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

Roger C. Paulen[1], Stephen J.A. Day[1], Robert D. King[2], Stephen J. Piercey[2] and I. Rod Smith[3]

[1] Natural Resources Canada, Geological Survey of Canada, 601 Booth Street, Ottawa, ON, Canada K1A 0E8.
[2] Memorial University of Newfoundland, Department of Earth Sciences, 9 Arctic Avenue, St. John's, NL, Canada A1B 3X5.
[3] Natural Resources Canada, Geological Survey of Canada, 3303 33 St NW, Calgary, AB, Canada T2L 2A7.

https://doi.org/10.70499/JDQF4206

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.

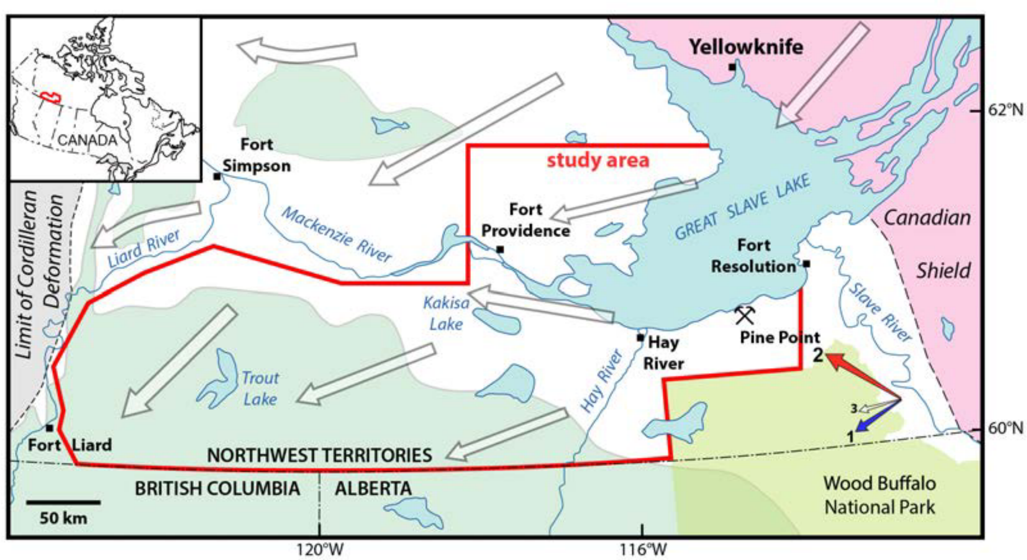

Figure 1. Study area for surficial mapping and heavy mineral studies, southwest Northwest Territories, Canada. The study area is contained within the WCSB, underlain by Paleozoic carbonate (white) and Cretaceous (pale green) bedrock, west of the Canadian Shield and east of the Cordilleran deformation. 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

continued on page 5

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.

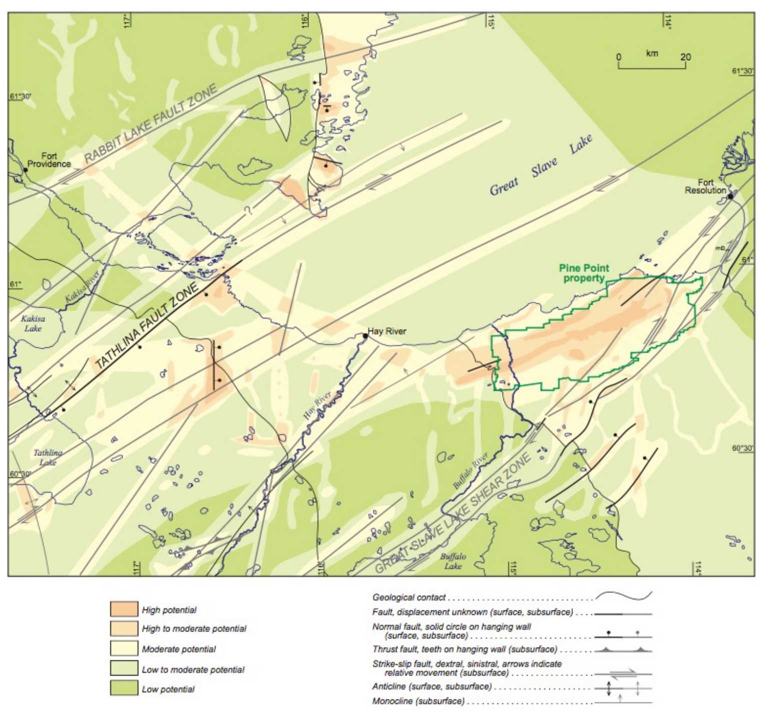

Figure 2. Mineral prospectivity map of the southern Northwest Territories, with ratings for the potential to host MVT mineralization (from Hannigan 2006b, p. 339).

continued on page 6

New base metal mineral potential…… *continued from page 5*

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).

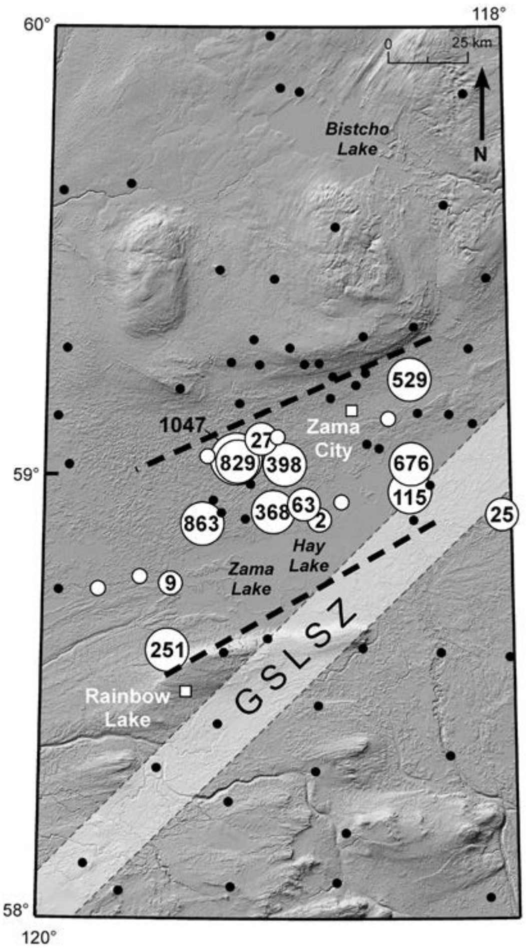

Figure 3. Number of sphalerite grains in the 0.25-0.5 mm heavy mineral fraction (normalised to a 30 kg till sample mass) recovered from till samples in northwest Alberta and the delimitated dispersal train (bounded by the thick black dashed lines) plotted on hillshade digital elevation model from Shuttle 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).

continued on page 8

New base metal mineral potential… *continued from page 6*

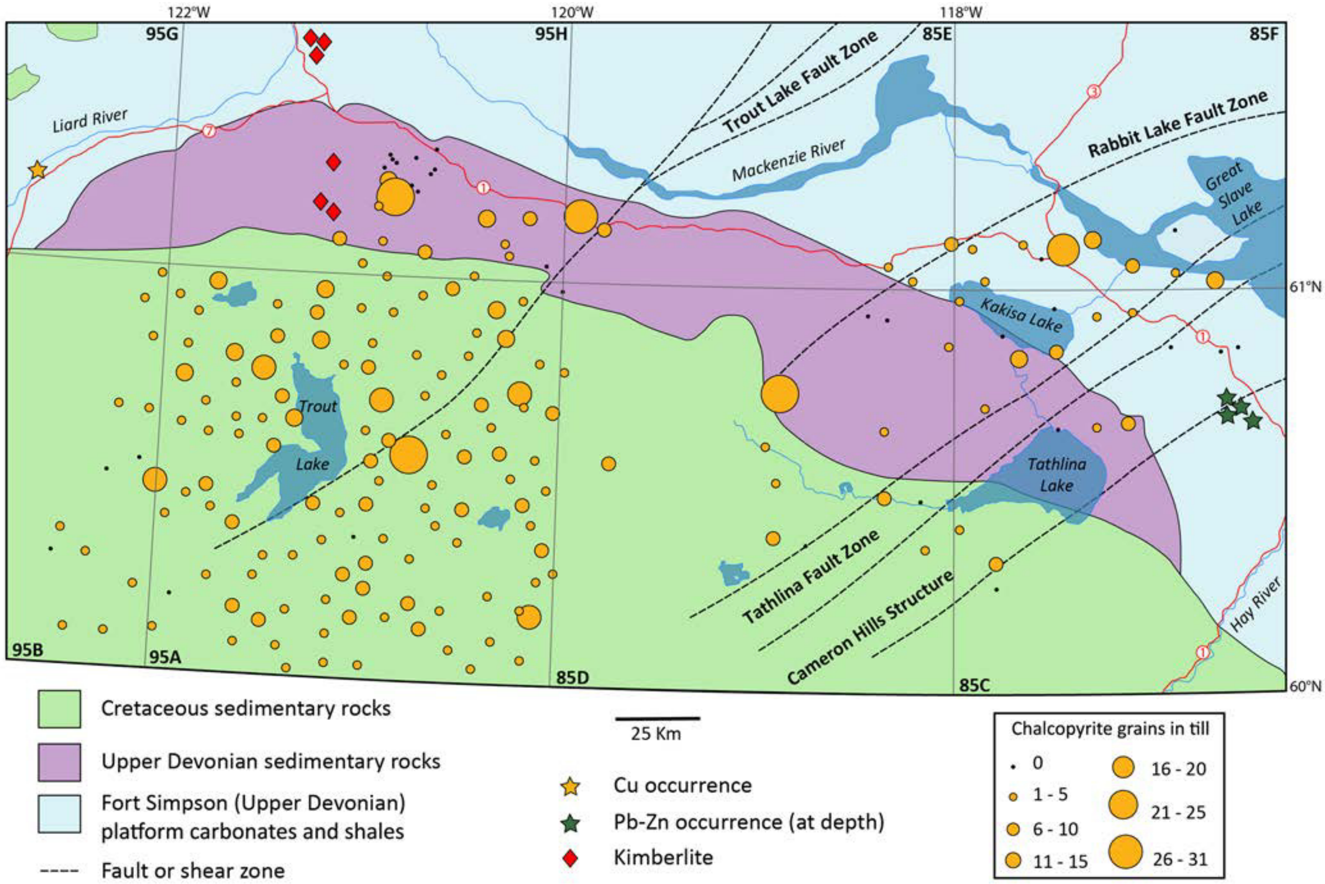

Figure 4. Number of chalcopyrite grains in the 0.25-2.0 mm heavy mineral fraction (normalised to 25 kg of <2 mm table feed weight) recovered from till samples in the Trout Lake (left) and Kakisa Lake (right) PAS surveys (Watson 2011a, b). General glacial ice flow direction here was from northeast to 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

continued on page 9

New base metal mineral potential… *continued from page 8*

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

continued on page 10

New base metal mineral potential… *continued from page 9*

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).

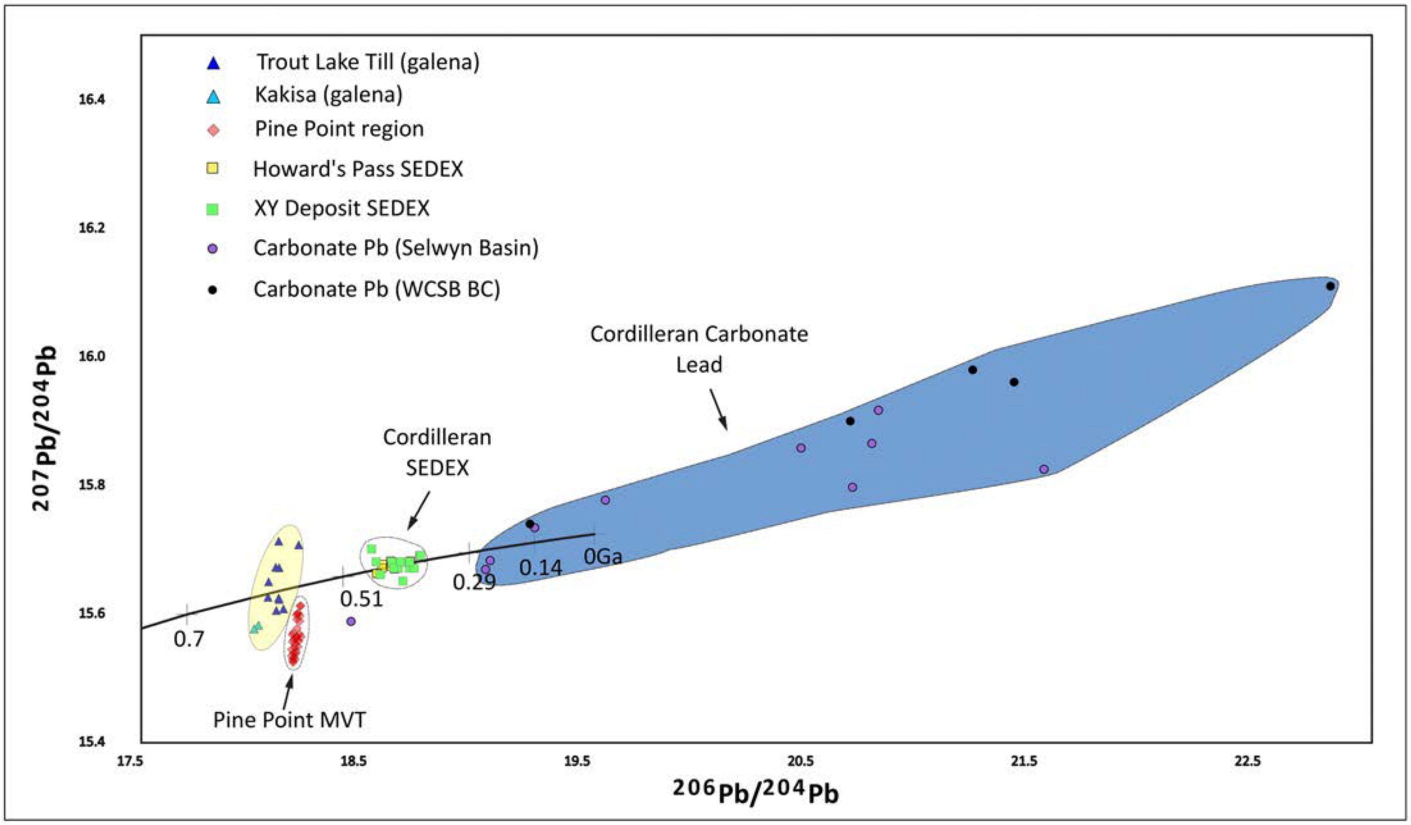

Figure 5. Lead isotopic bivariate plot of $^{206}Pb/^{204}Pb$ versus $^{207}Pb/^{204}Pb$ for galena grains from the Trout Lake (dark blue triangles) and Kakisa Lake (light blue triangles) regions inside yellow polygon (from King et al. 2018). Shown for comparison are bedrock samples from Pine Point (pink 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

continued on page 11

New base metal mineral potential… *continued from page 10*

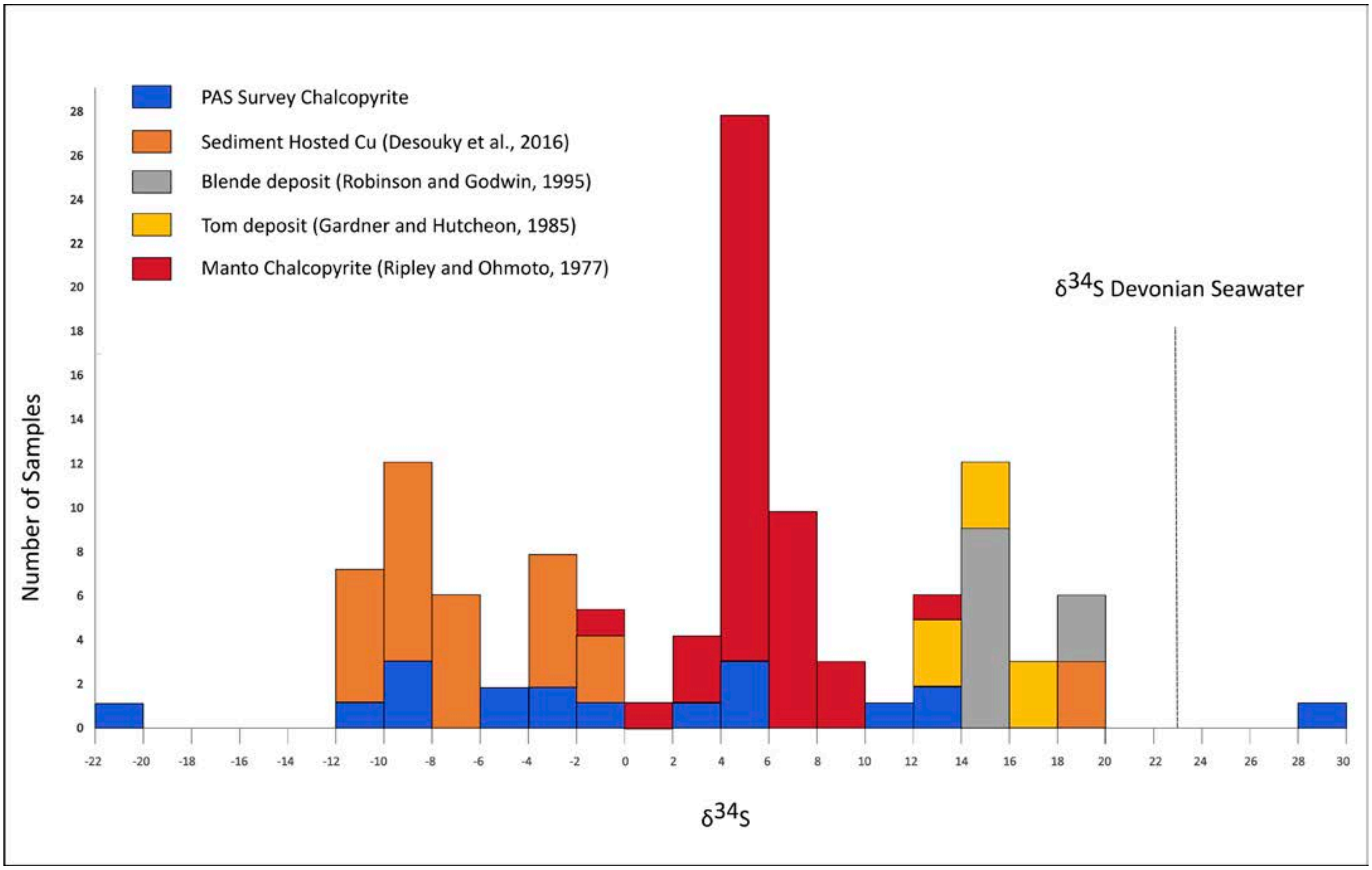

Figure 6. Histogram of $\delta^{34}S$ values of PAS survey chalcopyrite (blue; King et al. 2018) compared with values from Manto-style mineralization in Peru (red; Ripley and Ohmoto 1977), the Tom sedimentary exhalative (SEDEX) deposit in the Yukon Territory (yellow; Gardner and Hutcheon, 1985), the 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. $\delta^{34}S = 0\pm3‰$; 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

continued on page 12

New base metal mineral potential… *continued from page 11*

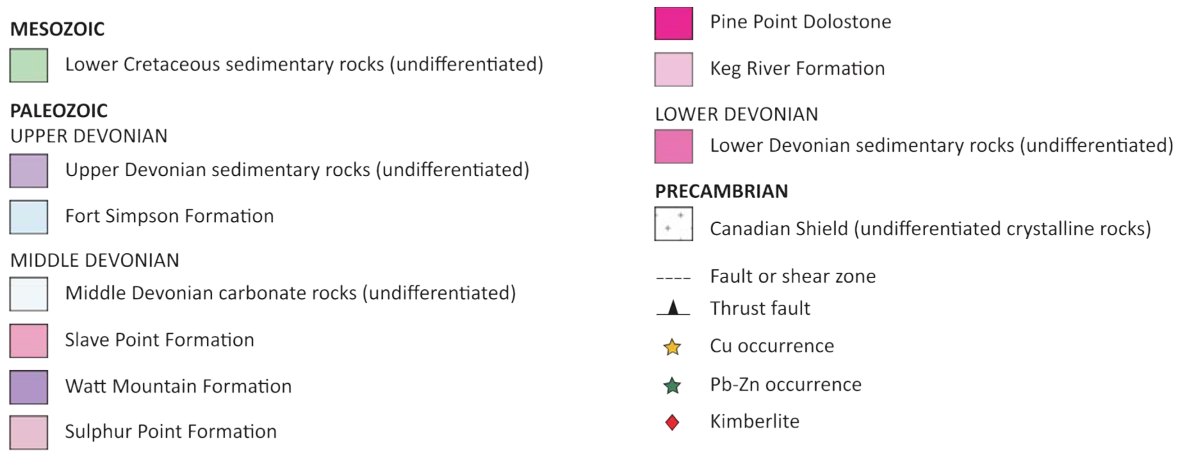

Figure 7. Legend for bedrock geology of the Western Canada Sedimentary Basin between the Canadian Shield and Cordillera used in Figures 8 and 9. Note that the bedrock geology is shown projected under the lakes (after Douglas 1974 and Okulitch 2006). Major fault systems and mineral occurrences are also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

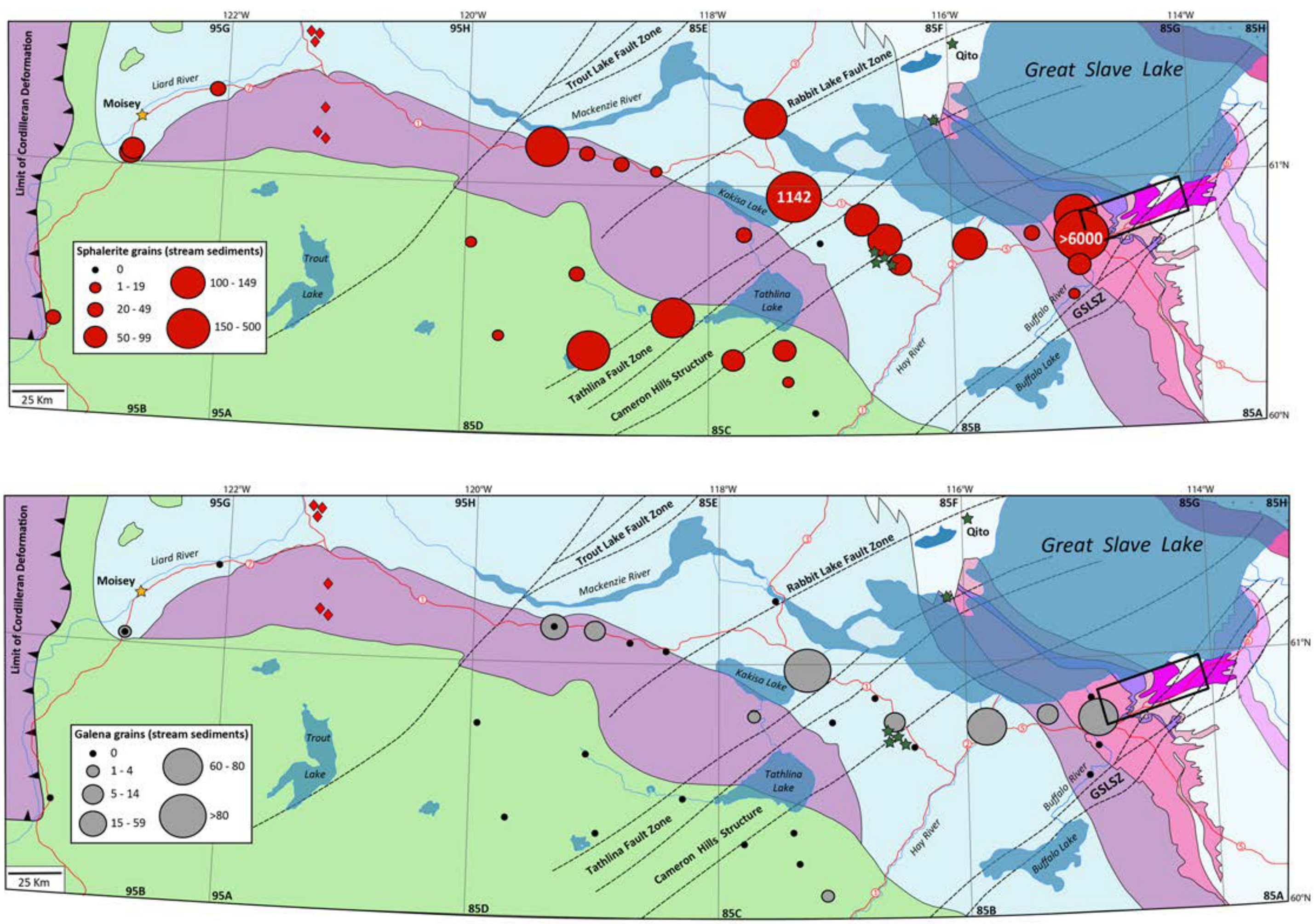

Figure 8. Number of (A) sphalerite grains and (B) galena grains in the 0.25-0.5 mm heavy mineral fraction (normalised to a 50 g heavy mineral fraction weight) recovered from stream sediment samples in the 2017 GSC GEM stream sediment survey (Day et al. 2018a). The large black rectangle is the Pine Point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

continued on page 13

New base metal mineral potential… *continued from page 12*

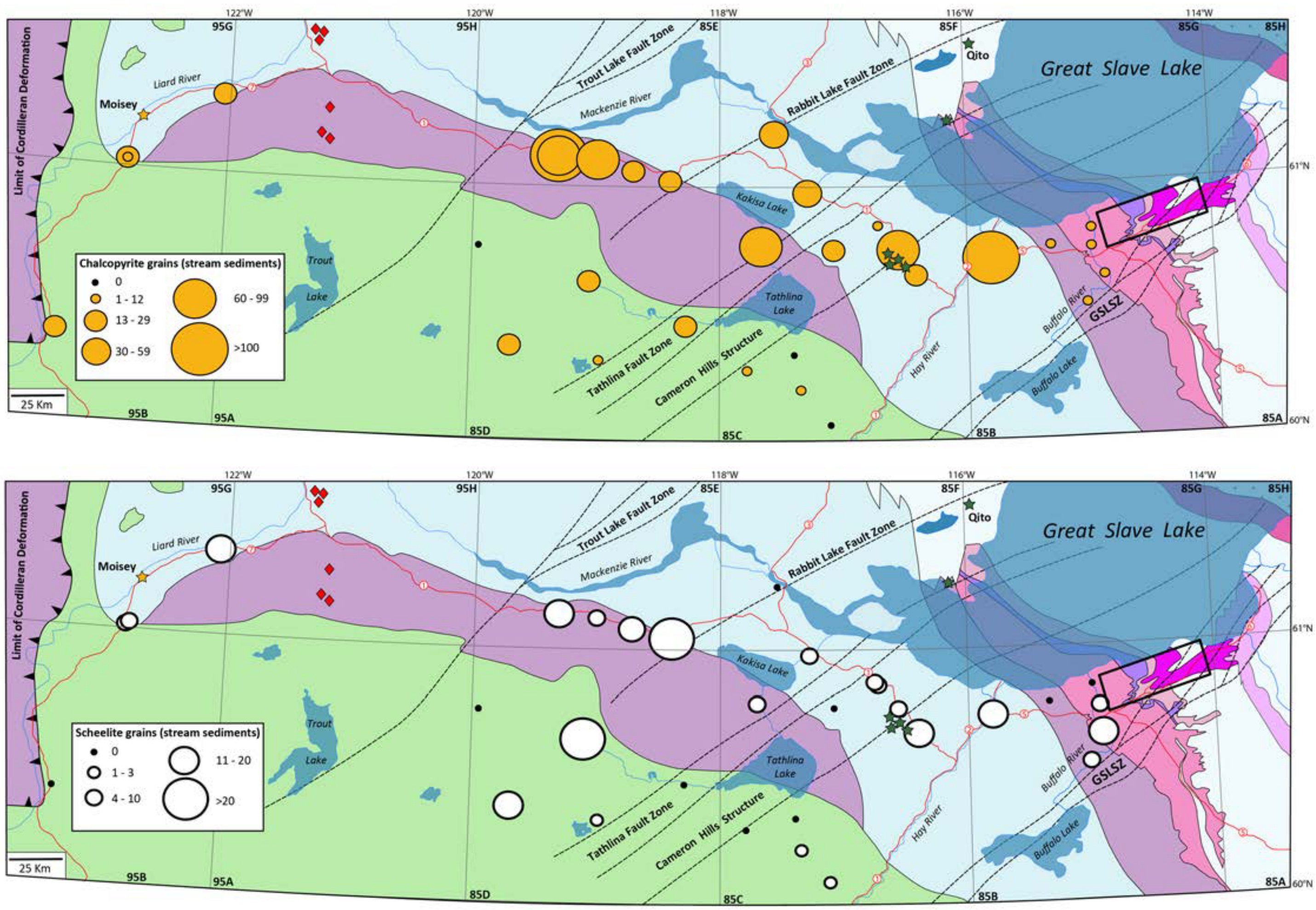

Figure 9. Number of (A) chalcopyrite grains and (B) scheelite grains in the 0.25-0.5 mm heavy mineral fraction (normalised to a 50 g heavy mineral fraction weight) recovered from stream sediment samples in the 2017 GSC GEM stream sediment survey (Day et al. 2018a). The large black rectangle is the Pine 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.

continued on page 14

New base metal mineral potential… *continued from page 13*

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 $\delta^{34}S$ 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 $\delta^{34}S$ 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 $\delta^{34}S$ 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, $\delta^{34}S$ 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 $\delta^{34}S$ and Pb-isotopic data from PAS survey samples will be available in future GSC publications. On-going research at Memorial University will provide additional $\delta^{34}S$, 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

continued on page 15

New base metal mineral potential… *continued from page 14*

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.

REFERENCES

Averill, S.A. 2001. The application of heavy indicator minerals in mineral exploration with emphasis on base metal indicators in glaciated metamorphic and plutonic terrain. *In* Drift Exploration in Glaciated Terrain. M.B. McClenaghan, P.T. Bobrowsky, G.E.M. Hall, & S. Cook (eds.). Geological Society of London, London, Special Volume **185**, 69-82.

Bednarski J.M. 2008. Landform assemblages produced by the Laurentide Ice Sheet in northeastern British Columbia and adjacent Northwest Territories – constraints on glacial lakes and patterns of ice retreat. Canadian Journal of Earth Sciences, **45**, 593-610.

Bostock, H.S. 1970. Physiographic regions of Canada. Geological Survey of Canada, Map 1254A, scale 1:5 000 000.

Brabec, D. 1976. Geochemical soil survey Qito claims group, Mackenzie M.D., NWT. Department of Indian Affairs and Northern Development, Assessment Report No. 080449.

Brabec, D. 1983. Evaluation of soil anomalies by discriminant analysis in geochemical exploration for carbonate-hosted lead-zinc deposits. *Economic Geology,* **78**, 333-339.

Cumming, G.L., Kyle, J.R. & Sangster, D.F. 1990. Pine Point: A case History of Lead Isotope Homogeneity in a Mississippi Valley-Type District. *Economic Geology,* **85**, 133-144.

Day, S.J.A., Lariviere, J.M., McNeil, R.J., Friske, P.W.B., Cairns, S.R., McCurdy, M.W. & Wilson, R.S. 2007. National Geochemical Reconnaissance: regional stream sediment and water geochemical data, Horn Plateau area, Northwest Territories (parts of NTS 85E, 85F, 85K, 85L, 95H, 95I and 95J) including analytical, mineralogical and kimberlite indicator mineral data. Geological Survey of Canada, Open File 5478.

Day, S.J.A, Paulen, R.C., Smith, I.R. & King, R.D. 2018a. Heavy-mineral and indicator-mineral data from stream sediments of southwest Northwest Territories: new potential for undiscovered mineralization. Geological Survey of Canada, Open File 8362.

Day, S.J.A., Smith, I.R., Paulen R.C. & King, R.D. 2018b. Stream Sediment Geochemistry and Heavy Minerals Southern Mackenzie, Northwest Territories. *In* GEM2 Southern Mackenzie Surficial Activity 2018 report: Surficial Geology and Heavy Mineral Studies in Southern Northwest Territories. R.C. Paulen, I.R. Smith and S.J.A. Day (eds.). Geological Survey of Canada, Open File 8477, p. 27-31.

Dixon, J. 1999. Mesozoic-Cenozoic stratigraphy of the northern Interior Plains and Plateaux, Northwest Territories. Geological Survey of Canada, Bulletin 536.

Douglas, R.J.W. 1959. Great Slave and Trout River map-areas, Northwest Territories. Geological Survey of Canada, Paper 58-11.

Douglas, R.J.W. 1974. Geology, Trout River, District of Mackenzie. Geological Survey of Canada, Map 1371A, scale 1:500,000.

Dudek, D. 1993. Report of Geological work and drilling carried out on the Moisey Property, Mackenzie District, Northwest Territories. Noranda Exploration Company Limited, Northwest Territories Geoscience Office, Assessment Report 083110.

Dyke, A.S. 2004. An Outline of North American Deglaciation with Emphasis on Central and Northern Canada. *Developments in Quaternary Science,* **2**, 373-424.

Dyke, A.S., & Prest, V.K. 1987. Late Wisconsinan and Holocene History of the Laurentide Ice Sheet. *Géographie physique and Quaternaire*, **41**, 237-263.

Eaton, D.W. & Hope, J. 2003. Structure of the crust and upper mantle of the Great Slave Lake shear zone, northwestern Canada, from teleseismic analysis and gravity modelling. *Canadian Journal of Earth Sciences,* **40**, 1203-1218.

El Desouky, H.A., Muchez, P., Boyce, A.J., Schneider, J., Cailteux, J.L.H., Dewaele, S. & von Qualdt, A. 2010. Genesis of sediment-hosted stratiform copper-cobalt mineralization at eh Luiswishi and Kamoto, Katanga Copperbelt (Democratic Republic of Congo). *Mineralium Deposita,* **45**, 735-763.

Friske, P.W.B. & Hornbrook, E.H.W. 1991. Canada's National Geochemical Reconnaissance programme. Transactions of the Institution of Mining and Metallurgy, London, Section B; **100**, 47-56.

Gardner, H.D. & Hutcheon, I. 1985. Geochemistry, mineralogy, and geology of the Jason Pb-Zn Deposits, Macmillan Pass, Yukon, Canada. *Economic Geology,* **80**, 1257-1276.

Godwin, C.J. & Sinclair, A.J. 1982. Average lead isotope growth curves for shale-hosted zinc-lead deposits, Canadian Cordillera. *Economic Geology,* **77**, 675-690.

Godwin, C.I., Gabites, J.E. & Andrew, A. 1988. Leadtable: A galena lead isotope database for the Canadian Cordillera, with a guide to its use by explorationists. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1988-4.

Hannigan, P.K. 2006a. Introduction. *In* Potential for Carbonate-hosted Lead-zinc Mississippi Valley-type Mineralization in Northern Alberta and Southern Northwest Territories: Geoscience Contributions, Targeted Geoscience Initiative. P.K. Hannigan (ed.). Geological Survey of Canada, Bulletin **591**, 9-39.

Hannigan, P.K. 2006b. Synthesis of Mississippi Valley-type lead-zinc deposit potential in northern Alberta and southern Northwest Territories. *In* Potential for Carbonate-hosted Lead-zinc Mississippi Valley-type Mineralization in Northern Alberta and Southern North-

continued on page 16

New base metal mineral potential… *continued from page 15*

west Territories: Geoscience Contributions, Targeted Geoscience Initiative. P.K. Hannigan (ed.). Geological Survey of Canada, Bulletin 591, p. 305-347.

Huntley, D., Mills, A. & Paulen, R. 2008. Surficial deposits, landforms, glacial history, and reconnaissance drift sampling in the Trout Lake map area, Northwest Territories. Geological Survey of Canada, Current Research 2008-14, 14 p.

Kerr, D.E. 2006. Surficial geology and exploration geochemistry, Yellowknife area. In Gold in the Yellowknife Greenstone Belt, Northwest Territories: Results of the EXTECH III Multidisciplinary Research Project. C.D. Anlin, H. Falck, D.F. Wright & E.J. Ambrose (eds.). Geological Association of Canada, Mineral Deposits Division, Special Publication No. 3, pp. 301-324.

King, R.D., Piercey, S.J. & Paulen, R.C. 2018. In situ microanalytical sulphur and lead isotopic compositions of sulphide indicator minerals from surficial sediments in southwestern Northwest Territories. Geological Survey of Canada, Open File 8449.

Kramers, J.D. & Tolstikhin, I.N. 1997. Two terrestrial lead isotope paradoxes, forward transport modelling, core formation and the history of the continental crust. *Chemical Geology,* **139**, 75-110.

Kyle, J.R. 1981. Geology of the Pine Point lead–zinc district. In Regional and Specific Deposits, Volume 9 (Handbook of Strata-Bound and Stratiform Ore Deposits). K.H. Wolf (ed.). Elsevier, pp. 643-741.

Lane, R.W. 1980. Assessment report for program of geological investigation of soil geochemical and geophysical (I.P.) anomalies undertaken on Qito claims 2, 9, and 74, Mackenzie M.D., Northwest Territories. Department of Indian Affairs and Northern Development, Assessment Report 081238.

Leblanc, M. & Arnold, M. 1994. Sulfur isotope evidence for the genesis of distinct mineralization in the Bleida stratiform copper deposit (Morocco); *Economic Geology,* **89**, 931–935.

Lehtonen, M.L., Lahaye, Y., O'Brien, H., Lukkari, S. Marmo, J.S. & Sarala, P. 2015. Novel technologies for indicator mineral-based exploration. Geological Survey of Finland, Special Paper **57**, 23-62.

Lemmen, D.S., Duk-Rodkin, A. & Bednarski. J.M. 1994. Late Glacial Drainage Systems along the Northwest Margin of the Laurentide Ice Sheet. *Quaternary Science Reviews,* **13**, 805-828.

MacQueen, R.W. 1997. Introduction. In Exploring for minerals in Alberta: Geological Survey of Canada geoscience contributions, Canada- Alberta Agreement on Mineral Development (1992–1995). R.W. MacQueen (ed.). Geological Survey of Canada, Bulletin 500, p. 1-12.

Marini, L., Moretti, R. & Accornero, M. 2011. Sulfur isotopes in magmatic-hydrothermal systems, melts, and magmas. *Mineralogy and Geochemistry,* **73**, 423–492.

McClenaghan, M.B. 2011. Overview of common processing methods for recovery of indicator minerals from sediment and bedrock in mineral exploration. *Geochemistry: Exploration, Environment, Analysis*, **11**, 265-278.

McClenaghan, M.B. & Paulen, R.C. 2018. Application of Till Mineralogy and Geochemistry to Mineral Exploration. In Past Glacial Environments, 2nd Edition. J. Menzies & J.J.M. van der Meer (eds.). Elsevier, pp. 689-751.

McClenaghan, M.B., Plouffe, A., McMartin, I., Campbell, J.E., Spirito, W.A., Paulen, R.C., Garrett, R.G. & Hall, G.E.M. 2013. Till sampling and geochemical analytical protocols used by the Geological Survey of Canada. *Geochemistry: Exploration, Environment, Analysis,* **13**, 285-301.

McClenaghan, M.B., Parkhill, M.A., Pronk, A.G., Seaman, A.A., McCurdy, M. & Leybourne, M.I. 2017. Indicator mineral and geochemical signatures associated with the Sisson W-Mo deposit, New Brunswick, Canada. *Geochemistry: Exploration, Environment, Analysis,* **17**, 297-313.

McClenaghan, M.B., Paulen, R.C. and Oviatt, N.M. 2018. Geometry of indicator mineral and till geochemistry dispersal fans from the Pine Point Mississippi Valley-type Pb-Zn district, Northwest Territories, Canada. *Journal of Geochemical Exploration*, **190**, 69-86.

McCurdy, M.W., Smith, I.R., Plouffe, A., Bednarski, J., Day, S.J.A., Friske, P.W.B., McNeil, R.J., Kjarsgaard, I.M., Ferbey, T., Levson, V.M., Hickin, A.S., Trommelen, M. & Demchuk, T.E. 2007. Indicator mineral content and geochemistry of stream and glacial sediments from the Etsho Plateau Region (094I, P) as an aid to kimberlite and base metal exploration, northeast British Columbia. *In* Geological Fieldwork 2006, Paper 2007-1 (Geoscience BC, Report 2007-1), p. 361-372.

Meijer Drees, N.C. 1993. The Devonian succession in the subsurface of the Great Slave and Great Bear Plains, Northwest Territories. Geological Survey of Canada, Bulletin 393.

Ohmoto, H. & Goldhaber, M. 1997. Sulfur and carbon isotopes. *In* Geochemistry of Hydrothermal Ore Deposits, V. III. H.L. Barnes (ed.). John Wiley & Sons, New York, pp. 517-611.

Ohmoto, H. & Rye, R.O. 1979. Isotopes of sulfur and carbon. *In* Geochemistry of Hydrothermal Ore Deposits, Second Edition. H.L. Barnes (ed.). John Wiley & Sons, pp. 509-567.

Okulitch, A.V. (compiler) 2006. Phanerozoic bedrock geology, Slave River, District of Mackenzie, Northwest Territories. Geological Survey of Canada, Open File 5281, scale 1:1 000 000.

Oviatt, N.M., McClenaghan, M.B., Paulen, R.C., Gleeson, S.A., Averill, S.A. and Paradis, S. 2013. Indicator minerals in till and bedrock samples from the Pine Point Mississippi Valley-type district, Northwest Territories. Geological Survey of Canada, Open File 7423.

Oviatt, N.M., Gleeson, S.A., Paulen, R.C., McClenaghan, M.B. & Paradis, S. 2015. Characterization and Dispersal of Indicator Minerals Associated with the Pine Point Mississippi Valley-Type (MVT) District, Northwest Territories, Canada. *Canadian Journal of Earth Sciences,* **52**, 776-794.

Paradis, S., Turner, W.A., Coniglio, M., Wilson, N. & Nelson, J.L. 2006. Stable and radiogenic isotopic signatures of mineralized Devonian carbonates of the Northern Rocky Mountains and the Western Canada Sedimentary Basin. *In* Potential for Carbonate-Hosted Lead-zinc Mississippi Valley-type Mineralization in Northern Alberta and Southern Northwest Territories: Geoscience Contributions, Targeted Geoscience Initiative. P.K. Hannigan (ed.). Geological Survey of Canada, Bulletin 591, p. 75-104.

Paulen, R.C., Paradis, S., Plouffe, A. & Smith, I.R. 2011. Pb and S isotopic composition of indicator minerals in glacial sediments from NW Alberta, Canada: implications for Zn-Pb base metal exploration. *Geochemistry: Exploration, Environment, Analysis*, **11**, 309-320.

Paulen, R.C., Smith, I.R., Day, S.J.A., Hagedorn, G.W., King, R.D. & Pyne, M.D. 2017. GEM2 Southern Mackenzie Surficial Activity

continued on page 17

New base metal mineral potential… *continued from page 16*

2017 report: surficial geology and heavy mineral studies in southern Northwest Territories. Geological Survey of Canada, Open File 8322.

Paulen, R.C., Smith, I.R. & Day S.J.A. (ed.) 2018. GEM2 Southern Mackenzie Surficial Activity 2018 report: surficial geology and heavy mineral studies in southern Northwest Territories. Geological Survey of Canada, Open File 8477.

Pitman, P. 2014. Technical report on the HOAM Project, Northwest Territories Canada, NTS map sheets 85L, 85M, 95A, 95G, 95H, 95I, 95O, 95P, 96A and 96B. Olivut Resources, National Instrument 43-101 Technical Report (www.sedar.com).

Plouffe, A., Paulen, R.C. & Smith, I.R. 2006. Indicator mineral content and geochemistry of glacial sediments from northwest Alberta (NTS 84L, M): new opportunities for mineral exploration. Geological Survey of Canada, Open File 5121 and Alberta Geological Survey, Special Report 77.

Plouffe, A., Paulen, R.C., Smith, I.R. & Kjarsgaard, I.M. 2008. Sphalerite and indicator minerals in till from the Zama Lake region, northwest Alberta (NTS 84L and 84M). Geological Survey of Canada, Open File 5692 and Alberta Geological Survey, Special Report 96.

Plouffe, A., McClenaghan, M.B., Paulen, R.C., McMartin, I., Campbell, J.E. & Spirito, W.A. 2013. Processing of glacial sediments for the recovery of indicator minerals: protocols used at the Geological Survey of Canada. *Geochemistry: Exploration, Environment, Analysis,* **13**, 303-316.

Porter, J.W., Price, R.A. & McCrossan, R.G. 1982. The Western Canada Sedimentary Basin. Philosophical Transactions of the Royal Society of London, A 305, 169-192.

Poulin, R.S., Kontak, D.J., McDonald, A.M. & McClenaghan, M.B. 2018. Assessing scheelite as an ore-deposit discriminator using its trace element and REE chemistry. *The Canadian Mineralogist*, **56**, 265-302.

Prest, V.K., Grant, D.R. & Rampton, V.N. 1968. Glacial map of Canada. Geological Survey of Canada, Map 1253A, scale 1:5 000 000.

Prior, G.J., McCurdy, M.W. & Friske, P.W.B. 2009. Stream sediment sampling for kimberlite indicator minerals in the Western Canada Sedimentary Basin: the Buffalo Head Hills survey, north-central Alberta. *In* Application of till and stream sediment heavy mineral and geochemical methods to mineral exploration in Western and Northern Canada. R.C. Paulen and I. McMartin (eds.). Geological Association of Canada, Short Course Notes 18. pp. 111-124.

Rhodes, D., Lantos, E.A., Lantos, J.A., Webb, R.J. & Owens, D.C. 1984. Pine Point orebodies and their relationship to the stratigraphy, structure, dolomitization, and karstification of the middle Devonian Barrier complex. *Economic Geology,* **79**, 991-1055.

Rice, J.M., Paulen, R.C., Menzies, J.M., McClenaghan, M.B. & Oviatt, N.M. 2013. Glacial stratigraphy of the Pine Point Pb-Zn mine site, Northwest Territories. Geological Survey of Canada, Current Research 2013-5, 14 p.

Richards, B.C. 1989. Uppermost Devonian and Lower Carboniferous Stratigraphy, Sedimentation, and Diagenesis, Southwestern District of Mackenzie and Southeastern Yukon Territory. Geological Survey of Canada, Bulletin 390.

Ripley, E.M. & Ohmoto, H. 1977. Mineralogic, sulfur isotope, and fluid inclusion studies of the stratabound copper deposits at the Raul Mine, Peru. *Economic Geology,* **72**, 1017-1041.

Robinson, M. & Godwin, C.I. 1995. Genesis of the Blende carbonate-hosted Zn-Pb-Ag deposit, north-central Yukon Territory: Geologic, fluid inclusion and isotopic constraints. *Economic Geology,* **90**, 369–384.

Smith, D.G. 1994. Glacial Lake McConnell: paleogeography, age, duration and associated river deltas, Mackenzie River basin, western Canada. *Quaternary Science Reviews*, **13**, 829-843.

Smith, I.R. & Lesk-Winfield, K. 2010. Drift isopach, till isopach, and till facies reconstructions for Northwest Territories and northern Yukon. Geological Survey of Canada, Open File 6324.

Spirito, W.A., McClenaghan, M.B., Plouffe, A., McMartin, I., Campbell, J.E., Paulen, R.C., Garrett, R.G. & Hall, G.E.M. 2011. Till Sampling and Analytical Protocols for GEM Projects: from field to archive. Geological Survey of Canada, Open File 6850.

Turner, W.A. 2006. Microthermometric study of fluids associated with Pb-Zn mineralization in the vicinity of the Pine Point mining camp. *In* Potential for Carbonate-hosted Lead-zinc Mississippi Valley-type Mineralization in Northern Alberta and Southern Northwest Territories: Geoscience Contributions, Targeted Geoscience Initiative. P.K. Hannigan (ed.). Geological Survey of Canada, Bulletin 591, pp. 221-240.

Wanless, R.K., Boyle, R.W. & Lowdon, J.A. 1960. Sulfur isotope investigation of the gold-quartz deposits of the Yellowknife district. *Economic Geology*, **55**, 1591-1621.

Watson, D.M. 2011a. Sambaa K'e Candidate Protected Area Phase II Non-renewable Resource Assessment – Minerals, Northwest Territories, Parts of NTS 085D, 095A, B, H. Northwest Territories Geoscience Office, NWT Open File 2010-08.

Watson, D.M. 2011b. Ka'a'gee Tu Area of Interest, Phase II Non-renewable Resource Assessment – Minerals, Northwest Territories, Parts of NTS 85C, 85D, 85E and 85F. Northwest Territories Geoscience Office, NWT Open File 2011-001.

Watson, D.M. 2013. Non-Renewable resource assessment (minerals): Łue Túé Sųlái candidate protected area, NTS 095H6 and 095H7. Northwest Territories Geoscience Office, Open File 2013-03.

Zartman, R.E. & Haines, S.M. 1988. The plumbotectonics model for Pb isotopic systematics among major terrestrial reservoirs—A case for bi-directional transport. *Geochimica et Cosmochimica Acta*, **52**, 1327-1339.