EXPLORE
Newsletter for the Association of Applied Geochemists
www.appliedgeochemists.org
NUMBER 181 DECEMBER 2018

New base metal mineral potential in southern Northwest Territories, Canada

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INTRODUCTION

The use of indicator minerals for mineral exploration in glaciated terrain has evolved to a point where many different suites of indicator minerals, indicative of specific deposits types, are now being used (cf., Averill 2001; Lehtonen et al. 2015; McClenaghan & Paulen 2018, and references therein). These methods are particularly suited for reconnaissance surveys where heavy and mid-density indicator minerals collected from stream sediments and/or till allow a broad region to be assessed for the presence of potential mineral deposits. As part of the Geological Survey of Canada's (GSC) Geo-mapping for Energy and Minerals (GEM-2) Program (2013-2020), the Southern Mackenzie Surficial activity (2017-2020) collected stream sediments and till samples across a 35,000 km^2 region and examined their heavy mineral content. This research activity is being conducted in a region with no prior surficial mapping and very limited surficial sampling for heavy minerals by Cominco Limited in the early 1980s (mostly industry-confidential data; cf., Brabec 1976, 1983; Lane 1980). Despite hosting the past-producing world-class Mississippi Valley-type (MVT) Pine Point Pb-Zn district, almost no other mineral showings have been reported in this extensive region, despite significant interpreted potential for additional mineral resources, and extensive reports of Pb-Zn mineralization at depth (Hannigan 2006a). In this technical article, we provide new results which illustrate the potential for new, undiscovered targets in the region, and further highlight how heavy mineral assemblages and geochemical and isotopic compositions are powerful tools for exploration in glaciated regions (Paulen *et al.* 2017, 2018; Day *et al.* 2018a; King *et al.* 2018).

Location and Physiography

Surficial mapping, targeted surficial geology studies, and stream sediment and till sampling for geochemistry and heavy mineral indicators were initiated in 2017 in the southern Northwest Territories (NWT) of northern Canada (Fig. 1). Samples were collected between 114°W to 124°W longitude, east of the Liard River, and from 60°N along the Northwest Territories – Alberta provincial border to 62°N latitude. Surficial mapping was focussed within National Topographic Map sheets (NTS) 85-C, F, and G.

The district lies in the Great Slave Plain and Alberta Plateau physiographic regions of the Western Interior Plains (Bostock 1970) and is relatively flat, other than the Cameron Hills upland area along the southern part of the study area. The vegetation is typical of the northern Boreal forest of Canada; black spruce bogs and open fens in the poorly-drained lowlands with poplar and jack pine forests in upland regions that have better drainage.

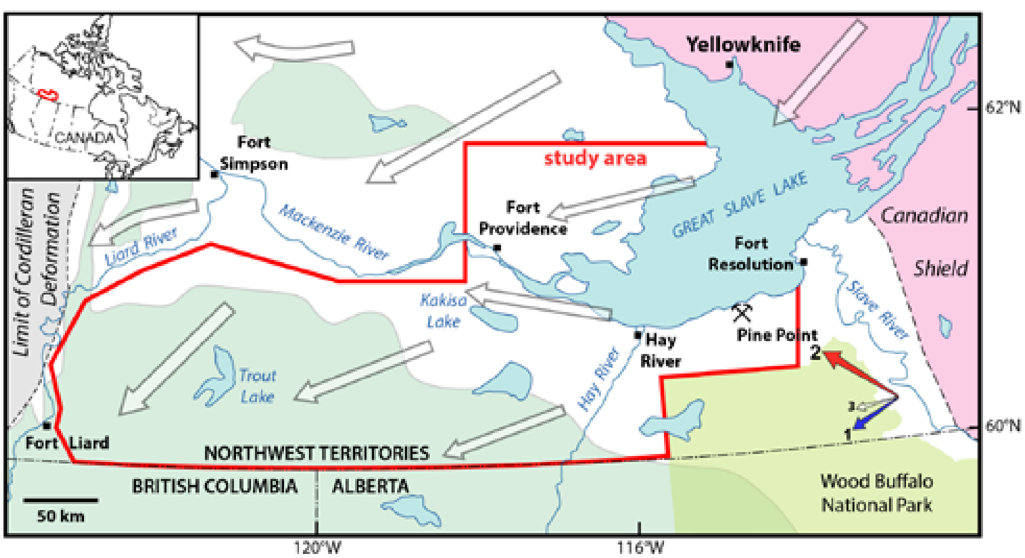

Figure 1. Study area for surficial mapping and heavy mineral studies, southwest Northwest Territories, Canada. The study area is contained within the WCSB, underlain by Paleozoic carbonate (white) and Cretaceous (pale green) bedrock, west of the Canadian Shield and east of the Cordilleran deformation. Arrows indicate direction of regional ice flow of the Laurentide Ice Sheet that impacted the area; ice-flow vectors from Prest et al. (1968); Kerr (2006); Bednarski (2008), Huntley et al. (2008), and ice-flow history at Pine Point from Oviatt et al. (2015), arrow sizes indicate relative erosional vigour, and numbers indicate relative ice-flow chronology.

Bedrock and Surficial Geology

This study area is situated in the Western Canada Sedimentary Basin (WCSB), which consists of a wedge of Phanerozoic sedimentary rocks that overlap the Precambrian

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EXPLORE

Newsletter No. 181 December 2018

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Back Issues: AAG Website (www.appliedgeochemists.org)

EXPLORE is published quarterly by the Association of Applied Geochemists, P.O. Box 26099, 72 Robertson Road, Ottawa, ON Canada K2H 9RO.

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Type and layout of EXPLORE: Vivian Heggie, Heggie Enterprises, Thornton, CO (303) 288-6540; vjmheggie@comcast.net

EXPLORE Publication Schedule

Quarterly newsletters in March, June, September, December

Deadlines for submission of articles or advertisements:

March newsletter: January 15
June newsletter: April 15
September newsletter: July 15
December newsletter: October 15

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Formats for headings, abbreviations, scientific notations, references and figures must follow the Guide to Authors for Geochemistry: Exploration, Environment, Analysis (GEEA) that are posted on the GEEA website at: http://www.geolsoc.org.uk/template.cfm?name=geea_instructions_for_authors

In addition to the technical article, authors are asked to submit a separate 250 word abstract that summarizes the content of their article. This abstract will be published in the journal **ELEMENTS** on the 'AAG News' page.

Submissions should be sent to the Editor of **EXPLORE**:
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ADVERTISERS

Notes from the Editor

Welcome to the fourth and final **EXPLORE** issue of 2018. Issue No. 181 includes one technical article that describes the identification of new base metal mineral potential in northern Canada using indicator minerals in stream sediments and glacial till. It was written by Roger Paulen, Steve Day, Robert King, Steve Piercey, and Rod Smith.

EXPLORE thanks all those who contributed to the writing and/or editing of this issue as well as all other issues in 2018, listed in alphabetical order: Steve Adcock, Steve Amor, Dennis Arne, Al Arsenault, Glenn Bark, Graham Closs, David Cohen, Steve Cook, Ole Christiansen, Steve Day, Colin Dunn, Réginald Fettweis, Travis Ferbey, Mike Gadd, Bob Garrett, John Gravel, Nikita La Cruz, Joshua Hughes, David Huntley, Robert King, Owen Lavin, Chris Lawley, David Leng, Rob Mackie, Rick McCaffrey, Paul Morris, David Murphy, Mike Parkhill, Roger Paulen, Steve Piercey, Madhu Raghav, Denis Schlatter, Katerina Schlöglova, Dave Smith, Rod Smith, Wendy Spirito, Pim van Geffen, Graham Wilson, Scott Wood, and Peter Winterburn.

In this last issue of 2018, **EXPLORE** gratefully acknowledges our advertizers for their continuing financial support. Below is the team that has provided readers with four excellent issues this year. We wish all AAG members and other readers of **EXPLORE** a successful year in 2019.

Beth McClenaghan, Editor
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Steve Amor, Calendar of Events
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President's Message

As I write this, my final President's message of 2018, and reflect upon the past year, I'm pleased to say that it has been an active and fruitful one. We held a successful 28th IAGS (International Applied Geochemistry Symposium) in Vancouver as part of the wider Resources for Future Generations (RFG 2018) conference, and awarded gold and silver medals of the Association to three esteemed colleagues at our gala dinner at the Vancouver Aquarium. Planning is also well underway for the next Symposium to be held in Viña del Mar, Chile in 2020. We have a new Editor-in Chief, Dr. Scott Wood, for our journal Geochemistry: Exploration, Environment, Analysis (GEEA), and our Association is on a solid financial footing. Both our website and our newsletter, **EXPLORE**, provide AAG information and technical articles to geochemists and other geoscientists at a high standard of content and presentation. Finally, the incoming 2019-2020 AAG Councilors have been determined, and the Australian Geoscience Council Convention in Adelaide SA, for which AAG was a co-sponsor, has wrapped up.

For all this, we can thank our Council, our coordinators and committee chairs, the members of the IAGS LOC, and indeed all of the members of the AAG for their solid support of their time and energies over the course of this and previous years. As the calendar prepares to turn to 2019, it is now time to think strategically of the future direction of the Association, and how to position it for continuing success and growth in the coming years. In an earlier message, I stated that two of my objectives as President were to increase our membership and to expand our level of educational research support for the next generation of geochemists. The success of the two will be closely related. The membership of the AAG currently stands at 396, comprising 131 Fellows, 246 Regular Members, 18 Students and 1 subsidized member. This membership includes 26 new members (17 Regular Members and 9 students), although our total membership is down slightly from 403 members in 2017. Over the coming months, we will be devising and implementing action plans to increase our membership, transition eligible current Members to Fellows and, very importantly, increase our levels of student sponsorship and educational support. In the latter case, this will enable us to both further geochemical research and help develop the next generation of geochemical leaders. An example for your attention is our co-sponsorship of the upcoming PACRIM (Mineral Systems of the Pacific Rim) conference in New Zealand in April 2019, where we will be supporting travel of up to three AAG members to Auckland to present research results and short courses on applied geochemistry.

Finally, although our gaze here is forward, I do not wish to neglect the rich history of the Association and the evolution of exploration geochemistry by the giants of our discipline. First, I remind all our readers that Gold and Silver Medal nominations for 2018 are open, and I encourage you to submit nominations of deserving individuals for consideration. The Gold Medal is awarded for outstanding scientific contributions and achievement in applied geochemistry, whereas the Silver Medal is awarded in recognition of dedicated service to the Association. Secondly, as we rapidly approach the 50th anniversary of the AAG's founding in 1970, an updated short history of the Association would be a fitting foundation from which to launch our next 50 years of geochemical research and exploration. I call on any Fellows and Members who might be interested in contributing their time and energy, as well as stories, anecdotes and photographs, to contact me directly.

Stephen Cook,
AAG President

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Dennis Arne, Elements content
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Beth McClenaghan, *Editor*

New base metal mineral potential… *continued from page 1*

craton and thicken westward towards the deformed belt of the Cordillera (Fig. 1; Porter et al. 1982; Okulitch 2006). The Precambrian crystalline basement rocks are overlain by Lower and Middle Devonian sedimentary rocks, primarily platform carbonates which contain the Presqu'ile dolomitized complex that hosts to the Pine Point MVT district (Rhodes et al. 1984; Meijer Drees 1993). Two significant sedimentary successions constitute the fill of the WCSB. The older and deeper succession consists dominantly of Paleozoic marine carbonates which were later buried by shallow marine and nonmarine clastic sediments of Mesozoic age (Douglas 1959; Richards 1989).

Both sedimentary successions have been affected by cratonic arching and faulting in the underlying crystalline Proterozoic basement. In southern Northwest Territories this faulting is most prominently displayed by the northeast-southwest trending Great Slave Lake Shear Zone and other subparallel faults (Eaton & Hope 2003). Upper Devonian rocks are composed of thick shale (up to 1.5 km), which are locally pyritic and bituminous, and are interbedded with reefal carbonate beds. Shallow-dipping Cretaceous sandstone, siltstone and shale dominate the southern part of the study area and consist of upper and lower Cretaceous units that unconformably overly Paleozoic strata (Dixon 1999). In 1998, kimberlites were discovered near Fort Simpson, hosted in Upper Devonian bedrock (Pitman 2014).

The study area was inundated by the Laurentide Ice Sheet (LIS) during the late Wisconsin glaciation (~24-10 ^{14}C ka BP; Dyke & Prest 1987; Dyke 2004). Predominant glacially streamlined landforms (flutings and drumlins) indicate a southwest ice flow across the study area. At Pine Point, 70 km east of Hay River town site, bedrock striae (Oviatt *et al.* 2015) and clast fabric measurements (Rice *et al.* 2013) record at least 3 ice flow trajectories: earliest to the southwest (230°), intermediary to the northwest (300°), and a final west-southwest (250°) flow (Fig. 1). West of Hay River, LIS flow was influenced by the rising topography of the Cordillera and was deflected south-southwestward across the Cameron Hills and Trout Lake uplands, and northward down the Liard and Mackenzie river valleys (Bednarski 2008).

During deglaciation, retreating ice became increasingly topographically confined and prominent lobes extended south and west down the Hay and Mackenzie river valleys, respectively. Ice retreated from the study area between 11-10 ^{14}C ka BP (Dyke 2004). Blockage of regional drainage and impoundment within glacioisostatically depressed basins led to the formation of glacial Lake McConnell along the retreating ice margin (Lemmen et al. 1994). After 8.5 ^{14}C ka BP, glacial Lake McConnell continued to drain largely through a process of decantation by glacioisostatic uplift (Lemmen et al. 1994; Smith 1994). The study area is blanketed by thick till deposits (>20 m thick; Smith & Lesk-Winfield 2010), with local thicknesses infilling karst collapse structures exceeding 100 m. The rim of the Devonian platform carbonates paralleling the southwest shore of Great Slave Lake are the only exposed bedrock at surface. Where areas were submerged by glacial Lake McConnell, an often prominent, thin (<50 cm) winnowed till and cobble-boulder lag is found. Accumulations of glaciolacustrine sediments are generally thin, with thickest deposits found around the western and southern shores of Great Slave Lake. The modern surface is covered by expansive peat bogs and fens, underlain by discontinuous permafrost displaying widespread active thermokarst (Paulen *et al.* 2017).

Rationale and Background

The impetus to conduct heavy mineral studies in the southern NWT was the identified base metal mineral potential reported by Hannigan (2006a), as well as positive results from several adjacent heavy mineral surveys conducted in regions underlain by Paleozoic and Cretaceous bedrock, for which there was no known surface bedrock mineralization (Plouffe *et al.* 2006; McCurdy *et al.* 2007), and the recent discovery of kimberlites and abundant kimberlite indicator minerals (Day *et al.*, 2007; Pitman, 2014).

Research conducted during the GSC's Targeted Geoscience Initiative (TGI) project investigating the potential for MVT mineralization in northern Alberta and the Great Slave Plain of southern Northwest Territories (Hannigan 2006a) produced a mineral prospectivity map showing MVT mineralization potential in the carbonate platform of the southwest Great Slave Lake region around and west of the Pine Point mining district (Fig. 2; Hannigan 2006b). Concurrently, a two-year reconnaissance stream and glacial sediment sampling project, funded by Geoscience BC and the GSC in northeast British Columbia documented elevated values of Pb and Zn in till and stream sediment samples (McCurdy *et al.* 2007) about 400 km west-southwest of Pine Point.

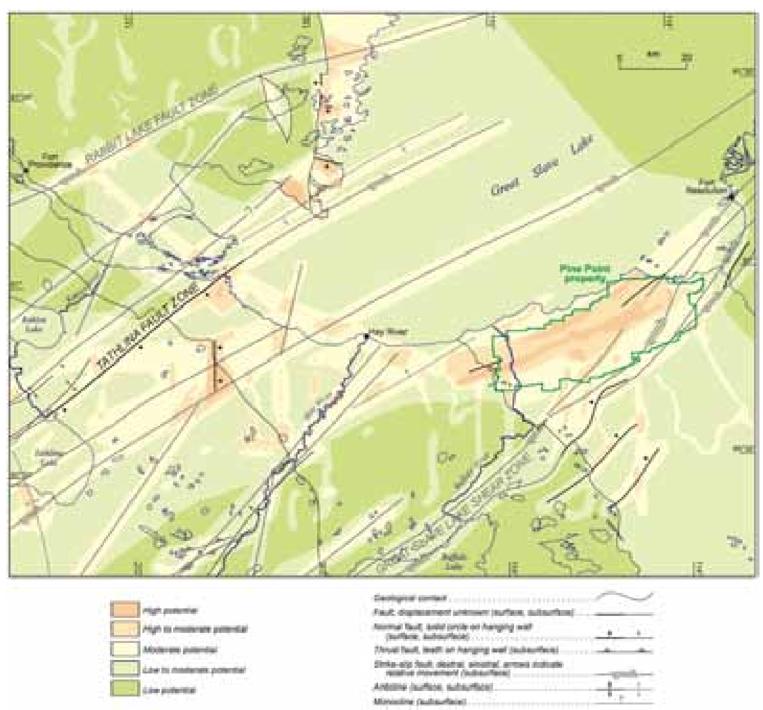

Figure 2. Mineral prospectivity map of the southern Northwest Territories, with ratings for the potential to host MVT mineralization (from Hannigan 2006b, p. 339).

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The GSC, under the Northern Resource Development Program (2003-2007), and the Alberta Geological Survey, also funded a surficial mapping and reconnaissance till sampling program in northwest Alberta that led to discovery of a significant sphalerite dispersal train in the Zama Lake lowlands, 300 km southwest of Pine Point (Fig. 3; Plouffe *et al.* 2006; Paulen *et al.* 2011). Historically, the Cretaceous sedimentary rocks of the WCSB renowned for their hydrocarbon resources, in which these two independent studies documented elevated Pb and Zn concentrations, have seldom been considered to have potential to host base metal mineralization (MacQueen 1997).

Based further on the reconnaissance study results in neighbouring British Columbia and Alberta, a stream sediment and till heavy mineral sampling program was included in the Protected Area Strategy (PAS) studies in the Sambaa K'e (Trout Lake; Watson 2011a) and Ka'a'gee Tu (Kakisa Lake; Watson 2011b) regions. Results from these PAS surveys identified significant elevated abundances of sphalerite, galena, and chalcopyrite in till samples overlying Paleozoic carbonate and Cretaceous sedimentary rocks (Fig. 4).

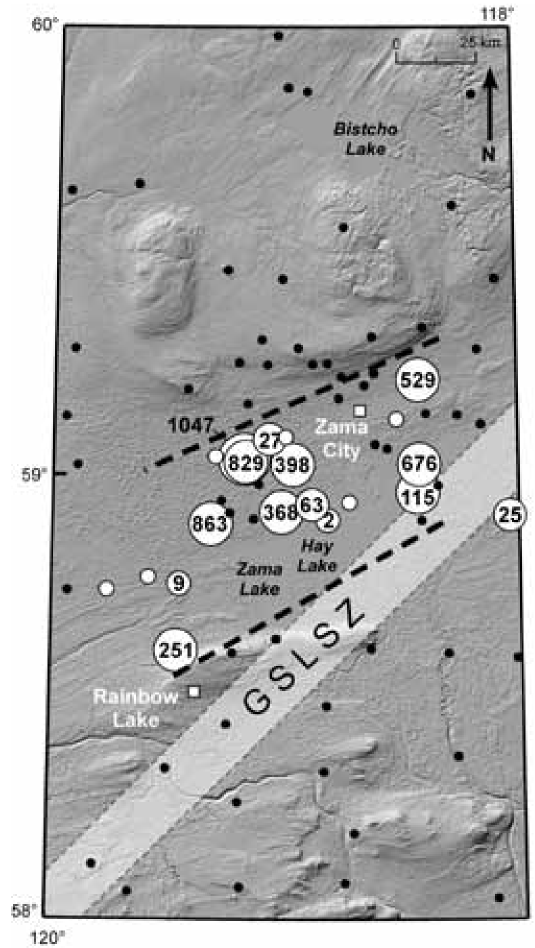

Figure 3. Number of sphalerite grains in the 0.25-0.5 mm heavy mineral fraction (normalised to a 30 kg till sample mass) recovered from till samples in northwest Alberta and the delimitated dispersal train (bounded by the thick black dashed lines) plotted on hillshade digital elevation model from Shuttle Radar Terrain Model (SRTM) of northwest Alberta (modified from Plouffe et al. 2008). Small white circles represent a single grain; small solid black circles indicate samples with no sphalerite. The highlighted light gray zone marks the approximate location of the Great Slave Lake shear zone (GSLSZ; Eaton and Hope 2003) projected to surface (modified from Paulen et al. 2011).

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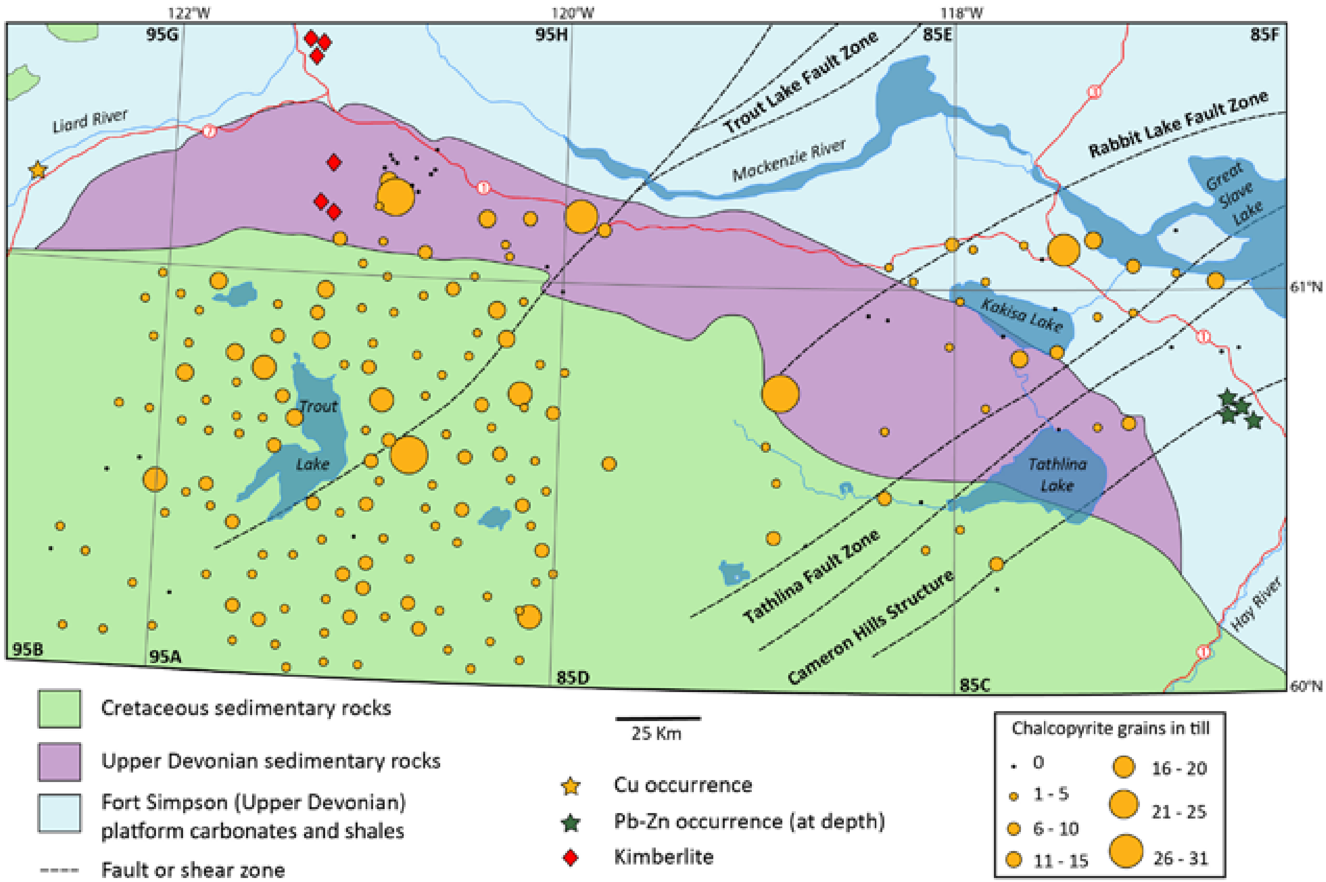

Figure 4. Number of chalcopyrite grains in the 0.25-2.0 mm heavy mineral fraction (normalised to 25 kg of <2 mm table feed weight) recovered from till samples in the Trout Lake (left) and Kakisa Lake (right) PAS surveys (Watson 2011a, b). General glacial ice flow direction here was from northeast to southwest. Classification intervals were arbitrarily assigned to the control variation in the number of grains per sample. Bedrock geology modified from Douglas (1974) and Okulitch (2006).

Drift prospecting research conducted around deposits within the Pine Point district under the GSC's GEM-1 Program (2008-2013) demonstrated that indicator minerals methods applied to till and stream sediments are effective tools for MVT exploration. The main indicator minerals, galena and sphalerite, survive glacial and fluvial transport and post-glacial weathering in this carbonate terrain (Oviatt *et al.* 2013, 2015; McClenaghan *et al.* 2018). Another important observation from their research was that chalcopyrite was not recovered in till or streams immediately down ice of from the Pb-Zn deposits.

METHODS

PAS indicator mineral analysis

Under the previous PAS surveys (Watson 2011a,b, 2013), numerous sand-sized (0.25–2.0 mm) grains of sphalerite, galena, chalcopyrite, and arsenopyrite were recovered from sediments. These mineral grains were donated by the Northwest Territories Geological Survey (NTGS) to the GSC for inclusion in this study. Note, indicator mineral results discussed for the PAS till samples have been normalised to a 25 kg table feed weight. In the previous PAS study, sphalerite, which ranges in colour from red to orange to black, was recovered in 57

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samples with the highest count per sample being 334 grains. Chalcopyrite grains (n≤31) were picked from 135 samples (Fig. 4). Several of the till samples containing sphalerite also contained galena and arsenopyrite grains, complete results of which are reported in King et al. (2018).

In this study, the donated sphalerite, galena, chalcopyrite, and arsenopyrite grains were mounted in 25 mm circular epoxy mounts and carbon coated. Imaging and semi-quantitative mineral compositions were determined using scanning electron microscopy (SEM) and energy dispersive spectrometry (EDS). These grains were then further analyzed for Pb and S ($\delta^{34}S$) isotopes using secondary ion mass spectrometry (SIMS). Details of SEM and SIMS work for are outlined in King *et al.* (2018).

GEM-2 stream sediment survey

Stream sediment samples collected as part of this activity followed the GSC's former National Geochemical Reconnaissance (NGR) programme's protocols for sample collection and analysis, in order to ensure consistent and reliable results, regardless of the area, date of the survey, or the analytical laboratory used (Friske & Hornbrook 1991). Bulk stream sediment, silt sediment, and water samples were collected from 31 sites in 2017 and 8 sites in 2018 (Day et al. 2018b). At each stream sample site, an on-site (0.45 μm) filtered water sample, a grab sample of silt-sized sediment, and a wet-sieved (<2 mm) bulk sediment sample were collected. The wet-sieved bulk sediment samples were processed to obtain the HMC fraction, from which indicator minerals, including sphalerite and galena, were counted, and representative grains picked. Indicator mineral grains of interest will be analysed to obtain their chemistry and isotopic composition which will assist in determining bedrock source and mineral potential.

GEM-2 till heavy mineral survey

Samples of till were collected throughout the study area at an approximate 10-15 km spacing for NTS sheets 85C, 85F and 85G. Additionally, samples were collected along two transects from east (up-ice) of Pine Point to the Liard River, to test for potential long-distance transport of MVT indicator minerals from Pine Point. Till samples were collected from 137 sites in 2017 and 54 sites in 2018 (Paulen *et al.* 2018).

Sample sites were located opportunistically along the few highway and trails that bisect the study area, but were largely conducted by helicopter, where landing areas were found often with great difficulty in former forest burn sites, or along the margins of bogs, fens and lakes. Till sample collection and quality control guidelines followed established GSC

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till sampling and analytical protocols (Spirito *et al.* 2011; McClenaghan *et al.* 2013; Plouffe *et al.* 2013). A bulk sample of till (~25 kg) was collected for heavy mineral concentrate (HMC) processing using the methodology outlined by McClenaghan (2011) and similar to that used for the stream sediment samples.

PRELIMINARY RESULTS AND INTERPRETATIONS

PAS indicator mineral analysis

Sulphur and Pb isotope data and interpretations of the PAS survey galena grains in till samples are presented in King *et al.* (2018). In summary, the galena grains have $^{206}Pb/^{204}Pb$ ratios ranging from 18.00 to 18.20 and $^{207}Pb/^{204}Pb$ ratios ranging from 15.58 to 15.71. These cluster proximal to the shale curve, a crustal Pb isotope curve that is representative of local basement in western Canada (i.e., western Laurentian continental crust; Fig. 5; Godwin and Sinclair 1982; Cumming *et al.* 1990). Such Pb ratios are indicative of an evolved upper crustal source; however, they have a more radiogenic Pb signature than Pine Point district samples, suggesting that the fluids responsible for the formation of the PAS galena grains tapped separate, older, more radiogenic Pb sources (e.g., Zartman & Haines 1988; Cumming *et al.* 1990; Kramers & Tolstikhin 1997).

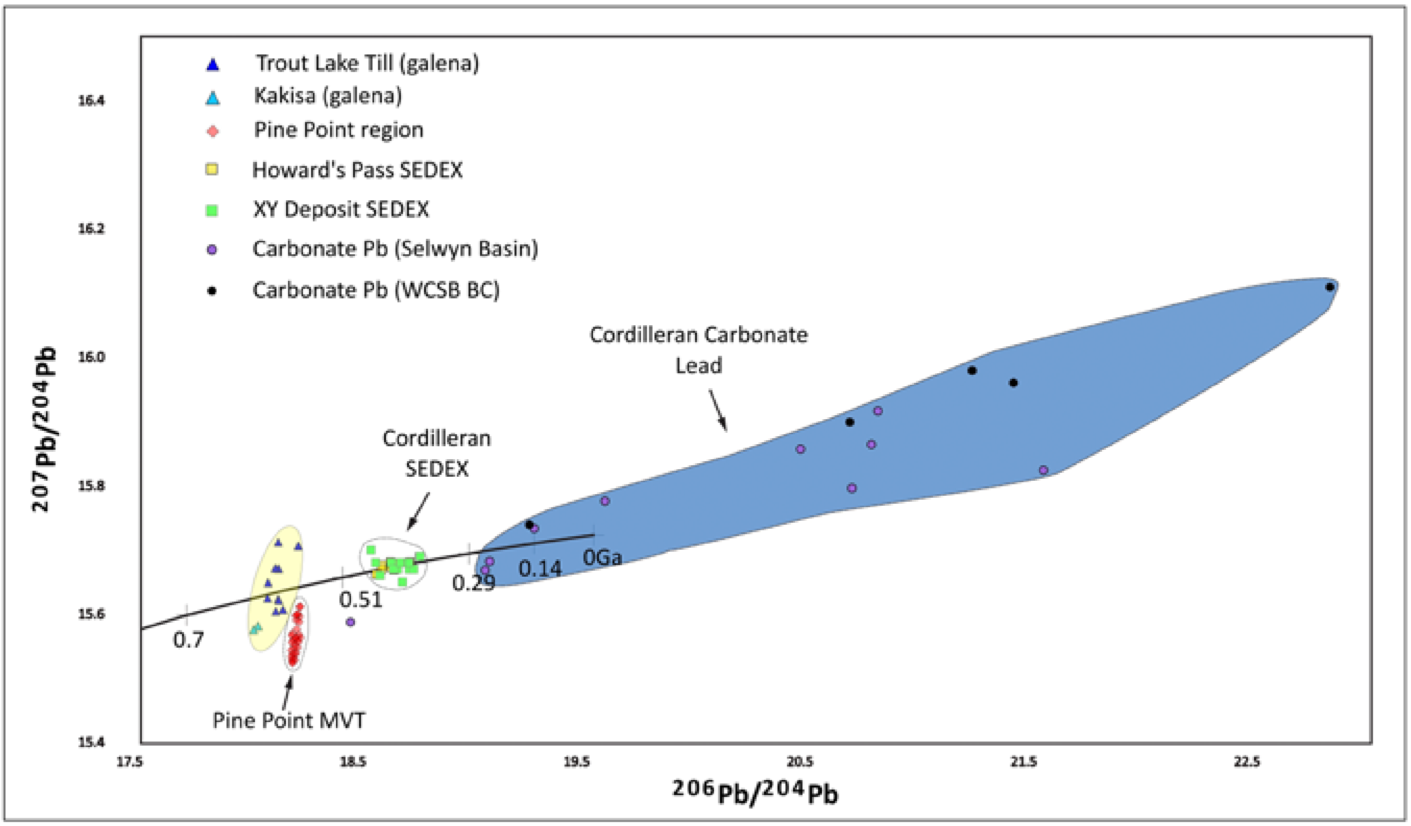

Figure 5. Lead isotopic bivariate plot of $^{206}Pb/^{204}Pb$ versus $^{207}Pb/^{204}Pb$ for galena grains from the Trout Lake (dark blue triangles) and Kakisa Lake (light blue triangles) regions inside yellow polygon (from King et al. 2018). Shown for comparison are bedrock samples from Pine Point (pink diamonds; Cumming et al. 1990; Paradis et al. 2006; Oviatt et al. 2015). Data are plotted about the shale curve of Godwin and Sinclair (1982). Additional data from other Mississippi Valley-type (MVT) deposits in northern British Columbia and sedimentary exhalative (SEDEX) Pb-Zn deposits in Yukon and values from the Western Canada Sedimentary Basin (Godwin et al. 1988; Paradis et al. 2006) are also included.

Secondary ion mass spectrometry (SIMS) $\delta^{34}S$ values for galena range from +0.63 to +26.87‰, like the values found in previous studies at Pine Point, indicating galena grains have a similar sulphur source to Pine Point (Kyle 1981; Oviatt *et al.* 2015). Chalcopyrite has $\delta^{34}S$ values ranging from -20.64 to +28.33‰ and arsenopyrite has $\delta^{34}S$ values ranging from -2 to +2‰. The $\delta^{34}S$ values found in chalcopyrite are similar to

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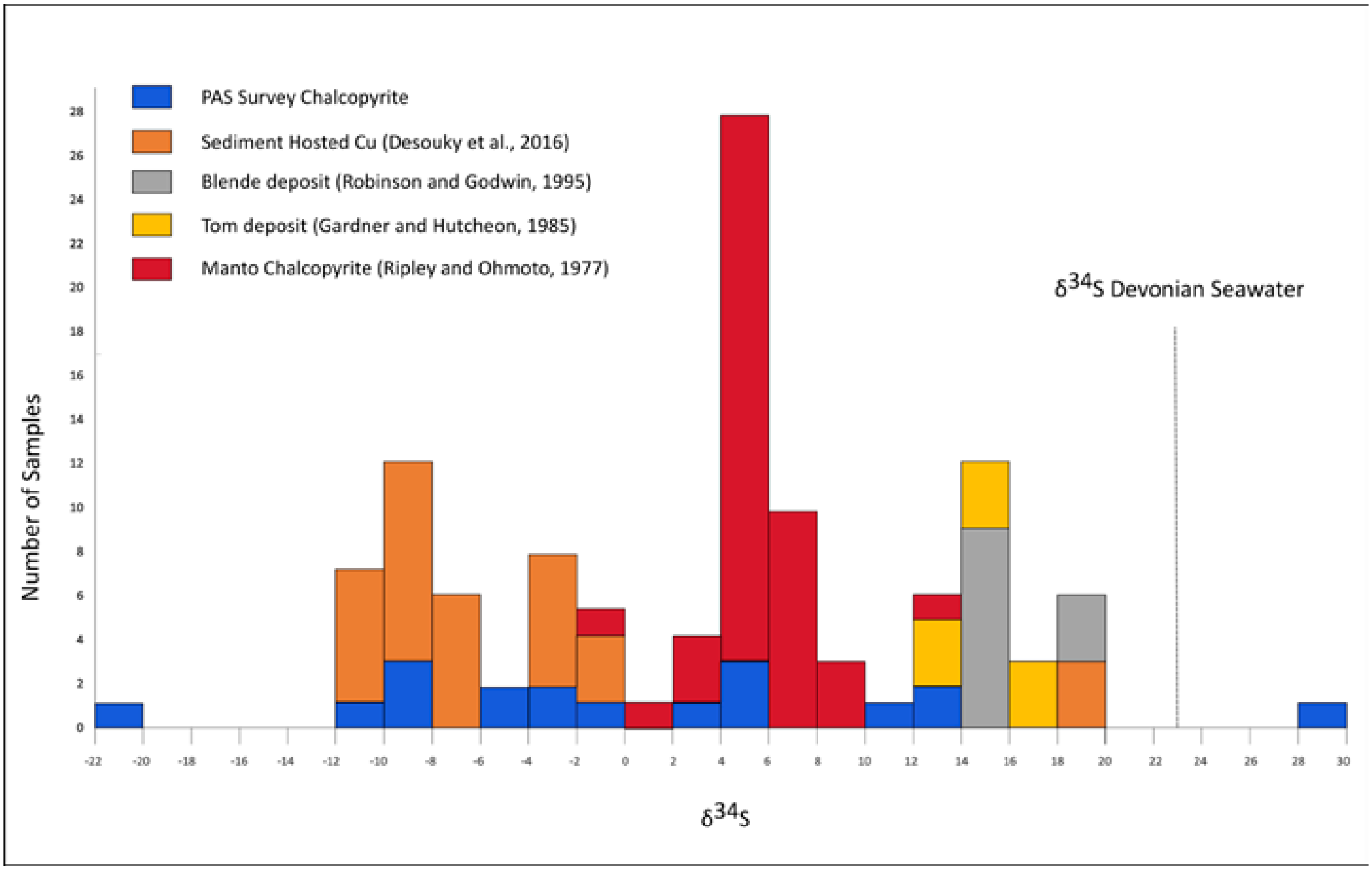

Figure 6. Histogram of $\delta^{34}S$ values of PAS survey chalcopyrite (blue; King et al. 2018) compared with values from Manto-style mineralization in Peru (red; Ripley and Ohmoto 1977), the Tom sedimentary exhalative (SEDEX) deposit in the Yukon Territory (yellow; Gardner and Hutcheon, 1985), the Blende carbonate-hosted Pb-Zn deposit, Yukon Territory (grey; Robinson and Godwin 1995), and sediment-hosted Cu deposits in Africa (orange; El Desouky et al. 2010).

sediment-hosted Cu deposits and chalcopyrite from magmatic hydrothermal Manto-type deposits, suggesting potential for either deposit type in the region (e.g., Ripley & Ohmoto 1977; El Desouky *et al.* 2010). Arsenopyrite $\delta^{34}S$ have values similar to igneous rocks (e.g. $\delta^{34}S$ = 0±3‰; Ohmoto & Rye 1979; Ohmoto & Goldhaber 1997), which could indicate that sulphur in arsenopyrite grains was derived from igneous basement rocks. Additionally, orogenic gold deposits near Yellowknife contain arsenopyrite that have $\delta^{34}S$ values similar to those in the PAS samples, suggesting that the arsenopyrite grains from the study area may be sourced from orogenic Au systems hosted in the Canadian Shield, well (>250 km) up-ice of the region (Wanless *et al.* 1960; Marini *et al.* 2011).

GEM-2 stream sediment survey

Results for 31 samples collected in 2017 were published in Day *et al.* (2018a). In order to counter potential sample bias due to the hydrodynamic forces active within a flowing stream and variability of HMC content of stream sediments within and between sites (cf., Prior *et al.* 2009), the indicator mineral counts for stream sediments were normalised to the weight of the heavy mineral fraction rather than the weight of the total sample (<2 mm table feed). Mineral grain plots presented here are values normalised to the weight of the heavy mineral fraction, plotted on a bedrock base map (Okulitch 2006); legend for the bedrock base is provided in Figure 7.

The highest grain counts for sphalerite ((Zn,Fe)S) plus galena (PbS) reported in stream sediments (Day *et al.* 2018a) is a site on the Buffalo River, approximately 20 km down-ice (west) of the closest known subcrop of mineralization in the Pine Point mining district (Kyle 1981; S. Clemmer pers. comm., July 2018). This sample contains one of the highest number of grains ever reported for a GSC NGR regional heavy mineral survey in northern Canada with more than 6000 grains of sphalerite and 40 grains of galena (Fig. 8a). Large numbers of sphalerite grains were also recovered from stream sites along NE-SW structural trends parallel to, and between, the Trout Lake Fault Zone and Tathlina Fault Zone, >200 km west of the Pine Point district. Elevated counts of galena (60 grains) were also obtained on the Hay and Kakisa rivers, ~75 and 150 km, respectively, down-ice from the Pine Point district (Fig. 8b).

Chalcopyrite ($CuFeS_2$) abundance in stream sediments (Fig. 9a) shows an arcuate 200 km trend of elevated values from the Hay River to the Mackenzie River. Scheelite ($CaWO_4$) is a mineral which was not be expected to be present in stream sediment HMCs because of the underlying bedrock geology. Scheelite is physically robust and known to survive

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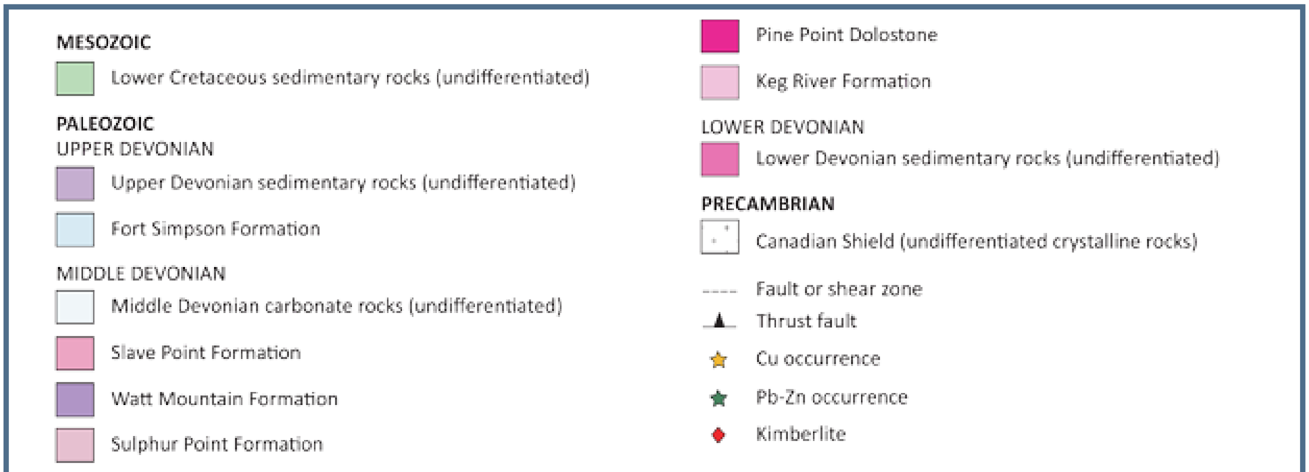

Figure 7. Legend for bedrock geology of the Western Canada Sedimentary Basin between the Canadian Shield and Cordillera used in Figures 8 and 9. Note that the bedrock geology is shown projected under the lakes (after Douglas 1974 and Okulitch 2006). Major fault systems and mineral occurrences are also noted.

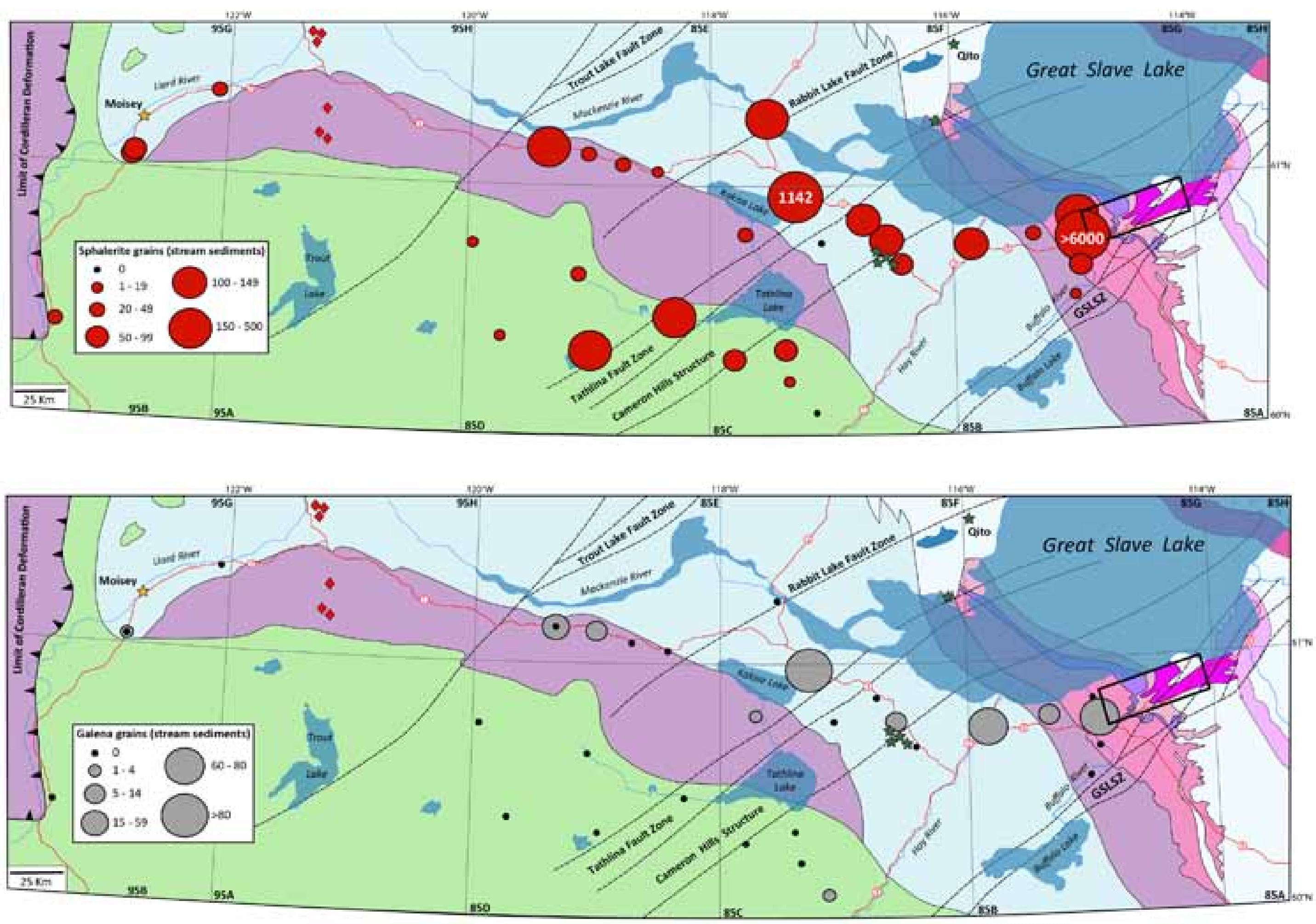

Figure 8. Number of (A) sphalerite grains and (B) galena grains in the 0.25-0.5 mm heavy mineral fraction (normalised to a 50 g heavy mineral fraction weight) recovered from stream sediment samples in the 2017 GSC GEM stream sediment survey (Day et al. 2018a). The large black rectangle is the Pine Point mining district containing >100 Pb-Zn ore bodies distributed over 1600 km2 (Hannigan 2006b). See Figure 7 for bedrock legend.

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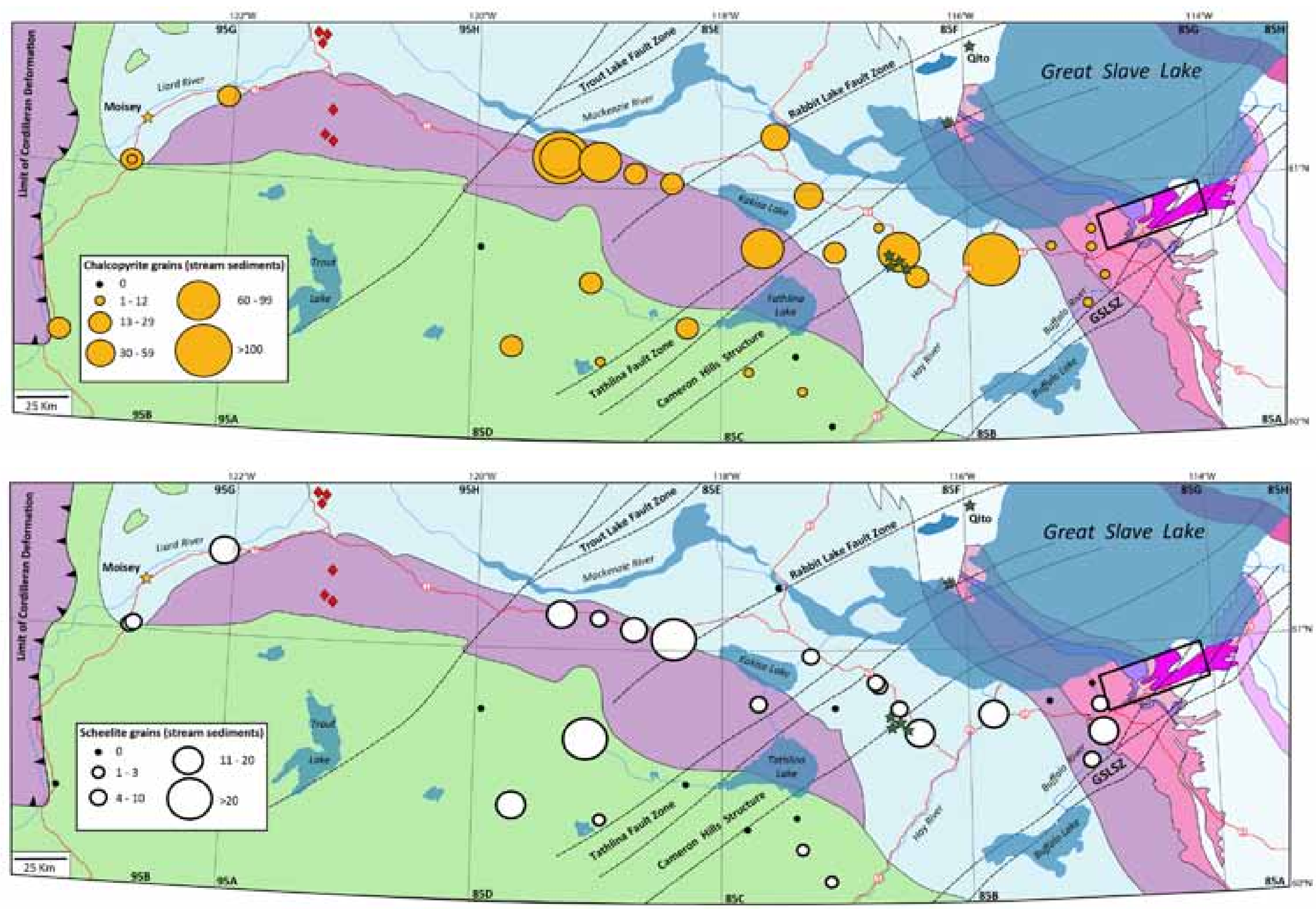

Figure 9. Number of (A) chalcopyrite grains and (B) scheelite grains in the 0.25-0.5 mm heavy mineral fraction (normalised to a 50 g heavy mineral fraction weight) recovered from stream sediment samples in the 2017 GSC GEM stream sediment survey (Day et al. 2018a). The large black rectangle is the Pine Point mining district containing >100 Pb-Zn ore bodies distributed over 1600 km2 (Hannigan 2006b). See Figure 7 for bedrock legend.

glacial and stream transport (e.g., McClenaghan *et al.* 2017). Scheelite grain counts are highest along a trend parallel to the Rabbit Lake Fault Zone immediately west of Kakisa Lake (Fig. 9b).

GEM-2 till heavy mineral survey

Indicator mineral counts have yet to be published for the 191 till samples collected in the study area. However, chalcopyrite occurs in more than 90% of the till samples west of Hay River and east of the Trout Lake PAS survey, and there are additional sites with elevated sphalerite and galena grains more than 150 km west of Pine Point. Publication of results from the 2017 survey are anticipated in early 2019.

DISCUSSION

Sphalerite and galena mineralization has long been known and exploited in the past-producing Pine Point Pb-Zn mining district. Carbonate-hosted sphalerite and galena outcrop and subcrop beneath till in the Pine Point area; however, to the west of the Hay River there are no documented occurrences of bedrock mineralization exposed at the bedrock surface, only reports of sphalerite and galena mineralization at depth in drillcore (Hannigan 2006a). This is important to note, because galena and sphalerite could only be incorporated into the glacial and post-glacial sediments if the bedrock mineralization subcrops and was exposed to an overriding glacier. A single Pb-Zn mineral occurrence, Qito, is located near the northern limit of the study area, on the west side of Great Slave Lake, on the Rabbit Lake Fault Zone and is described as galena and sphalerite mineralization hosted in Presqu'ile dolostone (Turner 2006). This site is >100 km to the northeast of the nearest stream sediment anomaly near Kakisa Lake. The presence of elevated sphalerite and galena grain counts in stream sediment HMCs documented in this study, distal to Pine Point district, is significant in that it implies that the Laurentide Ice Sheet eroded sphalerite and galena mineralization exposed at bedrock surface at unknown sources. Mineral-rich glacial sediments were deposited, which were subsequently reworked into local stream sediments.

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EXPLORATION TARGETS

Preliminary S and Pb isotope data from galena grains in regions around Trout and Kakisa lakes indicate that grains are from proximal sources and not dispersed from Pine Point (King *et al.* 2018). Based on the similarity of the δ^{34}S values for galena grains from the PAS surveys to those from known MVT deposits, the galena in the study area likely originated from MVT-style mineralization. Glacial dispersal studies in the Pine Point mining district by Oviatt *et al.* (2015) and McClenaghan *et al*. (2018) showed that 700 m down-ice from mineralization, till samples generally contain tens of grains of galena, which is a reflection of the low hardness of galena (2.5–3) and its brittle nature due to its cubic cleavage. Galena rarely survives glacial transport beyond 1 km because of its softness. Thus, it is assumed that the galena grains in the PAS till samples are locally derived (i.e., likely <1 km from their source). As previously suggested by Hannigan (2006b), Pb-Zn exploration should be focused in carbonate units proximal to the faults in the region, including the Trout Lake, Rabbit Lake, and Tathlina fault zones, as well as the Cameron Hills structure (Fig. 4).

Chalcopyrite found in tills throughout the study area may have been sourced from sediment-hosted Cu mineralization, as indicated by the significant variations in δ^{34}S values, a feature found in sediment-hosted Cu deposits globally (Leblanc & Arnold 1994; El Desouky *et al.* 2010). The presence of chalcopyrite grains in the PAS till surveys in the Trout Lake-Kakisa area (Fig. 4) pose an intriguing question of provenance. Bedrock lithologies underlying the study area are essentially an undeformed sedimentary package of Paleozoic carbonates and Mesozoic shales, siltstones and sandstones cross-cut by the NE-SW trending Great Slave Lake Shear Zone and several significant subparallel fault structures (Eaton & Hope, 2003). A single Cu-Zn mineral occurrence, Moisey, is located within the study area, adjacent to the Liard River, and is described as Kipushi/Manto-type mineralization hosted in the carbonate and shale units of the Upper Devonian Fort Simpson Formation (Dudek 1993). Note, the Moisey site cannot be the source of the elevated HMC chalcopyrite grains as it is situated glacially down-flow, at the western edge of the study area. The arcuate chalcopyrite trend is either coincident with, or is proximal to the same host lithologies and warrants further investigation as to whether the chalcopyrite grains recovered from the stream sediment HMC samples are genetically related.

Arsenopyrite grains have δ^{34}S values similar to orogenic Au deposits near Yellowknife (400 km to the northeast), indicating grains found in the study region may have been sourced from similar deposits up-ice of this region (Wanless et al. 1960). The significance of scheelite in the stream sediments is undetermined; however, future mineral chemistry studies may shed light on bedrock provenance and potentially glacial transport history.

FUTURE WORK

In addition to *in situ* isotope methods, δ^{34}S isotopes of sphalerite, chalcopyrite and galena grains in till were measured at the University of Ottawa G.G. Hatch Stable Isotope Laboratory. Full interpretations of δ^{34}S and Pb-isotopic data from PAS survey samples will be available in future GSC publications. On-going research at Memorial University will provide additional δ^{34}S, Pb, and geochemical data from GEM2 GSC till and stream sediment samples (Paulen *et al.* 2017, 2018; Day *et al.,* 2018a, b).

Future work will include SEM-EDS, EPMA, LA-ICP-MS, SIMS and conventional sulphur isotope work on sulphide phases including sphalerite, galena, chalcopyrite and arsenopyrite grains recovered from 2017 till and stream sediment samples. Several bedrock samples collected from the Pine Point district will also be used in conjunction with data from previous studies (Oviatt 2013; Oviatt *et al*. 2015), along with bedrock and drill core samples from other mineral occurrences in the area, to compare potential source regions for sulphide species recovered from surface till samples. Mineral chemistry studies also will be undertaken on scheelite grains, so as to determine potential bedrock sources of the scheelite and deposit type of origin (e.g., Poulin *et al.* 2018).

ACKNOWLEDGEMENTS

This research is part of the Geological Survey of Canada's Geo-mapping for Energy and Minerals GEM-2 Program, Southern Mackenzie Surficial activity, conducted under NWT Scientific Research Licence #16110. The Northwest Territories

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Geological Survey is thanked for providing the PAS base metal indicator minerals for analyses. The authors would like to acknowledge Glenn Piercey and Dr. Graham Layne (Memorial University) for SIMS Pb and S isotopic analysis. Additionally, Dr. Wanda Aylward (Memorial University) is acknowledged for assistance with preliminary SEM imaging and analysis. Additional support for grain analysis is provided by a NSERC Discovery Grant to Stephen Piercey. Assistance with all aspects of fieldwork was cheerfully provided by GEM-2 funded students Grant Hagedorn (University of Waterloo), Robert King (Memorial University), Joeli Plakholm (Carleton University) and Jamie Sapera (Brock University). Excellent assistance in the field and wildlife monitoring was provided by Irene Graham and Pat Martel (Kátł'odeeche First Nation), Darcy Simba (Ka'a'gee Tu First Nation) and Henry Sabourin, James Nadli and Alan Farcy (Deh Gah Got'ie Koe First Nation). David Huntley (GSC Vancouver) and **EXPLORE** editor Beth McClenaghan are thanked for critical reviews of earlier drafts of this paper. NRCan contribution number 20180342.

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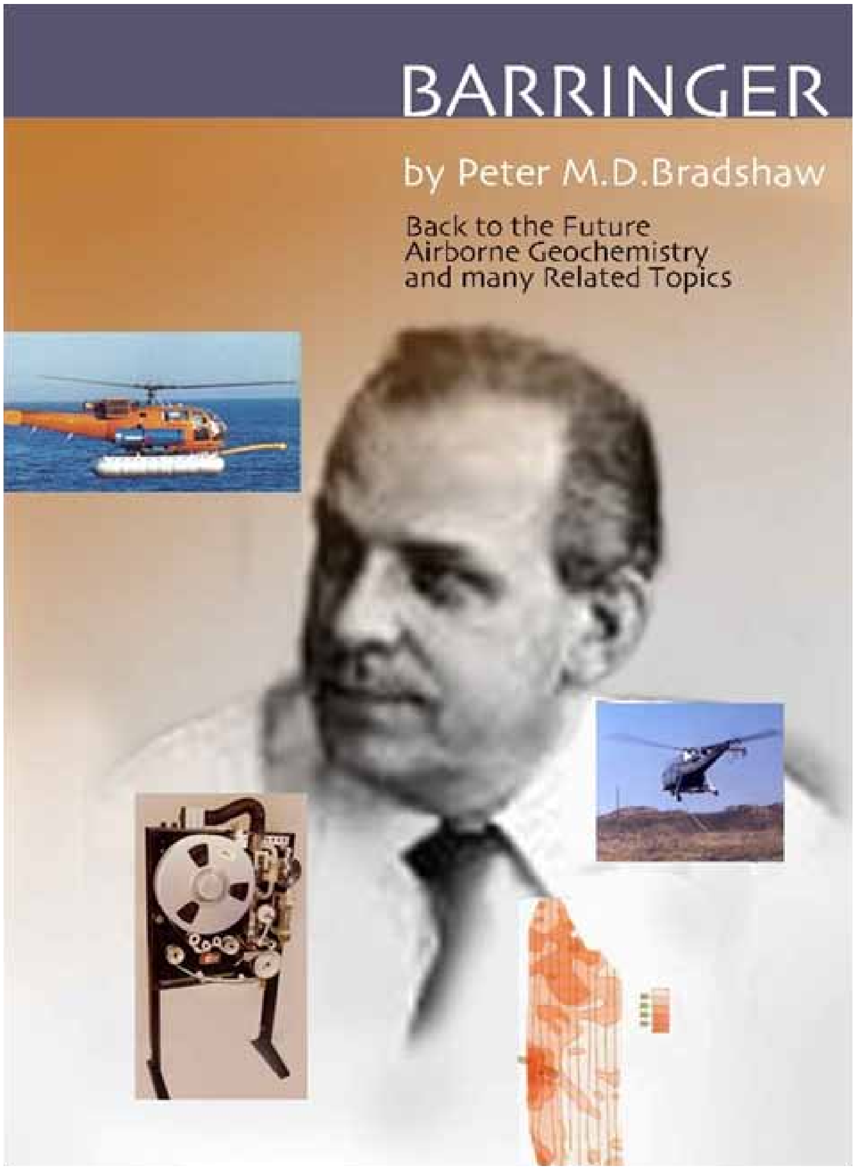

BARRINGER - THE BOOK

Exploration, Remote Sensing, Environment, Analysis, Security

The 1960's and 70's were marked by an explosion in mineral exploration and remote sensing technology. A leader throughout this period was Dr. Anthony (Tony) Barringer and his team at Barringer Research Ltd. (BRL). The highly successful airborne geophysical methods created at BRL are well known while the contributions to exploration geochemistry and many other fields are not. This book documents the many advances in geochemical theory, as well as the ground, airborne and remote sensing techniques plus analytical methods that were conceived and developed under the leadership of Tony Barringer. Innovative concepts backed by pioneering research funded by BRL on the movement of metals in rock, soil and vegetation remain important areas of investigation. Tony Barringer's ability to bring together a diverse team including geologists, geochemists and physicists with electrical, optical and aeronautical engineers under one roof, provide leadership, a highly stimulating environment and financial support, was truly remarkable. This led to ground breaking advances in a number of different fields, including: exploration geochemistry for minerals and oil and gas; environmental monitoring from the ground, aircraft and space; and civilian and armed forces security. The underlying scientific principles for many of the inventions, now upgraded with modern electronics, are still considered state of the art. One of the many inventions from the BRL "incubator" described in this book is Ionscan, the drug and explosive screening device used in most airports today, which was conceived and developed by BRL in conjunction with technology for the detection of mineral deposits.

Hard Cover book, including shipping US$ 68.00, ***
Soft Cover book, including shipping US$ 58.00, ***
International shipping is by surface mail, for air mail please add US$ 20.00/ volume

*Note, for US$48 and US$38 or $C65 and $C55 respectively (to avoid shipping charges) there will be limited number of both the hard and soft cover books available the MDRU booth at Roundup in Vancouver (first come first served) or directly available in Vancouver for a limited time from Pbradshaw@firstpointminerals.com
**Note there will also a very limited number at the MDRU both at the PDAC. To reserve your copy for pick up at the MDRU booth please email Pbradshaw@firstpointminerals.com at the latest by Feb 22nd.

HOW TO ORDER:
ASSOCIATION OF APPLIED GEOCHEMISTS. All payments must be made in one of the following formats: bank draft, personal cheque (drawn on a US$ account), or money order made out to the Association of Applied Geochemists, sent to
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short course

EXPLORATION GEOLOGY

Ore deposit models, alteration geochemistry and ore textures

COURSE TOPICS

- exploration geology: objectives, approaches and methods
- sampling, analytical methods and data processing
- geochemical discrimination
- alteration geochemistry and vectoring
- visualization of geochemical data: ioGAS software
- ore microscopy
- exploration case studies

COURSE STRUCTURE

- 3 days of lectures (50 %) and practical sessions (50%)
- poster session of participants
- 1 day field trip (optional)

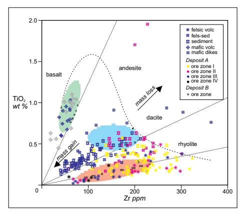
PRACTICAL INFORMATION

- participants may use their own or university-provided PC
- geochemical visualization softwarewill be provided
- participants my obtain 2 ECTS credits after succesful completion of the course and written examination

OVERVIEW

This short course offers theoretical foundations and practical training in exploration geology, alteration geochemistry and ore interpretation. We welcome participants from universities, research institutions as well as exploration or industrial companies wishing to further their professional development. In addition, the short course will host a poster session for participants who wish to present and discuss their own projects. The course contents are aimed at master and doctoral students but the course is open to early career scientists and participants from industry and private sector as well. The official language will be English.

An optional one-day excursion to ore deposits in Schwarzwald (Black Forest) is planned for March 21, 2019. The field trip will demonstrate various styles of mineralization related to rifting of the Upper Rhine graben.



INSTRUCTORS

Prof. David Dolejš (lectures and practical sessions) holds chair of mineralogy and petrology at the University of Freiburg. He conducts research on magmatic and hydrothermal systems, including field and theoretical approaches to geochemical processes and hydrothermal fluid flow during the formation of mineral deposits.

Dr. Kateřina Schlöglová (software sessions and field trip) is an assistant at the University of Freiburg and a consultant for mineral exploration. She gained her industry experience as an exploration geologist for Dragon Mining Ltd. She is interested in physico-chemical processes responsible for formation of magmatic-hydrothermal deposits and exploration methods.

Dr. Malte Junge (ore microscopy) is a lecturer in mineralogy and mineral resources at the University of Freiburg, with previous employment at the Federal Institute for Geosciences and Natural Resources (BGR) in Hanover. His research interest focuses on ultramafic-mafic, granitic and VMS-type ore deposits.

Dr. Denis Schlatter, EurGeol (exploration models and case studies) is the CEO of the Helvetica Exploration Services GmbH. He has over 20 years of experience in mineral exploration in industry, academia and government, particularly gold and base metal exploration in the Arctic with 15 field seasons in Archean provinces of Greenland.

March 18-21, 2019

Institute of Earth and Environmental Sciences, University of Freiburg, Germany

Albertstrasse 23b, 79104 Freiburg im Breisgau www.minpetro.uni-freiburg.de/expgeo

COSTS include registration, course materials, coffee breaks, social

- 50 EUR - students and early career scientists*
- 400 EUR - non-academic and industry atendees
- 30 EUR - excursion fee

**non-resident student members of the DMG are eligible for travel support of 50 €*

REGISTRATION deadline January 10, 2019

- for registration, see: www.minpetro.uni-freiburg.de/expgeo
- for further inquiries contact: Dr. Katerina Schlöglova katerina.schloglova@minpet.uni-freiburg.de

CALENDAR OF EVENTS

International, national, and regional meetings of interest to colleagues working in exploration, environmental and other areas of applied geochemistry. These events also appear on the AAG web page at: www.appliedgeochemists.org.

Please let us know of your events by sending details to:
Steve Amor
Geological Survey of Newfoundland and Labrador
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Email: StephenAmor@gov.nl.ca Tel: +1-709-729-1161
Or Tom Meuzelaar, AAG Webmaster,
Email: Tom_Meuzelaar@golder.com

2019

6-9 JANUARY	International Soil Science Meeting. San Diego CA USA. Website: tinyurl.com/y9oorlm4
10-11 JANUARY	ICCEEST 2019 : 21st International Conference on Chemical, Ecological, Environmental Science and Technology. Singapore. Website: tinyurl.com/y7yo7r6r
24-25 JANUARY	21st International Conference on Organic Geochemistry and Geochemical Engineering. Paris France. Website: tinyurl.com/y7et6aa7
28-31 JANUARY	Mineral Exploration Roundup. Vancouver BC Canada. Website: roundup.amebc.ca
30-31 JANUARY	21st International Conference on Environmental Pollution, Public Health and Impacts. Dubai UAE. Website:tinyurl.com/yava77l5
3-8 FEBRUARY	European Winter Conference on Plasma Spectrochemistry. Pau France. Website: winterplasma19.sciencesconf.org
8-9 FEBRUARY	Atlantic Geoscience Society 45th Colloquium and Annual General Meeting. Fredericton NB Canada. Website: tinyurl.com/ydhkz8tz
26-28 FEBRUARY	Janet Watson Meeting 2019: From core to atmosphere: Deep carbon. London UK. Website: www.geolsoc.org.uk/jwatson19
3-6 MARCH	Prospectors and Developers Association of Canada Annual Convention. Toronto ON Canada. Website: www.pdac.ca/convention
10-14 MARCH	Minerals, Metals & Materials Society Annual Meeting & Exhibition. San Antonio TX USA. Website: www.tms.org/tms2019
11-14 MARCH	SIAM Conference on Mathematical & Computational Issues in the Geosciences. Houston TX USA. Website: www.siam.org/Conferences/CM/Main/gs19
18-21 MARCH	Exploration Geology short course. Theoretical foundations and practical training in mineral exploration geochemistry and geology, alteration geochemistry and ore interpretation. Uni Freiburg, Freiburg im Breisgau, Germany. Website: http://www.minpetro.uni-freiburg.de/expgeo
7-12 APRIL	EGU General Assembly. Vienna Austria. Website: www.egu2019.eu
28 APRIL - 1 MAY	CIM Convention. Montreal QC Canada. Website: convention.cim.org
3-5 MAY	International Conference on Geographical Information Systems Theory, Applications and Management. Heraklion Greece. Website: www.gistam.org
6-9 MAY	9th World Conference on Sampling and Blending. Beijing China. Website: www.wcsb9.com
13-15 MAY	GAC-MAC-IAH/CNC Annual Meeting. Quebec City QC Canada. Website: tinyurl.com/y9dffld5
3-8 JUNE	8th International Workshop on Compositional Data Analysis. Terrassa Spain. Website: tinyurl.com/y7prnhoo
23-28 JUNE	Gordon Research Conference: Catchment Science: Interactions of Hydrology, Biology and Geochemistry. Andover NH. Website: tinyurl.com/y9dsvkac
24-27 JUNE	Quantitative Microanalysis 2019. Minneapolis MN USA. Website: tinyurl.com/y8fayprt
14-19 JULY	Gordon Research Conference: Discovering Chemical Processes and Mechanisms in a Changing Ocean. Holderness NH USA. Website: tinyurl.com/yahb7f7o
15-18 JULY	6th Annual International Conference on Geology & Earth Science. Athens Greece. Website: www.atiner.gr/geology
21-26 JULY	16th International Symposium on Water-Rock Interaction. Tomsk Russia. Website: wri16.com
22-23 JULY	6th Annual International Conference on Geology & Earth Science. Athens Greece. Website: www.atiner.gr/geology

continued on page 27

CALENDAR OF EVENTS... *continued from page 26*

25-31 JULY	INQUA 2019. Dublin Ireland. Website: www.inqua2019.org
4-8 AUGUST	Microscopy & Microanalysis 2019 Meeting. Portland OR. Website: tinyurl.com/y9ejytzy
18-23 AUGUST	Goldschmidt 2019. Barcelona, Spain. Website: goldschmidt.info/2019
27-30 AUGUST	15th Biennial Meeting of the Society for Geology Applied to Mineral Deposits. Glasgow UK. Website: www.sga2019glasgow.com
2-5 SEPTEMBER	2nd Australasian Exploration Geoscience Conference. Perth WA Australia. Website: 2019.aegc.com.au
8-13 SEPTEMBER	14th International Conference on Mercury as a Global Pollutant. Krakow Poland. Website: www.mercury2019krakow.com/gb
17-18 SEPTEMBER	21st International Conference on Isotope Hydrology and Geochemistry. Rome Italy. Website: tinyurl.com/y8excuwr
7-20 OCTOBER	SEG 2019: South American Metallogeny: Sierra to Craton. Santiago Chile. Website: tinyurl.com/y7k4dm6j
27-30 OCTOBER	6th International Conference on Selenium in the Environment and Human Health. Yangling/Xi'an China. Website: icsehh2019.csp.escience.cn
29-30 OCTOBER	12th Fennoscandian Exploration and Mining. Levi Finland. Website: fem.lappi.fi/en

2020

2-8 MARCH	36th International Geological Congress. Delhi India. Website: 36igc.org
20-24 MAY	Geological Society of Nevada 2020 Symposium Vision for Discovery: Geology and Ore Deposits of the Basin and Range. Sparks NV USA. Website: www.gsnv.org/2020-symposium
17-21 AUGUST	34th International Geographical Congress. Istanbul, Turkey. Website: www.igc2020.org/en
24-28 AUGUST	Eurosoil 2020. Geneva, Switzerland. eurosoil2020.com

Recently Published in Elements

Volume 14, no. 4, Central Andes: Mountains Magmas, and Minerals

This volume offers an eclectic mix of topography, magmatism, heat flow and mineral deposits. The new AAG councillors for 2018 and 2019 are profiled in this issue, as well as our new editor for GEEA, Scott Wood.

Volume 14, no. 5, Deep-ocean Mineral Deposits
Issue 5 this year examines deep-ocean mineral deposits and their potential exploitation from an ecological and regulatory perspective. AAG news in this issue acknowledged the worthy medal recipients from the 2018 IAGS.

Dennis Arne

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