Altered ultramafic and layered mafic-ultramafic intrusions: new economic and carving stone potential on northern Hall Peninsula, Baffin Island, Nunavut

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This work was part of the 2012–2014 Hall Peninsula Integrated Geoscience Program (HPIGP), led by the Canada-Nunavut Geoscience Office (CNGO) in collaboration with the Government of Nunavut, Aboriginal Affairs and Northern Development Canada, and the Geological Survey of Canada. It involved strong contributions from the universities of Alberta, Dalhousie, Laval, Manitoba, Ottawa and Saskatchewan, and the Nunavut Arctic College. It has benefited from support by local and Inuit-owned businesses and the Polar Continental Shelf Program. The focus is on bedrock (1:250 000 scale) and surficial (1:100 000 scale) geology mapping. In addition, a range of thematic studies is being conducted that includes Archean and Paleoproterozoic tectonics, geochronology, landscape uplift and exhumation, microdiamonds, sedimentary-rock xenoliths and permafrost. The goal is to increase the level of geological knowledge and better evaluate the natural-resource potential in this frontier area.


Abstract

Regional bedrock mapping stemming from the 2012–2014 Hall Peninsula Integrated Geoscience Project has led to the discovery and documentation of a number of localities of potential economic interest. Two large layered mafic-ultramafic intrusions, identified in the northern and southwestern portions of the peninsula, show potential for Ni-Cu-platinum element group mineralization. The compositional layering and geological setting of the mafic-ultramafic intrusions appear comparable to those reported for the Raglan-type deposits in the Cape Smith Belt of northern Quebec. Several ultramafic intrusions dominantly exposed on the eastern side of northern Hall Peninsula exhibit postemplacement hydrothermally altered mineral assemblages. Altered ultramafic rock is the most common type of carving stone used in Nunavut, a valuable commodity that is currently in high demand as the traditional art form expands to reach new global markets. Understanding the precise geological context and tectonic evolution of potentially economic sites on Hall Peninsula is critical when exploring for similar resources elsewhere in the territory.

Résumé

La cartographie régionale du substratum rocheux réalisée en 2012–2014 dans le cadre du Projet géoscientifique intégré de la péninsule Hall a permis de découvrir et de documenter un certain nombre de sites présentant un intérêt économique. Deux grandes intrusions mafiques-ultramafiques rubanées découvertes dans le nord et le sud-ouest de la péninsule présentent des signes de minéralisation possible en Ni-Cu-éléments du groupe du platine. La différentiation pétrographique et le cadre géologique de ces intrusions mafiques-ultramafiques s’apparentent à ceux qui caractérisent les gisements de type Raglan de la ceinture de Cape Smith dans le nord du Québec. Quelques intrusions ultramafiques affleurant dans la partie orientale du nord de la péninsule Hall présentent des assemblages minéraux qui ont été altérés par des fluides hydrothermaux après la mise en place des intrusions. Les roches ultramafiques altérées constituent le type de pierre à sculpter utilisé le plus couramment au Nunavut; il s’agit d’un produit précieux pour lequel la demande est actuellement très élevée en raison de l’entrée sur de nouveaux marchés mondiaux de cette forme d’expression artistique traditionnelle. Une bonne compréhension du contexte géologique précis et de l’histoire tectonique des sites d’intérêt économique possibles dans la péninsule Hall s’impose lorsqu’il s’agit de découvrir des ressources semblables ailleurs dans le territoire.

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Introduction

Regional bedrock mapping was conducted in the summer of 2013 on northern Hall Peninsula as part of the 2012–2014 Hall Peninsula Integrated Geoscience Project (Machado et al., 2013; Steenkamp and St-Onge, 2014). Hall Peninsula is an area of high economic potential, as demonstrated by the presence of the Chidliak diamond district currently held by Peregrine Diamonds Ltd. The Chidliak property, discovered in 2008, boasts 64 kimberlite occurrences, of which seven are considered potentially economic (O’Connor and Coopersmith, 2013). Late Jurassic to Early Cretaceous kimberlites are emplaced in Archean orthogneiss, approximately 120 km northeast of Iqaluit (Heaman et al., 2012; Nichols et al., 2013; Pell et al., 2013; Rayner, 2014). In addition to kimberlitic diamonds, bedrock mapping on southern Hall Peninsula in 2012 led to the discovery of several ultramafic intrusions with carving stone and Ni-Cu-platinum group element potential (Beauregard et al., 2013; Machado et al., 2013; Senkow, 2013). Observations, early geological interpretations and economic considerations related to two layered mafic-ultramafic intrusions and several altered ultramafic intrusions examined during the 2013 mapping campaign on northern Hall Peninsula (Figure 1) are reported in this paper. The mafic-ultramafic bodies are high priorities for further geochemical investigation and may be of interest to the exploration industry. The altered ultramafic intrusions may be useful as carving stone sources, a highly sought commodity for local artisans.

Regional setting

Southern Baffin Island is situated within the upper-plate collage (Churchill Plate) of the Paleoproterozoic Trans-Hudson Orogen (THO; Hoffman, 1988; Lewry and Collerson, 1990). Hall Peninsula (Figure 1) preserves a midcrustal cross-section of a progressive transition from orogenic foreland in the east to hinterland in the west, and comprises Archean basement orthogneiss (Scott, 1999; From et al., 2014) and Paleoproterozoic supracrustal rocks (Braden, 2013; MacKay et al., 2013; Rayner, 2014; Skipton and St-Onge, 2014). A gradual east-to-west increase in metamorphic grade and three distinct deformation phases attributed to the terminal collision of the THO have been documented across the peninsula (St-Onge et al., 2009; Dyck and St-Onge, 2014; From et al., 2014; Skipton and St-Onge, 2014; Steenkamp and St-Onge, 2014). The polymetamorphic Archean orthogneiss dominates the eastern half of Hall Peninsula and contains several felsic phases, ranging in composition from tonalite to granite, with variably distributed intrusive syenogranitic to monzo-granitic dikes (Scott, 1999; From et al., 2013; Machado et al., 2013; From et al., 2014; Rayner, 2014). Paleoproterozoic metasedimentary supracrustal strata disconformably overlie the basement orthogneiss and dominantly comprise quartzite, psammitic, semipelite, pelite, amphibolite, calcisilicate and ironstone (Machado et al., 2013; Skipton et al., 2013; Rayner, 2014; Skipton and St-Onge, 2014; Steenkamp and St-Onge, 2014). Discrete sections of supracrustal strata are present within thick-skinned, east-verging thrust imbricates that have been documented across the eastern field area (Steenkamp and St-Onge, 2014). Supracrustal strata dominate the peninsula west of Chidliak Bay and are intruded by panels of Paleoproterozoic tonalite to quartz diorite, which locally contain orthopyroxene, clinopyroxene and/or magnetite (Rayner, 2014; Steenkamp and St-Onge 2014).

Layered mafic-ultramafic intrusions

Two separate layered mafic-ultramafic intrusive sills hosted in Paleoproterozoic metasedimentary rocks were discovered in southwestern and northern Hall Peninsula (Figure 1). Both supracrustal and intrusive units have been imbricated, folded and thrust to the east due to east-west crustal shortening during the terminal collision of the THO (St-Onge et al., 2009; Dyck and St-Onge, 2014; Skipton and St-Onge, 2014; Steenkamp and St-Onge, 2014). The northern sill (lat. 64°33.683’N, long. 66°55.006’W; Figure 2) is located approximately 28 km west of the southern end of Ptarmigan Fiord, within the Chidliak property held by Peregrine Diamonds Ltd. This intrusion is well-exposed in three segments, separated by low-relief till cover that extends parallel to the regional moderately-dipping north-south foliation. The southwestern sill (63°21.937’N, 66°52.961’W) is located approximately 90 km southeast of Iqaluit, between two ultramafic rock localities noted during mapping of the southern Hall Peninsula in 2012 (Machado et al., 2013). The main body is approximately 100 m wide, 300 m long and foliated parallel to the regional subvertical north-south fabric (Figure 3a). The body thins to only tens of metres at the southern end, but outcrops intermittently along strike for about another 3 km to the south.

Field relationships

The field relationships described here specifically pertain to the three outcrop segments of the northern sill. The northern segment (Figure 2) is approximately 250 m wide by 1400 m long and contains a complete ultramafic-to-mafic layered compositional sequence (Figure 2b, 3b). It outcrops on the overturned west-dipping limb of an antiform in the footwall of an east-verging imbricate thrust. This interpretation is supported by the observed inversion of the ultramafic-to-mafic compositional sequence and the discovery of several in situ rip-up clasts of the country rock embedded in well-exposed basal clinopyroxenite on the western side of the outcrop (Figure 3c). A matching mafic-ultramafic body in the hangingwall of the east-verging thrust was not observed to the west. This may be due to
Figure 1: Simplified geology of Hall Peninsula (after Steenkamp and St-Onge, 2014), Nunavut, indicating the locations of the southwestern and northern (detailed in Figure 2) layered mafic-ultramafic intrusions (LM-UI) and altered ultramafic occurrences. The Chidliak and Qilaq mineral claims held by Peregrine Diamonds Ltd. are overlain for reference (boundaries current as of November 2013). Abbreviations: bio, biotite; cpx, clinopyroxene; gar, garnet; mag, magnetite; opx, orthopyroxene.
structural displacement on the east-verging thrust and/or subsequent erosion of the hangingwall.

The central segment is preserved in an overturned south-plunging antiform (Figure 2a). The eastern limb outcrop is 1600 m long by 50 m thick and the western limb, which is 20 m thick, discontinuously outcrops for 1400 m.

The southern segment is interpreted as an outcrop constituting the two limbs of a south-plunging synform (Figure 3d). The western limb outcrop measures about 2600 m in length and up to 85 m in width, whereas the eastern limb outcrop is 300 m long by 75 m wide. In total, the northern sill outcrops along a 6.7 km distance oriented north-south.

The relative timing of emplacement of the northern mafic-ultramafic intrusion is constrained by observed field relationships and the timing of deformation events. The sill intrudes Paleoproterozoic metasedimentary cover rocks, requiring emplacement after sedimentary deposition. Both the intrusion and the host metasedimentary units are folded and later cut by leucogranitic dikes associated with peak-metamorphic conditions related to the THO on Hall Peninsula (Dyck and St-Onge, 2014; Steenkamp and St-Onge, 2014).

**Internal magmatic stratigraphy**

Detailed textural and compositional observations of the northern segment, described in this section, were recorded from the footwall psammitic metasedimentary strata to the stratigraphic top of the layered intrusive body. Representative samples of each compositional layer were taken for whole-rock geochemical and assay analyses to be completed in early 2014.

The exposed base of the intrusion is parallel to compositional layering in the underlying, grey-weathering to locally gossanous garnet-biotite psammite. The basal composition of the intrusion is a clinopyroxenite layer 0.5–1 m thick containing thinly-spaced (3–10 cm) clinopyroxene+orthopyroxene laminae. In general, this layer has a cumulate texture comprising coarse clinopyroxene (5–8 mm long grains) and minor, fine-grained interstitial orthopyroxene and magnetite. Metamorphosed rip-up clasts of psammite 10–20 cm long were identified in situ in the basal clinopyroxenite (Figure 3c), and appear to be completely recrystallized (indurated) with minor magnetite and phlogopite at their rims.

Stratigraphically above (and structurally below) the basal clinopyroxenite is a compositionally layered peridotite up

**Figure 2:** Northern layered mafic-ultramafic intrusion (LM-UI) on Hall Peninsula, Nunavut: a) simplified geology illustrating field relationships and the locations of major structures; b) close-up showing approximate (dashed) internal compositional stratigraphy, strike and dip of compositional layering, and geochemistry and geochronology sample locations in the northern segment outcrop. Abbreviations: bio, biotite; gar, garnet.
Figure 3: Layered mafic-ultramafic sills on Hall Peninsula, Nunavut: a) view looking west at the southwestern sill; b) view of the northern segment of the northern sill looking east-southeast (d, e, f refer to the respective images in this figure); c) in situ metamorphosed rip-up clasts embedded in basal clinopyroxenite on the western side of the northern segment outcrop; d) view looking southeast at the southern segment of the northern sill; the intrusion outcrops as the western (foreground) and eastern limbs (background) of a south-plunging synform (approximate hinge indicated in yellow); e) looking north at a cross-section of compositionally-layered peridotite (B; yellow dashed line) with superimposed mineral fabric (S; red dashed line) defined by flattened orthopyroxene phenocrysts in the northern segment outcrop; f) gabbro containing blue quartz, plagioclase and clinopyroxene on the eastern side of the northern segment outcrop. Hammer for scale in photograph is 40 cm long. Abbreviations: bio, biotite; cpx, clinopyroxene; gar, garnet; plag, plagioclase; qtz, quartz.
to 150 m in stratigraphic thickness, containing minor laterally continuous clinopyroxenite layers 5–10 cm wide. Compositional layering is defined by changing proportions of olivine relative to orthopyroxene and clinopyroxene (Figure 3e). The peridotite contains flattened orthopyroxene phenocrysts that define a mineral fabric that is parallel to the regional north-south foliation and slightly steeper than the internal compositional layering.

At the stratigraphic top of the peridotite, the composition of the layered sill gradually changes from ultramafic to mafic. The mafic phase is a medium- to very coarse-grained gabbro, with clinopyroxene crystals up to 1 cm long. The gabbro ranges in stratigraphic thickness from 15 m to 25 m along the eastern side of the northern segment outcrop. Blue quartz was locally observed in the gabbro (Figure 3f) and a sample was collected for U-Pb zircon geochronology to determine the age of emplacement of the mafic-ultramafic intrusion.

In one location on the eastern side of the northern segment outcrop, the gabbro was observed to compositionally grade into an anorthositic layer up to 6 cm thick. The plagioclase is flattened into a ribbon-like texture, which may be related to either crystallization concurrent with internal flow, or deformation due to the emplacement of a second, overlying, compositionally layered mafic-ultramafic sequence 2 m thick. The upper stratigraphic contact of the northern segment of the mafic-ultramafic intrusion with the host garnet-biotite psammite cover unit was not observed.

Altered ultramafic intrusions

In addition to the previously described layered mafic-ultramafic intrusions, 25 variably altered ultramafic intrusions with primary compositions likely ranging from pyroxenite to peridotite were documented on northern Hall Peninsula (Figure 1). Most of these intrusions were identified in the eastern portion of the field area, and were typically recognized by their distinctive dull brown- to orange-weathering colour that contrasts well with both the grey-weathering Archean orthogneiss complex and the grey- to white-weathering psammite and pelite that dominate the supracrustal stratigraphy (Steenkamp and St-Onge, 2014).

Field relationships

The ultramafic intrusions on northern Hall Peninsula can be grouped, based on field relationships, into basement hosted or supracrustal hosted. Some ultramafic intrusions hosted in Archean basement orthogneiss are well-exposed, small-scale isolated plugs up to 60 m wide (Figure 4a). Locally, the basement orthogneiss is more strongly foliated in proximity to the ultramafic contact, with the basement fabric wrapping around the plug. Other ultramafic rocks hosted in crystalline basement generally occur as discontinuous, variably boudinaged dikes intermittently exposed over 100–500 m. One exception is a discontinuous ultramafic dike exposed in the 4.5 km long valley between the southern end of Tawsig Fiord and Littlecote Channel (Figure 4b). Most of the basement-hosted ultramafic intrusions are characterized by a weakly-developed west-dipping foliation, defined by platy minerals or elongated phenocrysts, consistent with the regional S1a fabric attributed to east-west crustal shortening on Hall Peninsula during the THO (Skipton and St-Onge, 2014; Steenkamp and St-Onge, 2014).

Ultramafic intrusions hosted in Paleoproterozoic supracrustal strata typically occur as laterally continuous sills up to 30 m thick. These sills were commonly documented within psammite and pelite near the base of the supracrustal strata. At some localities, metagabbro and amphibolite, locally containing garnet, were found at the upper and lower contacts of the supracrustal-hosted sills. On an island southeast of the Finger Land area, where supracrustal units containing ultramafic pods are exposed in the footwall of a D2 thick-skinned thrust (Steenkamp and St-Onge, 2014), a schuppen zone comprising outcrop-scale fold and thrust imbricates and a chaotic reorientation of the supracrustal units and metamorphic fabrics around partially boudinaged ultramafic sills was documented (Figure 4c). The schuppen zone is interpreted as having developed in response to the strong rheological contrast between the relatively rigid ultramafic sill and the more pliable supracrustal rocks. In general, most ultramafic sills preserve a pervasive S1a foliation defined by platy minerals; this fabric has locally been reoriented by D2 east-verging imbricate folding and thrusting, and later D3 north-south crustal shortening (Figure 4d; Dyck and St-Onge, 2014; Steenkamp and St-Onge, 2014). A single ultramafic plug-type intrusion 5 m wide was documented in the lower supracrustal strata between the southern ends of Ptarmigan Fiord and Tawsig Fiord.

Mineralogy

On northern Hall Peninsula, all of the observed ultramafic intrusions are variably altered. The original pyroxenite to peridotite compositions have dominantly been replaced by hydrated mineral assemblages. The most commonly observed mineral assemblages include tremolite+actinolite+phlogopite+ magnetite+serpentine+talc, with minor amounts of primary orthopyroxene+clinopyroxene+olivine remaining.

In general, the interiors of basement-hosted plug-type and sill intrusions are dominated by massive, fine- to medium-grained tremolite, actinolite and phlogopite that partially to completely replace primary orthopyroxene, clinopyroxene and olivine. Minor disseminated magnetite was noted at most localities. At the contact with the surrounding host orthogneiss, outcrop-scale alteration zones penetrate up to 5 m into the ultramafic intrusion and contain medium- to coarse-grained prismatic tremolite and/or actinolite, with minor talc and/or serpentine (Figure 4b). Fibrous tremolite
Figure 4: Hydrothermally altered ultramafic intrusions on Hall Peninsula, Nunavut: a) aerial view of a plug-type ultramafic intrusion (within black dashed outline) hosted in Archean basement orthogneiss; b) laterally discontinuous ultramafic dike in Archean basement orthogneiss at Tawsiq Fiord; the white- to green-weathering periphery of the intrusion contains a hydrated mineral assemblage, whereas the brown-weathering interior (labelled peridotite) preserves some primary mineralogy (photo courtesy of Z. Braden); c) foliation in Paleoproterozoic psammite ($S_2$) is deflected around a peridotite sill with preserved $S_{1a}$ mineral fabric in the footwall of a $D_2$ thrust; the contact between psammite and peridotite is delineated by the white line (solid, confirmed; dashed, approximate); d) preserved $S_{1a}$ mineral fabric defined by aligned phlogopite and $F_{1b}$ folds in a Paleoproterozoic supracrustal-hosted hydrated ultramafic sill reoriented by later $D_2$ east-west, and $D_3$ north-south crustal-shortening events (view to the west); e) massive fibrolitic tremolite with medium-grained, euhedral actinolite inclusions at the periphery of the Tawsiq Fiord basement-hosted ultramafic dike; f) fine-grained serpentine clots wrapped by phlogopite define the pervasive $S_{1a}$ mineral fabric in the supracrustal-hosted ultramafic sills (photo courtesy of R. From). Hammer for scale in photographs is 40 cm long. Abbreviations: act, actinolite; ol, olivine; phl, phlogopite; srp, serpentine; tr, tremolite.
and actinolite were documented at two basement-hosted localities, including Tawig Fiord (Figure 4e). The single plug-type deposit hosted in the supracrustal strata contains radiating acicular actinolite that creates florets 1 cm wide. The documented alteration mineral assemblages, and the intensity and location of altered areas, suggest penetrative hydrothermal activity throughout most basement-hosted intrusions, with the most thorough alteration taking place at the boundary between the ultramafic intrusions and the host orthogneiss.

The primary ultramafic mineral assemblages in supracrustal-hosted intrusions are completely replaced by hydrated mineral assemblages. Aligned phlogopite was observed in many of the supracrustal-hosted sills to define the S1a mineral fabric (Figure 4d; Steenkamp and St-Onge, 2014). Locally the fabric deflects around knots comprising varying proportions of tremolite, actinolite and/or serpentine, creating an augen texture (Figure 4f). Magnetite was observed disseminated throughout the intrusions, concentrated in thin ribbons and/or in rare clots up to 2 cm wide.

In general, the abundance of tremolite and actinolite (in the presence of serpentine) in compositionally altered ultramafic rocks implies silica-saturated hydrothermal breakdown of calcic clinopyroxene, namely diopside, at amphibolite-facies conditions (for a list of possible reactions, see Frost and Beard, 2007). Olivine and orthopyroxene breakdown to serpentine+talc can occur over a range of temperatures and pressures, provided amenable silica and fluid activities exist (Frost and Beard, 2007). The source of the hydrothermal fluids is not clear from field observations on northern Hall Peninsula, although one potential mechanism is progressive dehydration of pelitic strata during prograde metamorphism related to the THO. The interpreted S1a mineral fabric is locally defined by the hydrated mineral assemblage, which supports the hypothesis of alteration of the ultramafic intrusions during prograde metamorphism.

**Economic considerations**

A broad group of potentially economic deposits containing nickel, copper and platinum group elements are associated with a variety of mafic and ultramafic magmatic rocks (Eckstrand et al., 2004; Naldrett, 2004; Eckstrand and Hulbert, 2007). On Hall Peninsula, the discovery of two layered mafic-ultramafic sills hosted in supracrustal strata warrants further field and analytical investigations. The observed internal magmatic layering and field relationships of the mafic-ultramafic sills on Hall Peninsula are comparable with those of the higher-level Raglan deposit of the Cape Smith Belt in northern Quebec (St-Onge and Lucas, 1993; Lesher, 2007). The Ni-Cu-platinum group element sulphide mineralization in the Raglan horizon is attributed to ultramafic sills (or flows) emplaced in pelitic metasedimentary rocks, from which sulphur was assimilated (St-Onge and Lucas, 1993; Lesher, 2007).

Hydrothermally altered ultramafic rocks, such as serpentine and soapstone, are the most sought after carving stone materials in Nunavut (Beauregard et al., 2013; Senkow, 2013). As traditional Inuit carvings become increasingly desirable in an expanding worldwide market, the demand for locally sourced, high-quality carving materials is increasing. The discovery and documentation of altered ultramafic bodies in the territory helps to meet this need and can also lead to a better understanding of the metasomatic processes and geological settings required to generate carving stone materials. Such information can help to identify areas with increased potential for hosting ultramafic rocks, allowing for more targeted and efficient exploration of new sources of carving stone. Samples from the most prospective ultramafic intrusions on Hall Peninsula have been sent to a local artisan, who will produce test carvings and evaluate the quality of the stone. Representative samples of the hydrated mineral assemblages were also collected for further petrological analyses.

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