8	0.015	0.5
Total	**6.240**	**194**	**6.450**	**201**	**0.720**	**22.4**
Plus recycled material	0.645	20.1	0.410	12.8	0.123	3.8

* Units in millions of troy ounces per annum (1 troy ounce = 31.1035 g; 1 million troy ounces = 31.1035 tonnes).

Table II. Percentage Demand by Market Sector for 2003*

Pt	Pd	Rh
Automobile–39	Automobile–58	Automobile–86
Jewelry–37	Electronics–17	Chemical–6
Industrial–23	Dental–14	Glass–5
Investment–0.2	Other–11	Other–3

* The figures for automobiles reflect the demand for new material only (i.e., recycled materials are excluded).

Table III. Smelter Production Figures for 2003*

	Pt	Pd	Rh	Pt + Pd + Rh
Primary producers of PGMs				
Anglo Platinum, South Africa	2.31	1.19	0.23	3.73
Impala Platinum, South Africa	1.96	1.05	0.25	3.26
Lonmin Platinum, South Africa	0.93	0.42	0.14	1.49
Stillwater, United States	0.13	0.45	0.005	0.58
Northam Platinum, South Africa	0.21	0.10	0.02	0.33
Zimplats, Zimbabwe	0.09	0.07	0.01	0.17
Producers of PGMs as by-products				
Norilsk Nickel, Russia	0.65	2.70	0.06	3.41
Falconbridge, Canada	0.11	0.33	0.002	0.44
Inco, Canada	—	—	—	0.21

* All units are in millions of troy ounces per annum.

Table IV. Platinum Group Metal Producers

Company	Abbreviation	Location	Web Address
Anglo Platinum–Rustenburg (Waterval)	Anglo 1	Rustenburg, South Africa	*www.angloplatinum.com*
Anglo Platinum–Mortimer	Anglo 2	Swartklip, South Africa	*www.angloplatinum.com*
Anglo Platinum–Polokwane	Anglo 3	Polokwane, South Africa	*www.angloplatinum.com*
Impala Platinum	Impala	Rustenburg, South Africa	*www.implats.co.za*
Lonmin Platinum	Lonmin	Marikana, South Africa	*www.lonmin.com*
Northam Platinum	Northam	Northam, South Africa	*www.northam.co.za*
Zimplats–Makwiro Platinum	Zimplats	Selous, Zimbabwe	*www.zimplats.com*
Stillwater	Stillwater	Columbus, Montana, United States	*www.stillwatermining.com*
Norilsk Nickel, Nickel Smelter	Norilsk 1	Taimyr Peninsula, Siberia, Russia	*www.nornik.ru/en/*
Norilsk Nickel, Nadezhda Smelter	Norilsk 2	Taimyr Peninsula, Siberia, Russia	*www.nornik.ru/en/*
Norilsk Nickel, Copper Smelter	Norilsk 3	Taimyr Peninsula, Siberia, Russia	*www.nornik.ru/en/*

Table V. PGM Converter Data

Producer	Year of First Production	Type of Converter	No. of Converters	Converter Dimensions (m)	No. of Tuyeres per Converter
Anglo 1	2002	Ausmelt (ACP)	1	—	1
		Peirce-Smith	6	3.0 × 7.6	—
Anglo 2	—	None	—	—	—
Anglo 3	—	None	—	—	—
Impala	—	Peirce-Smith	2	3.6 × 7.3	32
		Peirce-Smith	4	3.0 × 4.6	16
Lonmin	1971, 2002–2003	Peirce-Smith	3	3.0 × 4.6	18
Northam	1992	Peirce-Smith	2	3.0 × 6.1	22
Zimplats	1998	Peirce-Smith	2	3.0 × 4.6	16
Stillwater	1999	Kaldo (TBRC)	2	2.0 × 3.32	—
Norilsk 1	Early 1940s	Russian	6	100 t capacity	—
Norilsk 2	—	Peirce-Smith	6	—	—
Norilsk 3	—	Peirce-Smith	9	4 × 9	—

as investment metals and for jewelry purposes.

Platinum was formally discovered only in 1751, although it (possibly mistaken for silver at that time) was used as far back as the 7th century B.C. in Egypt, when the Thebes casket was produced. (This was made for Shepenupet, the daughter of the king of Thebes, and has gold hieroglyphics on one side and platinum on the other.) The catalytic properties of PGMs were described in the period of 1823–1838. Interestingly, jewelry and catalysis remain the most important applications of these metals today.

Platinum group metals have extraordinary physical and chemical properties that have made them indispensable to the modern industrial world. The PGMs have high melting points and are chemically inert to a wide variety of substances (even at high temperatures), and thus resist corrosion. They also have excellent catalytic properties and are widely used in the chemical industry and in automobile catalytic converters. Commercial substitution by cheaper metals has rarely been successful, although an individual PGM may readily be replaced by another.

Platinum group elements are generally associated with nickel-copper sulfides in magmatic rocks. Depending on the relative concentrations (and market prices) of the precious and base metals, the PGMs are produced either as the primary products or as by-products of the nickel and copper. The primary PGM-rich deposits include the Bushveld Complex in South Africa (the largest known layered igneous complex of its type in the world, extending some 350 km from west to east and some 250 km from north to south, containing more than two-thirds of the world's reserves of PGMs), the Great Dyke in Zimbabwe (the second largest known deposit of PGMs in the world), the Stillwater deposit of the United States, and the Lac des Isles deposit of Canada. Platinum group metals are produced in significant quantities as by-products from the Norilsk-Talnakh area of Russia and the Sudbury deposit of Canada. Other deposits occur in Finland, the Jinchuan deposits of northwest China, the Duluth complex of the United States, and in numerous smaller deposits. Platinum group metals are also produced in small quantities as by-products from the nickel-copper industry in Australia and Japan.[1]

The most economically important of the PGMs are platinum, palladium, and rhodium, with ruthenium, iridium, and osmium being less prevalent and less in demand. Gold, though it is a precious metal, is not one of the PGMs although it is often lumped together with the PGM content when talking about the valuable products from PGM smelting. The base

Table VI. PGM Smelter System Information

			Annual Production					
			Millions of Ounces				Thousands of Tonnes	
Smelter	Year of First Production	Total PGMs	Pt	Pd	Rh	Au	Ni	Cu
Anglo 1	1926	4.162	2.308	1.191	0.233	0.116	22.1	12.9
Anglo 2	1973	(0.754)	(0.46)	(0.22)	(0.06)	(0.014)	(2.6)	(1.5)
Anglo 3	2003	—	—	—	—	—	—	—
Impala	1969	3.725	1.961	1.046	0.251	0.069	16.4	8.7
Lonmin	1971	1.758	0.933	0.417	0.141	0.018	3.18	2.12
Northam	1992	0.385	0.212	0.103	0.018	0.007	1.51	0.86
Zimplats	1997	0.187	0.085	0.073	0.008	0.011	1.63	1.0
Stillwater	1990	0.599	0.134	0.450	<0.005	<0.010	0.75	0.5
Norilsk 1	Early 1940s	3.410	0.650	2.700	0.060	0.136	239	451
Norilsk 2	Early 1980s	—	—	—	—	—	—	—
Norilsk 3	—	—	—	—	—	—	—	—

metals nickel, copper, and cobalt commonly occur together with the PGMs and are produced as co-products in the smelters and refineries. The PGM market is fundamentally strong, particularly in platinum, where demand has outstripped supply for the past five years. Platinum saw a price increase of almost 30% in the past year, reaching the highest point in more than 20 years. However, palladium and rhodium dropped by almost 40% in the same period, following periods of very high prices. Over recent years, there has been good growth in jewelry demand and in autocatalysts, especially for diesel vehicles.

Table I shows the geographical distribution of the most important PGMs, and Table II shows the demand by market sector for Pt, Pd, and Rh, courtesy of Johnson Matthey.[2]

The comparative tables presented here include all known primary PGM smelters around the world, as well as Norilsk Nickel. Although not strictly a primary PGM smelter, Norilsk Nickel is the world's largest producer of nickel and palladium and also one of the leading producers of copper, platinum, and gold. Leaving out Norilsk would result in an incomplete picture of PGM smelting, so it is included here even though other nickel smelters such as Inco and Falconbridge are not. (Further details on those smelters will be presented in due course as part of the nickel smelter survey.) Most company production figures are taken from their current annual reports (for 2003 in most cases) that are mostly available from their company websites. Note that Russia does not as yet allow the release of official production figures for PGMs and cobalt, although new laws have been enacted recently to allow for the release of much of this information in the year ahead. However, estimated production figures produced by Johnson Matthey[2] for the Polar Division (which produces the bulk of Norilsk's PGMs) are believed to be fairly reliable. Table III shows the Pt, Pd, and Rh production figures for the various PGM smelters.

South Africa has the greatest concentration of primary PGM-producing companies,[3,4] each of which has its own approach to smelting. (See Table IV for a list of PGM-producing companies.) The historical background to these smelters up to 1999 has been provided elsewhere[3] and will not be repeated here. Production takes place in differing amounts of the three currently exploited strata of the Bushveld Complex. The Merensky Reef has the PGMs occurring in conjunction with base metal sulfides; the Platreef has an even greater quantity of base metal sulfides present; and the UG2 chromitite layer has a high chromite content together with relatively low quantities of base metal sulfides. The extent to which UG2 ore is processed has a major influence on the smelting behavior, as traditional six-in-line furnaces are susceptible to build-ups of high-melting chromite spinels if the Cr_2O_3 content of the feed is too high.

The chromite problem is seen as increasingly important as the amount of UG2 ore being mined continues to grow faster than the amount of Merensky ore. A recent trend is to break the tradition of recycling converter slag to the primary smelting furnace. The converter slag can be treated either in a slag-cleaning furnace (as practiced at Anglo Platinum) or by subsequent milling and flotation.

There is an increasing move to higher-intensity furnaces fitted with copper cooling, both for rectangular furnaces (at Anglo Platinum's Polokwane smelter) and circular furnaces (such as those at Lonmin Platinum and Zimplats). Containment issues are important, especially at the higher operating temperatures used to cope with increasing chromite contents in the furnace feed.

A variety of techniques have been used in the attempt to reduce SO_2 emissions from smelters, with different degrees of success. Continuous converting was introduced recently by Anglo Platinum as a way of ensuring a steady stream of SO_2 that can be fed to a sulfuric acid plant. Anglo Platinum chose to have one central facility where all convert-

Table VI. PGM Smelter System Information

Dryer Type	Granulation: Furnace Slag	Granulation: Furnace Matte	Granulation: Converter Slag	Granulation: Converter Matte	Stack Height (m)	Sulfuric Acid Plant	Gas Cleaning Equip.	Converter Slag Recycl. to Furnace
Flash (4)	Yes	Yes	Yes	No[a]	183	Yes	Ceramic Filters	No
Flash	Yes	No[b]	—	—	100	No	ESP	N/A
Flash (2)	Yes	No[b]	—	—	165	No	Baghouse	N/A
Spray (4)	Yes	No	Yes	Yes	77 (91)	Yes[c]	ESP	No
Flash[d]	Yes	No	Yes	Yes	120	No	Baghouse for drier; ESP and dual-alkali wet scrubber	No
Flash	Yes	No	No	Yes	200	No	ESP and wet scrubber	Yes
Flash (1)	Yes	No	No	Yes	105	No	ESP	Yes
Fluid bed	No	Yes	Yes	Yes	26	No	Baghouse and SO_2 wet scrubber	Yes[e]
Sinter plant	—	—	—	—	—	—	—	Yes[f]
Niro spray (6)	—	—	—	—	—	No	6 x ESPS and elemental sulfur production	—
Rotary (3)	—	—	—	—	180	Yes	Wet gas cleaning and elemental sulfur production	Yes[g]

a – slow cooling; b – cast and crushed; c– and sulfacid; d–also 2 old spray towers; e–in granulated form; f–from copper smelter; g–to reverb furnace

Table VII. PGM Furnace Data*

Producer	Year of First Production	Furnace Type	Power	Power Flux, kW/m²	Dimensions (m)	Electrode Diameter (mm)	Cooling System
Anglo 1	1990s	Six-in-line rectangular (Hatch)	34 MW (39 MVA)	165	25.8 × 8.0	1,100	Copper finger/ plate coolers
	1990s	Six-in-line rectangular (Hatch)	34 MW (39 MVA)	165	25.8 × 8.0	1,100	Copper finger/ plate coolers
	2003	Three-electrode AC circular slag cleaning	28 MVA	—	—	1,200	Copper coolers
Anglo 2	1973	Six-in-line rectangular	19.5 MVA	110	25.3 × 7.0	1,250	Forced-air cooled
Anglo 3	2003	Six-in-line rectangular	68 MW (168 MVA)	250	28.7 × 9.6	1,600	Copper waffle coolers
Impala	2001 (No. 3)	Six-in-line rectangular	38 MW	180	25.9 × 8.2	1,140	Copper plate coolers
	1992 (No. 5)	Six-in-line rectangular	35 MW	180	25.9 × 8.2	1,140	Copper plate coolers
	1974 (No. 4)–dormant	Six-in-line rectangular	15 MW	—	—	—	—
	1972 (No. 2)–mothballed	Six-in-line rectangular	7.5 MW	—	—	—	—
Lonmin	2002	Three-electrode AC circular (Hatch)	28 MW (60 MVA)	320	11 (dia.)	1,400	Copper waffle coolers
	1991–mothballed	Three-electrode AC circular (Pyromet)	5 MVA (three)	235	5.2 (I.D.)	500	Falling film
	1991–mothballed	Six-in-line rectangular (Barnes-Birlec, Merensky)	12.5 MVA	120	18.2 × 5.3	900	—
Northam	1992	Six-in-line rectangular (Davy)	15 MW (16.5 MVA)	90	25.9 × 8.7 × 5.6	1,000	None
Zimplats	1997 (2002)	Three-electrode AC circular (Elkem/Hatch)	12.5 MW (9–10 MW, 13.5 MVA)	90	12 (O.D.)	1,200	Copper plate coolers
Stillwater	1999	Three-in-line rectangular (Hatch)	5.0 MW (5.3 MVA)	150	9 × 5	305	Copper plate coolers
	1990–mothballed	Three-in-line rectangular (Lectromelt)	1.5 MW (1.68 MVA)	150	7.5 × 2.6	305	Copper finger coolers
Norilsk 1	Early 1940s	5 × six-in-line furnaces (3 working; 1 standby, 1 repair)	75 MW (normal operation 45 MW)	—	—	—	—
		2 × slag-cleaning electric furnaces (for converter slag) (1 working, 1 standby)	20 MW	—	—	—	—
		6 × electric anode furnaces (3 graphite electrodes) using coal for reduction	—	—	20 t capacity	1,500	—
Norilsk 2	Early 1980s	2 × Outokumpu flash	—	—	245 m² hearth area	—	—
		1 × Vanyukov	—	—	—	—	—
		4 × 3-electrode slag-cleaning furnaces	18 MW each (normally 8–11 MW)	—	—	—	—
		1 × slag-cleaning rotating vessel	—	—	—	—	—
		4 × rotating anode furnaces	—	—	—	—	—
Norilsk 3	—	2 × Vanyukov	—	—	15.6 × 2.3 hearth	—	—
		1 × Vanyukov	—	—	20 m² hearth area	—	—
		reverb	—	—	250 m² hearth area	—	—
		reverb	—	—	92 m² hearth area	—	—
		4 × reverb anode furnaces (green poles for reduction)	—	—	—	—	—

* All furnaces are electric except those of Norilsk.

ing and subsequent treatment by slow cooling and magnetic separation prior to refining can take place. (Converter and smelter data by PGM producer are shown in Tables V and VI, respectively.) Furnace matte from all three of its smelters is treated in the Anglo Platinum Converting Process (ACP) that uses Sirosmelt submerged lance technology from Ausmelt with copper waffle coolers from Hatch. This strategy of decoupling their furnaces and converting operations provides operational flexibility as well as offering a range of siting possibilities for future expansions.

Matte smelting has been in use for the production of PGMs for many decades, but new processes continue to emerge. (Furnace information by PGM producer is shown in Table VII.) An alternative PGM smelting process has recently been developed using alloy smelting in a direct current arc furnace.[5,6] This process has been implemented on a large-scale continuous demonstration basis.[6] The ConRoast process eliminates many of the traditional constraints on feed composition and also has environmental advantages in the control of SO_2 emissions.

Tables IV through VII provide further details about PGM producers, including furnace and converter data.

Table VII. PGM Furnace Data

Concentrate Smelting Rate (t/h)	Energy Consumption, kWh/t of Concentrate	Slag Tapping Temperature (°C)	Matte Tapping Temperature (°C)	Matte Fall** (%)	PGM Concentrate Grade (g/t)
71 (total for both furnaces)	700	1,550	—	22	150
Combined with above total	700	1,550	—	22	150
—	—	—	—	—	—
20	820–850	1,650	1,550	15	145
87 capacity	800–850	1,600	1,550	15	150–200
92 (total for both furnaces)	720	1,460	1,300	12	130
combined with above total	720	1,460	1,300	12	130
—	—	—	—	—	—
—	—	—	—	—	—
30	850	1,600–1,650	1,500–1,550	14	300–350
—	880	—	—	—	—
—	1,270	—	—	—	—
10	1,044	1,485	1,385	18	130
10	750–850	1,580	1,420	12	75
5.0	850–950	1,500–1,550	1,150–1,250	14–25	600–1,200
1.3	900–1,000	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
135–180 (each)	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—

** Matte fall is the mass of matte relative to the mass of the original concentrate feed.

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