

11th International Platinum Symposium

“PGE in the 21st Century: Innovations in Understanding Their Origin and Applications to Mineral Exploration and Beneficiation”

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Every few years an International Platinum Symposium is organised to provide a forum for discussion of the geology, geochemistry, mineralogy and beneficiation of major and minor platinum group element (PGE) deposits worldwide. The theme of the 11th International Platinum Symposium, which took place in Sudbury, Canada, from 21st–24th June 2010 (1), was “PGE in the 21st Century: Innovations in Understanding Their Origin and Applications to Mineral Exploration and Beneficiation”.

Participants from mining and exploration companies, geological surveys, consulting companies and universities on all continents attended to listen to 85 papers and read 54 posters. Such meetings normally take place every four years although it is five years since the previous meeting in Oulu, Finland in 2005, with a smaller interim meeting held in India. The organisation was impeccable throughout, for field trips, poster sessions, the social programme and the main conference. The committee was led by Professor C. Michael Lesher (Laurentian University, Canada), Edward Debicki (Geoscience Laboratories, Canada), Pedro Jugo (Laurentian University), James Mungall (University of Toronto, Canada) and Heather Brown (Ontario Geological Survey, Canada). Sudbury proved an excellent venue, a mining town that has developed into a pleasant tree-rich area that has overcome all the earlier issues of environmental degradation.

Delegates were told in an overview of the global pgm industry that the Bushveld Complex in South Africa and the Norilsk deposit in Russia together account for roughly 90% of newly mined platinum and 85% of newly mined palladium supply. The Stillwater Complex in the USA is a significant source of palladium but not platinum, while the Great Dyke in Zimbabwe offers the possibility of significant expansion (**Figure 1**). Russian stockpiles of palladium are thought to be nearly exhausted, but recycling is growing rapidly to become another dominant source of supply. Demand for platinum, palladium and the

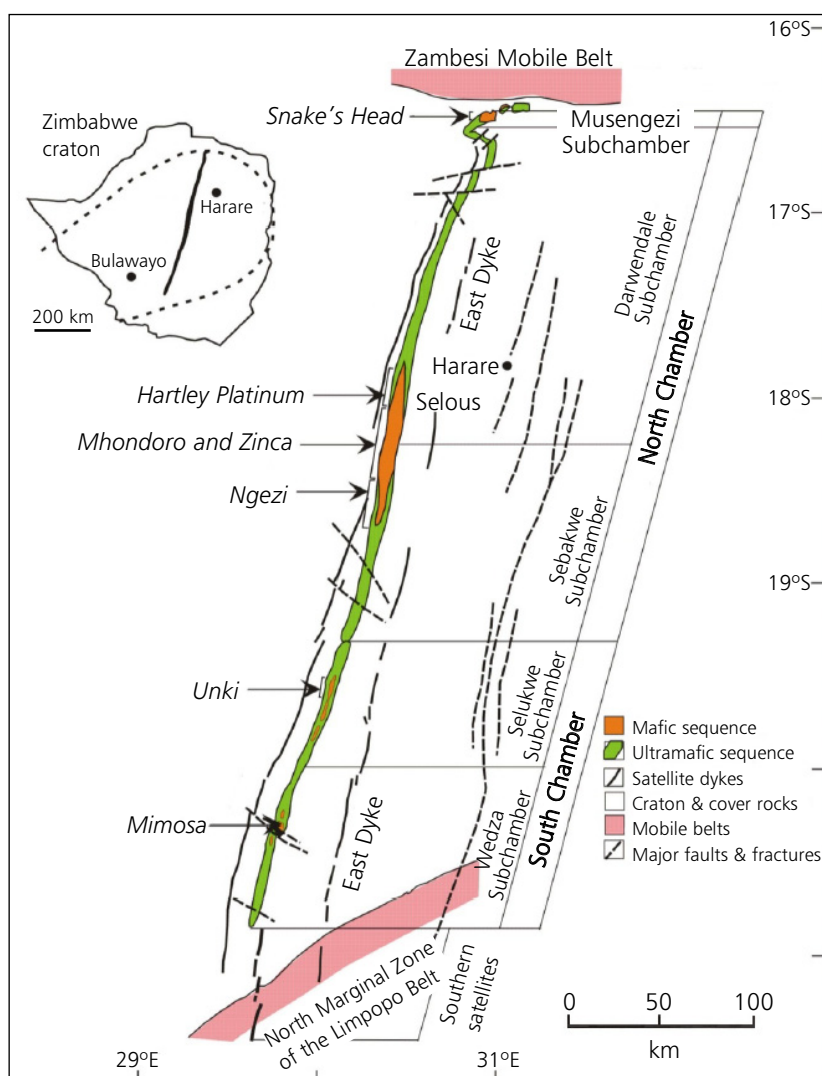


Fig. 1. Large-scale map of the Great Dyke in Zimbabwe, showing major lithological subdivisions and areas of current exploitation. The Great Dyke is the largest resource of platinum outside the Bushveld Complex of South Africa. Its size has encouraged active exploration and mining, and in 2010 there were three major mines in operation and several intensive exploration initiatives (Courtesy of A. H. Wilson and A. J. du Toit, from 'Great Dyke Platinum in the Region of Ngezi Mine, Zimbabwe: Characteristics of the Main Sulphide Zone and Variations that Affect Mining', 11th International Platinum Symposium, Sudbury, Ontario, Canada, 21st–24th June, 2010)

other pgms is expected to grow strongly, however, and new deposits of PGEs are of interest as possible sources of future supply. It is therefore interesting that the PGEs attract just 2% of overall global exploration spending, which is focused on Africa, Canada and Russia.

It was therefore not surprising that several recent discoveries of deposits of PGEs around the world were discussed at this meeting, with much progress made towards understanding their geological origins and their potential for exploitation as future ore bodies. Existing deposits were also discussed, but data on grades were sometimes lacking, and data were presented as tenors (i.e. the grade calculated in 100% sulfide only). Other studies focused on experimental

measurements, analytical techniques and results, new geochemical criteria for the identification of PGE-enriched deposits, characterisation of platinum group mineral assemblages and the processes that extract platinum from ore.

Papers of particular interest have been collated and summarised below, according to geographical region. All abstracts are available on the conference website (1). It is important to note that there are six platinum group elements (PGEs): platinum, palladium, rhodium, iridium, osmium and ruthenium. Geologists use the term 'PGM' to mean platinum group minerals as the PGEs occur in minerals rather than metallic form in natural deposits, whereas metallurgists use 'pgm' to mean platinum group metals.

Southern Africa

The opening day of the symposium focused on South Africa's Bushveld Complex and Zimbabwe's Great Dyke, as is fitting for the largest producers of platinum. For the Bushveld, chromitite layers were described from at least six cyclic units of ultramafic Lower Zone in the northeastern limb, that have previously been regarded as Marginal Zone but no platinum grades were given. Profiles of PGEs through chromitites in the layered mafic-ultramafic suite showed that platinum per unit metre through the complex was highest in the north west. The atypical stratigraphic sequence of the 'contact-type' basal nickel-copper-PGE mineralisation of the satellite Sheba's Ridge at the western extremity of the eastern limb is unique with discontinuous UG2 Reef and Merensky Reef analogues above a basal 'Platreef'-style sulfide-rich ore body with grades of <2 parts per million (ppm) Pt and <2.5 ppm Pd and a Pt:Pd ratio typically ~0.5, in contrast to the UG2 and Merensky Reefs of the western and eastern limbs where platinum exceeds palladium. This ratio is similar to that for the composite Platreef of the northern limb, which is up to 500 m thick. The Platreef also does not correlate closely with the Merensky Reef although the Platreef was shown to be the same age.

In the Great Dyke of Zimbabwe, PGEs are contained in the stratiform Main Sulphide Zone near the top of the ultramafic succession. In this zone there is a consistent pattern of a lower Pd-enriched subzone (Pt:Pd ratio of 0.7:1) with Pd <2 ppm and an upper Pt-enriched subzone (Pt:Pd ratio of 2.5:1) with values of Pt up to 4 ppm, which are separated by a narrow transition zone.

North America and Canada

The Midcontinent Rift in North America, which has been known for its undeveloped low-grade disseminated deposits, may become the next major Cu-Ni-PGE mining district as several new, higher-grade discoveries have been made which together have *in situ* metal values over US\$325 billion. The bulk of these resources have been discovered in or near the Duluth Complex in northeastern Minnesota, USA, and include the following:

- The Nokomis deposit: a large, PGE-rich disseminated sulfide deposit with a reported estimate of 5 million ounces of Pt and nearly 10 million ounces of Pd;
- The Current Lake Complex near Thunder Bay in Ontario, Canada: a Pt-rich disseminated to

net-textured sulfide deposit. Disseminated Cu-Ni-Pt-Pd sulfide mineralisation is hosted within a tubular to tabular magma conduit with local high grade zones (4.5 ppm Pt, 4.3 ppm Pd, 1.0% Cu and 0.6% Ni) and 14 m of higher-grade net-textured and massive sulfide near the base of the intrusion which averages 16.2 ppm Pt, 13.9 ppm Pd, 3.5% Cu and 1.2% Ni;

- The Eagle deposit in Michigan: a high-grade massive to net-textured ore body with a reported resource estimated at 4.05 megatonnes (Mt) at an average grade of 0.73 ppm Pt, 0.47 ppm Pd, 2.9% Cu and 3.57% Ni;
- The Tamarack deposit in Minnesota: similarly a high-grade massive to net-textured ore body.

All these deposits have higher Pt:Pd ratios (commonly $\geq 1:1$) than the 'typical' Duluth Complex disseminated deposits (where ratios are typically $\leq 1:2$). Such discoveries, which are regarded as analogous to Norilsk in Russia, have led to significant exploration in the region for similar conduit-style ores.

In ancient Archaean rocks of northern Ontario, the recently discovered Eagle's Nest Ni-Cu-PGE mineralisation is interpreted as a feeder conduit beneath an extensive complex of sills and related volcanic rocks with pools of massive sulfide at or near the lower contact. The Archaean Blackbird chromite-bearing sill found in the James Bay Lowlands in 2008 is a sill-hosted chromite deposit analogous to the Kemi deposit in Finland. The chromitites have no sulfides, and PGE grades are low.

Canada's East Bull Lake intrusive suite hosts several contact-style Cu-Ni-PGE occurrences within several of the larger intrusions, most notably in the River Valley area. Grades of up to 25 parts per billion (ppb) Pt and 33 ppb Pd were described for some of the intrusions.

The West Raglan Ni-Cu-PGE project, in the early Proterozoic Cape Smith Fold Belt of northern Quebec, hosts several economic Ni-Cu-PGE sulfide deposits (such as Xstrata's Raglan deposits) and several more recent discoveries (Goldbrook Ventures' Mystery prospect and Canadian Royalties' Mesamax deposit, for example). Nickel sulfide deposits are spatially associated with mafic-ultramafic sills and intrusive complexes. Since 2003, drilling of the Raglan trend has identified several discrete mineralised lenses at West Raglan which include a 36.43 m interval at a grade of 2.54 ppm PGEs, 1.1% Cu and 2.66% Ni.

The PGE deposits of the Lac des Iles Complex in Canada (the Roby, Twilight and High-Grade Zones) differ from most other PGE deposits as they occur in a small, concentrically-zoned mafic intrusion rather than in a large layered intrusion and the ore zone is ~900 m by 700 m in size and open at depth rather than thin and tabular. Pentlandite controls 30% of whole-rock palladium, the rest is present as PGMs.

In spite of more than a century of mining in the Sudbury district of Canada, new discoveries are still being made. The principal styles of Cu-Ni sulfide mineralisation that have been mined are:

- (a) in the Sublayer at the lower contact of the Sudbury Igneous Complex;
- (b) in quartz diorite Offset Dykes (with grades of <10 ppm Pt and <10 ppm Pd); and
- (c) the Froid-Stobie Breccia Belt.

However, in the past 20 years, there has been a progressive shift towards mining footwall deposits that are enriched in Cu, Ni and PGEs. The recently recognised 'low-sulfide' Cu-Ni-PGE systems represent the most Pt- and Pd-enriched mineralisation type within the footwall in the North and East Ranges of the 1.85 Ga complex (**Figure 2(a)**). When present, mineralisation is generally peripheral to footwall deposits and can also occur in the footwall immediately adjacent to Cu-rich portions of the offset ore bodies. The newly-discovered Capre 3000 mineralised zone in the East Range has PGE abundances similar to other North Range footwall vein-style systems. These are associated with sulfides at a brecciated contact between granite and gneiss. In the South Range, the 109 FW Zone low-sulfide deposit is a new discovery in the footwall of the Crean Hill Mine adjacent to a previously exploited contact sulfide deposit (**Figure 2(b)**).

Russia and Northern Finland

The Kemi intrusion in northern Finland hosts the largest economic chrome deposits outside the Bushveld Complex but PGEs are low in abundance, with a maximum combined Pt and Pd grade of <50 ppb and typical grades ranging between about 20–30 ppb in the lower half and <10 ppb in the upper half of the intrusion. By contrast, the Kievev ore body in the Fedorovo-Pansky layered mafic intrusion of the Kola Peninsula in Russia has a combined Pt, Pd and Au grade varying from 0.8 ppm to 18.2 ppm (Pd:Pt = 6.7) with an average Cu grade of 0.15% and Ni grade of 0.13%.

New information on the geology and PGE mineralisation of two other intrusions of the Kola region was presented. The Volchetundra layered mafic intrusion is 40 km long and 2–4 km wide, with marginal and irregular sulfide-rich lenses in the steeply-dipping eastern contact zone. These are up to 30 m thick with PGE grades ranging from 0.1–3.7 ppm (typically 0.1–0.3 ppm) and Pd:Pt ratios from 2–5, although sulfide-rich pods with higher-grade (up to 5 ppm) PGEs have been delineated. In addition, reef-type mineralisation in layered gabbro-gabbronorite of the Main Zone is 1–18 m thick, with low to no sulfides, PGE grades from 2–20 ppm and Pd:Pt ratios of 0.4–1. The lenticular shaped Monchatundra layered intrusion extends over almost 500 km² and ranges in composition from dunite to anorthosite. The 'Frequently Interlayered Zone' within the mafic-ultramafic part of the intrusion has disseminated sulfides (usually 0.5–2%, but locally up to 30%) and PGE mineralisation. The zone varies up to 130 m in thickness but the ore-bearing interval ranges from 0.3 m to 42 m, typically between 3 m and 18 m. The PGE grade varies between 1.5–3.5 ppm with Pd:Pt ratios of 1.5–3.

Several papers reviewed aspects of the world class Cu-Ni-PGE deposits of the Norilsk mafic-ultramafic intrusions in Siberia. All important resources are concentrated in three intrusions: the Talnakh, Kharaelakh, and Norilsk 1 (Krivolutskaya) massifs. The newly-discovered Cu-Ni-PGE Maslovskoe deposit in the north of the Norilsk Trough comprises a Northern intrusion which is very similar to the Norilsk 1 massif and may be a southwest branch, and a separate Southern Maslovskoe intrusion. Both massifs contain disseminated ores and veins and belong to the Norilsk Intrusive Complex. The veinlet-disseminated ores of the Northern Maslovskoe deposit are enriched in up to 25 ppm PGEs.

China

The Jinchuan nickel-copper deposit is the third largest magmatic sulfide deposit in the world. It occurs in a small, dyke-like ultramafic intrusion (6500 m × 400 m × 1100 m) in the western margin of the Northern China Craton. Mineralisation is disseminated, net textured or massive according to sulfide content. PGE abundances are given in **Table I**.

Brazil

Several favourable settings for Ni-Cu-PGE deposits in Brazil include numerous large layered intrusions

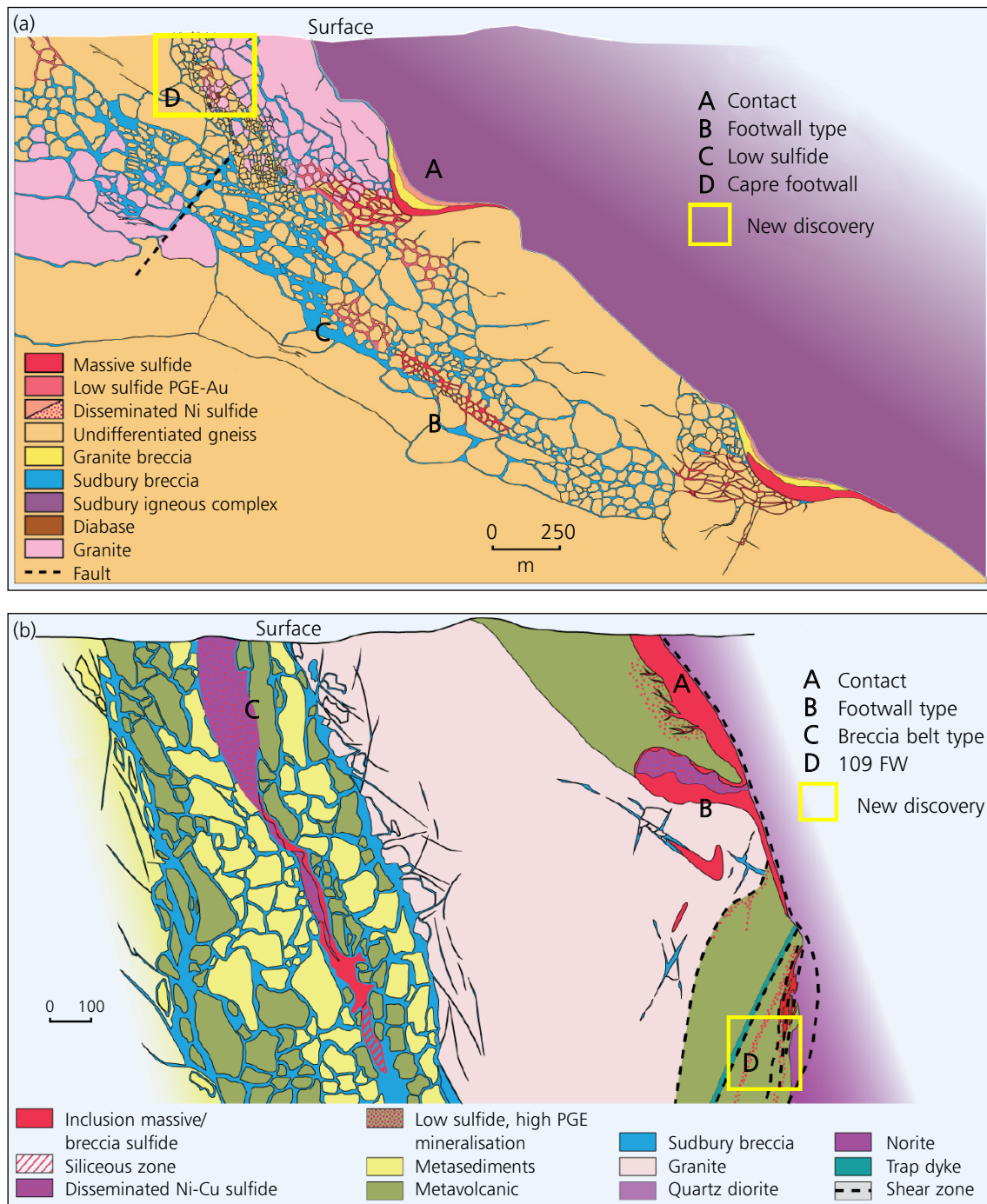


Fig. 2. Composite cross-sections of typical geological settings for Footwall Deposits of PGEs and sulfide in the Sudbury Igneous Complex, Canada, in (a) the North and East Range and (b) the South Range (Courtesy of P. C. Lightfoot and M. C. Stewart, from 'Diversity in Platinum Group Element (PGE) Mineralization at Sudbury: New Discoveries and Process Controls', 11th International Platinum Symposium, Sudbury, Ontario, Canada, 21st–24th June, 2010)

Table I

Platinum Group Element Abundances of the Jinchuan Deposit in China

Ore type	Platinum grade, ppb	Palladium grade, ppb	Rhodium grade, ppb	Iridium grade, ppb	Ruthenium grade, ppb
Disseminated	35.8–853	74.8–213	2.5–19.5	5.1–38.5	4.2–33.1
Net-textured	12.7–1757 ^a	171–560	0.7–5.1	0.4–4.0	1.5–3.5
Massive	11.6–102	218–1215	78.1–201	211–644	91–553

^aOne exceptional occurrence of 3343 ppb

in cratonic areas, several clusters or lineaments of mafic and mafic-ultramafic intrusions where feeder dykes and the lowermost parts of layered intrusions are exposed, a continental-scale province of flood basalts, and several areas of extensive komatiitic magmatism in Precambrian greenstone belts. The Fortaleza de Minas komatiite-hosted Ni-Cu deposit is quoted as an estimated resource of 6 Mt at grades of 0.7 ppm combined Pt, Pd and Au, 0.4% Cu and 2.5% Ni. The layered mafic-ultramafic lithologies of the Tróia Unit of the Cruzeta Complex in north-eastern Brazil have been the focus of platinum exploration for more than 30 years. Local chromitite horizons, 0.3 m to 3 m thick, contain up to 8 ppm Pt and 21 ppm Pd.

Other Occurrences

Komatiite-hosted Ni-Cu deposits with PGEs from Australia and Canada were discussed. PGE-bearing chromitites from eastern Cuba and elsewhere were described. Data from the Al'Ays ophiolite complex in Saudi Arabia have shown that podiform chromitites with high PGE concentrations (above 1.4 ppm) also have distinctive minor element concentrations that provide an improved fingerprint for further exploration. The Ambae chromites of the Vanuatu Arc in the south-west Pacific have grades of 75.8 ppb Rh, 52.1 ppb Ir, 36.8 ppb Os and 92.6 ppb Ru, whereas Pd, Pt and Au are below the detection limit. These values account for 56% of the Ir, over 90% of the Ru and 22% of the Rh present in the Ambae lavas. Reconnaissance studies of the PGEs potential of four chromite mining districts in southern Iran showed that chromites have concentrations of 6 PGEs (combined Pt, Pd, Rh, Ir, Os and Ru) from 57 ppb to 5183 ppb with an average of 456 ppb.

New Discoveries

New Cu-Au-PGE mineralisation was reported from the Togeda macrodyke in the Kangerlussuaq region of East Greenland. A metasediment-hosted deposit from Craignure, Inverary, in Scotland hosts sulfide mineralisation with PGE concentrations locally exceeding 3 ppm and, although small, this raises the possibility of other metasediment-hosted Ni-Cu-PGE mineralisation in Scotland. Amphibolites and their weathered equivalents on the northwest border of the Congo Craton in South Cameroon have a PGEs plus Au content of 53 ppb to 121 ppb. The Pd:Pt ratios are ~ 3. Ni-Cu-PGE mineralisation was described from the Gondpipri area of central India but Ni and Cu dominate and PGE content is low.

Process Mineralogy in the Platinum Industry and Future Trends

This was perhaps a new topic for these events. Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) mapping provides critical information on the distribution of the PGEs in and around magmatic sulfides and is useful in characterising PGE deposits. As an example of the insights that can be gained with this technique, new data for samples from the Merensky Reef and Norilsk-Talnakh show that the behaviour of Pt is very different from that of Pd and Rh, which are generally hosted by pentlandite. Pt often forms a plethora of discrete phases in association with the trace and semi-metals. The variable distribution of these phases has implications for geometallurgical models and PGE recoveries.

While the PGEs are most often concentrated in sulfide minerals such as pyrrhotite, pentlandite and chalcopyrite, there were several reports at the

symposium of pyrite hosting appreciable amounts of Rh and Pt. Pyrite from the McCreedy and Creighton deposits of Sudbury has a similar Os, Ir, Ru, Re (rhenium) and Se (selenium) content to that of coexisting pyrrhotite and pentlandite, whereas Rh (at up to 130 ppm), arsenic (up to 30 ppm), Pt and Au show a stronger preference for pyrite than for pyrrhotite or pentlandite. In the Canadian Cordilleran porphyry copper systems, up to 90% of the Pd and Pt in mineralised samples occurs in pyrite.

Concluding Remarks

With reports of a number of new discoveries alongside much new information on existing resources, the 11th International Platinum Symposium provided the industry with the most comprehensive overview yet of platinum group element deposits worldwide. While many of these deposits have relatively low grades of PGEs, they may still prove to be viable and valuable sources of pgms in the future. Exploration efforts are also expected to become more efficient as a greater understanding of the geological

process behind the formation of PGE deposits is gained.

Reference

- 1 The 11th International Platinum Symposium at Laurentian University: <http://11ips.laurentian.ca/Laurentian/Home/Departments/Earth+Sciences/NewsEvents/11IPS/> (Accessed on 7th January 2011)

The Reviewer



Judith Kinnaird is a Professor of Economic Geology at the School of Geosciences at the University of the Witwatersrand, South Africa, and Deputy Director of the University's Economic Geology Research Institute (EGRI). Her research interests include Bushveld Complex magmatism and mineralisation especially of the Platreef in the northern limb, while her research team is currently conducting studies on chromitite geochemistry, mineralogy and PGE grade distribution; tenor variations; zircon age-dating; Lower Zone mineralogy and geochemistry of the Bushveld Complex in South Africa.