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# Magma recharge and mixing processes in continental flood basalt reservoirs: evidence from melt inclusions in basalts from the High Arctic Large Igneous Province, Axel Heiberg Island, Nunavut

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## FOREWORD

The Geo-mapping for Energy and Minerals (GEM) program[1] is laying the foundation for sustainable economic development in the North. The Program provides modern public geoscience that will set the stage for long-term decision making related to investment in responsible resource development. Geoscience knowledge produced by GEM supports evidence-based exploration for new energy and mineral resources and enables northern communities to make informed decisions about their land, economy and society. Building upon the success of its first five-years, GEM has been renewed until 2020 to continue producing new, publically available, regional-scale geoscience knowledge in Canada's North.

The volcanic terrain of Cretaceous age exposed in the east-central Sverdrup Basin, known as the Canadian portion of the High Arctic Large Igneous Province (HALIP; Figure 1), was the focus of an activity approved for the second phase of NRCan's Geo-Mapping for Energy and Minerals Program (Western Arctic Region Project).

The main objective of the HALIP Activity, from 2014 to 2017, was to identify areas on Axel Heiberg Island and Ellesmere Island that show a high potential for Ni-Cu-PGE deposits (Figure 1). Specific activities include (1) detailed mapping of sills and dykes not included in current 1:250 000 scale geological maps; (2) the collection of samples for mineralogical and geochemical studies; (3) the development of geological models and a regional stratigraphic and structural framework to identify volcanic-intrusive complexes that could host nickel sulphide deposits; and (4) the transfer of data, maps and knowledge to decision-makers and stakeholders in northern communities, government, and industry.

The data presented in the poster and report were acquired as part of Objective 2, mineralogical and geochemical studies. Field studies and geochemical analyses on HALIP volcanic successions and associated intrusive rocks are described in Dewing (2015), Saumur and Williamson (2016), Williamson (2016) and Williamson et al. (2017).

## THE HIGH ARCTIC LIP

Exposures of flood basalts, dyke swarms, and sills of Cretaceous age located in circum-Arctic regions are referred to as the High Arctic Large Igneous Province (HALIP). HALIP rocks exposed in the Canadian Arctic Archipelago are predominantly basaltic, a characteristic of large igneous provinces associated with continental break up (Ernst, 2014). Spectacular outcrops of volcanic rocks and associated intrusive complexes are found on Axel Heiberg Island and northern Ellesmere Island (e.g. Embry and Osadetz, 1988; Villeneuve and Williamson, 2006; Jowitt et al., 2014).

The poster presents the results of mineralogical and geochemical analyses on flood basalts in the Strand Fiord Formation. The poster was presented at the Annual Meeting of the Geological Association of Canada-Mineralogical Association of Canada[2] held in Kingston, Ontario (Williamson et al., 2017). The report provides additional information on (1) the objectives of the study; (2) methods; and (3) results.

[1] http://www.nrcan.gc.ca/earth-sciences/resources/federal-programs/geomapping-energy-minerals/18215
[2] GAC-MAC 2017: http://www.kingstongacmac.ca/en/home/

## RESEARCH OBJECTIVES AND RATIONALE

Studies of lava-hosted mineral textures and zoning patterns provide information on the evolution of the host magma during ascent in volcanic conduits. For example, the composition and textural features of feldspar phenocrysts are widely used to investigate the relative contributions of magma recharge, contamination and mixing during basalt petrogenesis (Streck, 2008). Small pockets of melt trapped as inclusions during crystal growth may provide additional constraints on the compositional diversity of melts in basaltic magmatic systems (Kent, 2008). Melt inclusions preserved in continental flood basalts (CFB) often preserve more primitive, primary melt compositions than the erupted magmas. As a result, their study deepens our understanding of CFB magma petrogenesis (e.g. Jennings et al., 2017).

Lava flows in the Strand Fiord Formation exposed near Bunde Fiord, Axel Heiberg Island[3], show compositional evidence of open system processes, namely magma recharge and mixing (Williamson, 1988). For example, many of the inclusion-rich plagioclase phenocrysts found in the lava flows display complex zoning patterns and have higher anorthite (An) contents than the plagioclase laths in the matrix. Our scientific hypothesis is that these melt inclusions have more primitive compositions (e.g. lower total rare earth element (REE) concentrations) than the bulk rock. The objectives of the study were to: (1) acquire major and trace element data on melt inclusions to constrain the composition of parental melts; and (2) use the data to investigate the role of open system processes in the genesis of HALIP flood basalts.

HALIP igneous rocks exposed in the east-central Sverdrup Basin present most of the attributes of prospective Ni-Cu-PGE continental flood basalt provinces (Williamson and MacRae, 2015). A recent lithogeochemical study concluded that the Strand Fiord Formation basalts and associated intrusive rocks exposed on Axel Heiberg Island are prospective for Ni-Cu-PGE (Jowitt et al., 2014). New field and laboratory data acquired during the GEM 2 HALIP Activity provided additional constraints on the economic prospectivity of these intrusions at a more local scale (Saumur et al., 2016). In spite of this progress, compositional data on primitive (i.e. Mg-rich) HALIP magmas are lacking. Melt inclusions provide a snapshot of magmatic compositions during different stages in the evolution of volcanic systems, including replenishment by Mg-rich magmas from deeper reservoirs (Streck, 2008). Therefore, such data have the potential to further constrain metallogenic processes associated with Ni-Cu ore genesis (Naldrett, 2011).

## METHODS

The analytical methodology involved the following steps: (1) detailed textural analysis of melt inclusions using the Scanning Electron Microscope (SEM); (2) selection of targets in four thin sections of basaltic lava; (3) major element analysis of seventeen inclusions by Electron Probe Microanalysis; and (4) LA-ICP-MS spot analyses of melt inclusions using a Teledyne Photon Machines Analyte G2 excimer laser ablation system and an Agilent 7700x ICP-MS.

## RESULTS

SEM studies of plagioclase phenocrysts in AC basalts led to the discovery of homogeneous melt bubbles preserved in large, well-defined inclusions. Replicate analysis of individual melt inclusions demonstrated that laser ablation applied to these pockets of melt can provide reliable trace element data. However, the interpretation of results is critically dependent on two factors: (1) the availability of

[3] Arthaber Creek volcanic succession, herein referred to as AC basalts.

textural information at the micron scale; and (2) the careful selection of time-integrated windows following LA-ICP-MS analysis. Our data show excellent measurement repeatability, particularly for the rare earth and high-field strength elements. A comparison of rare earth patterns for bulk rocks and melt inclusions leads us to conclude that some of the glass inclusions represent primitive melts trapped during magma recharge and mixing in shallow reservoirs; and that partial crystallization modified a significant number of large, plagioclase-hosted melt inclusions. A detailed study encompassing a wide range of trace elements is in preparation. Overall, the results further our understanding of the economic potential of the Canadian portion of the High Arctic Large Igneous Province by providing the first direct evidence for open system processes in the genesis of HALIP basalts.

## ACKNOWLEDGEMENTS

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## REFERENCES

Dewing, K., (ed), 2015. 2015 Report of Activities for High Arctic Large Igneous Province (HALIP) GEM 2 Western Arctic Region Project; Geological Survey of Canada, Open File 7976, 57 p. https://doi.org/10.4095/297367

Embry, A.F., and Osadetz, K.G., 1988. Stratigraphy and tectonic significance of Cretaceous volcanism in the Queen Elizabeth Islands, Canadian Arctic Archipelago; Canadian Journal of Earth Sciences, v. 2, p. 1209-1219.

Ernst, R. E., 2014. Large Igneous Provinces; Cambridge University Press, 653 p.

Jennings, E.S., Gibson, E.A., Maclennan, J., and Heinonen, J.S., 2017. Deep mixing of mantle melts beneath continental flood basalt provinces: Constraints from olivine-hosted melt inclusions in primitive magmas; Geochimica et Cosmochimica Acta, v. 196, p. 36-57.

Jowitt, S.M., Williamson, M.-C., and Ernst, R.E., 2014. Geochemistry of the 130 to 80 Ma Canadian High Arctic Large Igneous Province (HALIP) event and implications for Ni-Cu-PGE prospectivity; Economic Geology, v. 109, no. 2, p. 281-307. https://doi.org/10.2113/econgeo.109.2.281

Kent, A.J.R., 2008. Melt inclusions in basaltic and related volcanic rocks; Reviews in Mineralogy & Geochemistry, v. 69, p. 273-331.

Naldrett, A.J. 2011. Fundamentals of Magmatic Sulfide Deposits; Reviews in Economic Geology, 17: 1–50

Saumur, B.-M., Dewing, K., and Williamson, M.-C., 2016. Architecture of the Canadian portion of the High Arctic large Igneous Province and implications for Ni-Cu-PGE potential; Canadian Journal of Earth Sciences, v. 53, p. 528-542. https://doi.org/10.1139/cjes-2015-0220

Saumur, B.-M., and Williamson, M.-C., 2016. Geochemistry of volcanic rocks from the High Arctic Large Igneous Province (HALIP), Axel Heiberg Island and Ellesmere Island, Nunavut, Canada; Geological Survey of Canada, Open File 8002, 22 p. https://doi.org/10.4095/297894

Streck, M.J., 2008. Mineral textures and zoning as evidence for open system processes; Reviews in Mineralogy & Geochemistry, v. 69, p. 595-622.

Villeneuve, M., and Williamson, M.-C., 2006. 40Ar-39Ar dating of mafic magmatism from the Sverdrup Basin magmatic province *in* Proceedings of the Fourth International Conference on Arctic Margins (ICAM IV); R.A. Scott and D.K. Thurston (eds.), Department of the Interior, p. 206-215.

Williamson, M.-C., 1988. The Cretaceous igneous province of the Sverdrup Basin, Canadian Arctic: Field relations and petrochemical studies; Unpublished Ph.D. thesis, Dalhousie University, Halifax, Canada, 417 p.

Williamson, M.-C., and MacRae, R.A., 2015. Mineralization potential in volcanic rocks of the Strand Fiord Formation and associated intrusions, Axel Heiberg Island, Nunavut, Canada; Geological Survey of Canada, Open File 7981, 34 p. https://doi.org/10.4095/297365

Williamson, M.-C. (ed.), 2016. Report of Activities for High Arctic Large Igneous Province (HALIP) – GEM 2 Western Arctic Region Project: Bedrock mapping and mineral exploration; Geological Survey of Canada, Open File 7950 (revised), 48 p. https://doi.org/10.4095/297781

Williamson, M.-C., Jackson, S.E., Yang, Z., Venance, K., and Hunt, P., 2017. Compositional evidence for magma recharge and mixing in CFB reservoirs: Evidence from melt inclusions in HALIP basalts; GAC-MAC 2017 Abstracts, v. 40, p. 418.

Williamson, M.-C., Saumur, B.-M., Grasby, S., and Hadlari, T., 2017. Field studies of High Arctic Large Igneous Province (HALIP) intrusions, Axel Heiberg Island and Ellesmere Island, Nunavut (GEM-2 report of activities, western Arctic region), Geological Survey of Canada, Open File 8169, 13 p. https://doi.org/10.4095/306303

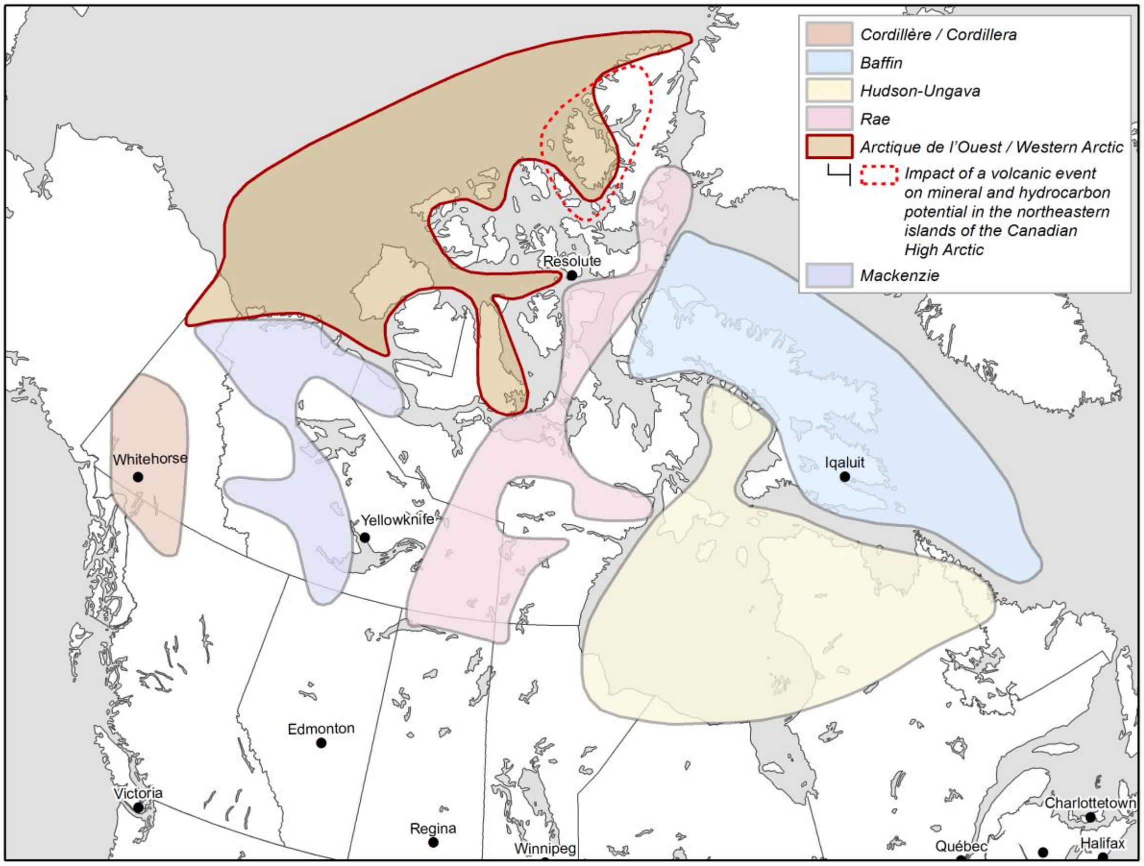


**Figure 1**. Regional map of the GEM 2 activities (2014-2017) showing the area covered by the Western Arctic Region Project. The area covered by the HALIP activity (red dotted line) includes Axel Heiberg Island and northern Ellesmere Islands, Nunavut.