9th International Platinum Symposium

AN EXCHANGE OF INFORMATION AND IDEAS ON GEOLOGICAL AREAS OF PLATINUM GROUP ELEMENTS MINERALISATION

By R. G. Cawthorn

Department of Geosciences, University of the Witwatersrand, PO Wits, 2050, South Africa

The geological community has been hosting International Platinum Symposia since 1971, the first being held in Melbourne, Australia. Since then Denver, U.S.A.; Pretoria, South Africa; Toronto, Canada; Espoo, Finland; Perth, Australia; Moscow, Russia; and Rustenburg, South Africa, have hosted the event at intervals of approximately four years. Over the years the number of delegates has increased by a factor of four (in exact proportion to the quantity of platinum group elements (PGEs) mined and the price of platinum), with over 200 people attending the latest, the 9th International Platinum Symposium, held in Billings, Montana, U.S.A., in July 2002. The venue was conveniently placed for excursions to the Stillwater Complex, a classic layered intrusion hosting major palladium reserves, exposed in the Beartooth Mountains in Montana.

The delegates to these symposia come from academic, exploration, mining and government organisations, probably in that relative order in terms of numbers. At this meeting most areas of the world were represented, with the exception of Australia, which was rather surprising because considerable exploration for PGEs is underway there. These meetings are primarily intended for the exchange of geological information and ideas, with less emphasis on mining, metallurgy, and extraction. Presentations generally range from documentation of exploration target areas, through the identification of assemblages of platinum group minerals in different deposits, and geochemical information and techniques, to ideas on the genesis of such mineralisation and identification of concepts aiding future exploration programmes.

Areas in which PGE mineralisation were documented included the U.S.A., Canada, Brazil, India, U.K., Finland, Russia, China, Zimbabwe and South Africa, but many of these were only of academic interest, since at this stage they host no significant grades above 1–2 g t^{-1}. However, they illustrate the type of host rocks in which mineralisation may occur, and the processes by which mineralisation was concentrated. There are several rock associations that host PGE occurrences: layered intrusions, concentric intrusions, brecciated rocks related to intrusions, ophiolite complexes, komatiites, meteorite impacts, and alluvial deposits.

Not mentioned at this meeting were the large tonnages, but very low-grade, occurrences found in mud rocks formed under oxygen-free conditions at the bottom of inland seas. However, in these the grades are extremely low and it is unlikely that they will be exploited. These different settings and processes are briefly summarised.

Intrusions

Layered intrusions form from the slow cooling of large volumes of lava or (more precisely from its underground equivalent) magma. Layers of crystals of different compositions (mainly of non-economic minerals) are deposited by this process, and extensive thin, parallel layers form that can be easily traced laterally. Examples, are the Bushveld (South Africa), Stillwater (Montana) and Great Dyke (Zimbabwe) intrusions, that may have one or two highly PGE mineralised layers. In other cases the underground magma did not form parallel layers of rocks, but produced a pipe-like body (like a volcanic feeder pipe), and each eruption produced a discrete concentric cylinder of rock. Several such PGE-bearing intrusions occur in the Urals in Russia.

There is another potential zone of mineralisation in layered intrusions. The heat from such magmas causes melting of the underlying rocks and reaction between the magma and the rocks in the floor can cause mineralisation, especially of nickel and copper, but PGEs may be a byproduct. This mechanism has produced the major palladium reserves at Noril'sk in Russia.

Igneous intrusions are always associated with much heated groundwater (as seen in natural geysers). The steam can react with low-grade mineralised intrusions and concentrate the PGEs into hydrothermal (literally hot water) deposits. The steam and later intrusions permeate through, and break up the original rocks into fragments (called breccias), and in that way can leach the PGEs from the original rocks to deposit them in high-grade areas. The Lac des Iles palladium-rich body in Canada is such an example.

Ophiolite Complexes

Lavas originate from deep inside the earth, in a part called the mantle, which lies at least 35 km below the surface of the earth. Low concentrations of PGEs occur in such mantle rocks. Usually these rocks never reach the surface. However, where continents are crushed together in mountain-building events (such as the Himalayas, Alps, Rockies and Urals) slices of mantle rock can be thrust up to the surface. These rocks are called ophiolites and are distinctive compared to surrounding rocks. They have been extensively explored since very minor concentrations of PGEs are found in them.

One of the characteristic rocks containing PGEs in an ophiolite is chromite, and while these bodies have been extensively investigated worldwide, none has yet proved economic. The continued interest in them possibly arises from the fact that the single largest resource of PGEs in the world is a layer of chromite in the Bushveld Complex (1), called the Upper Group 2 (UG-2) chromitite layer.

Komatiites

A relatively minor occurrence of PGEs lies at the base of lava flows, especially extremely ancient lavas known as komatiites. In these settings, molten lava has eroded a channel down the flanks of the volcano, and precipitated nickel-copper sulfides in which the PGEs are a minor commodity. Although these bodies can contain high grades of nickel, the tonnages and grades of PGEs, as mined in Canada and Western Australia, are relatively small.

Meteorite Impacts

Early in earth's history, numerous meteorites impacted the earth, and caused massive melting of the rocks on the surface. One such example, at Sudbury, Canada, produced a huge bowl-shaped mass of molten rock in an area where considerable copper, nickel and PGE mineralisation was already present. This mineralisation became concentrated in the molten rock and eventually produced the major deposits at the bottom of the bowl now being exploited at Sudbury.

Alluvial Deposits

Weathering of PGE-bearing rocks can produce secondary enrichment in the overlying soils or river systems. The PGEs are extremely dense minerals and also inert (not altered by surface processes). Hence, they become concentrated in soils and rivers, while all the other minerals are decomposed or washed away because of their lower densities. In this way a low-grade occurrence of PGE mineralisation may be upgraded in river systems. (Gold is also concentrated by this same process.) Such deposits are called alluvial deposits. The first platinum ever found, in South America, was concentrated by this process, but no high-grade source rock has ever been found there. In Russia considerable mining and exploration is being undertaken for such occurrences. Since they lie at the earth's surface it is unlikely that enormous deposits have escaped detection by the prospectors' pans.

The statement that the PGEs are inert is not absolutely correct. Under certain conditions extremely small concentrations can be dissolved in very corrosive heated groundwater systems. These concentrations can then be deposited when the water cools or is neutralised by mixing with fresh water. Clay minerals may adsorb the precipitating PGEs, and in ancient black mud-rocks in Europe extremely low concentrations (totally uneconomic) of PGEs have been reported. (This is the old Kupferschiefer, mined in central Europe for copper in the Middle Ages.)

Examples of all these rock types were documented at the 9th Internetional Platinum Symposium, and several examples from different parts of the world were reported on for the first time. In other cases, exploration programmes and academic studies on the origin and extent of known mineralisation were documented. There are still many challenging aspects as to how economic deposits of PGEs become concentrated, and exploration programmes are obviously influenced by such hypotheses, since each hypothesis makes certain predictions about what kinds of rocks, and especially their detailed chemical compositions, are the best pathfinders or fingerprints for mineralisation. For example, the PGE deposits in the Merensky Reef and the UG-2 chromitite in the Bushveld Complex, the J-M Reef in Stillwater and the Great Dyke, all occur in the middle of very large layered intrusions. One school of thought is that the mineralisation rains downward from the overlying magma and accumulates into a layer of crystals, like the well-known placer theory for gold mineralisation. An alternative view is that hot water systems dissolve the PGEs present in very minor concentrations from low down in the intrusion and precipitate the mineralisation in these reefs as the heated water percolates upward (like blotting paper sucking spilt wine from a tablecloth). Exploration strategies would then differ, depending upon which process was considered applicable in a certain area.

New Areas of Exploration Activity

By this stage readers are doubtless asking whether there are any new areas of exploration activity that might lead to future economic deposits. The answer is that there is probably nothing very new. The exploration in Finland that has been ongoing for twenty years has indicated multimillion ton resources in a few different intrusions and settings, and regional exploration is probably evolving more to feasibility studies and financial evaluation. Establishing continuity of grades and extraction processes is now occupying centre stage.

Lagging somewhat behind the Finnish progress is the exploration of the enormous intrusion in Duluth, Minnesota. This intrusion has been shown to have very large quantities of mineralisation, mainly of copper and nickel with minor PGEs, fairly near to the floor contact. However, this mineralisation is diffuse and variable in grade. Tonnages could be enormous, but grades are generally elusively low. Identification of specific open-pit or underground mining targets is still awaited.

In Ontario and Minnesota, there are a number of small intrusions, which have tantalising concentrations of PGEs. The general impression seems to be that broad zones (more than 10 m wide) of mineralisation at 1.5 to 2 g t^{-1} might be amenable to open-pit operations, but that thin (less than 2 m wide), high-grade (Merensky Reef-style) mineralisation, accessible only by underground mining is not likely to be identified there.

There was no mention at this meeting of some other exploration regions. The Muskox intrusion in the Canadian Arctic may have Duluth-style or Platreef-style (Bushveld) mineralisation (depending upon how bullish you want to be). In Australia, there are also a number of layered intrusions in which PGE mineralisation is known and currently being examined.

Extraction Challenges

Exploration for PGEs has an inordinately long lead time. One of the reasons is that the relative proportions of the different PGEs can be very variable, and an extremely wide range of platinum group minerals might be present. Given their exceptionally low abundance, determining the proportion of these minerals, and especially their intergrowth with various gangue minerals is challenging but fundamental to successful extraction.

It is this extremely complex relationship between the different platinum group minerals and the wide variety of gangue minerals that is causing the apparent extraction problems encountered by the Stillwater mines. The greater age of the Stillwater intrusion and the subsequent events that have faulted and altered the rocks and their mineralogy, compared to the Bushveld Complex, have caused mining and extraction problems. To the great relief of South African Bushveld mining companies, no other area or example better typifies the statement that 'grade isn't everything'.

It is for these reasons that many papers presented at the conference focused on documentation of the platinum group mineralogy in a great many different settings. Dealing with grains, typically about 0.001 cm across, and present at grades of 2 g t^{-1}, is an extremely challenging occupation. Academic studies presented on such minerals provide information on how the PGEs could be initially concentrated in the rocks, and by contrast, their counterparts in exploration are intent on getting them back out again!

A Global Inventory

The section above indicates that there are unlikely to be any changes in worldwide PGE production in the short term. In an address at the meeting, the Director of the U.S. Geological Survey, Dr Charles G. Groat, had two themes. His first observation was aimed largely at those people who suggest that oil deposits are running out. He pointed out that commodities were not necessarily running out, it was simply that a global inventory was not available, but that with a global village mentality there would always be suppliers. Second, and arising from this view, was the decision that the U.S. Geological Survey would be conducting a a cooperative international global programme to assess the undiscovered nonfuel mineral resources, and that platinum would be among the first group of commodities to be assessed. This plan is ambitious, and a comprehensive evaluation is expected to take seven to ten years.

This writer feels that the first conclusion should be applied with some caution to the platinum market. There is no other commodity in the world that remotely matches the PGEs for their uneven worldwide distribution. However quickly new targets are identified and brought to fruition, their contribution will be minor compared to the Bushveld Complex (2) and Noril'sk areas. No other commodity is so dominated by so few suppliers. Given the reserve and resource figures currently available, the Bushveld (mainly platinum) and Noril'sk (mainly palladium) areas will continue to supply 80 to 90 per cent of the world's platinum and palladium for the foreseeable future.

The 10th symposium in this series is expected to take place in Finland in 2006. It will then be interesting to see how far towards viable commercial operation some of the sources mentioned at the 9th symposium will have come. The conference website is www.platinumsymposium.org.

References

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2 R. G. Cawthorn, *S. Afr. J. Sci.*, 1999, 95, (11/12), 481

Addendum

Geologically inclined readers may wish to obtain a recent summary of PGE deposits worldwide, "The Geology, Geochemistry, Mineralogy and Mineral Beneficiation of Platinum-Group Elements", edited by L. J. Cabri, (Special Volume 54), Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, 2002; website: www.cim.org.

The Author

Grant Cawthorn is the Platinum Industry's Professor of Igneous Petrology at the University of the Witwatersrand, South Africa (E-mail: 065rgc@cosmos.wits.ac.za). His main interests are researching the origin of layered intrusions and their varied mineral deposits.

Recyclable Ruthenium-BINAP Catalysts

Ryoji Noyori has been involved in asymmetric homogeneous hydrogenation for over thirty years. His work in this important area has resulted in catalysts with high selectivity and wide application (T. J. Colacot, *Platinum Metals Rev.*, 2002, 46, (2), 82–83). Among catalysts he has helped to develop is Ru-BINAP, (BINAP = 2,2′-bis(diphenylphosphino)-1,1′-binaphthyl) which, as Ru(II)-BINAP dihalide complexes, provides a versatile general asymmetric hydrogenation of functionalised ketones.

Now, scientists from China have synthesised dendritic Ru-BINAP catalysts that are peripherally alkyl-functionalised (G.-J. Deng, Q.-H. Fan, X.-M. Chen, D.-S. Liu and A. S. C. Chan, *Chem. Commun.*, 2002, (15), 1570–1571). These catalysts can be used for asymmetric hydrogenation in an ethanol/hexane reaction medium. Acids: 2-arylacrylic, 2-phenylacrylic and 2-[*p*-(2-methylpropyl)phenyl]acrylic used for model reactions had high catalytic activity and enantioselectivity. Phase separation was induced by adding a small amount of water. The hexane catalyst-containing layer can be removed for reuse.