Ore Geology Reviews 90 (2017) 323–325

Contents lists available at ScienceDirect

Ore Geology Reviews

journal homepage: www.elsevier.com/locate/oregeorev

Editorial

Special Issue on the 13th International Ni-Cu-PGE Symposium, Fremantle, Western Australia

The 13th International Ni-Cu-PGE Symposium (13INCPS) was chaired by Steve Barnes (CSIRO) and was held at the Esplanade Hotel in Fremantle in September 2016, with associated workshops at the ARRC building in Kensington, Western Australia. The symposium was deemed to be a success on multiple fronts and was rated a major success by all comers. There was a very strong sense that the magmatic sulfide community has made some really significant progress in the last few years in moving the science forward. In particular, there was consensus that the continuing close collaboration and dialogue between the academic and exploration industry communities is key to any future breakthrough in the science associated with exploration targeting for Ni-Cu-PGE mineral systems.

Prior to looking at some of the specific details pertaining to the articles contained in this special issue, it is important to provide a few facts and figures for the record: 147 registrants attended the symposium proper, plus an additional 24 registrants and presenters for the workshops. Out of the total 171 participants, 45 came from 11 different countries outside Australia. The workshops alone attracted over 100 individual registrants. The best attended one was an industry focused Nickel Exploration workshop, which attracted over 90 people, mostly from industry. The post-conference field excursion took 21 people to outcrops and mines around the Kambalda-Kalgoorlie-Leonora area, in the Yilgarn Craton of Western Australia. Independence Group (IGO), Royal Canadian Nickel and Poseidon Nickel are acknowledged for arranging entrance to mine sites and facilitating the visit of the most important outcrop localities. The lucky few who got to go underground at Long-Victor saw one of the most remarkable exposures of spinifex-textured nickel ore ever seen by anyone.

This special issue provides a very comprehensive overview of some of the latest advances in the field of research on magmatic nickel-sulfides associated with mafic and ultramafic rocks. The topics are very varied and comprise studies focused on: 1) the latest advances in analytical techniques and data analytics used to provide new insights and assist data visualization in order to unravel some of the most controversial problems in magmatic ore deposits; 2) new experiments investigating the processes that lead to sulfide saturation and ore genesis; 3) physical processes related to magma emplacement and sulfide transport; 4) deposit-scale documentation of poorly known magmatic systems in new districts; and 5) re-evaluation of well-known mineral districts on the basis of new data and exploration results.

In terms of studies applying the latest advances in analytical techniques to unravel the geochemical behavior of chalcophile and siderophile elements, **Duran et al**. and **Samalens et al**. apply laser ablation ICP-MS technology to investigate the varying concentrations of Te, As, Bi, Sb and Sn (TABS) in different magmatic Ni-Cu-PGE deposits. These studies are significant as the geochemical behaviour of TABS is poorly constrained, despite their critical role in forming platinum-group minerals (PGM). In terms of latest advances in the translation of outcomes from research into concrete exploration outputs, by a powerful combination of various datasets, **Burley et al**. combine Shortwave Infrared (SWIR) and Thermal Infrared (TIR) hyperspectral data, Portable X-Ray Fluorescence (pXRF) and whole-rock geochemical data to assess different analytical techniques in the exploration of komatiite-hosted nickel-sulfide deposits.And another study by **LeVaillant et al**. discusses new exciting ways to visualise large 3D geochemical datasets in order to get reproducible and objective results and allow scientists to better understand these large datasets and extract interesting insight on ore genesis.

From an experimental point of view, by both experimental petrology and thermodynamic modeling **Iacono Marziano et al**. investigate how sulfate and organic matter assimilation occur in mafic-ultramafic magmas, affecting magma composition, crystallisation and sulfide saturation. Their observation have bearings on the understanding of the genesis of the giant Noril'sk ore bodies.

Over the last decade within our research community, more efforts have been made to acquire a better understanding of the fundamental physical processes underlying the genesis of magmatic Ni-Cu-PGE sulfide deposits, such as sulfide transport, concentration and accumulation mechanisms, the importance of the dynamics of magmatic systems, or the behaviour of sulfides in relation to silicate melts, vapour bubbles and volatiles. A large number of papers within this special issues present the results of such work.

A number of studies *investigate* the mechanisms by which magma flow pathways develop and form into continuous networks and *better constrain* how dense immiscible Ni-Cu-PGE sulfide liquids are transported and concentrated within these networks. **Barnes et al**. investigate the nature of the complex assemblages of extremely heterogeneous rocks that occur at Voisey's Bay. These range from polymict breccias, with rock fragments in sulfide-rich and/or sulfide-poor matrices, to heterogeneous "vari-textured" gabbros with rapid short range variations in grain size and content of hydrous phases. Using a combination of desk-top microbeam XRF mapping at cm scale and 3D X-ray tomography, the authors show that both sulfide-poor and sulfide-rich breccias comprise heterolithic assemblages of clasts within a matrix of olivine gabbro. The observed range of textures is explained by a model of percolation of molten sulfide through variably crystalline inter-clast matrix, displacing the silicate melt to leave the

http://dx.doi.org/10.1016/j.oregeorev.2017.08.033
Received 23 August 2017; Accepted 23 August 2017
Available online 09 September 2017

refractory plagioclase-olivine or in some cases plagioclase-only component, now entirely within a sulfide matrix. This sulfide infiltration model offers an alternative to the current model for upward emplacement of a slurry of silicate melt, sulfide melt and breccia fragments as a late stage injection into the dyke-sill complex.

Using analogies with other engineering and mineral systems, **Saumur et al**. evaluate the structural and physical controls on the ingress of sulfide liquid into brittle host rocks. In fact, field observations and theoretical considerations suggest that dense magmatic sulfide liquids are injected into and/or passively infiltrate surrounding wall rocks late in the emplacement history of intrusion-hosted magmatic ore systems. The authors put forward the exciting hypothesis that gravity-driven infiltration of sulfide liquid out of the host igneous intrusion into country rock may be analogous to the behaviour of dense immiscible fluids in groundwater systems, which is controlled by the body force of the liquid itself. In that framework, downward penetration of sulfide liquid into micro-fractures may occur once a sufficient thickness of sulfide, known as the critical accumulation height, is reached in the overlying intrusion.

In light of all the recent studies showing the capacity of hot liquid sulfides to create their own pathways, **Staude et al**. revisit the nature and origin of the embayments that host komatiite-hosted nickel deposits at Kambalda, Western Australia. The currently favoured model invokes pre-existing topographic features filled in by the komatiite and sulfide melt, and subsequently modified by thermomechanical erosion. New evidence from sulfide deposits on the eastern limb of the Kambalda Dome suggests that the entire embayment was formed uniquely by thermomechanical erosion. New observations show that the sulfide melt itself played a major role in the process owing to its high density, high heat content and very low viscosity, but the hydrated nature of the underlying altered basalt was also critical. The proposed new model provides an exciting way to explain the formation of the cryptic pinchout structures observed in numerous komatiite-hosted nickel-sulfide deposits.

The study of **Lesher et al**. investigates the transport mechanisms of sulfide liquids. The authors indicate that xenovolatiles may retard settling of – or in some cases float – dense sulfide droplets. Reactions of sulfide melts with felsic country rocks may generate Fe-rich skarns that may allow sulfide melts to fractionate to more extreme Cu-Ni-rich compositions. Xenoliths, xenocrysts, xenomelts, and xenovolatiles are more likely to be preserved in cooler basaltic magmas than in hotter komatiitic magmas, and are more likely to be preserved in less dynamic (less turbulent) systems/domain/phases than in more dynamic (more turbulent) systems/domains. Therefore, the authors conclude that massive to semi-massive Ni-Cu-PGE and Cr mineralisation and xenoliths are generally localised within footwall embayments, dilations/jogs in dikes, throats of magma conduits, and the horizontal segments of dike-chonolith and dike-sill complexes, which represent fluid dynamic traps for both ascending and descending sulfides/oxides. The significant outcome from this study is that if residues/skarns, xenoliths, xenocrysts, xenomelts, and/or xenovolatiles are present, they provide important constraints on ore genesis and they are valuable exploration indicators.

One last article within this special issue that increases our understanding of the behaviour of sulfide blebs is presented by **Sessa et al**. Within their study, theylook at the field relationships as well as the minero-chemical and morphological features of sulfide blebs hosted in a mantle-derived volatile-rich alkaline mafic pipe that intruded the lower continental crust of the Ivrea Zone of northwest Italy. The authors notice that beside a cotectic-like family of smaller (< 1–2 mm) and rounded intra- and intergranular sulfide blebs, largely made up of pyrrotite ± pentlandite, the pipe also contains a population of larger blebs (5–50 mm), with a core commonly made up of pyrrotite and rims comprising pyrrotite ± pentlandite ± chalcopyrite ± mackinawite ± cubanite and platinum-group minerals. The morphology of the larger blebs reveals the presence of embayments and protrusions, in and around which a halo of sulfide mirmekites and patches of magmatic dolomite and calcite commonly reside, displaying intergrowth features that indicate wetting behavior between carbonates and sulfides. Sessa et al., put forward the exciting hypothesis that upon emplacement at the base of the crust, sulfide-saturated mantle-derived magmas originating from the metasomatised lithospheric mantle may exsolve a carbonatitic liquid, which could wet and physically entrain sulfide blebs. These could coalesce forming much larger aggregates during ascent of the silicate magma.

Finally, a large number of papers within this special issue increase our understanding of magmatic Ni-Cu-PGE sulfide deposits by 1) presenting rigorous detailed studies of poorly known magmatic systems, 2) revisiting and re-evaluating well known mineral systems, or 3) reviewing and combining knowledge from multiple mineralized systems.

Some interesting studies provide detailed documentation of poorly known magmatic systems in remote mineral districts, such as the Musgrave Province of Western Australia, the Munali Intrusive Complex in the Zambezi belt of southern Zambia, and the Dido Batholith in north Queensland (Australia). In the Musgrave Province, **Polito** document some promising mafic-hosted, magnetite-related prospects (called Jameson, Navigator and Latitude Hill) located in the most evolved, upper parts of the 1078 Ma layered intrusions belonging to the Giles Complex. In north Quensland, the study of **Best** assesses for Ni-Cu-PGE fertility four elongate, km-scale, mafic to ultramafic bodies within the Ordovician-Silurian Dido Batholith. Finally, In Zambia, **Holwell et al**. documents the geometry of the Ni-Cu-PGE deposit associated with the Munali Intrusive Complex, which is a flattened tube-shaped, mafic-ultramafic intrusion located close to the southern Congo Craton margin. Applying high-precision geochemical and geochronological tools, these authors suggest that Munali is an example of a complex conduit-style Ni sulfide deposit affected by multiple stages and sources of magmatism during rifting at a craton margin. They also put forward the exciting hypothesis that carbonatite and mafic melts may have interacted along deep seated crustal fault systems to produce a mineralogically unusual deposit.

The special issue also provides an interesting overview of some Permian magmatic mineral systems from Western China, including a magmatic Ni-Cu sulfide deposit in the Kalatongke district of the Southern Chinese Altai Orogenic Belt (**Qian et al**.) and the Huangshannan magmatic Ni-Cu sulfide deposit located in the southern Central Asian Orogenic belt in the Eastern Tianshan (**Mao et al**.). In Northern China, **Li et al**. provides a comprehensive description of the Beiligaimiao magmatic Ni-Cu sulfide deposit located in the northern rim of the North China Block. This deposit has never been studied before but is an excellent example of magmatic sulfide mineralisation that formed in an arc setting. Finally, the study of **Zhong et al**. focus on the Qingmingshan magmatic Fe-Ni-Cu sulfide deposit located in the southern margin of the Yangtze Craton, in the western part of the Proterozoic Jiangnan orogenic belt.

Two of the contributions within this special issue investigate komatiite-hosted nickel sulfide systems. Just like **Barnes et al**. revisit the well-studied Voisey's Bay deposit, **Moroni et al**. provide a very detailed account of the chemical and mineralogical stratigraphy of the Fe-Ni-Cu-PGE Wannaway deposit in the well characterised Widiemooltha Dome district of the Eastern Goldfields, Western Australia. And in Finland, **Makkonen et al**. provide a comprehensive review of the existing knowledge to evaluate the nickel-sulfide potential of komatiite systems as well as of a series of other mineralised occurrences associated with mafic systems.

Finally, three interesting studies focus on the recent advances on the characterisation of the metallogenic features of three Canadian PGE-rich mineral systems: the Lac des Iles Complex, the W Horizon, Marathon Cu-Pd deposit and the Coldwell Alkaline Complex. **Djon et al**. focus on the results from newly observed field relationships from the Northern Ultramafic Centre (NUC) of the Lac des Iles Complex, Northwest Ontario, and put forward new hypotheses for the genesis of the four subparallel, stratiform PGE-enriched intervals exposed within the cyclically layered eastern flank of the NUC. **Ames et al**. provide new compelling evidence showing that the PGE-enriched W Horizon ores in the Marathon Cu-Pd deposit exhibit a complex post-magmatic history dominated by the effects of oxidation during cooling of a Cu-PGE enriched magma source from a deep reservoir. Finally, **Good et al**. present results for a comprehensive evaluation of platinum group minerals (PGM) at four copper-PGE occurrences hosted within separate but co-genetic gabbro or troctolite intrusions in the Coldwell Alkaline Complex and confirm that accurate surveys are possible with sufficient sample material and efficient PGM concentration methods.

The editorial board would like to thank the following reviewers: Steve Beresford, Jon Hronsky, Zoran Seat, Carl Spandler, Michelle Huminicki, Derek Wilton, David Holwell, Rais Latypov, Stephen Barnes, Wolfgang Maier, Nicholas Arndt, Sebastian Staude, Charley Duran, John Bowles, Federica Zaccarini, Anna Vymazalova, Marina Yudovskaya, Tapio Haloaho, Tony Roache, Chusi Li, James Mungall, Paul Duuring, Giovanni Grieco, Ya-Jing Mao, Shenghong Yang, Xie-Yan Song, Caroline Perring, Zhuangzhi Qian, Rebecca Sproule, Belinda Godel, Marek Locmelis, Valentina Taranovic, Martin Gole, Mark Lindsay, Ferenc Molnar, Steve Beresford, David Williams, Tim Ivanic, Marina Yudovskaya, Raphael Baumgartner, Marilena Moroni. Their contribution in the form of careful and insightful reviews was very much appreciated.

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