PINCOCK perspectives

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CALENDAR

- ***Runge XERAS Maintenance Budgeting Software in Action***
  April 2, 2008
  Star Restaurant
  216 Silver Street, Elko, Nevada
  Paul Shattuck
  Email: pshattuck@runge.com.au

- ***Asia Mining Congress 2008***
  April 7 – 11, 2008
  Raffles City Convention Centre
  Singapore, Singapore
  Email: elin.tan@terrapinn.com

- ***ExpoMIN 2008 – The Center for the World Mining Industry in Chile***
  April 15 – 18, 2008
  Centro de Eventos Espacio Riesco
  Santiago, Chile
  Email: info@fisa.cl

- ***MiningWorld Russia 2008***
  April 16 – 18, 2008
  Crocus Expo
  Moscow, Russia
  Email: anna.aleinikova@ite-exhibitions.com

- ***CIM Conference and Exhibition 2008***
  May 4 – 7, 2008
  Shaw Conference Centre
  Edmonton, Alberta, Canada
  Email: cmurphy@cim.org
  Visit PAH/Runge at Booth 0101

- ***Africa Mining Congress 2008***
  June 9 – 12, 2008
  Sandton Convention Centre
  Johannesburg, South Africa
  Email: Taryn.vanzanten@terrapinn.co.za

- ***Mining for Non-Miners Runge Professional Development Course***
  June 19 –20, 2008
  Inn on Mcleod Trail
  Calgary, Alberta, Canada
  Email: mschmidt@runge.com.au

The Processing of Platinum Group Metals (PGM) – Part 1

With soaring PGM prices (platinum exceeding $2000/oz and rhodium approaching $9000/oz), the PGM business is really booming, particularly in South Africa, Russia and North America. And so it is for PAH, who has assessed several PGM projects in recent years. It is an industry that is not well known, particularly where PGMs are the primary minerals recovered. In the first part of this article, PAH provides a brief background to PGMs, followed by a review of the technical challenges in the processing of South African PGM ores.

The PGMs consist of a family of six greyish to silver-white metals with close chemical and physical affinities and belong to the transition metals of Group VIII in the Periodic Table. Three of the PGM family, namely platinum (Pt), iridium (Ir) and osmium (Os), have high melting points, are very inert and are the heaviest known elements (~22 g/cm^3). The remaining three PGMs, palladium (Pd), rhodium (Rh) and ruthenium (Ru) are much lighter (~12 g/cm^3).

PGM production is dominated by South Africa which supplies over 80% of the world's PGM needs (refer to Table 1). Russia is, however, the largest producer of palladium, with North America making a significant contribution. The primary demand driver is the burgeoning automobile market, with the manufacture of autocatalysts consuming over 60% of both platinum and palladium production as well as 85% of the rhodium mined. World demand for ruthenium and iridium in 2006 was 30.5 tonnes and 6 tonnes respectively.

PGMs are principally extracted from two types of deposits, namely the platinum-rich layered mafic intrusions (e.g. the Bushveld in South Africa and the Great Dyke in Zimbabwe) and the palladium-rich nickel sulfide deposits (e.g. Noril'sk-Talnakh in Russia). In both types of deposits, there is a strong association between PGMs (particularly palladium) and pentlandite.

The ability of South Africa to dominate world PGM production arises from the massive resource base (refer to Table 2) contained in the Bushveld Igneous Complex (BIC), located 50 kilometres north of Pretoria. Covering over 66,000 km^2, the BIC has outcrop extremities 450 kilometres east-west and 300 kilometres north-south, with a thickness of between 7 and 9 kilometres (refer to Figure 1). Slow cooling allowed the PGMs and base-metal sulfides (BMS) to coalesce and concentrate into two main economic layers known as the Merensky and Upper Group 2 or UG2 Reefs, the latter is located between 15 to 400 metres beneath Merensky Reef. The layers typically dip 10-20 degrees towards the centre of the BIC and are mined down to 2,000 metres. A third, considerably thicker PGM horizon formed in the Northern Limb, known as the Platreef, which is located near the surface and mined as an open cut. The BIC contains over 80% of the worlds' resources of PGMs, chromium and vanadium as well as significant quantities of titanium, iron and fluorspar.

The Merensky Reef was first mined in the 1926 near Rustenburg on the Western Limb, which today has more than twelve operating mines producing 4.5 million ounces of platinum annually. UG2 ores were first processed in the 1980s and PGM recovery remains an ongoing challenge.

The South African PGM industry is dominated by three major players, namely Anglo-Platinum, Impala Platinum and Lonmin, all of which are fully vertically integrated and produce pure PGMs. It is a very competitive and secretive business and information has not been readily available. The general exception is Merensky Reef ores, which been processed and studied extensively for more than half a century. With significant changes recently in the South African mining legislation, the opportunity for other mining companies to join in the PGM rush has arisen, with most new developments occurring on the Eastern Limb.

The extraction of PGMs can be broken down into four parts, namely mining, processing, smelting and refining, each stage technically challenging. Key features of the PGM business are presented in Table 3. Notably, mining accounts for up to 75% of the total PGM production cost. This arises because the Merensky and UG2 Reef layers are thin and need to be mined by underground methods. These ores are difficult to mine by bulk, mechanised methods (mainly due to significant dilution of the head grade); however, progress is being made.

The processing of PGM ores poses a number of challenges due to the nature of the mineralogy and the subsequent smelting requirements. Merensky Reef ores are the easiest to treat, followed by Platreef ores and UG2 Reef ores.

Processing

A summary of the various characteristics of the three PGM ore types mined in the Bushveld are presented in Table 4. The figures in this Table and following discussion are based on ores from the Western Limb, whose characteristics are well known. The PGM mineralogy changes significantly on the Eastern Limb, where the PGM minerals are not only finer, but have a greater association with bismuth and antimony, resulting in more difficult flotation metallurgy. Similarly, on the Northern Limb, although superficially similar to Merensky Reef ores, Platreef ores have a different PGM mineralogy which results in a poorer process response.

The Merensky Reef is characterized by high PGM grades and a high ratio of platinum to the other PGMs. Although the grade and the PGM proportions are relatively constant, the PGM mineralogy varies considerably. In general, the Pt-Pd sulfides are dominant (60%), followed by the PGE tellurides (11%) and arsenides (6%), with the balance mostly PGE alloys and Ag/Au phases. There are three PGM associations: enclosed in or attached to BMS, enclosed in silicates, and enclosed in or attached to chromite. The first association is the most dominant in Merensky Reef ores. The BMS content is around 1 wt. % and consists of mainly pyrrhotite (~67%), pentlandite (~35%) and chalcopyrite (~16%). The PGMs are coarse (20 to 150 microns) and are well liberated after comminution. They generally float quickly, reporting with the chalcopyrite to the first rougher cell concentrates. Most composites are with the BMS and also float well. The remainder of the ore consists of mostly silicate minerals such as pyroxene and plagioclase, with some talc and chromite. Although neither pyroxene nor feldspar show any natural flotation tendencies, they can become activated by base-metal ions and subsequently float after interaction with collectors. Talc, a naturally floating mineral, can also rim the pyroxene particles, resulting in flotation.

TABLE 1 : PGM Production in 2006

PGM	South Africa (t)	Russia (t)	North America (t)	Total Supply (t)
Platinum	170	29	13.3	221
Palladium	85	98.4	28.4	224
Rhodium	21.8	2.8	0.5	25.6

Source: USGS data

TABLE 2 : PGM Resources

Country	Reserves (tonnes)	Resources (tonnes)
South Africa	63,000	70,000
Russia	6,200	6,600
United States	900	2,000
Canada	310	390
Other countries	800	850
World Total	71,000	80,000

Source: USGS data

TABLE 3 : Key Features of the PGM Extraction Business

Parameter	Mining	Comminution & Flotation	Smelting & Converting	Base Metal Refining	Precious Metal Refining	Total
Percent of Total Cost	65–75	9–12	6	7	4–5	100
PGM grade	4–6 g/t	100–600 g/t	640-6000 g/t	30–65%	>99.8%	-
PGM Recovery (%)	-	80–90	95-98	>99	98–99	75–85
Concentration Ratio	-	30–80	20	75	2	200,000
Processing Time (days)	-	2	7	14	30-150	Up to 170

Source : Lonmin website

During the processing of Merensky ores, the BMS and PGMs are recovered using conventional sulfide ore flotation practice to produce a bulk concentrate. A standard roughing-scavenging operation is followed by several cleaning stages. The treatment strategy employs the Mill-Float-Mill-Float or MF2 approach where the ore is coarsely milled and floated and the flotation tailings further milled to a finer size and re-floated. Comminution is undertaken in low aspect ratio semi-autogenous (SAG) mills using high-chrome grinding media with typical sequential grind sizes of 60% and 75% passing 74 microns. With such a low BMS, successful flotation recovery of the PGMs relies on the flotation of gangue minerals to stabilize the froth until the very last stages of cleaning. The reagent suite consists of a sodium isobutyl xanthate/sodium isopropyl xanthate-diothiophosphate (SIBX/SIPX-DTP) collector combination, copper sulfate (pyrrhotite activator), a talc depressant carboxymethylcellulose (CMC/guar gum) and a strong frother triethoxybutane (polygylcol or TEB). The process water is saturated with calcium and is high in magnesium with a pH of around 9, which is not ideal conditions for pyrrhotite recovery.

A Merensky Reef final concentrate has a grade of 130-150 g/t PGM, 2-4% Ni ,1.5-2.1% Cu and 5-9% sulfur, with typical flotation recoveries of 85-90% PGMs, 82-85% nickel and 85% copper (4% mass pull). The bulk of the concentrate is made up of pyroxene containing less than 0.1% chromite.

There are some differences in the equipment and operations employed by the various producers. Where platinum alloys are more abundant, a dedicated flotation circuit is used to produce a metallic PGM concentrate that is sufficiently rich to by-pass the smelter and is sent straight to base-metal refinery (BMR). Some producers adopt a MF1 approach and chase PGM recovery rather than grade, which is only possible when sufficient smelting capacity is available.

The UG2 Reef ores are dominated by chromite, high rhodium, however they are very low in BMS. There are generally more PGM sulfides than in Merensky Reef ores, however they are considerably finer grained (3 to 10 microns). Although the mineralogy is different, a similar approach is used. Due to the fineness of the PGM minerals and their gangue associations, the process flowsheet employs three sequential stages of milling and flotation (MF3), with a final grind size of 80% passing 74 microns. This approach attempts to minimize the over-grinding of the brittle chromite phase, which is exacerbated during classification of the high SG chromite by hydrocyclones. Mainly due to size effects, the liberated PGM minerals float more slowly than the BMS.

Table 4 : Characteristics of Bushveld PGM Ore Types

Characteristic	Merensky Reef	Plat Reef	UG2 Reef
Thickness (m)	0.9-1.2	0.45-0.65	3-90
Grade PGM (g/t)	5-9	3-4	6-7
Grade Ni (%)	0.13	0.36	0.07
Grade Cu (%)	0.08	0.18	0.018
Gangue minerals	50-80% pyroxene 20-40% plagioclase 3-5% chromite 0.5-5% talc	80-90% pyroxene 10-20% plagioclase 3-5% chromite 0.5-3% talc	60-90 % chromite 5-25% pyroxene 5-15% plagioclase 1-5% talc
PGM grain size (microns)	20-150	40-200	3-10
PGM Minerals	30-40% Cooperite (PtS) + Braggite (Pt,Pd)S 10-30 % Kotulskite (PdTe) + Michenerite (PdBiTe) 10-15% Ru phases 5-8% Sperrylite ($PtAs_2$) 3-6% Isoferroplatinum (Pt_3Fe) 3% Au/Ag phases	Moncheite [(Pt,Pd)(Bi,Te]$_2$ - $PtTe_2$) + Merenskyite [(Pd,Pt)(Bi,Te)$_2$ - $PdTe_2$] >> Sperrylite ($PtAs_2$) > Isoferroplatinum (Pt_3Fe) > Braggite (Pt,Pd)S	Cooperite (PtS) > Laurite (RuS_2) > Braggite (Pt,Pd)S > Malanite ($CuPt_{1.5}Ir_{0.5}S_4$) > Isoferroplatinum (Pt_3Fe) > Sperrylite ($PtAs_2$)
PGM analysis			
Pt (%)	59	42	41
Pd (%)	25	46	34
Rh (%)	3	3	9
Ru(%)	8	4	12
Ir(%)	1	0.8	1.9
Os (%)	0.8	0.6	1.7
Au (%)	2.5	3.4	0.4

Various sources

While some PGM recovery is due to the flotation of chromite composites, PGMs associated with silicates are generally lost. Typically, a final concentrate has a grade of 400g/t PGM and 3%Cr_2O_3 (1% mass pull) and a 87+% PGM recovery. This is achieved by carefully managing the entrainment of fine chromite; better PGM metallurgy (1000g/t PGM at 90+% PGM recovery) is possible at 6 to 10% Cr_2O_3 grades.

As noted earlier, the processing methods for UG2 ores is constantly evolving. In order to maximize PGM recoveries, one producer screens the primary mill discharge at 800 microns to produce a High Grade stream (-800 micron fraction with 90% of the PGM in 65% of the mass) and a Low Grade stream for separate treatment. A more holistic approach has been by a new PGM entrant, where bulk mechanised mining is used to produce a heavily diluted ore that is pre-treated by Heavy Media Separation (HMS) to yield a saleable chromite product and feed for the processing circuit. Other producers are exploring the potential of fine milling technologies such as the IsaMill to produce high grade concentrates (>2000 g/t) that can bypass the smelting stage.

The Platreef ore has an equal platinum to palladium ratio and a substantial nickel content. The PGM mineralogy tends to be erratic and the dominant class is Pt-Pd tellurides, followed by the arsenides, alloys and sulfides. While the PGMs are coarser than those in the Merensky Reef ores, the PGM tellurides and arsenides are encapsulated in the silicate gangue. After milling, typically only 70% of the PGMs are liberated. Like the Merensky Reef ore, it is a pyroxenite ore with a similar assemblage of gangue minerals and a similar processing approach is employed. Not surprisingly, oxidized ores are mined from time to time and poor flotation metallurgy is experienced.

In Part 2 of this article, the smelting and refining aspects of the PGM extraction business are reviewed.

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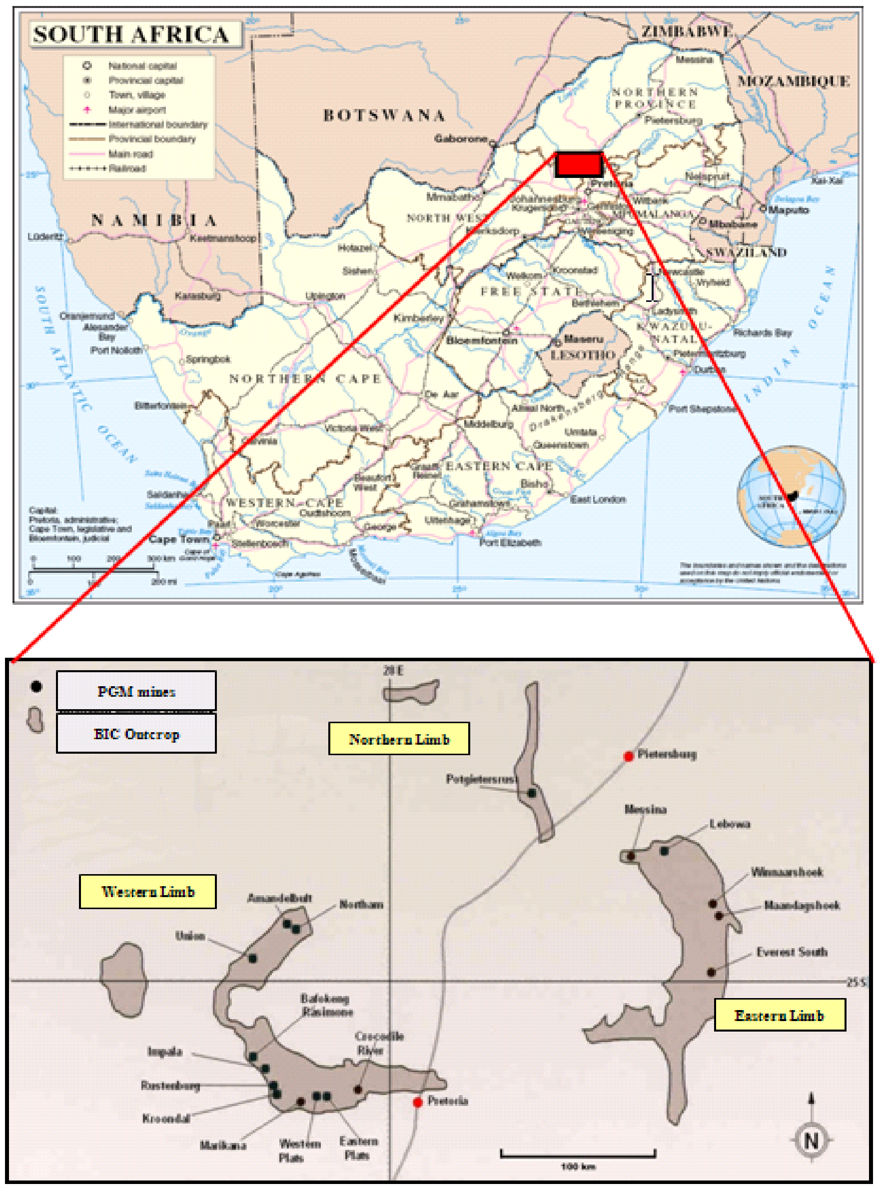

Figure 1 : The Bushveld Igneous Complex

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