Lowe, S. 2013. Potential for magmatic Nickel-Copper-Platinum Group Element deposits (Ni-Cu-PGE) in northern Guyana. *Caribbean Journal of Earth Science*, **46**, 43-50. © Geological Society of Jamaica. Available online 5th November 2013.

Potential for magmatic Nickel-Copper-Platinum Group Element deposits (Ni-Cu-PGE) in northern Guyana

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ABSTRACT. The assessment of undiscovered mineral deposits poses special problems, especially in a country like Guyana where geological and mineral exploration datasets are inadequate. Outside of gold, uranium and a few other economic minerals, little assessment has been done of mineral resources on a systematic and regional basis in Guyana. The demand for national assessments of mineral potential has recently increased in urgency since the country's adoption of a low-carbon/low deforestation development strategy under the UN's Reduced Emission from Deforestation and Forest Degradation (REDD+) initiative. As mining is seen as a significant contributor to deforestation and degradation, support for its continuation as a major land use will depend largely on its actual and projected economic value to the nation. Much of Guyana's potential mineral wealth remains undiscovered due poor accessibility within the rainforests and a thick weathering profile. Therefore, an assessment of its value based on current mine production (particularly, of gold) is likely to severely undersell mining as a main contributor to the future economy. This paper seeks to assess this undiscovered mineral potential, in particular for magmatic Cu-Ni-PGE deposits in northern Guyana. Given the insufficiency of detailed geological data, a qualitative approach is employed. The methodology involves three steps: (i) selection of suitable descriptive deposit models for magmatic Ni-Cu-PGE deposits, (ii) identification and/or delineation of regions geologically permissive for such mineralization, (iii) within each region, a qualitative assessment of the extent to which components of the deposit models match ground features identified from available geological and exploration data. The large number of favorable geological conditions strongly suggests a high probability of occurrence of this important deposit class in northern Guyana.

Key words: mineral resource assessment, Guyana, Ni-Cu-PGE deposits, low carbon, mining.

1. INTRODUCTION

Magmatic Ni-Cu sulphide and PGE deposits are a broad group of deposits containing nickel, copper, and platinum group elements (PGE) associated with a variety of mafic and ultramafic magmatic rocks. These deposits provide most of the world's Ni and contain substantial reserves. In terms of PGEs, these deposits are the source of essentially all of the world output (Eckstrand and Hulbert, 2007). Worldwide exploration for PGEs remains fairly strong, averaging just over US$215m in 2010 (Metals Economic Group, 2011).

Several occurrences and anomalies of these deposit types exist in Guyana, the most prominent occurrence being associated with the ultrabasic flows or intrusions at Kauremembu in northern Guyana. In addition, the country possesses large tracts that are geologically favourable for such mineralization, though no discoveries with economic potential have yet been made.

2. METHODOLOGY

In assessing the potential for undiscovered deposits of these classes in northern Guyana, the methodology involved three steps: (i) selection of descriptive deposit models for magmatic Ni-Cu-PGE deposits suitable for Guyana, (ii) identification and/or delineation of regions geologically permissive for such mineralization, (iii) within each region, a qualitative assessment or rating of the extent to which components of the deposit models match local geological factors identified from available geological and exploration data.

The paucity of, but slowly increasing, substantive information on Guyana's mineral wealth outside of gold, diamonds, manganese and a few other minerals presents challenges in conducting such mineral resource assessments. In better explored regions worldwide, quantitative (instead of qualitative) assessments have been attempted to provide estimates of the number of undiscovered deposits, their sizes and grades. (e.g., Singer, 2007; Rasilainen et al., 2010). In poorly explored regions, such as northern Guyana, a quantitative approach would be highly speculative. Nevertheless, mineral assessments have become urgently necessary to support decisions on land use policy and to calculate opportunity costs within the low carbon/low deforestation development strategy that Guyana is presently pursuing. Pending more abundant data, qualitative assessments can provide a firmer and more evidence-based understanding of the country's mineral endowment.

3. Descriptive deposit models

On the basis of their principal metal production, magmatic sulfide deposits in mafic rocks can be divided into two major types: (i) those that are sulfide-rich, typically with 10 to 90 percent sulfide minerals, and have economic value primarily because of their Ni and Cu contents. These ores are associated with differentiated mafic and/or ultramafic sills and stocks, and ultramafic (komatiitic) volcanic flows and sills; and (ii) those that are sulfide-poor, typically with 0.5 to 5 percent sulfide minerals, and are exploited principally for PGEs. These are associated with sparsely dispersed sulphides in very large to medium-sized, typically mafic/ultramafic layered intrusions. Layered intrusions are also major hosts of Ni-Cu-PGE, Cr and Fe-Ti-V deposits.

The mafic and ultramafic magmatic bodies that host the Ni-Cu (± PGE) sulphide ores are diverse in form and composition, and can be subdivided into the following four subtypes (Eckstrand and Hulbert, 2007):

- A meteorite-impact mafic melt sheet that contains basal sulphide ores (Sudbury, Ontario is the only known example).
- Rift and continental flood basalt-associated mafic sills and dyke-like bodies (such as Noril'sk-Talnakh in Russia).
- Komatiitic (magnesium-rich) volcanic flows and related sill-like (such as Kambalda and Agnew in Australia).
- Other mafic/ultramafic intrusions (such as Voisey's Bay in Labrador, Canada).

The uniqueness of the first subtype (associated with meteorite impacts) rules out its possible existence in Guyana. Likewise, the third subtype (based in komatiites) is unlikely to be of major importance as such rock types are rare in northern Guyana. The existence of the second and fourth sub-types of Ni-Cu sulphide deposits is more likely and they form one focus of the current study.

For this deposit type, the study used a modified model derived mostly from the USGS Descriptive Model 2b for the Merensky Reef PGE (Cox and Singer, 1986).

PGE-dominant magmatic ores are associated with mafic/ultramafic intrusions. There are two principal subtypes of deposits (Eckstrand and Hulbert, 2007):

- Reef-type or stratiform PGE deposits, which occur in well layered mafic/ultramafic intrusions.
- Magmatic breccia type, which may occur in stock-like or layered mafic/ultramafic intrusions.

For this second deposit type, the study used the deposit model for PGE stratabound mineralization in layered mafic/ultramafic intrusions in the Australian Precambrian, compiled by Hoatson (1998). In both the Ni-Cu sulphide and PGE deposit classes, the chosen models provided descriptive and genetic information on tectonic setting, ore controls, host rocks, mineralogy, geochemical and geophysical signatures among other aspects.

4. Metallogenesis and permissive domains in northern Guyana

The permissive host environments for this broad Ni-Cu-PGE deposit type include areas with mafic and ultramafic flows and intrusives in the northern Guyana. Domains in northern Guyana can be demarcated based on this first-order criterion and then possibly fine-tuned using evidence based on mineral occurrences and geochemical and geophysical anomalies.

Four episodes of mafic magmatism can be identified in northern Guyana (e.g., Gibbs and Barron, 1993; Choudhuri et al., 1990). These four episodes can be equated to four distinct metallogenic epochs and provinces for magmatic Ni-Cu-PGE sulphide mineralization and are, from oldest to youngest:

(i) the mafic/ultramafic flows and intrusions of Guyana's greenstone belts;

(ii) the flood basalts and intrusions of the Avanavero Suite;

(iii) the minor intrusions of PAPA (Post-Avanavero-Pre Apatoe) dykes; and

(iv) the widespread dykes of the Apatoe Suite.

Table 1 shows the stratigraphic positions and ages of the four episodes of basic magmatic intrusions in Northern Guyana. Figure 1 shows their geographic location, and in terms of age, they can be placed in two large groups: (i) those emplaced and metamorphosed during the Trans-Amazonian Episode (2.2 – 1.9 Ga), an event encompassing the entire Guiana Shield, marked by regional metamorphism, deformation, and widespread granitic emplacement; and

(ii) those emplaced in the post-Trans-Amazonian period. This latter group of intrusions is unmetamorphosed.

The first emplacements of magmatic bodies are the mafic and ultramafic intrusions formed during the Trans-Amazonian orogeny. In northern Guyana, these mafic-ultramafic metavolcanics form the

Table 1: Basic stratigraphic column for northern Guyana

ERA	AGE (Ga)	LITHOSTRATIGRAPHIC UNITS		TECTONISM			LITHOLOGY
Cenozoic							
Mesozoic	0.019	Apatoe Suite			TECTONIC STRESSES RELATED TO THE OPENING OF THE ATLANTIC OCEAN		Dolerite dykes
		PAPA dykes					
Paleoproterozoic	1.79	Avanavero Suite				K'MUDKU EPISODE (1.3 – 1.2 Ga)	Basic magmatic Large Igneous Province (LIP). Gabbro-norite sills and dykes
	1.89	Roraima Supergroup					Conglomerate, arkose, orthoquartzite and smaller amounts of shale and tuff with jasper, deposited in fluvio-deltaic and lacustrine environments.
	1.9 – 1.8	Iwokrama Formation	Burro-Burro Group	TRANS-AMAZONIAN EPIDODE			Acid volcanics, volcaniclastics and associated subvolcanic intrusives.
		Muruwa Formation					Quartzose and arkosic sandstones, siltstones and conglomerates of fluviodeltaic origin and minor fine-grained cherty sediments of deeper-water origin.
	2.2 – 1.9	Volcano-sedimentary sequences / Multi-phase or continuous plutonism	Granitoid-greenstone basement				Granites to diorites Low-grade metamorphic metasediments. Felsic- intermediate metavolcanics. Basic and minor ultrabasic metavolcanics.

lower members of three greenstone belts, known in Guyana as the Barama-Mazaruni Supergroup. Gibbs (1980) estimated that 50% of the metavolcanics in the northern Guiana shield is of basaltic composition and 2% of ultramafic composition. Ultramafic rocks are known in over twenty localities in the greenstone belts of northern Guyana (Gibbs and Barron, 1993). Considering that the greenstone belts cover approximately 30,ooo km2 and have a stratigraphic thickness of at least 9 km, mafic and ultramafic rocks are volumetrically very significant in this region (Gibbs, 1980).

A second major pulse of mafic magmatism is related to sills and dykes of the post-Transamazonian Avanavero Suite of Paleoproterozoic (Statherian) age. The Avanavero Suite constitutes the most important Paleoproterozoic mafic magmatism event in the Guiana Shield, northern Amazonian Craton, and is described as a Large Igneous Province (LIP) (e.g., Reis et al., 2012). LIPs are key hosts for Ni-Cu-PGE, Cr and Fe-Ti-V deposits (Ernst and Peck, 2010). Paleomagnetic studies show that there were two pulses of mafic magma in the Avanavero Suite corresponding to 1.80-1.84 and 1.61-1.67 Ga., but there appears to be no geochemical difference between them (Choundhuri, et al., 1990). Using U-Pb dates, Reis et al. (2012) support the two-pulse hypothesis but provide different ages: a first pulse at 1793–1795 Ma and a second pulse at ca. 1780 Ma. Both sets of authors, nonetheless, suggest a short life span for Avanavero magmatism of approximately 15 – 20 Ma.

This short lifespan is significant, as a correlation exists between the mineralization potential of mafic bodies and the number of pulses and duration of the magmatic event.

The sills and the larger dykes of the Avanavero Suite form thick differentiated bodies varying from norite to ferrodiorite and granophyres. Sills can reach thicknesses of around 500 m, and the NE-striking dykes can be followed for several kilometers. Collectively, these bodies are volumetrically significant in northern Guyana.

The Avanavero magmatic system is permissive for both the rift and continental flood basalt-associated mafic sills and dyke-like bodies subtype of the Ni-Cu type, and for the stratiform PGE deposits in layered mafic/ultramafic intrusions subtype of the PGE type.

A third pulse of mafic magmatism produced relatively few intrusions, which are referred to as "PAPA" dikes (post-Avanavero-pre-Apatoe) (Gibbs and Barron, 1993). Their ages spread from 300-1300 Ma.

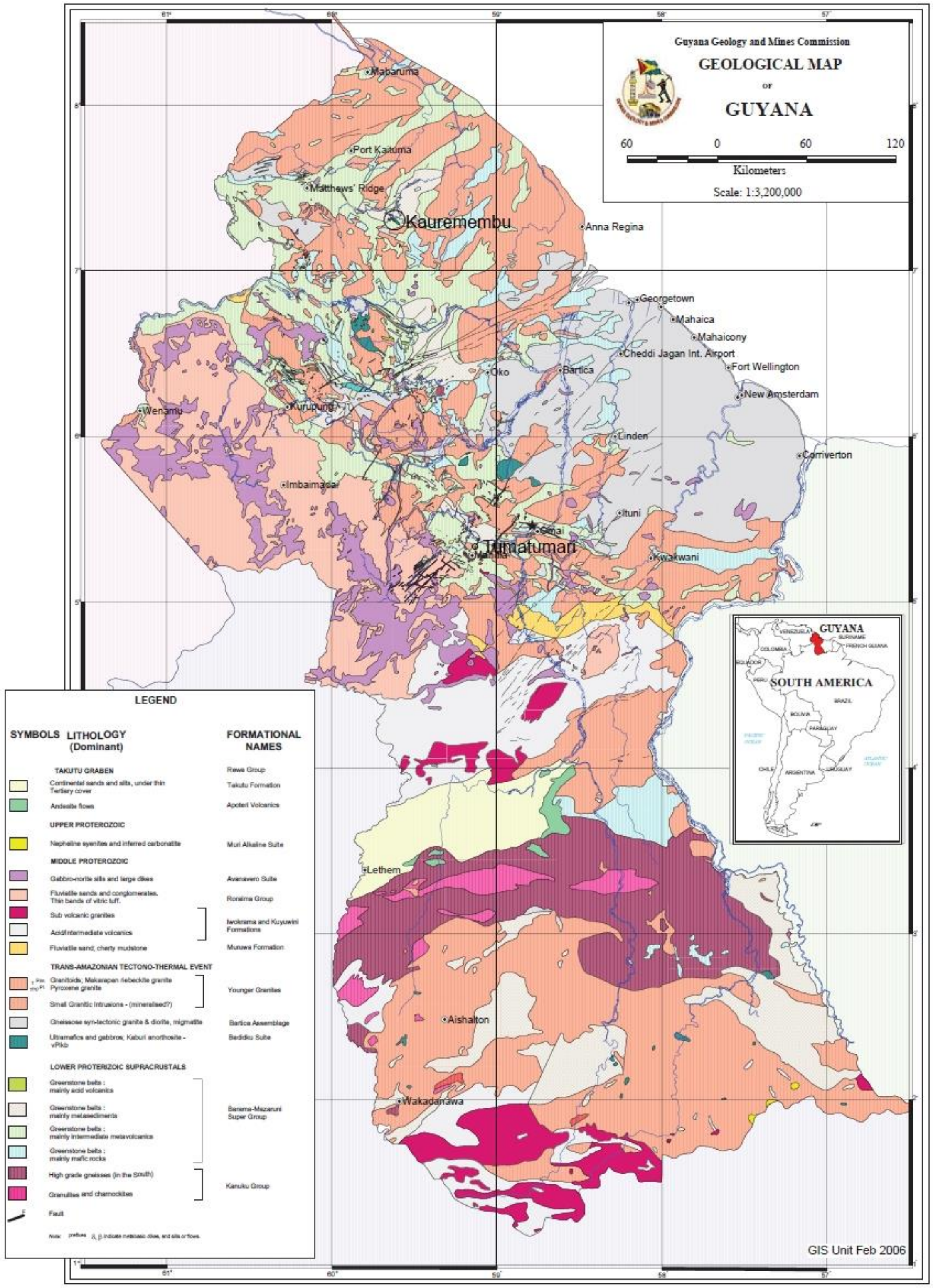

Figure 1. Geological Map of Guiana (reproduced at 2/3rds original size – see separate file for full sized version).

The fourth and last phase of post-Transamazonian basic magmatism relates to the dykes of the Apatoe Suite of Jurassic age. These form extensive dyke swarms throughout the shield, with individual bodies reaching as much as 50 m in width and a length of several hundred kilometres (Gibbs and Barron, 1993). The Apatoe dolerites mark the precursor stages in the opening of the South Atlantic Ocean during the Mesozoic (around 200 Ma), and belong to the JACT (Jurassic Atlantic Continental Tholeiites) association.

These last two magmatic phases could potentially host the mafic/ultramafic intrusions subtype of the Ni-Cu type.

5. Mineral resource assessment

In assessing the mineral potential of the four major basaltic magmatic systems in northern Guyana for magmatic Ni-Cu sulphide and PGE deposits, this study used the following factors from the descriptive models as the main criteria of assessment.

- Tectonic setting. Rift systems or reactivated deep-seated faults are likely to produce large volumes of magma in repeated pulses. The emplacement of such large volumes of mafic and ultramafic magma is attributed to the rise and impingement of mantle plumes on continental and oceanic lithospheric plates.
- Age. Older magmatic systems are more deeply eroded, which increases the possibility that their more prospective feeder systems are likely to be exposed as giant dike swarms, sill complexes, and layered intrusions.
- Volume of magma. The small percentage of PGE, Ni and Cu in basaltic magmas requires a high concentration factor (and hence a massive volume of magma) to produce economic concentrations of the metals. Lightfoot (2007, p. 643), however, points out that small ("volumetrically trivial") bodies of mafic-ultramafic rock can contain exceptionally large economic Ni sulphide deposits. He cites as examples the Ovoid Deposit at Voisey's Bay in Canada and China's Jinchuan Intrusion which has a projected surface outcrop area of less than 1.4 km2, yet contains a historic and present reserve and resource of over 500 Mt of mineralized ultramafic rock.
- Number of pulses or cycles of magmatism within one and the same system. The more often the magmatic system is replenished, the higher the chances of large economic mineralization are likely to be.
- Magmatic differentiation. Economic mineralization depends on efficient separation of metal-rich phases from silicate melts. Layering and cumulate textures are key signs of magmatic segregation.
- Presence of deep seated faults. These deposits are formed from mantle-derived magma. Faults provide access and a conduit to bring such magma to the surface.

In addition, the assessment will take into consideration other factors such as exploration history, the presence of known mineral occurrences/deposits and geochemical and geophysical anomalies in northern Guyana and in the shield as a whole.

Table 2 provides a matrix to assess the permissive domains in northern Guyana against these selected criteria, which are rated as either optimistic (O) in red cells, if a criterion enhances the prospectivity of the domain, or pessimistic (P), if it lowers it. Where no or little information exists to make a judgment, ND (no data) applies. The PAPA dykes are not considered as they are poorly studied and relatively few in numbers.

6. Conclusion

In comparing and assessing the descriptive models against the geological and exploration information from northern Guyana, optimistic factors outweigh pessimistic factors by over a two to one ratio. The likelihood for Ni-Cu-PGE is therefore considered high. The results reflect only a snapshot of our current knowledge. We therefore caution that the limited available data leave open the estimation of the scale of this potential. With increasing exploration work and academic studies, assessment of undiscovered resources can become more quantitative. To have attempted such an approach now would have rendered the assessment excessively subjective.

Among the most favorable factors is the presence of several associations of mafic magmatic rocks, in particular the volumetrically-significant mafic metavolcanics of the greenstone belts and the mafic magmatism of the Avanavero LIP. The small number of known commercial deposits across the entire Guiana Shield counts among the more pessimistic factors.

In assessing the opportunity costs of foregoing mineral exploitation as a trade-off for forest-based carbon credits in Guyana's low carbon development strategy, we submit that the high likelihood of magmatic Ni-Cu-PGE deposits strengthens the case for mining as the best use of the land. Any compensation therefore to the country to forego mineral development would have to be greater than that calculated for known deposits of gold (e.g., Office of the President, 2012). Similar studies should be undertaken on the wide range of deposit types likely or found in Guyana, such as albitite-hosted and unconformity-related uranium deposits and volcanogenic massive sulphide deposits.

TABLE 2: Assessment of prospectivity of identified domains for magmatic Ni-Cu-PGE deposits

Favourable conditions	Greenstone metavolcanics		Avanavero Suite		Apatoe Suite	
Tectonic setting	Related to island-arc volcanism, during the Trans-Amazonian Episode.	O	Continental rifting. Possibly signifying a failed arm (Choudhuri et al., 1990).	O	Continental. Intrusions precursor to opening of Central Atlantic ocean during the Mesozoic.	O
Age	Palaeoproterozoic. No mention of feeder systems.	ND	Paleoproterozoic. Exposure of feeder dykes in some areas (Gibbs and Barron, 1993).	O	Jurassic. Mainly small individual dykes.	P
Volume of magma	Significant. Metavolcanic rocks in northern Guyana comprise 50% mafic and 2% ultramafic. The entire volcano-sedimentary sequence is over 9 km thick covering 30, 000 km^2.	O	Significant. Sills up to 500 m thick and strike for hundreds of km. Total volume of sills - 30,000 km^3 (Gibbs and Barron, 1993).	O	Dykes up to 50 m in width, some up to several hundred of kilometers in length. Dykes are in swarms of up to ten. Very abundant across the Shield.	O
Number of pulses/cycles of magmatism.	No age differences reported among basic/ultrabasic members of the greenstone belts.	P	Possibly two pulses (Choudhuri et al., 1990; Reis et al., 2012).	P	Likely one pulse.	P
Magmatic differentiation. **Layering/cyclic units/compositional interface, i.e, ultramafic-gabbroic contacts.**	Reported for ultrabasic rocks at Kauremembu in the Barama belt. Commonly form layered complexes in the Guiana Shield.	O	Major element plots by Choudhuri et al. (1990) show vague differentiated trend. Differentiation possibly prior to emplacement, leading to sills of different compositions, and within the sills themselves. Later exploration work in 2002 reports only little evidence of modal layering in large sills. Cumulate textures and rhythmic layering in the Tumatumari-Kopinang dike and sill complex (Hawkes, 1966).	P	None reported, but unlikely given the smallness of the bodies and rate of emplacement.	P
Presence of deep-seated faults.	Presence of deep-seated faults.	O	Presence of deep-seated faults.	O	Dykes are fault-controlled.	O
Exposure of plumbing or feeder systems or conduits/depth of erosion.	None reported.	ND	Sills are found at the base of the sedimentary succession or exposed when the overlying rocks of the Roraima Supergroup have been eroded. Massive feeder dykes exposed (up to a kilometer in width).	O	Mainly small dykes.	P

Exploration and mining	Relatively little exploration effort directed toward the search for Ni and Cu sulphides in ultramafic rocks. Ni laterites preferred targets. No commercial deposits identified to date.	P	Preliminary exploration conducted in 2002, involving geological mapping, lithogeochemistry at two sites. No clear signs of PGE mineralization reported. Further work recommended.	P	No exploration attention received.	P
Geochemical signature	Most of the examined ultramafic rocks contain only background Ni values (0.2 - 0.3%). Only few occurrences of distinctly higher Ni values found (Gibbs and Barron, 1993). However, lowermost mafic metavolcanic rocks of the greenstone belts spatially associated with anomalous Ni values at Five Stars in Baramita and at Kauramembu, where drilling has indicated a lateritic horizon containing 10-20 million tons of Ni averaging 1% Ni over serpentinite (Walrond, 1980). Stream sediment geochemistry draining the Tenapu formation returned anomalous values of Cr, Cu and Zn. The northernmost sector of the Omai area show anomalous Cu-Ni-Cr values, and probably overlie ultrabasic rocks.	O	Presence of palladium-bearing mineral (potarite) in stream sediments over the Avanavero. Significance in dispute. Ore minerals detected: ilmenite. magnetite, pyrrhotite and chalcopyrite (Choudhuri, et al., 1990). Lithogeochemistry in 2002 returns inconclusive results at two sites.	ND	None reported.	ND
Geophysical signature	Aero-magnetic and aero-electromagnetic signature detected over Itaki gabbro stock.	O	Deep seated faults below the Avanavero basalts detected by Airborne Total Intensity Magnetic survey. (Nadeau, 2009).	O		ND
Presence of deposits in other parts of the Guiana Shield.	i) The USGS (1993) estimates there is a 1 percent chance of one or more deposits of nickel-copper-platinum group elements associated with pyroxenite and gabbroic intrusive rocks in permissive domains of the Venezuelan Guiana Shield. ii) The large PGM-bearing gabbroic-ultramafic De Goeje body in E Suriname. Its continuation in French Guiana (Tampok) dated at approximately 2.15 Ga (Delor *et al*., 2003). iii) Chromite deposits in Bacuri mafic-ultramafic complex, in the eastern part of the Guiana Shield, Amapa State, Brazil. (Spier and Filho, 2001). iv) Chromitite deposits also in the Suriname shield.	O	None reported.	P	None reported.	P

REFERENCES

Choudhuri, A., Sial, A. N. and Oliveira, E. P. 1990. Unmetamorphosed Proterozoic tholeiitic dykes from the northern Amazon Craton, Guiana, the evolution of basaltic magmatism, in Mafic Dykes and Emplacement Mechanisms. In: **Parker, A.J. et al. (Ed.)**, *Proceedings of the Second International Dyke Conference, Adelaide/South Australia/ 12-16 September 1990*, 275-283.

Cox, D. P. and Singer, D. A. 1986. Mineral Deposit Models. *US Geological Survey, Bulletin* **1693**, 379 pp.

Eckstrand, O. R. and Hulbert, L. J. 2007. Magmatic nickel-copper-platinum group element deposits. In: **Goodfellow, W. D. (Ed.),** *Mineral deposits of Canada—A synthesis of major deposit-types, district metallogeny, the evolution of geological provinces, and exploration methods: Geological Association of Canada, Mineral Deposits Division*, Special Publication No. **5**, p. 205–222.

Ernst, R. E. and Peck, D. C. 2010. Using Large Igneous Provinces for Mineral Exploration (e.g., for Ni-Cu-PGE Deposits). *11th International Platinum Symposium. Ontario Geological Survey, Miscellaneous Release–Data* **269**.

Gibbs, A. K. 1980. *Geology of the Barama-Mazaruni Supergroup of Guyana*, Unpub. Ph.D. Thesis, Harvard Univ., Cambridge, Massachusetts, USA.

Gibbs, A. K. and Barron, C. N. 1993. *Geology of the Guyana Shield*, Oxford University Press, 246 pp.

Hawkes, D. D. 1966. Differentiation of the Tumatumari-Kopinang dolerite intrusion, British Guiana. *Geological Society of America, Buletin*, **77**, 1131-1158.

Hoatson, D. M. 1998. Platinum-group mineralisation in Australian Precambrian layered mafic-ultramafic intrusions. *AGSO Journal of Australian Geology & Geophysics*, **17**(4), 139-151.

Kinnaird, J. 2011. Review: PGE in the 21st Century: Innovations in understanding their origin and applications to mineral exploration and beneficiation. *11th International Platinum Symposium. Platinum Metals Review, 2011*, **55**(2), 117–123.

Klaus, J. S., Chandler, V.W., Nicholson, S.W., Piatak, N., Seal, R.R., Woodruff, L.G. and Zientek, M.L. 2010. Magmatic sulfide-rich nickel-copper deposits related to picrite and (or) tholeiitic basalt dike-sill complexes: a preliminary deposit model. *USGS Open-File Report* **2010–1179**. U.S. Department of the Interior.

Lightfoot, P. C. 2007. Advances in Ni-Cu-PGE sulphide deposit models and implications for exploration technologies. In: **Milkereit, B. (Ed.)**, *Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration*, 629-646.

Metals Economic Group. 2011. World Exploration Trends. *Special Report from Metals Economics Group for the PDAC International Convention*, 8 pp.

Nadeau, S. 2009. *Preliminary report of Upper Potaro Project 2009*. GGMC unpublished report.

Office of the President, Republic of Guyana. 2010. *Low Carbon Development Strategy: Transforming Guyana's Economy While Combating Climate Change*.

Rasilainen, K., Eilu, P., Halkoaho, T., Iljina, M. and Karinen, T. 2010. Quantitative mineral resource assessment of platinum, palladium, gold, nickel, and copper in undiscovered PGE deposits in mafic-ultramafic layered intrusions in Finland. *Geological Survey Finland Report of Investigation*, **180**.

Reis, N. J., Teixeira, W., Hamilton, M. A., Bispo-Santos, F., Almeida, M. E. and D'Agrella-Filho, M. S. 2012. Avanavero mafic magmatism, a late Paleoproterozoic LIP in the Guiana Shield, Amazonian Craton: U–Pb ID-TIMS baddeleyite, geochemical and paleomagnetic evidence. *Lithos*, **174**, 175-195.

Singer, D. 2007. Estimating Amounts of Undiscovered Mineral Resources. In: **Briskey, J.A., and Schulz, K.J., (Eds.)**, *Proceedings for a Workshop on Deposit Modeling, Mineral Resource Assessment, and Their Role in Sustainable Development: U.S. Geological Survey Circular* **1294**, 143 pp.

Spier, C. A. and Filho, C. F. F. 2001. The Chromite Deposits of the Bacuri Mafic-Ultramafic Layered Complex, Guyana Shield, Amapá State, Brazil. *Economic Geology*, **96**, 817–835.

US Geological Survey and Corporacion Venezolana de Guayana, Tecnica Minera, C.A. 1993. Geology and Mineral Report Assessment of the Venezuelan Guyana Shield. *US Geological Survey Bulletin* **2062**, 121 pp.

Walrond, G. W. 1980. A metallogenetic scheme for the Guyana Shield. In: **Moreno, J.L.L. (Ed.)**, *Metalogenesis en Latinoamerica. Simposium Internacional, Mexico*, 141-164.

Accepted 3rd November 2013