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TILL-INDICATOR MINERAL DISPERSAL AND ICE FLOW IN THE NORTHERN HOPEDALE BLOCK: IMPLICATIONS FOR MINERAL EXPLORATION

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ABSTRACT

In the Hopedale Block, orthopyroxene and olivine grains, together, comprise over 80% of the indicator minerals in individual till samples, thus masking the presence of other indicator minerals. These grains are weathered from plutonic bedrock of the Harp Lake Intrusive and Nain Plutonic suites, west, northwest and north of the study area. Dispersal trains of orthopyroxene and sillimanite extend 40 km from a source in the Nain Plutonic Suite, east toward Udjoktok Bay, terminating south of the discontinuous till cover, 30 km west of Hopedale.

Gold grain background counts are low, with single unmodified, eroded or transported pristine grains overlying, and 300 m, up-ice of the Aucoin Au + Ag + Te prospect. A single pristine grain was also recovered 9 km northeast of Aucoin, and two pristine grains in a sample 24 km northeast of Shapio Lake. The pristine grains occur within larger northeast-trending gold dispersal trains, which leads to a complex interpretation of their source.

Although previous studies documented locally constrained ice flow that occurred during deglaciation, this study elucidates the extent of eastward ice flow, which appears to have occurred after the last glacial maximum (LGM) ca. *25 000 years ago. In addition, a preliminary ice-flow timeline suggests an early north-northeast ice flow, with later widespread northeast flow, followed by final eastward and local east-northeast and southeast flow, with some local variations, where ice channeled into valleys.*

Ice flow has locally reworked till, hence multiple exploration techniques should be considered, including till geochemistry, indicator minerals, traditional boulder tracing and pebble counts. In regions where weathered, coarse-grained orthopyroxene and olivine-rich plutonic units are abundant, automated identification of the fine-sand fraction in tills using Scanning Electron Microscope-Mineral Liberation Analysis techniques (SEM-MLA) may be more useful in detecting indicator minerals associated with mineralized bedrock. In regions where till is sparse, other techniques, such as lake- and stream-sediment sampling, may assist in identifying subsurface mineralization. Finally, striations and other ice-flow indicators should be measured in conjunction with the till sampling studies to clarify ice-flow directions, as post LGM ice flow has affected the dispersal of indicator minerals.

INTRODUCTION

Till-indicator mineral studies encompass the optical examination, identification and counting of heavy and erosion-resistant mineral grains, associated with specific bedrock and mineralizing environments. In indicator-mineral studies of till, these grains comprise the coarse fraction (*i.e.*, <0.25–2 mm) of the heavy mineral separates. Indicator minerals such as rutile, Cr-diopside, spinel, corundum and apatite that occur as accessory minerals can persist in environments affected by glacial erosion. Conversely, base-metal grains directly associated with deposits, oxidize and comminute easily by glacial processes (Averill, 2001). Mineral grains often have visually distinct features that make them identifiable in optical grain counts despite containing geochemically similar matrices (*e.g.*, kyanite, sillimanite, corundum, diopside). Hence, indicator-mineral identification is particularly important when geochemical results cannot be used to distinguish between minerals of similar composition (Averill, 2001).

Approximate dispersal distances of indicator minerals are obtained by studying the shape and erosion of gold grains, where present, as they are malleable and prone to glacial modification. Based on the degree of grain modification, pristine grains are closer (<100 m) to their source and modified and reshaped grains are from sources farther up-ice (*e.g.*, >500 m; DiLabio, 1990; Averill, 2001); however, grain-shape modification is heavily dependent on the occurrence of gold in the host rock, and can affect dispersal distances (McClenaghan, 2005). The decrease of anomalous abundances of indicator minerals (*e.g.*, mineral concentrations greater than the bulk of samples in the study) from the "head" nearest the source to the distal down-ice "tail" infers dispersal direction (Shilts, 1976).

This study, conducted between 2017–2019, collected heavy mineral samples to detect indicator minerals of possible masked subsurface mineralization. Outcrop-scale ice-flow indicators were also collected to highlight local ice-flow orientations that are important for mineral exploration. The indicator-mineral dispersal trains and ice-flow indicators allow for the interpretation of paleo-ice flow in the central eastern margin of the Laurentide Ice Sheet (LIS) in Labrador.

LOCATION

The study area, red box (index map of Labrador) in Figure 1, lies in central north Labrador in the southern part of the Nain tectonic province between latitudes 55 and 56°N and longitudes 62.5 and 60°W. It is located west of the coastal community of Hopedale (Aqvituq) and covers parts of NTS map areas 13M and 13N. Vale Canada Incorporated Voisey's Bay Ni–Cu–Co mine is the only operating mine in this region and is located 150 km north of the study area; the Central Mineral Belt is ~80 km south and is currently being explored for uranium and base-metal mineralization.

PHYSIOGRAPHY

Barren hills between 600 and 840 m above sea level (m asl) surround the study area, east of Sarah Lake and north of Hunt River and are eroded, in places, by glaciers into flat-bottomed valleys with sporadic tree cover. West of Sarah Lake, the terrain is a sparsely vegetated 500–600 m high plateau with abundant glacial deposits and sculpted bedrock outcrops. Southwest of Sarah Lake, weathered bedrock and vegetation cover the locally deeply incised Harp Lake uplands; Harp Lake occupies a prominent east-northeast linear valley that drains into the Adlatok River (Lopoukhine *et al.*, 1977). The Adlatok River jogs south of Harp Lake into a sand-filled valley, draining eastward into Udjoktok Bay. West of Hunt River, forest fires burned ridges and lowlands <300 m in 1994 and 2000 (NRCAN Canadian Wildland Fire Information System (https://cwfis.cfs.nrcan. gc.ca/interactive-map), exposing bouldery glacial deposits. Toward the coast from Hopedale to Udjoktok Bay, water has winnowed glacially scoured ridges at elevations less than 80 m. They are sparsely drift-covered, with isolated cobble, pebble and sand beaches.

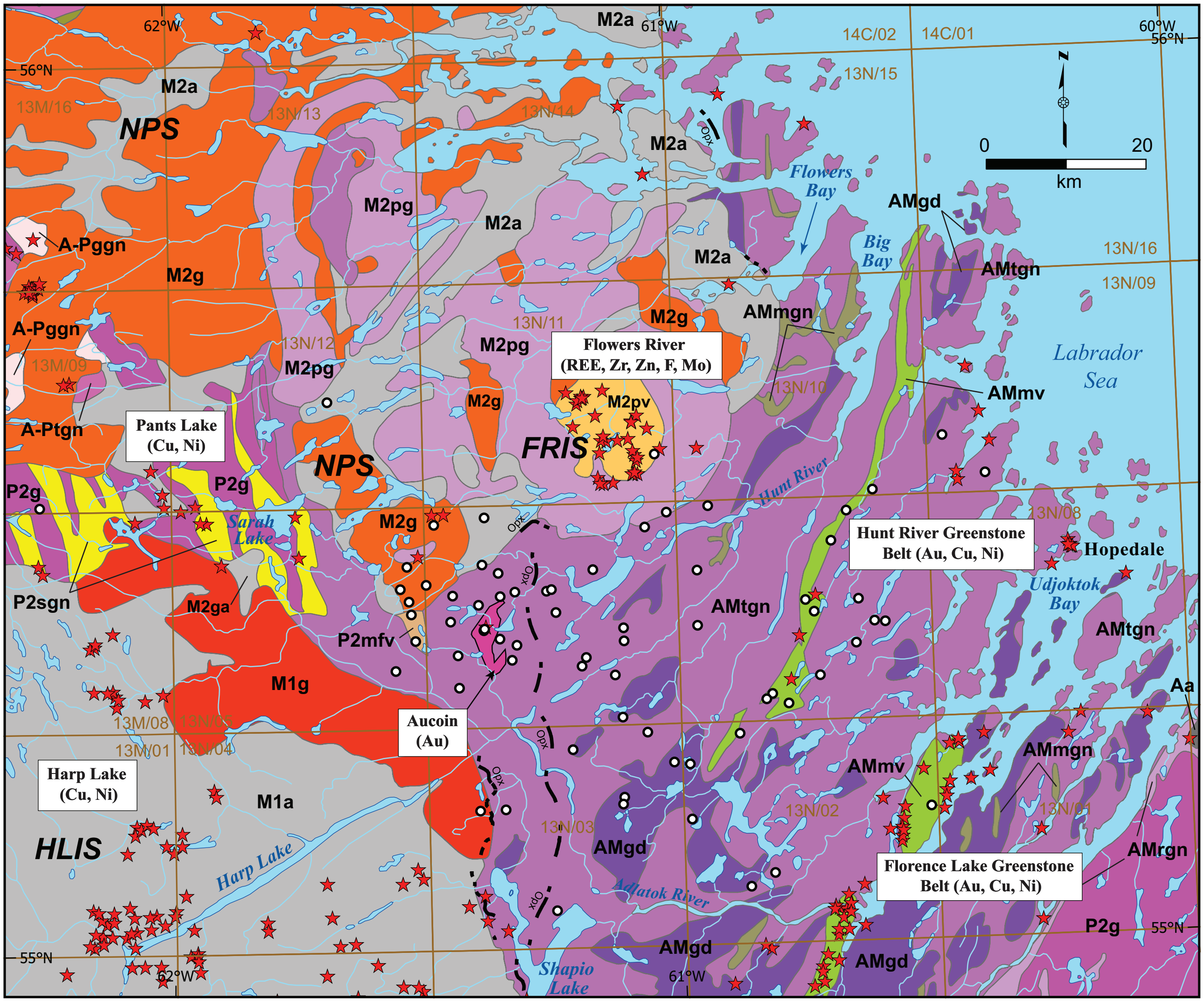
REGIONAL GEOLOGY AND MINERAL OCCURRENCES

The following section summarizes the bedrock geology of the Hopedale Block (*see* Wardle *et al.*, 1997). For a more detailed description of the bedrock geology, see Taylor (1972), Jesseau (1976), Emslie (1980), Hill (1982a–c), Ermanovics (1993), Thomas and Morrison (1991), Ryan *et al.* (1991), Cadman *et al.* (1993), Wasteneys *et al.* (1996), James *et al.* (1996, 2002), Wardle *et al.* (1997), Sandeman and Rafuse (2011), Sandeman and McNicoll (2015), Ducharme (2018), Hinchey and Corrigan (2019), Rayner (2022) and Sandeman *et al.* (2023).

The Archean (*ca.* 3.2 to 2.8 Ga) Hopedale Block includes the greenschist-to-amphibolite-facies volcanosedimentary Hunt River and Florence Lake greenstone belts (Figure 1–AMmv). The Hunt River and Florence Lake greenstone belts are surrounded by a composite, complex unit of amphibolite to locally granulite-facies orthogneiss called the Maggo Gneiss (Figure 1–AMtgn) and intruded by the Kanairiktok Plutonic Suite. Fine-grained amphibolites and volcanosedimentary rocks of the greenstone belts, and amphibolite rafts in the Maggo Gneiss (termed the Weekes Amphibolite; Figure 1–AMmgn), host nickel, pyrite, pyrrhotite, chalcopyrite and sphalerite indications and showings (*see* Ermanovics, 1993; James *et al.*, 2002; Sandeman *et al.*, 2023).

Late Neoarchean (*ca.* 2567 Ma) coarse-grained syenite, monzodiorite and monzogabbro units outcrop northwest of the Archean greenstone–granite terrane (Sandeman and McNicoll, 2015; Figure 1–Aucoin). Shear zones in these units host the Aucoin Au–Ag–Te prospect and associated Chance, Edge, Turpin and Ridge showings (Lehtinen *et al.*, 1997; Sandeman and Rafuse, 2011; Morgan *et al.*, 2014; Sandeman and McNicoll, 2015). Indicator minerals in these bedrock units and the associated showings are gold, chalcopyrite, pyrite, rutile, ilmenite, epidote and apatite. Gold is reported up to 478 g/t in bedrock grab samples (Hussey and Moore, 2006), with a gold intersection of 12.4 g/t Au (14 g/t Ag) over 1.05 m at the Aucoin prospect (Lehtinen *et al.*, 1996).

The Paleoproterozoic mafic and felsic volcanic, volcaniclastic and clastic sedimentary rocks of the Ingrid Group (Ermanovics, 1993; Hinchey and Corrigan, 2019; Figure 1–P2mfv), outcrop between the Aucoin prospect and the Paleoproterozoic gneisses derived from metasedimentary protoliths (Figure 1–P2sgn) and foliated granitic intru-



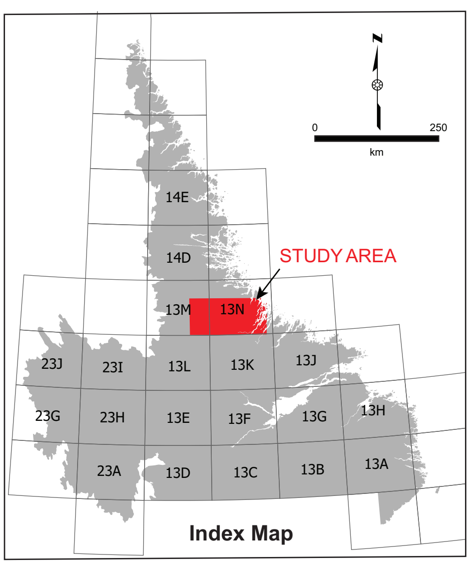


Figure 1. *Bedrock geology of the Hopedale Block (after Wardle* et al.*, 1997), showing indicator-mineral sample sites, prospects and mineral occurrences. Location of study area shown on index map of Labrador. HLIS=Harp Lake Intrusive Suite, FRIS=Flowers River Igneous Suite, NPS=Nain Plutonic Suite.*

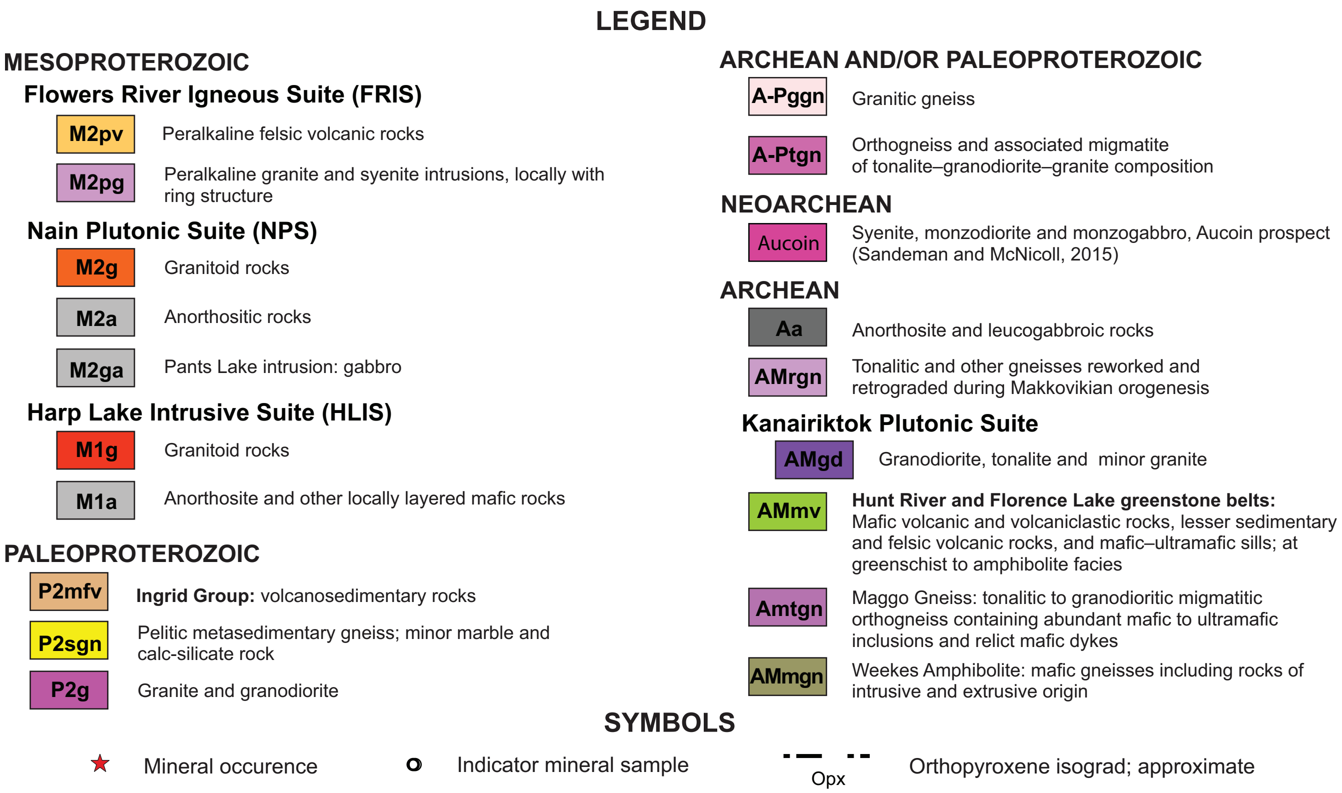


Figure 1. *Legend.*

sions (Figure 1–P2g) of the southeast Churchill Province (Wardle, 1983; Hill, 1982a, c; Thomas and Morrison, 1991).

Coarse-grained, olivine-rich and olivine-poor, orthopyroxene and plagioclase units occur in Mesoproterozoic gabbros, anorthosites and quartz monzonites that outcrop in the Harp Lake Intrusive Suite (HLIS; Figure 1–M1a, M1g), occupying a large portion of west-central Labrador (Emslie, 1980). The HLIS hosts numerous nickel and copper occurrences, commonly indicated by their gossanous weathering (Kerr, 2012). Coarse-grained, olivine-bearing anorthosite and pyroxene- and olivine-bearing monzonite in the Nain Plutonic Suite (NPS) outcrop in the northwest study area (Hill, 1982a, c; Ryan *et al.*, 1991; Thomas and Morrison, 1991; Figure 1–M2ga, M2a, M2g). These rocks host a copper indication (Wares and Leriche, 1996). Coarse-grained granites and fine-grained volcanic rocks comprise the Flowers River Igneous Suite (FRIS), as well as the rare-metal-bearing minerals bastnäsite, fluorocerite, monazite, parasite, synchesite, terskite, xenotime and zircon (Hill, 1982b, c; Miller, 1994; Ducharme, 2018; Figure 1–M2pg, M2pv).

Coarse-grained, olivine-bearing anorthosite, pyroxene, and olivine-bearing monzonites in the Nain Plutonic and Harp Lake Intrusive suites are locally weathered and disaggregated into carpets of mineral gravel (grus) that blanket the bedrock. Boulders from these units are in various stages of disintegration down-ice of their sources. In some areas, the bedrock forms "mushrooms" or "pedestals" due to compositional layering (Emslie, 1980). Deflation hollows near some rocks indicate wind erosion (Plate 1A, B).

PREVIOUS ICE-FLOW AND DISPERSAL STUDIES

Northeast flowing ice reached the continental shelf at a late glacial maximum *ca.* 25 000 years ago, scouring a large trough on the ocean floor (Hopedale Saddle Ice Stream – HSIS (Figure 2C), Josenhans *et al.*, 1986; Margold *et al.*, 2015; Dalton *et al.*, 2023). North-northeast, followed by northeast, and then east-northeastward ice flow and local topographically constrained flow to the southeast around the northern half of the HLIS have been identified in striation measurements and landform mapping (Klassen and Bolduc, 1986; Klassen and Knight, 1995; Klassen and Thompson, 1993, page 46; Batterson, 2000a–e). Northeast-oriented linear dispersal patterns occur in Nb and Y in the silt (<0.063 mm) and in Pb and Zn in the clay fraction (<0.002 mm) of till overlying the FRIS (Klassen and Thompson, 1993, page 42). Abundant values at the "head" of the dispersal train at the western end of the FRIS decrease to background values at the "tail" 40 km northeastward. The dispersal data and

Plate 1. *A) Picture of an eroded olivine- and orthopyroxene-rich boulder south of the Flowers River Igneous Suite (student 5'6" tall for scale; picture courtesy of Hamish Sandeman); B) The same student next to an anorthosite boulder derived from the Harp Lake Intrusive Suite on a ridge directly east of it. Emslie (1980) termed these rock formations "Pedestal rocks".*

striae measurements have indicated a relative ice-flow chronology of early northeast flow, followed by east-northeast flow that extends offshore, another east-northeast flow and then locally occurring southeast flow.

INDICATOR MINERAL METHODS

Bulk till samples (n=70; 10–15 kg per sample) were collected for indicator-mineral analysis at 2–10 km spacing in prospective regions based on historical datasets, including lake-sediment geochemical anomalies (Hornbrook *et al.*, 1979; Boyle *et al.*, 1981; Friske *et al.*, 1993; McConnell, 1999; McConnell and Finch, 2012), airborne magnetic anomalies (Coyle, 2019a–d) and Bouger gravity anomalies (Jobin *et al.*, 2017). The samples were collected from till east of Sarah Lake, east of the HLIS and north of the Adlatok River, eastward toward Udjoktok Bay, and south of the FRIS. Samples were shoveled from hand-dug test pits up to 90 cm deep or mudboils up to 40 cm deep. Most samples were collected from basal till in shallow (<2 m) pits. Subglacial deposits with limited sorting are ideal for sampling (Shilts, 1976). Pits were typically dug in mudboils, as the till is exposed at shallow depths (~30 cm), is well mixed, and unweathered (Shilts, 1978; McMartin and McClenaghan, 2001; McMartin and Campbell, 2009). A few samples were collected in subglacial melt-out till in a boulder covered region hypothesized to be a moraine (Campbell, 2020; Figure 2), southeast of Harp Lake where basal till was inaccessible. Disintegrated cobbles, pebbles and grus were avoided during sampling to prevent sample composition bias. Only one till layer was observed at each sample site.

Thirty-nine till samples were collected northeast and east of the HLIS and south of the FRIS (Figure 1). Discontinuous till exposure throughout the Hunt River greenstone belt made sampling more difficult; 16 samples were collected in shallow tills overlying and surrounding this belt. Burned regions southwest of Hunt River were difficult to access by helicopter due to the danger of the tail rotor entraining burnt debris. Thirteen samples were collected south of the Aucoin prospect and FRIS and north and west of the Adlatok River valley. Single samples were collected west of Pants Lake, north of Sarah Lake and the Florence Lake greenstone belt, overlying distal and unrelated bedrock units of differing mineralogical and geochemical characteristics to contrast with those in the study. Till matrix geochemical samples were collected at all of the sites whereas pebbles were collected at some of the sites, and these results will be presented in a forthcoming contribution.

The samples were shipped to Overburden Drilling Management (ODM), Ottawa, and processed using sieving, gravity and magnetic methods to recover indicator minerals. Samples were separated using heavy liquid separation in dilute methylene iodide with a specific gravity (SG) of 3.2 (*i.e.*, density of 3.2 g/cm^{-3} relative to the density of water (1 g/cm^{-3})). The 0.25–2.0 mm >3.2 SG heavy mineral fraction was examined for Kimberlite Indicator Minerals (KIMs) and Metamorphosed and Magmatic Massive Sulphide Indicator Minerals (MMSIMs®). Minerals that were difficult to identify visually were scanned using the scanning electron microscope (SEM). The individual indicator mineral data releases provide a flowchart detailing the sample processing, mineral grain separation and counting stages (Campbell and McClenaghan, 2019a, b, 2020).

STRIATION DATA

One hundred and twelve ice-flow indicators were collected during the study (Figure 2A, B) using a compass to measure (mostly) striations and a few grooves, where striations were absent. The protected lee sides of outcrops were

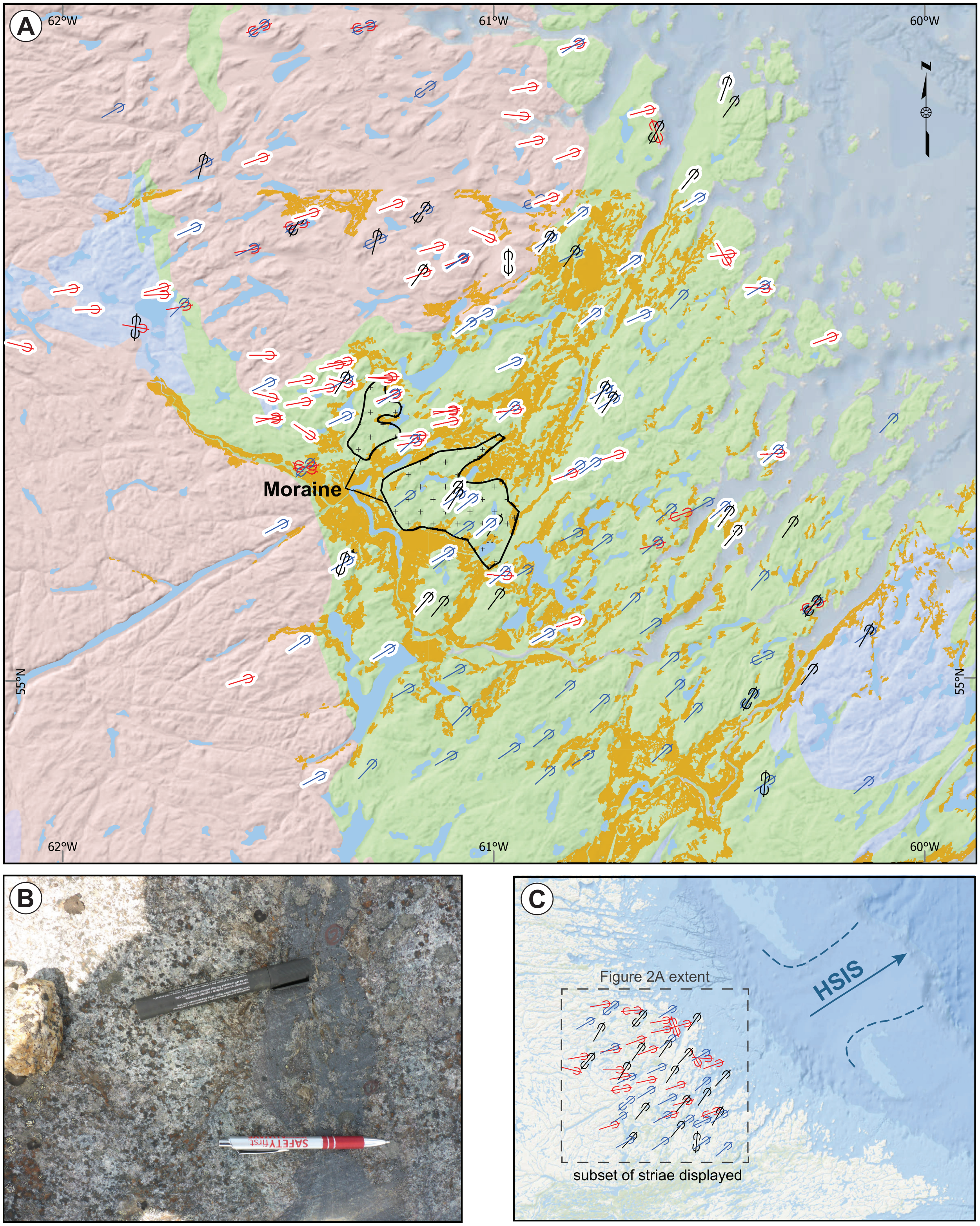


Figure 2. *A) Geological units simplified by age draped over a digital elevation map (ALOS World 3D" Japan Aerospace Exploration Agency; Takaku* et al.*, 2020) and ArcGIS online ocean basemap that includes imagery from GEBCO and striations from this study (solid arrows with white halos) and historical studies (solid arrows with no halos). Black striations indicate the earliest flow orientation, blue striae indicate northeast flow, red striations indicate the last flow events. The approximate location of the moraine is outlined on the map; B) East-northeast (075°) and east-southeast (094°) striations in a mafic dyke intruding conglomerate in the Ingrid Group; C) A small-scale map of the Hopedale Saddle Ice Stream (HSIS #168; Margold* et al.*, 2015) with a subset of the measured striae for reference.*

cleared to uncover striations from earlier ice-flow events not erased by later ice flow. Ice-flow direction was determined by the inspection of glacially polished and abraded rock surfaces ending in hackly vertical to subvertical surfaces on the down-ice (lee) sides of outcrops caused by glacial plucking. In rare sites where multiple striation orientations were visible, surfaces were carefully inspected to determine striations from earlier ice flow that were overprinted by later ice-flow striations.

INDICATOR-MINERAL RESULTS

Table 1 lists the indicator mineral abundances normalized to a sample weight of 10 kg and ranked and colourized (*e.g.*, green to red) in order of their total abundance. Individual indicator minerals (tourmaline, staurolite) are abundant in some samples whereas other indicator minerals (apatite, fayalite, orthopyroxene) are found in most samples; (Table 1, column 2).

Table 1. Comparison of the amount of samples containing specific indicator minerals grains and the total amount of grains in all of the samples (n=70) collected in 2017–2019 from the Hopedale Block

Minerals	Amount of samples containing grains	Total amount of grains
chondrodite	1	1
chalcopyrite	1	1
chrome grossular	1	1
grossular	1	1
sapphirine	1	1
galena	1	2
arsenopyrite	2	2
loellingite	2	2
ruby	2	3
sapphire	3	3
molybdenite	4	6
scheelite	6	11
spinel	8	11
kyanite	6	22
tourmaline	5	24
low-Cr diopside	21	28
rutile	22	29
gold	27	55
monazite	13	150
Mn-epidote	39	184
pyrite	33	250
goethite	24	316
staurolite	2	1153
sillimanite	48	6302
apatite	54	200642
fayalite	66	656045
orthopyroxene	69	8142827

Orthopyroxene (65–99% of all grains/normalized sample) and fayalite olivine (0–97%) were very common in the indicator-mineral suites in tills. Accessory grains in most of the samples include apatite (0–20%), sillimanite 0–2% and pyrite 0–0.5%. Mn-epidote (0–26 grains/sample) is also common. Other indicator minerals in till (0–100 grains) that are less equally distributed in samples include staurolite, goethite, monazite, tourmaline, rutile, kyanite, scheelite low-Cr diopside and gold. Galena, chalcopyrite, molybdenite, arsenopyrite, loellingite, chondrodite, grossular, corundum, sapphire, sapphirine and spinel are uncommon, ranging from 0–4 grains per normalized sample.

DISTRIBUTION OF GRAINS IN TILL

The distributions of indicator minerals in samples collected above the bedrock are summarized in Table 2. Orthopyroxene and olivine grain counts are anomalous in samples overlying most of the bedrock units and are thus not included in this table.

Ice Flow

The striation orientations and localities are displayed in Figure 2A, with an example of striations measured in this study (Figure 2B). Northward flow (020–045°) is observed in 30 striation sites throughout the study area, including 11 sites measured in this study. Most of these measurements fall between 030–040° and are overprinted locally by widespread northeast to east-northeast flow (046–068°). This flow direction is the most widespread, with 84 striations, 38 measured in this study. East to east–northeast and east–southeast flow (070–145°) is prevalent in the northwest and toward the coast, as observed in 63 striation sites (49 measured in this study). Most of these measurements lie between 070–090° with southeast flow indicators (129–145°) measured around the northeast margin of the HLIS. This striation set is deflected to the east-northeast around the northern margin of the proposed moraine (Figure 2A). Extreme southerly and northerly measurements are rare (eight measurements in historical datasets and from this study) and occur in areas where there may have been late local ice build-up (*e.g.*, near Sarah Lake) or where they may have been deflected into valleys (*e.g.*, FRIS) and bays (*e.g.*, along the coast north of Hopedale).

Indicator Mineral Dispersal

Dispersal patterns, recognized by anomalous minerals, at the “head” or source, decrease to a minimum at the “tail” (Shilts, 1976); examples of anomalous indicator minerals

Table 2. Indicator minerals in till overlying contrasting bedrock units of the Hopedale Block

Western study area (Gneiss - Churchill Province)	Study area overlying the Ingrid Group	Northern and western study area (Nain Plutonic Suite, Harp Lake Intrusive Suite)	Northern study area (Neoarchean rocks and Aucoin prospect)	Southern study area (Archean greenstone belt and gneiss)
chondrodite	grossular,	orthopyroxene	orthopyroxene	staurolite
gold	chrome grossular	apatite	apatite	kyanite
molybdenite	garnet	sillimanite	gold	pyrite
	Mn-epidote	Mn-epidote	galena	goethite
		gold	arsenopyrite	gold
		galena	loellingite	scheelite
		chalcopyrite	rutile	molybdenite
		arsenopyrite	tourmaline	low Cr-diopside
		loellingite	monazite	ruby
		goethite		sapphirine
		rutile		
		spinel		
		tourmaline		
		monazite		
		sapphire		
		ruby		

are orthopyroxene, apatite, sillimanite, Mn-epidote and gold (Figures 3–8). Anomalous grain counts of these minerals originate in samples above bedrock units in the northwestern study area and form linear patterns of decreasing abundance to the northeast, east and south-southeast.

Orthopyroxene is abundant in till across the entire study area making it difficult to identify discrete dispersal trains. The highest grain count of orthopyroxene (654 206) is in sample 17-4802, collected 300 m west of the Aucoin Au–Ag–Te prospect. Grain counts in other samples decrease in a linear pattern 15 km to the east-northeast. Two parallel linear dispersal trains are indicated to the east-southeast of granitic units from the NPS, and from sample 17-4802 in the northwest. The number of grains decreases similarly in the parallel trains over 8 and 12 km distances (Figure 3). A 41-km eastward linear decrease in orthopyroxene from sample 17-4802, terminates in the Hunt River greenstone belt, 31 km east of Hopedale (Figure 3).

The highest count of apatite grains occurs in the same sample (17-4802), with the grain count (168 224) decreasing to 5825 grains at 15 km, then to 13 grains 25 km to the northeast (Figure 4). The northeast dispersal pattern of apatite from the Aucoin prospect is similar in orientation (northeast) and distance (25–27 km) to those of Y and Zn indicated by Klassen and Thompson (1993, page 46) for regional dispersal trains sourced from the FRIS.

Anomalous sillimanite (645) decrease to 6 grains in a 9 km southeastward linear dispersion from a source in the NPS (Figure 5). Another southeast train occurs from the same source to 38 km eastward, where it decreases from 417 to 10 grains in the valley leading to the Hunt River southwest of Big Bay.

Anomalous grain counts (26) of Mn-epidote are highest in samples collected in the western study area. These decreased by 75% to 6 grains, 7 km to the northeast and increased slightly to 7 grains 14 km to the northeast along the dispersal path (Figure 6). This dispersal train merges with another originating from a source 6 km north of the Aucoin prospect, with the second highest grain count (20 grains). Southeastward dispersal over 13 km from the south of the Aucoin prospect is inferred from a decrease to 4 grains. The third-highest grain count (18) is located on the northwesternmost boundary of the study area. These decrease to eight grains in a sample 3.6 km away, to just 3 grains 11 km to the southeast.

The total gold grain count from the Ridge showing (18HC4015; two pristine grains and two modified) decreases to one grain 15 km east-northeast (Figure 7). Samples 18HC4010 and 18HC4042, collected within the dispersal train 9 and 9.5 km to the northwest, respectively, contain single pristine grains, along with reshaped (1 and 5 grains) and modified (1) grains. The Ridge showing is not likely the

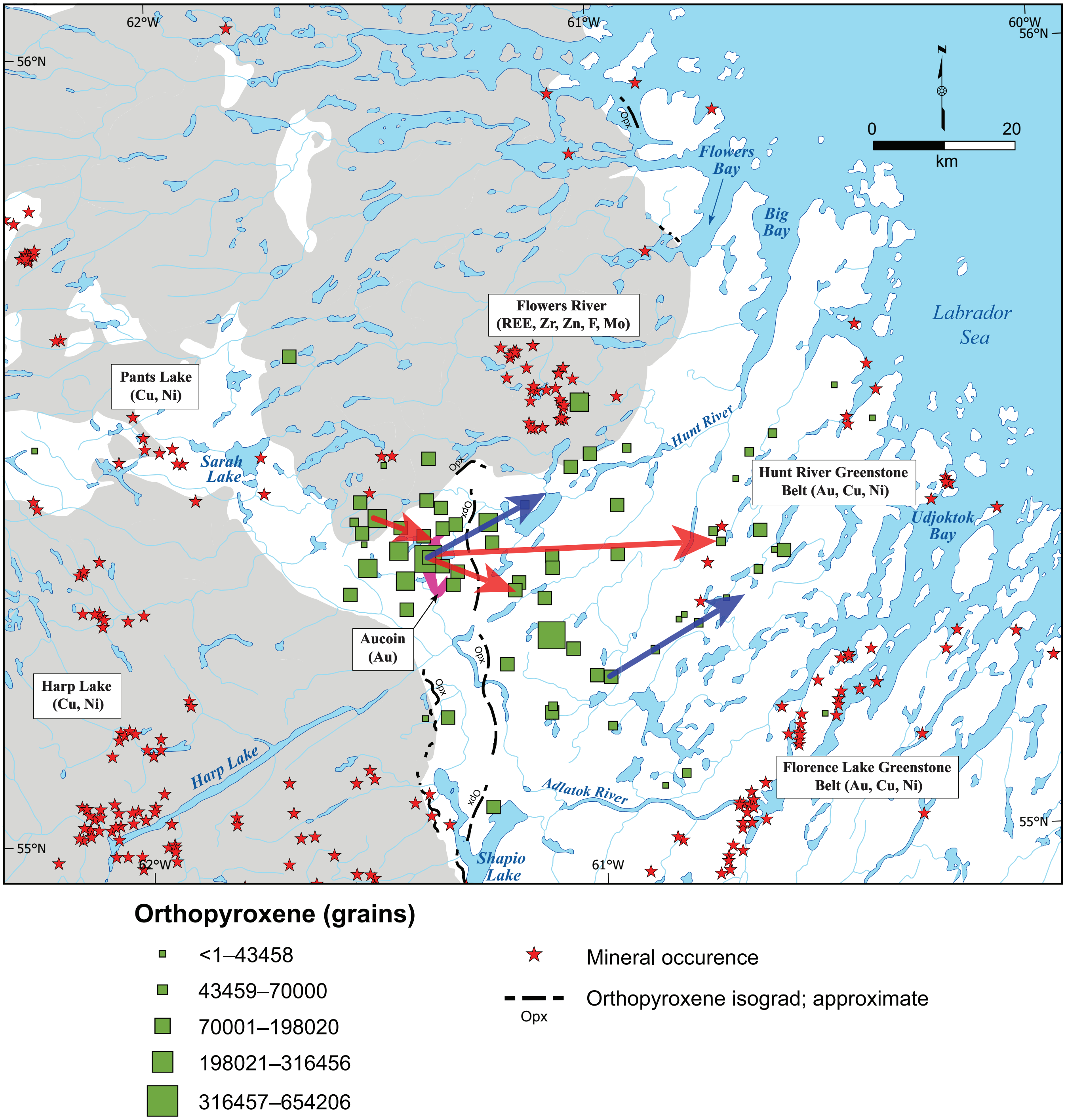


Figure 3. *Orthopyroxene distribution in till overlying the Hopedale Block. The blue arrows indicate northeast dispersal, and the red arrows indicate east to southeast flow. Plutonic rocks are signified by the grey shaded area. The Aucoin prospect is indicated by the pink polygon, which is the source of the orthopyroxene-dispersal trains in the northern part of the study.*

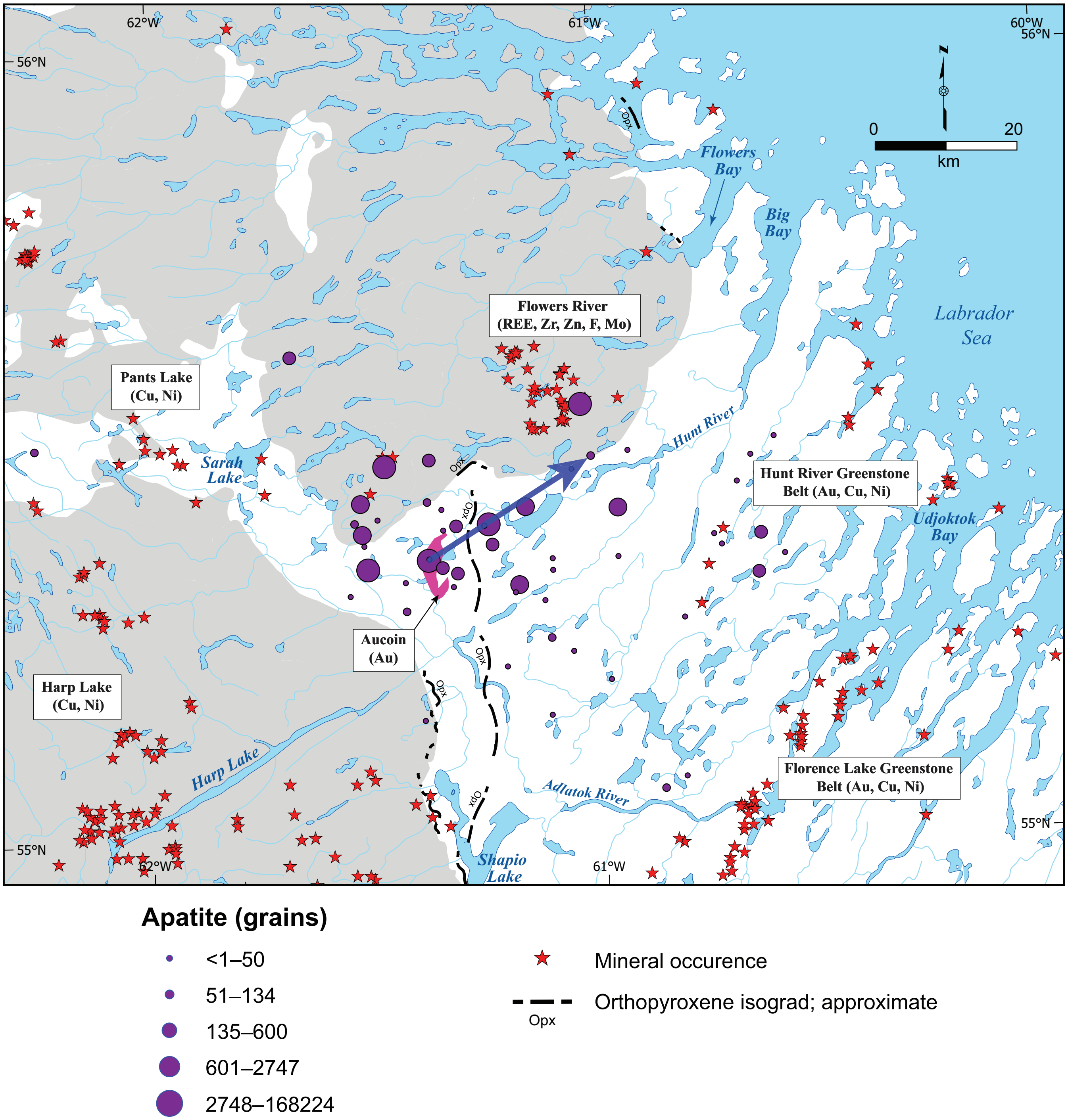


Figure 4. *Apatite distribution in till overlying the Hopedale Block. The blue arrow indicates northeast dispersal. Plutonic rocks are signified by the grey shaded area. The pink polygon indicates the Aucoin prospect which is the inferred source of the apatite-dispersal train.*

source of the pristine, unmodified grains, indicating the source should be closer, possibly ≤100 m.

Dispersal patterns are rare in the southern study area, except for a northeastward-oriented dispersal train in orthopyroxene and total gold grain counts northeast of Shapio Lake (Figure 7). The orthopyroxene grains decrease from 108 108 to 7692 grains over 22 km; gold grains decrease from 4 to 1 over 17 km northeast linear distance. However, sample 19HC4006, near the apparent "head" of

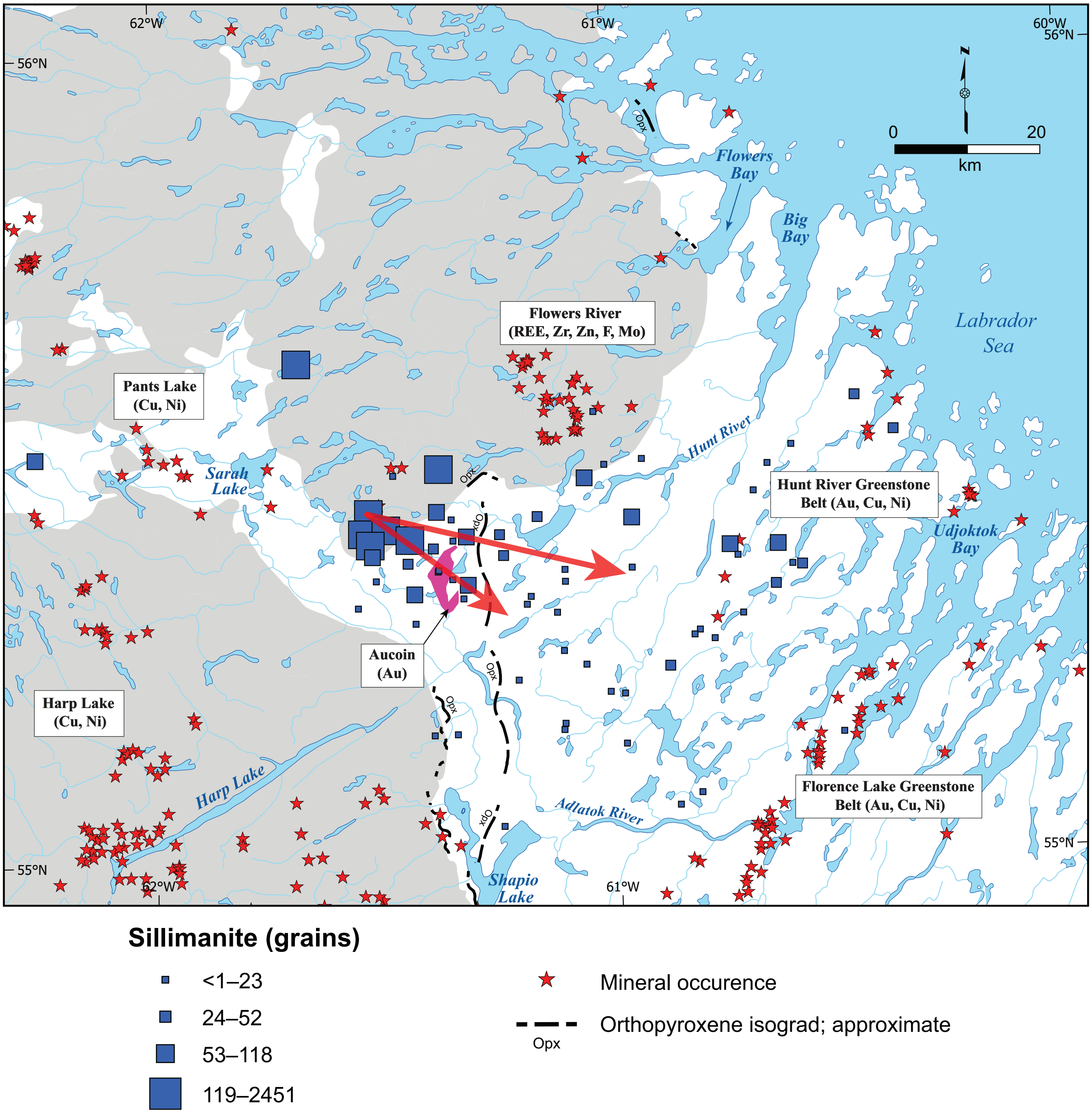


Figure 5. *Sillimanite distribution in till overlying the Hopedale Block. The red arrows indicate southeast dispersal. Plutonic rocks are signified by the grey shaded area. The pink polygon indicates the Aucoin prospect.*

the gold dispersal train, contains reshaped gold grains, whereas the next sample, 9-km down-ice (18HC4012), includes two pristine and one modified grain of gold (Figure 8). An unrecognized up-ice source at an unknown distance could contribute reshaped grains to 19HC4006, and an unrecognized bedrock source nearby (*e.g.*, <100 m) could contribute pristine gold grains to sample 18HC4012.

DISCUSSION

The abundances of these minerals and their spatial distribution (north and west *vs.* south) reflect the known mineralogy of some of the source bedrock units. However, there is a bias toward the coarse fraction (0.25–2 mm) of the heavy-mineral separates as smaller grains are not retained

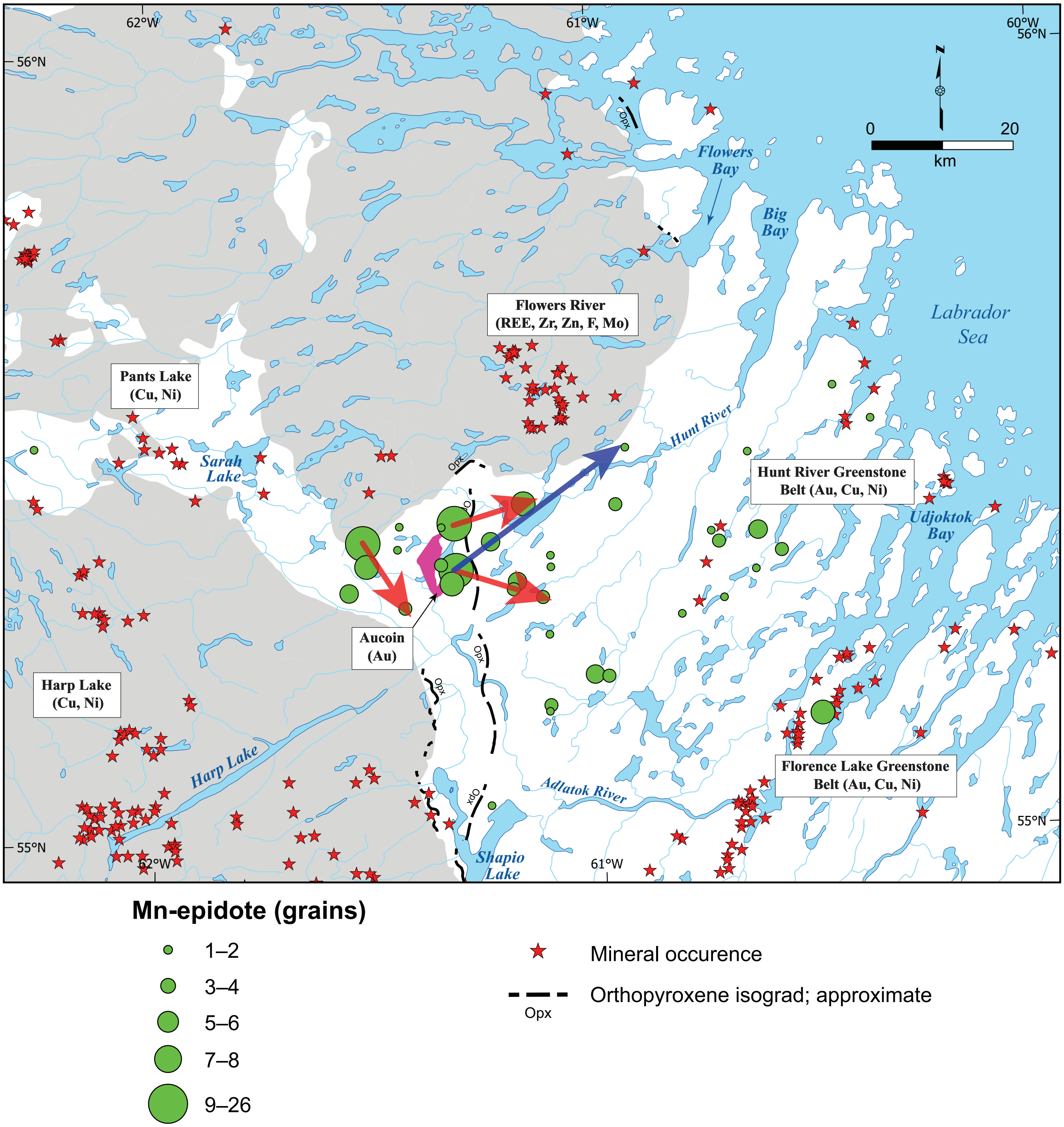


Figure 6. *Mn–epidote distribution in till overlying the Hopedale Block. The blue arrow indicates northeast dispersal. The red arrows indicate east- to east-southeast dispersal. Plutonic rocks are signified by the grey shaded area. The pink polygon indicates the Aucoin prospect.*

and identified optically. Many of the indicator minerals are from coarser grained bedrock units, such as the plutonic rocks in the study's northwest corner. As the NPS units are weathered and locally covered with a 5–15 cm layer of orthopyroxene and plagioclase crystals, they are more easily dispersed than the non-weathered bedrock. The larger crystals (2–4 cm) from these units are mixed down-ice and preferentially retained in the > 0.25 mm sieve size used for separating indicator minerals for identification. Minerals from finer grained bedrock units, including the volcanic and sed-

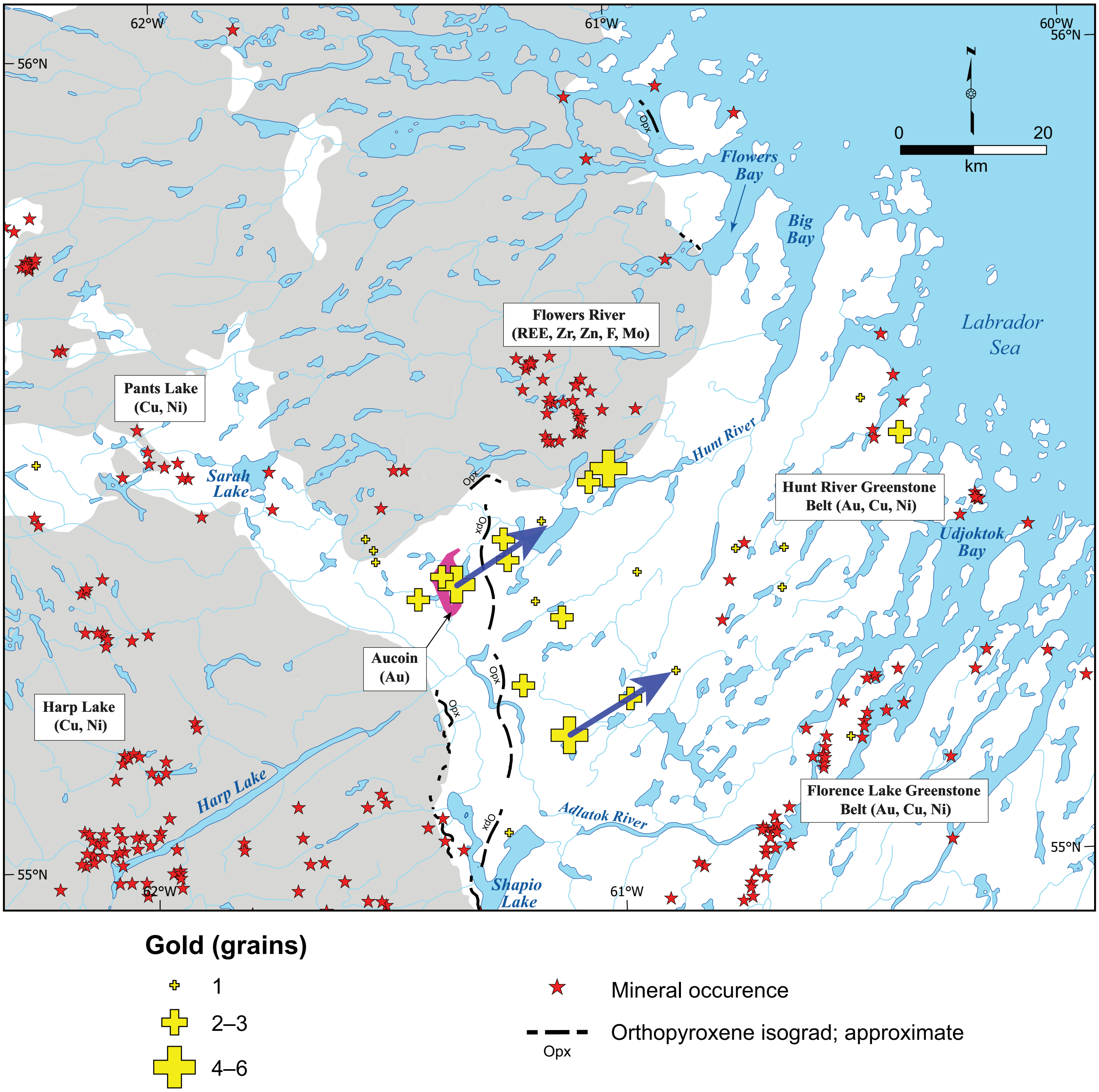


Figure 7. *Total gold grain distribution in till overlying the Hopedale Block. The blue arrows indicate northeast dispersal. Plutonic rocks are signified by the grey shaded area. The pink polygon indicates the Aucoin prospect.*

imentary rocks of the Archean Hopedale Block and their derivatives, would not be retained in the sieves used to concentrate indicator minerals. Less friable rocks occur in some of the rock types associated with the Aucoin prospect; these may not be eroded as easily as the weathered bedrock from the NPS. Grain size comparisons in select thin sections (Figure 9) illustrate size variability between apatite grains from the Aucoin syenite and the diorite from the NPS, and rutile from the Aucoin syenite *versus* the Hunt River belt metavolcanic rocks.

The orientation and relative timing of ice-flow events are constrained by 1) overprinting and lee preservation striation relationships (*e.g.*, northeast to east-northeast orientations overprinting east to east-southeast flow, or northeast flow preserved in the lee sides of landforms demonstrating

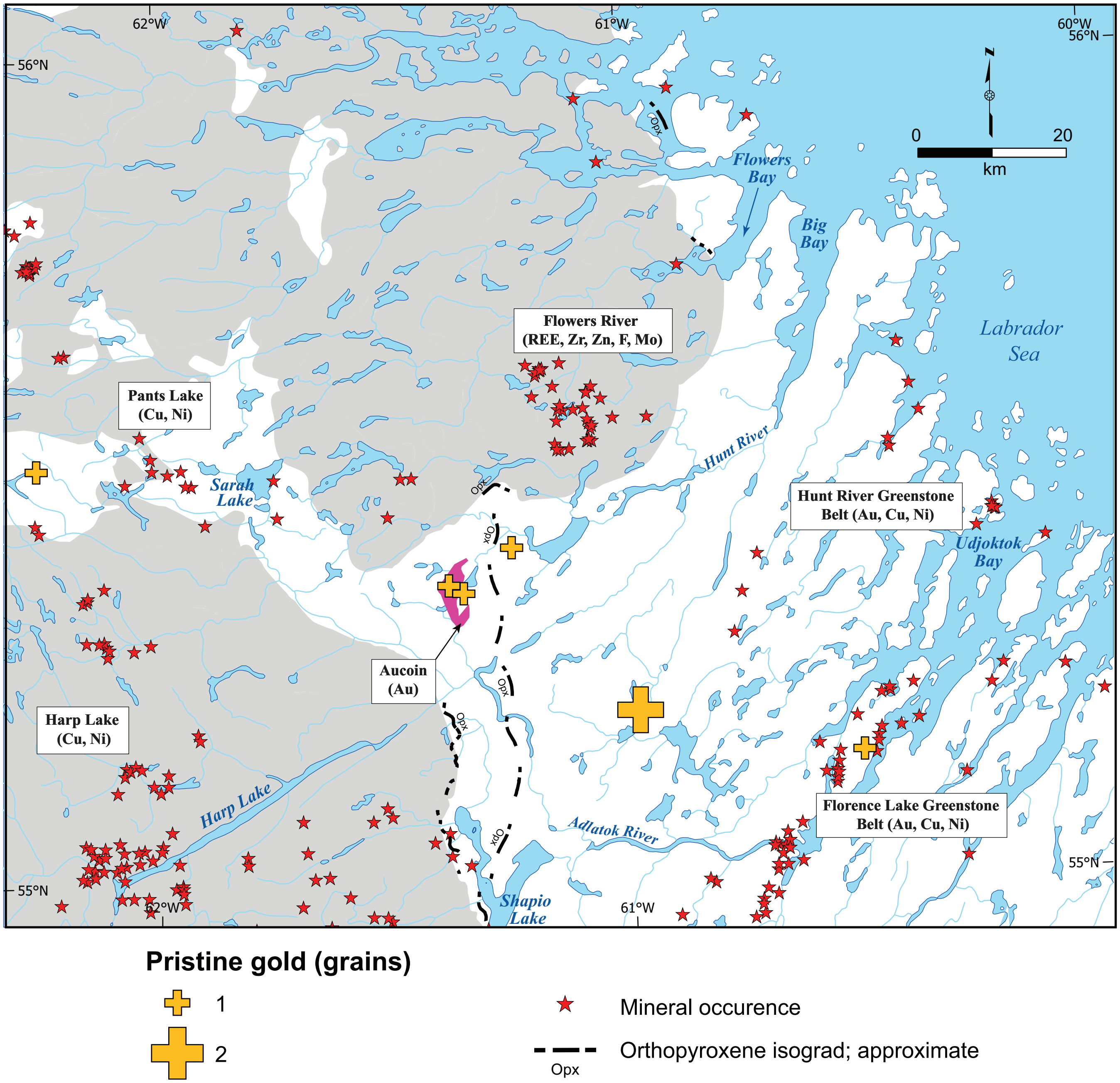


Figure 8. *Pristine gold grain distribution in till overlying the Hopedale Block. Plutonic rocks are signified by the grey shaded area. The pink polygon indicates the Aucoin prospect.*

eastward flow), and 2) the orientation and timing of the HSIS (#168), discussed earlier. In the northern Hopedale Block, the data indicate early north-northeast flow, followed by northeast to east-northeast flow (including ice flow to the shelf break). Later eastward and east-northeast to east-southeast flow and locally occurring southeast flow are indicated in both the striation measurements and in indicator-mineral dispersal data. The northeast-oriented indicator mineral dispersal patterns are comparable to those previously identified as the last ice-flow event of Klassen and Thompson (1993, page 42). However, this study demonstrates that east and southeast ice flow could have locally redispersed material after the northeast flow event.

Southeast dispersal terminates north of the moraine, and southeast striations were not identified in bedrock outcrops in the moraine (Figure 2A). North of the moraine, ice flow appears to have been deflected to the east, around a colder based? ice cap that deposited the moraine during deglaciation. This ice cap may have been coeval with a pro-

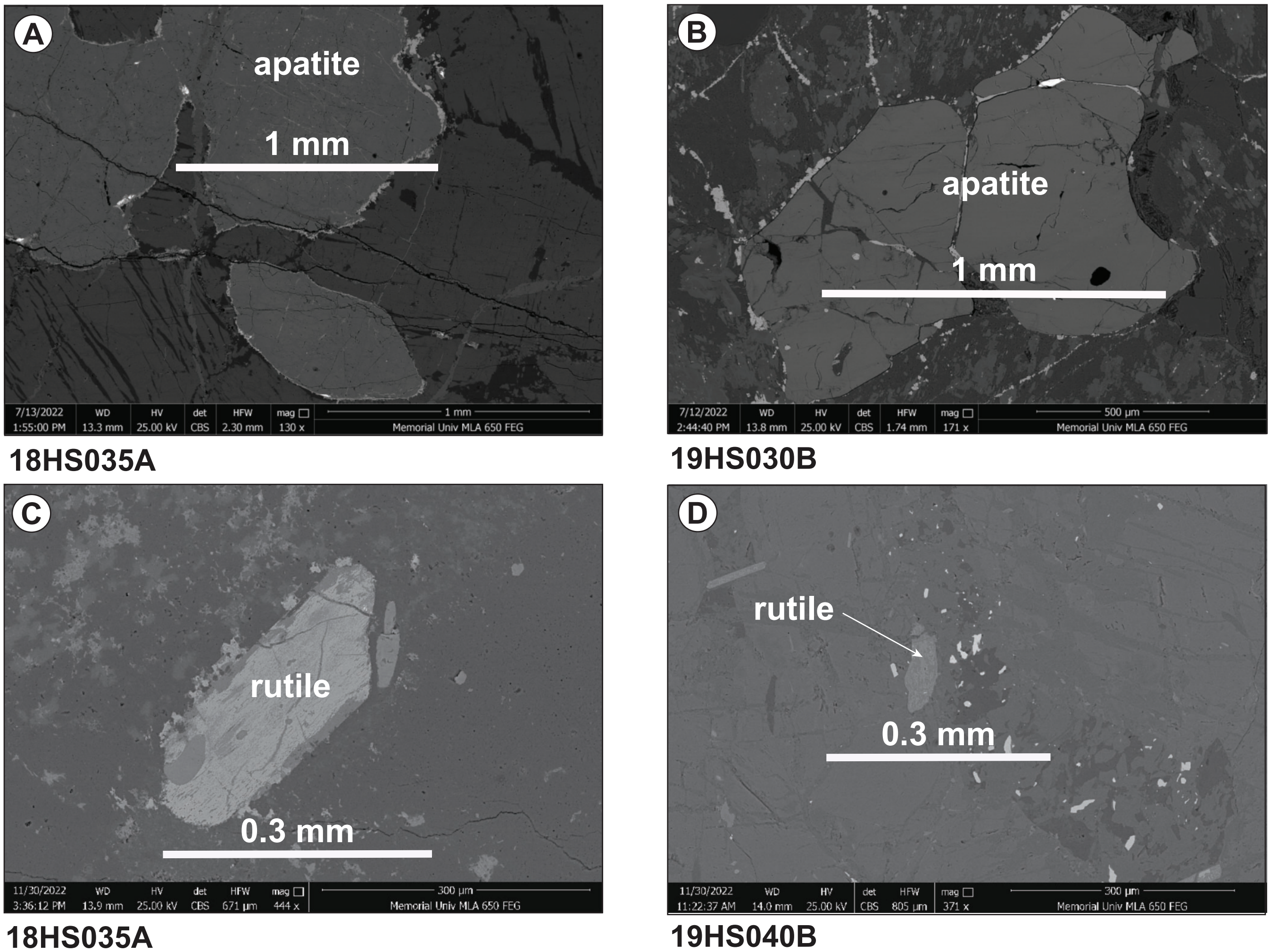


Figure 9. *Backscattered electron images of minerals from select rocks in the Hopedale Block. A) Apatite from sample 18HS035A from a syenite from the Aucoin prospect is greater than 2 mm; B) Apatite in samples 19HS030B from a diorite collected from the Nain Plutonic Suite; C) Rutile greater than 0.3 mm from sample 18HS035A from the Aucoin syenite; D) A rutile grain less than 0.3 mm from samples 19HS040B is from an amphibolite in the Hunt River belt (Campbell* et al.*, 2022).*

posed late ice cap in the Florence Lake area, 60 km south. These two ice caps would also preserve subglacial deposits at elevations close to or below the marine limit (*e.g.*, *see* Batterson, 1996).

IMPLICATIONS FOR EXPLORATION

Late glacial flow has important implications for exploration because it often reworks material deposited by earlier ice flows. Striation measurements constrain local dispersal directions because there is evidence of local topographic ice diversion. In the absence of ice-flow indicators, dispersal patterns in till geochemistry, indicator minerals or pebbles and boulders could be used to determine ice-flow direction, and tracing anomalies back to their source.

The occurrence of pristine gold grains in the middle of larger dispersal trains in the north and south demonstrates the challenges when interpreting the geometry of a dispersal train that override multiple sources. Total gold grains decrease from four to one over 14–17 km. This pattern likely reflects northeast ice flow, but the dispersal train crosses multiple bedrock units that could be prospective for gold, and the interpretation of grain distribution as a single dispersal train may be an oversimplification. Although total gold, orthopyroxene, sillimanite, apatite and Mn-epidote dispersal trains indicate dispersal distances of tens of kilometres, smaller dispersal patterns may exist within these larger dispersal trains. A denser sampling grid (*e.g.*, 1 sample/50–100 m) might help identify overlapping dispersal patterns and source contributions inside larger indicator mineral dispersal trains.

Grains from the 7 to 10 cm deep disintegrated layer of quartz, plagioclase, orthopyroxene and olivine crystals from the NPS and HLIS (Plate 1A, B) are easily entrained and comprise the bulk of the till as reflected in dispersal train data (Figure 3). This is problematic because orthopyroxene and olivine, which may be important indicator minerals in other studies, here mask indicator minerals of interest (*e.g.*, base and precious metals) due to their sheer abundance, and single indicator mineral grain counts of interest in samples warrant investigation. Comparison with regional till geochemical results may highlight the contrasts between the geochemical composition of the silt plus clay (<0.063 mm) fractions and the anomalous indicator-mineral compositions. Similarly, Scanning Electron Microscope Mineral Liberation Analyses (SEM-MLA, *e.g.*, Sylvester, 2012) of the fine sand fraction (0.125–0.250 mm) in till samples could identify the smaller indicator mineral grains that cannot be identified through optical investigations. This fine sand fraction is optimal for identifying corundum grains (Belley, 2023), gold (Girard *et al.*, 2021) and base metals (Lougheed *et al.*, 2021).

Sampling in valleys or coastal areas should be confined to subglacial deposits (*e.g.*, lodgement/basal till) as other glacial deposits are reworked by water (glaciomarine, marine and fluvial processes) and transported far from the source(s). Sampling strategies should also consider the sampled landforms (*e.g.*, till ridges and reworked streamlined landforms vs. basal till or till from mudboils). Previous studies in the Florence Lake greenstone belt and Central Mineral belt emphasized the compositional differences between reworked material at lower elevations and basal till on the highlands (Batterson *et al.*, 1987; Batterson, 1996). Till at higher elevations is not modified by topographically diverted, valley ice flow. Thus, it should contain locally derived geochemical and indicator-mineral signatures, especially in till overlying or proximal to bedrock. Reworked till contains material derived from several sources up-ice, has been partially water-sorted (Shilts, 1976), and may contain lower geochemical background values from basal till or mudboils at higher elevations. Indicator-mineral abundances in this study were similar between the few samples from reworked landforms (*e.g.*, the moraine southeast of Harp Lake) compared to nearby samples from non-reworked landforms. Indicator-mineral counts could be useful in regions where reworked landforms are prevalent (*e.g.*, valleys, moraines), as they are heavy and retained in till, even after water sorting. However, their source(s) are more difficult to determine than those of till collected in mudboils and at higher elevations (*e.g.*, >300 m in this study), as they may have been dispersed (and re-dispersed) farther down-ice. A focused study on the contrast of anomalous content in heavy mineral and till geochemical results in reworked versus non-modified till would be useful, as ridges, streamlined landforms, and moraines are prevalent across Labrador.

Finally, integrating results from different exploration media (*e.g.*, lake and stream sediments, geophysics) is important for detecting buried mineralization in till-poor regions near the coast and southeast of Hopedale around the Florence Lake belt. The results of recent geophysical (Coyle *et al.*, 2019a–d) and geochemical studies (McCurdy *et al.*, 2023), along with forthcoming till geochemistry data releases, can be used in conjunction with the results of this study to assist in evaluating mineral potential in central north Labrador.

FUTURE WORK

New landform maps of this region are underway; these reflect the complexity of the sediments and ice-flow history, including a more accurate assessment of the abundance of ridges and streamlined features with multiple orientations. This work, documenting subglacial erosional features, should complement striation data and help unravel the late ice-flow history in the central coastal margin of Labrador.

CONCLUSIONS

Northeast ice flow dispersed material from the HLIS and other sources near or west of the Aucoin prospect. During deglaciation, east to southeast ice flow deflected ice northward around an ice mass southeast of Harp Lake, entraining orthopyroxene and olivine from the NPS and dispersing them eastward toward the coast. The recognition of the extent and timing of eastward ice flow may affect interpretation of sediment distribution. The abundance of orthopyroxene and olivine crystals derived from the weathering of plutonic units in the west, northwest and north study areas hinders the identification of other important indicator mineral distributions in till.

To maximize the value of indicator-mineral studies for surface exploration in this region, multiple particle size fractions (*e.g.*, silt and clay, fine sand, coarse sand, pebbles and boulders) of till should be investigated, as anomalous minerals may be recovered from the fine fraction of till affected by multiple ice flows. In till,which overlies or is dispersed from bedrock, whose fundamental composition includes the coarse-grained heavy minerals orthopyroxene and olivine, automated identification of the fine sand grains (*e.g.*, SEM-MLA) in till may optimize the detection of fine grained indicator minerals associated with mineralization. Sample spacing in prospective regions should be less than 4 km^2 to detect mineralization in tills derived from multiple bedrock sources.

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