GEOLOGICAL SURVEY OF CANADA
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Physical features indicating the glacial transport distance of gahnite from the Izok Lake Cu-Zn-Pb-Ag VMS deposit, Nunavut

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Abstract
This small study of gahnite from the Izok Lake deposit and associated glacial dispersal train northwest of the deposit is the first to evaluate and report on the shape and surface characteristics of gahnite in glacial sediments. It demonstrates that increased distance of glacial transport results in: 1) a significant decrease in the proportion of attached quartz and muscovite on individual gahnite grains; 2) no discernable wear on the actual gahnite grains; 3) a significant decrease in the number of gahnite grains in till; and, 4) reduced grain sizes. Further work is recommended on other gahnite glacial dispersal trains to confirm and refine the proposed classification system and, in particular, to determine the distances at which a) none, and b) all, of the gahnite grain are completely free of quartz and muscovite.

Future studies should ideally include only till samples where gahnite populations have been picked to completion, and no grains have yet been removed for other uses such as EMP analysis, in order to avoid any bias. In samples with very large gahnite populations, a split should be picked to completion rather than trying to pick a representative population of grains from the entire sample. Whereas quartz and muscovite are universal gahnite associates in all of the significant gahnite glacial dispersal trains that Overburden Drilling Management Limited has examined to date, other minerals such as spessartine may occur in sufficient concentrations in some metamorphosed VMS alteration zones to be in direct contact with gahnite and thus potentially to adhere to some of the dispersed grains.

Introduction

Gahnite (Zn-spinel) is a known indicator of highly metamorphosed volcanogenic massive sulphide (VMS) deposits (Spry and Scott, 1986a,b; Averill, 2001; Heimann et al., 2005). Gahnite was identified in the amphibolite grade metamorphosed Izok Lake Cu-Zn-Pb-Ag VMS deposit and surrounding alteration zone in northern Canada (Fig. 1), as well as in till samples at least 40 km down ice (NW) (McClenaghan et al., 2012a,b; Hicken et al., 2012; Paulen et al., 2013). This gahnite glacial dispersal train was discovered by an orientation study of the indicator mineral signature of the Izok Lake deposit by the Geological Survey of Canada (GSC). This research was conducted as part of the the Geological Survey of Canada through its Geo-mapping for Energy and Minerals GEM Program (2008-2013), in collaboration with Queen's University, Minerals and Metals Group Limited (MMG), and Overburden Drilling Management Limited (ODM).

The survey included the collection of 78 till samples around the deposit that were processed to recover metamorphosed magmatic sulphide indicator minerals (MMSIMs). Ice directional indicators for the Izok Lake region were compiled and preliminary interpretations made prior to field work. During field work in 2010, new ice directional indicators were mapped at the local scale (Paulen et al., 2013). Cross-cutting erosional relationships and depositional landforms indicate that the Izok Lake area was affected by four ice flow phases. This new glacial history interpretation was used to explain the gahnite indicator mineral dispersal train down-ice of the Izok Lake deposit as being the net effect of all known ice flow phases (Hicken et al., 2013a, b; Paulen et al. 2013). The fan-shaped morphology of the gahnite dispersal train is a function of the duration and vigour of two dominant glacial trajectories toward the southwest and northwest (Fig. 2).

Gahnite grains in the heavy mineral fraction of mineralized bedrock and till sampled proximal to the deposit are interlocked mainly with quartz and muscovite (Fig. 3), and to a lesser degree with Ca-amphibole, spinel, microcline, clinochlore, ripidolite, epidote, sillimanite, albite, corundum, dravite, apatite, spessartine, monazite, ilmenite, xenotime, magnetite, plagioclase, or titanite (Hicken et al., 2013a,b). From these initial observations the following questions arose: 1) How does individual gahnite-quartz-muscovite grain shape change with increasing distance of glacial transport from the

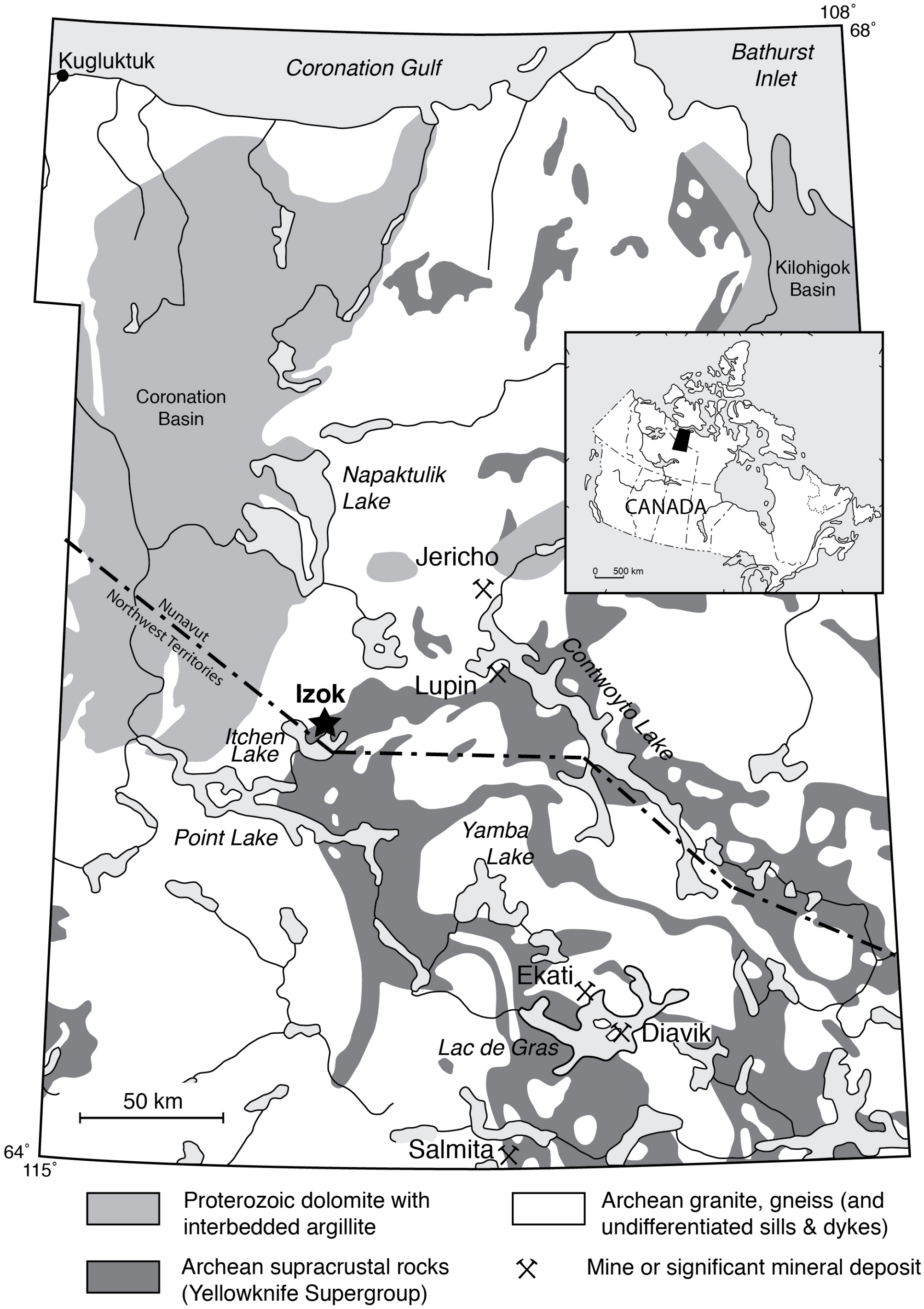

Figure 1. Location of the Izok Lake Cu-Zn-Pb-Ag VMS deposit in northern Canada (modified from Dredge et al., 1999, geology after Hoffman and Hall, 1993 and Mitchell et al., 2010).

bedrock source? 2) If changes are observable down ice, could a classification system be developed for gahnite based on an erosional continuum similar to that used for gold grain shape (e.g. DiLabio, 1990) to estimate glacial transport relative distance? The commercial laboratory, Overburden Drilling Management Limited (ODM), was asked to document the physical features of the gahnite grains in selected GSC and MMG till and bedrock samples and to develop a classification system of these features that could be used to estimate gahnite's glacial transport distance.

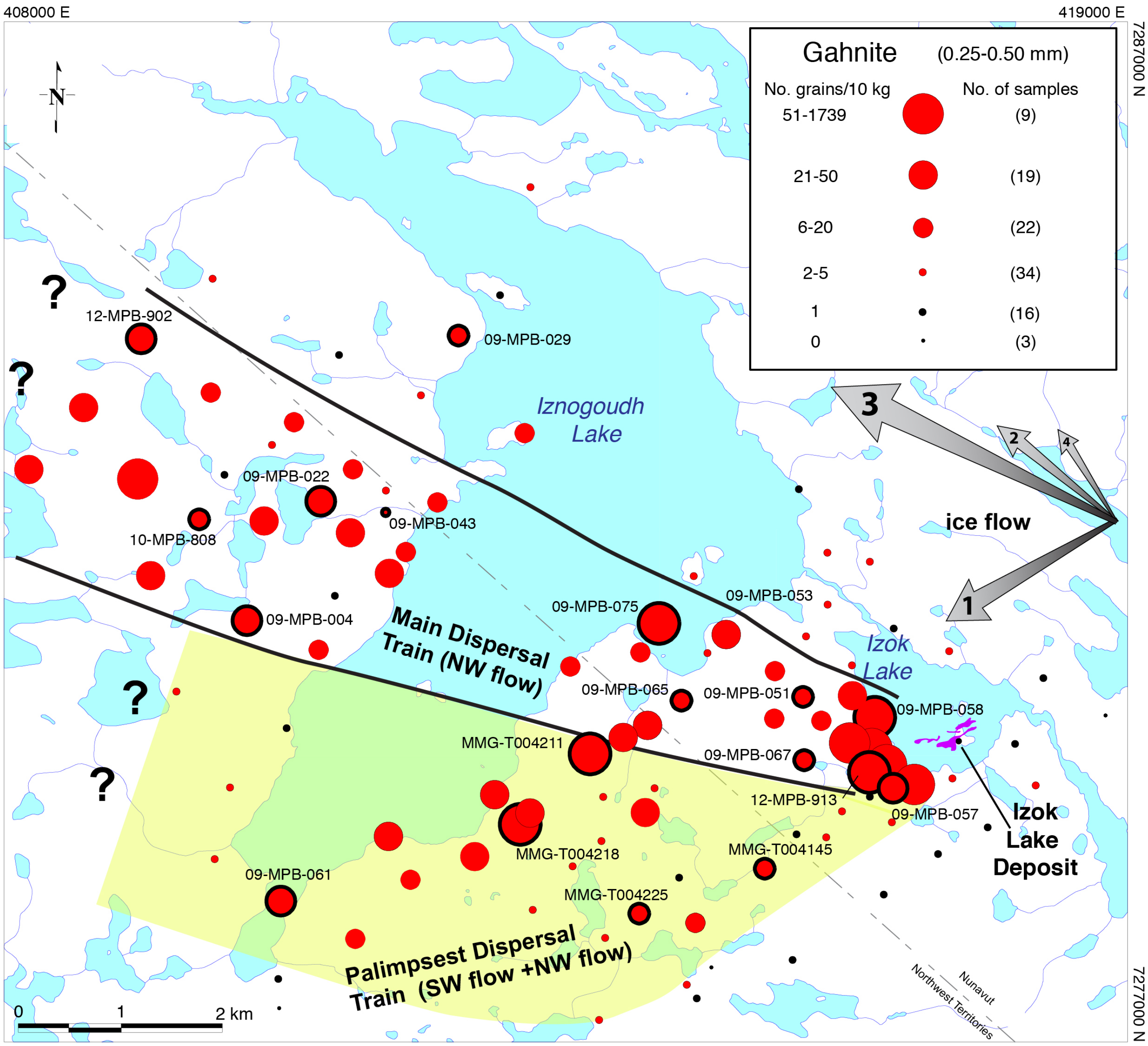

Figure 2. Distribution of gahnite in the 0.25-0.5 mm non-ferromagnetic fraction of till (normalized to 10 kg sample weight) which subcrops (indicated as violet polygons) down ice (SW and NW) of the Izok Lake VMS deposit (modified from Paulen et al., 2013). Regional dispersal train boundaries are indicated by the thick line and palimpsest dispersal train by the yellow shaded area. Ice flow arrows indicate relative chronology (1 = oldest) and vigour (arrow size) of glacial events. Geological Survey of Canada (09-MPB, 10-MPB and 12-MPB series) and MMG (T004 series) till samples used in this shape study are indicated with a thick black outline around a red dots.

Methods

A suite of samples were selected for this shape study: 14 GSC and 4 MMG till samples collected within ~0.5 km to 8 km down-ice (northwest) and up to 6.5 km SW from the deposit (Fig. 3, Table 1). Till samples were collected between 2009 and 2012, from mud boils developed in till located up ice, overlying, and down ice of the Izok Lake deposit based on the knowledge that the main erosive glacial events were toward the SW and NW. GSC till sampling procedures, sample locations, other field data, and indicator mineral abundance data for each site are reported in Hicken et al. (2012, 2013a,b) and McClenaghan et al. (2012a,b, 2013).

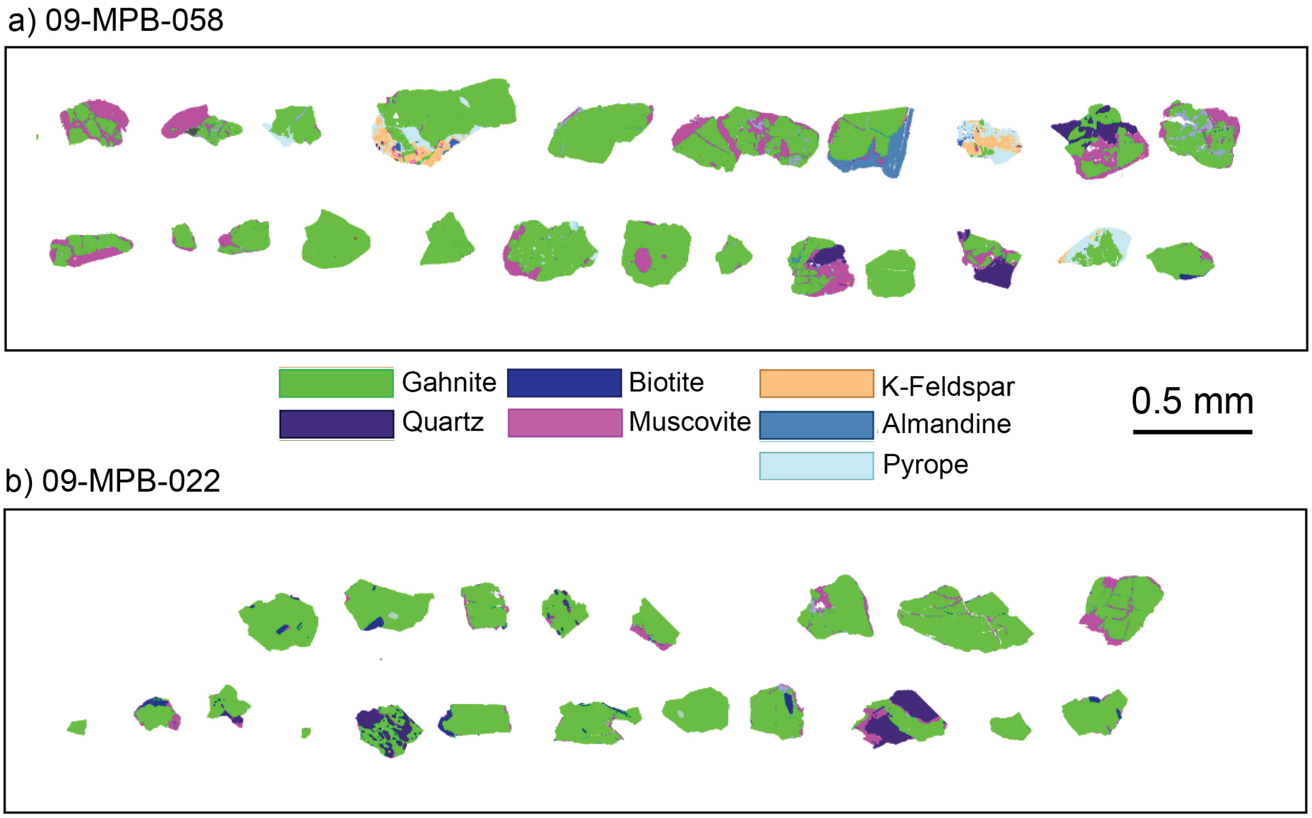

Figure 3. Color-coded mineral liberation analysis (MLA) image of mounted gahnite grains from local and distal till samples: a) till sample 09-MPB-058, 300 m down ice (northwest) of the deposit; and, b) till sample 09-MPB-022, 7500 m down ice (northwest) of the deposit.

For each sample, approximately 9-15 kg of till were processed at ODM using a combination of tabling, heavy liquids, and ferromagnetic separation to recover a 0.25-2.0 mm non-ferromagnetic heavy mineral fraction (SG >3.2) for examination of indicator minerals. Till sample preparation methods used by ODM, the weights of fraction produced, and gahnite grain counts for the 2009 and 2010 till samples are reported in McClenaghan et al. (2012a,b). Sample weights and indicator mineral counts for the 2012 GSC till samples are listed in Appendix A of this report. MMG till samples used in this study were processed by ODM using the same processing procedures used by GSC. Weight data and number of gahnite grains recovered in four MMG till samples (MMG-T004211, MMG-T004218, MMG-T004225, MMG-T004145) are listed in Table 1.

The heavy mineral concentrates of the selected till samples were initially examined by ODM, at which time they had determined the gahnite abundance and set aside selected grains in separate vials for further examination. Some grains in the separate vials were removed for electron microprobe (EMP) analyses reported in Table 1. All remaining gahnite grains originally picked from the 0.25-0.5 mm fraction of these samples were re-examined for this subsequent shape study. As well, additional gahnite grains were picked from till sample 12-MPB-913 for this study (Table 1).

One bedrock sample was also examined - 09-MPB-R112 from 529 m in diamond drill hole HEN 485 (UTM 417996.6E, 7279718.1N, NAD 83) which intersected the east part of the Izok Lake deposit. Data for a second bedrock sample (09-MPB-R113) collected from drill core that intersected the Izok Lake deposit is also reported here. This bedrock sample was not part of the gahnite shape study. It

Location	Sample No.	Material	Distance down ice (m)	No. grains counted 1.0-2.0 mm/10 kg	No. grains counted 0.5 -1.0 mm/10 kg	No. grains counted 0.25-0.5 mm/10 kg	No. grains available for shape study	No. grains of Adhering Quartz + Muscovite				Proportion of Grains with >25% Adhering Quartz + Muscovite (%)
								Negligible (0-Trace)	Minimal (1 - 25%)	Significant (26-50%)	Dominant (>50%)	
Bedrock source	09-MPB-R112	bedrock	0	5057* * grains/1 kg	50569* * grains/1 kg	>250,000* * grains/1 kg	200	18	53	75	54	65
Northwest of deposit	09-MPB-058	till	300	0	9	77	57	6	12	8	31	68
	09-MPB-067	till	1500	0	0	12	10	1	3	6	0	60
	09-MPB-051	till	2000	0	3	10	10	0	4	5	1	60
	09-MPB-065	till	2500	0	0	11	13	1	6	5	1	55
	MMG-T004211	till	3000	0	0	55	64	15	27	14	8	34
	09-MPB-075	till	3000	1	5	64	36	6	5	19	6	69
	09-MPB-029	till	7000	0	0	6	7	4	2	1	0	14
	09-MPB-043	till	7000	0	1	5	6	1	4	1	0	17
	09-MPB-022	till	7500	0	0	34	20	4	14	2	0	10
	09-MPB-004	till	7500	0	1	28	28	5	14	9	0	32
	10-MPB-808	till	8000	0	0	11	9	2	4	3	0	33
	12-MPB-902	till	9000	0	1	38	37	10	23	4	0	11
Southwest of deposit	09-MPB-057	till	200	1	348	1739	75	1	7	15	52	89
	12-MPB-913	till	800	4	39	339	125	10	41	47	27	59
	MMG-T004145	till	2000	0	0	7	8	6	2	0	0	0
	MMG-T004225	till	3500	0	0	16	16	3	10	3	0	19
	MMG-T004218	till	4500	0	1	32	29	4	12	13	0	45
	09-MPB-061	till	6000	0	0	31	22	0	8	12	2	60

Table 1. Number of gahnite grains in the 0.25-0.5, 0.5-1.0 and 1.0-2.0 mm non-ferromagnetic heavy mineral fractions of till and mineralized bedrock samples in this study. Samples are listed according to distance down ice of the Izok Lake VMS deposit, both for the older southwest ice flow, and the younger northwest ice flow. Gahnite grains are classified into four groups on the basis of proportion of interlocked quartz + muscovite that is attached to each grain.

was processed because it was suspected to contain gahnite, but it did not. The processing results are reported here simply to release the data, because it was processed in the same batch as bedrock sample 09-MPB-R112. It was collected from diamond drill hole HEN 325 (UTM 417331E, 7279975N, NAD 83) at a depth of 28.7 m.

Bedrock samples were disaggregated by ODM until 90% of each sample was <2 mm, using the custom built CNT Spark-2 electric pulse disaggregator (Rudashevski et al., 2002; Lastra et al., 2003; Cabri et al., 2008) to preserve natural grain sizes, textures, and shapes. ODM sample description and lab results are reported in Appendix A. The <2 mm fraction was processed using a combination of tabling, heavy liquids, and ferromagnetic separation to recover a 0.25-2.0 mm non-ferromagnetic heavy mineral fraction (SG >3.2) for examination of indicator minerals using methods reported in McClenaghan et al. (2012a,b). Gahnite counts in the bedrock sample 09-MPB-R112 are summarized in Table 1.

Initial observations of gahnite by ODM using binocular microscope reported no discernable wear on the surfaces of any of the gahnite grains in till, but rather significant differences between samples with respect to the numbers of grains preserving quartz and muscovite interlocked with the gahnite (Table 1). Therefore a classification system was designed based on the proportions of these associated minerals still visible on the grains. For each till sample, individual gahnite grains in each sample were assigned to one of the following four classes that reflect the amount of quartz and muscovite that is interlocked with gahnite in individual grains: 1) negligible (0%-trace); 2) minimal (1-25%); 3) significant (26-50%); or 4) dominant (>50%).

Mineral Liberation Analysis™ (MLA), an automated mineralogy system based on high-resolution BSE images, image analysis, and elemental chemistry from EDS, was used to identify gahnite and the minerals interlocked and included with gahnite in selected till and bedrock samples form Izok Lake.

MLA was used to produce a cross-sectional false-color maps (Fig. 3) of some gahnite grains mounted in 25 mm epoxy grain mounts. Layton-Matthews et al. (2013) have described the MLA method in detail as well as the many advantages of MLA over traditional optical microscopy.

Results

Color-coded MLA images were generated for a selection gahnite grains from local and distal till samples including those shown in Figure 3: a) till sample 09-MPB-058, 300 m down ice (northwest) of the deposit; and, b) till sample 09-MPB-022, 7.5 km down ice (northwest) of the deposit. These images show that gahnite grains in proximal till samples such as 09-MPB-058 are mostly interlocked/intergrown with other minerals. Gahnite from distal till samples, such as 09-MPB-22, are either free of other minerals or have fewer intergrown minerals.

Samples 09-MPB-057, -058 and 12-MPB-913 were collected closest to source, within ~0.5 km of the deposit (Fig. 2), and have large populations of gahnite grains: 1739, 77 and 339 (normalize/10 kg), respectively (Table 1). The proportions of grains having >25 % adhering quartz-muscovite in these three samples are high at 89, 68 and 59%, respectively (Table 1). Examples of all four quartz-muscovite survival classes for the gahnite grains from sample 12-MPB-913 are illustrated in Figure 4. Samples collected far from source, 7 to 8 km down-ice from the deposit, have fewer total gahnite grains and, in general, have lower proportions of grains with >25% surviving quartz-muscovite. For example, sample 12-MPB-902, collected 9 km down-ice from the deposit (Fig. 4), contains 38 grains/10 kg gahnite grains of which only 11% have >25 % adhering quartz-muscovite (Table 1). Examples of grains from the other two survival classes (negligible or minimal quartz-muscovite) from this sample are illustrated in Figure 5.

For samples in which a relatively large number of gahnite grains are available for examination, a direct relationship between the proportion of surviving quartz-muscovite and glacial transport distance was established. However, this is not possible for samples containing a limited number of gahnite grains or for those where a significant number of the grains were removed for EMP analysis, thereby leaving an unrepresentative population. For example, only 36 of the original 66 gahnite grains are available for examination in sample 09-MPB-075. Furthermore, there may be unknown bedrock sources of gahnite that have contributed some of the grains, or larger grains may have broken down during subsequent glacial flows. For example, sample 09-MPB-061 contains a high proportion (64%) of grains with >25 % adhering quartz-muscovite (Table 1) even though it was collected ~6 km down-ice (SW) of the Izok Lake deposit.

Discussion

The lack of wear of the gahnite grains, irrespective of transport distance, is illustrated by comparing the grains from bedrock sample 09-MPB-R112 with grains from proximal till sample 12-MPB-913 (Fig. 4), and distal till sample 12-MPB-902 (Fig. 5). The absence of wear is due to the hardness of both gahnite (H=7.5-8.0) and quartz (H=7.0), and the fact that the longest glacial transport distance for a sample in this study is only 8 km (Fig. 2). Also coarse-grained, sand-rich tills typical of those generated in the Slave Province, although highly erosive in nature, tend to generate lower amounts of finer-grained components from comminution and grain-to-grain interaction (Rose and Hart, 2008).

Conclusions

This small study of gahnite from the Izok Lake deposit and associated glacial dispersal train northwest of the deposit is the first to evaluate and report on the shape and surface characteristics of gahnite in glacial sediments. It demonstrates that increased distance of glacial transport results in: 1) a significant decrease in the proportion of attached quartz and muscovite on individual gahnite grains, 2) no

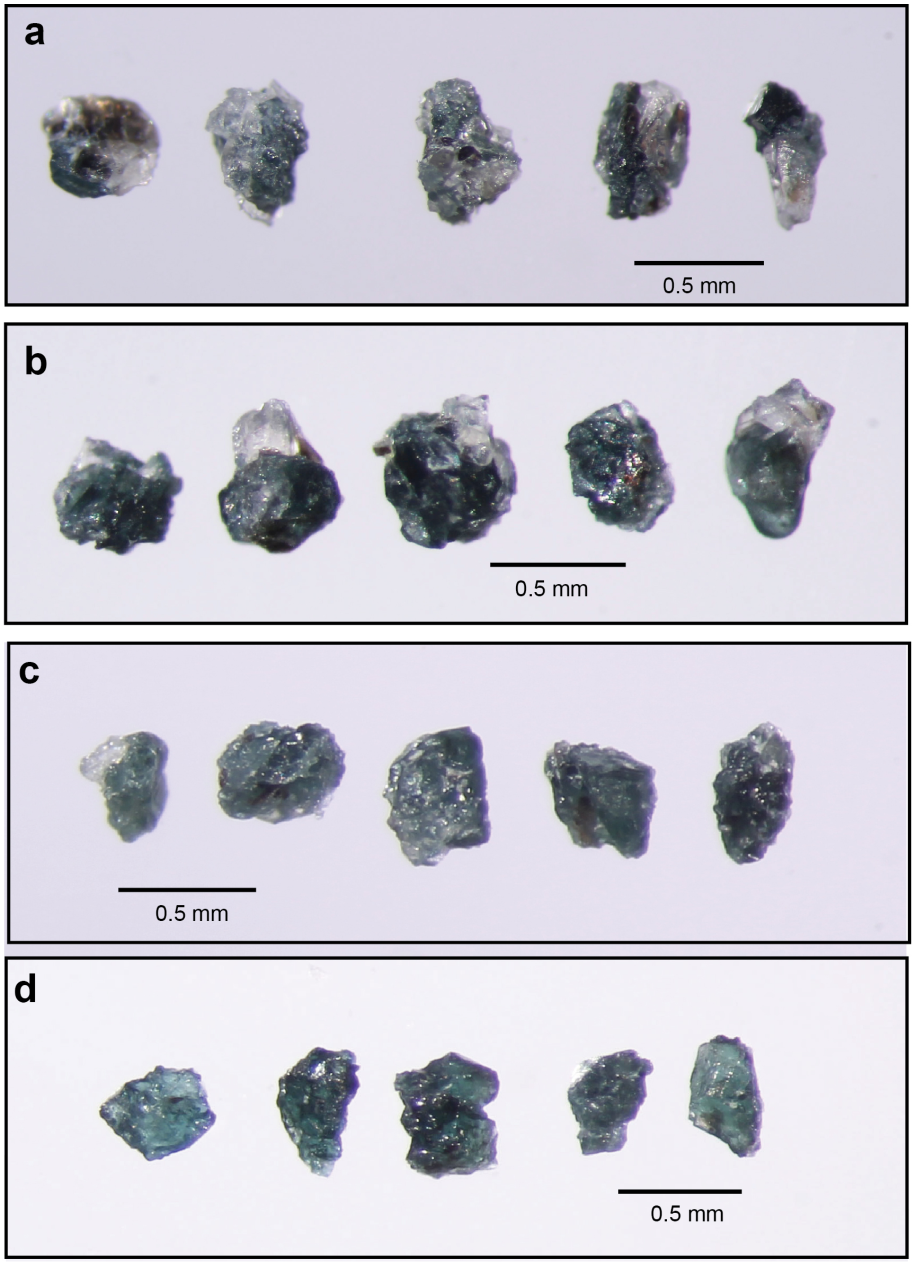

Figure 4. Colour photographs of individual grains of gahnite (dark blue-green) interlocked with quartz and muscovite from till sample 12-MPB-913, 800 m down ice (southwest) of the Izok Lake deposit, showing: a) >50%; b) 26-50%; c) 1-25%; and d) 0% to trace interlocked quartz-muscovite.

discernable wear on the actual gahnite grains;, 3) a significant decrease in the number of gahnite grains in till, and 4) reduced grain sizes. Further work on other gahnite glacial dispersal trains is recommended to confirm and refine the proposed classification system and, in particular, to determine the distances at which none vs. all of the gahnite grains are completely free of quartz and muscovite.

In order to reduce bias, future studies should include only till samples where gahnite populations have been picked to completion, and no grains have yet been removed for other uses such as EMP analysis,. In samples with very large gahnite populations, a split should be picked to completion rather than trying to pick a representative population of grains from the entire sample. Whereas quartz and

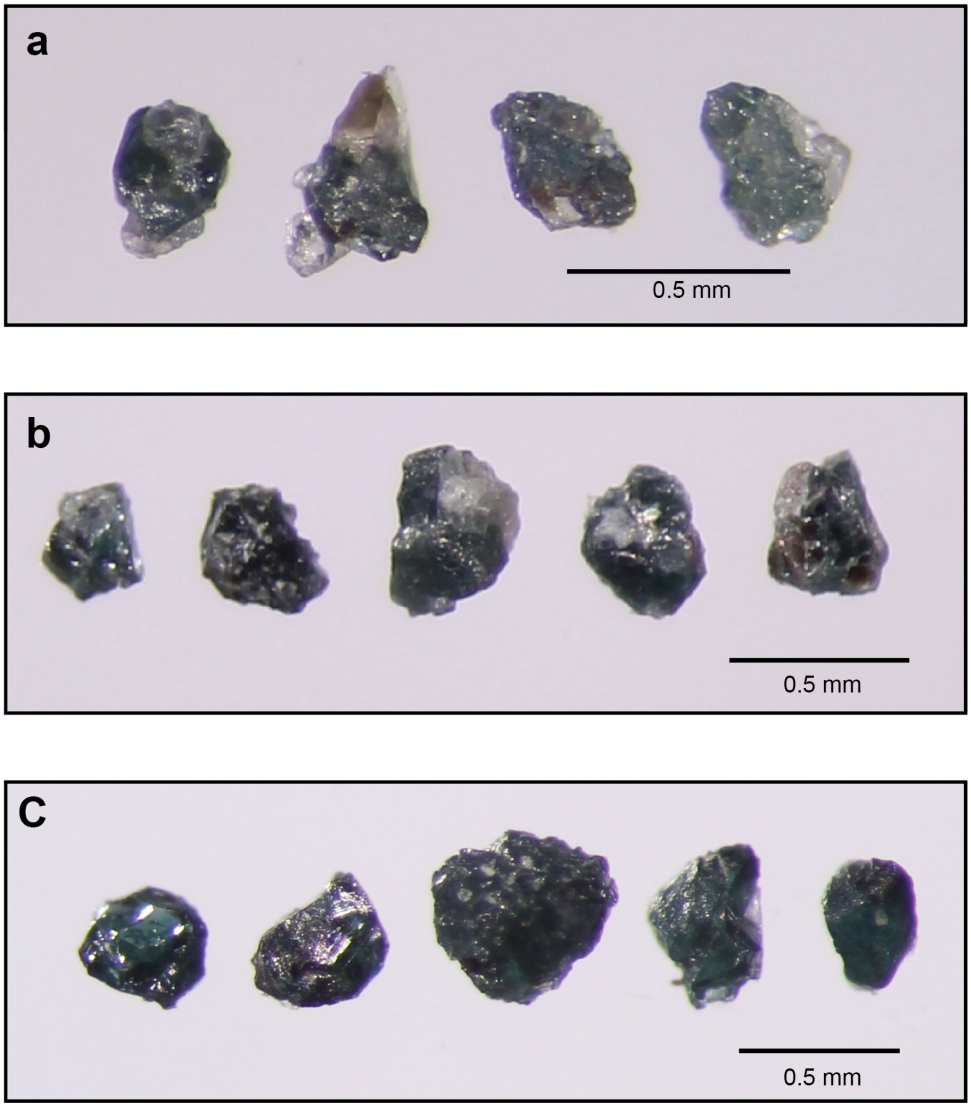

Figure 5. Individual grains of gahnite (dark blue-green) interlocked with quartz and muscovite from till sample 12-MPB-902, 9 km down ice (northwest) of the Izok Lake deposit, showing: a) 26-50%; b) 1-25%; and c) 0% to trace interlocked quartz-muscovite.

muscovite are universal associates of gahnite in all of the significant gahnite glacial dispersal trains that ODM has examined to date, other minerals such as spessartine may be present in sufficient abundances in some metamorphosed VMS alteration zones to be in direct contact with gahnite and thus potentially to adhere to some of the dispersed grains.

Acknowledgments
The Izok Lake study was conducted as part of the Geological Survey of Canada's Geo-mapping for Energy and Minerals (GEM) Program (2008-2013). The overall case study is a collaborative research effort between the Geological Survey of Canada, Minerals and Metals Group (MMG), Queen's University, and Overburden Drilling Management Ltd. MMG is thanked for providing logistical support, access to the property, drill core samples, confidential geological information about the Izok Lake deposit, and assistance with till and bedrock sampling. Charlie Jefferson (Geological Survey of Canada) is thanked for his constructive review of this open file.

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Appendix A1

Binocular Microscope Descriptions of Specimens of Sawn Diamond Drill Core

by S.A. Averill

09MPB-R112 - METAMORPHOSED SILICIFIED ZONE. Streaked pale grey and blue-green, nonmagnetic, metamorphically recrystallized, siliceous felsic volcanic or sedimentary rock consisting of alternating medium-grained (0.2-0.5 mm) and coarse-grained (2-3 mm) bands and wisps of polygranular quartz with no accompanying feldspar. Medium-grained bands constitute 80% of the sample and contain 10% biotite, 20% granular, blue-green gahnite concentrated in bands and streaks, and ~1% each of pyrrhotite, chalcopyrite and red-brown sphalerite.

09MPB-R113 PEGMATITE. Leucocratic, creamy white to faintly pink, massive, nonmagnetic, medium (0.5-1 mm) to very coarse-grained (up to 3 cm) granitoid rock consisting of 70% white, perthitic (string-type) alkali feldspar, 20% quartz, 5% muscovite, 5% brown-black schorl tourmaline and 0.5% mottled green and white apatite.