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

Rodney T. Jones

**Editor's Note:** *JOM* electronic subscribers and TMS members may acquire the raw spread sheets on which these tables are based by downloading this article from the TMS Document Center.

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,<br>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/m$^2$ | 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 m$^2$ 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 m$^2$ hearth area | — | — |
| | | reverb | — | — | 250 m$^2$ hearth area | — | — |
| | | reverb | — | — | 92 m$^2$ 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.

## ACKNOWLEDGEMENTS

*This paper is published by permission of Mintek. The assistance of many friends and colleagues in the platinum industry is gratefully acknowledged.*

### References

1. C.F. Vermaak, *The Platinum-Group Metals: A Global Perspective* (Randburg, South Africa: Mintek, 1995).
2. T. Kendall, *Platinum 2004* (London, England: Johnson Matthey, 2004), *www.platinum.matthey.com.*
3. R.T. Jones, "Platinum Smelting in South Africa," *South African Journal of Science,* 95 (November/December 1999), pp. 525–534; *www.mintek.co.za/Pyromet/Files/Platinum.pdf.*
4. A.M. Edwards and M.H. Silk, *Platinum in South Africa,* Special Publication No. 12 (Randburg, South Africa: Mintek, 1987).
5. R.T. Jones, "ConRoast: DC Arc Smelting of Dead-Roasted Sulphide Concentrates," *Sulfide Smelting 2002,* ed. R.L. Stephens and H.Y. Sohn (Warrendale, PA: TMS, 2002), pp. 435–456; *www.mintek.co.za/Pyromet/Files/ConRoast.pdf.*
6. R.T. Jones and I.J. Kotzé, "DC Arc Smelting of Difficult PGM-Containing Feed Materials," *Proceedings of the International Platinum Conference, 'Platinum Adding Value'* (Johannesburg, South Africa: The South African Institute of Mining and Metallurgy, 2004), pp. 33–36; *www.mintek.co.za/Pyromet/Files/2004JonesConSmelt.pdf.*

*Rodney T. Jones is a specialist consultant with Mintek in Randburg, South Africa.*

**For more information, contact R.T. Jones, Mintek, Private Bag X3015, Randburg, 2125, South Africa; +27-11-709-4602; fax +27-11-793-6241; e-mail rtjones@global.co.za.**