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Cretaceous Shale of Northern Alberta: A New Frontier for Base Metal Exploration

Paulen, R. C. [1], Prior, G. J. [1], Plouffe, A. [2], Smith, I. R. [3], McCurdy, M. W. [2], Friske, P. W. B. [2]

1. Alberta Energy and Utilities Board, Alberta Geological Survey
2. Natural Resources Canada, Geological Survey of Canada, Ottawa
3. Natural Resources Canada, Geological Survey of Canada, Calgary

ABSTRACT

Recent significant results from reconnaissance heavy mineral and geochemical surveys in northern Alberta draw attention to the prospect of base metal deposits hosted within the Cretaceous shale bedrock. The objective of these surveys, as part of a collaborative initiative undertaken by the Geological Survey of Canada and the Alberta Geological Survey, was to evaluate the potential of northern Alberta to host diamond-bearing kimberlite and other mineral deposits. These results highlight the potential for the area to contain primary bedrock-hosted deposits of zinc.

A glacial sediment heavy mineral survey in northwest Alberta has resulted in the discovery of a dispersal train containing highly elevated concentrations of sphalerite grains and secondary galena in the sand-size fraction. The presence of high sphalerite grain counts in seven samples situated within a geographically restricted area argue against long-distance glacial transport, comminution, and deposition of erratic material from the carbonate-hosted Pine Point zinc-lead deposits, located 300 km to the northeast. Instead, these results favour a proximal unknown mineral source, potentially hosted within the Cretaceous shales.

Results obtained from a stream water and stream sediment survey of the Buffalo Head Hills in north-central Alberta provide collaborative support of base metal and silver enrichment within the Cretaceous strata. The Shaftesbury Formation is the likely source of acidic, zinc-rich stream waters of the northern Buffalo Head Hills. Additional elements that are enriched in stream water and/or stream silt from the northern Buffalo Head Hills include nickel, copper, cadmium, molybdenum, silver, mercury and lead.

INTRODUCTION

The rocks of the Western Canada Sedimentary Basin, so prominent in hydrocarbon wealth, are seldom considered to have base metal potential. These sedimentary rocks, deformed in the eastern Cordillera of the Rocky Mountains and Foothills and relatively flat-lying in the Interior Platform of Alberta, have also discouraged those who presume that the Precambrian rocks of the Canadian Shield are more favourable hosts of base metal mineralization (cf., Edwards, 1988; Macqueen, 1997). Reconnaissance surveys for heavy minerals and geochemistry have thusly not been conducted in the northern part of the Western Canada Sedimentary Basin.

The Alberta Geological Survey (AGS) and the Geological Survey of Canada (GSC) conducted reconnaissance-scale sampling of glacial sediments and streams in northern Alberta to assess the occurrence of kimberlite indicator minerals (KIMs) and other economic minerals. These sampling programs represent the first systematic regional geochemical and mineralogical surveys of northwestern Alberta to be undertaken by government. The glacial sediment, stream sediment and stream water surveys were conducted as part of a collaborative project between the AGS and the GSC under GSC's Northern Resource Development Program (NRD Project 4450) with additional support through the Targeted Geoscience Initiative (TGI-2). Heavy mineral and geochemical results released in 2005 and 2006 (Prior et al., 2005a; McCurdy et al., 2006; Plouffe et al., 2006) resulted in significant mineral staking and exploration activity. This paper outlines the presence of low concentrations of KIMs and high concentrations of sphalerite grains in northwest Alberta and high concentrations of zinc in stream waters and sediments in north-central Alberta.

Location and geological setting

This study was divided into two programs. A glacial sediment sampling program was focused in the northwest part of Alberta that borders British Columbia and the Northwest Territories. The stream sampling program was undertaken over the Buffalo Head Hills in north-central Alberta (Figure 1). Quaternary deposits are the surface materials that constitute

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the local landforms over virtually all of northern Alberta. Bedrock, which controls the broad elements of the physiography, rarely crops out. The flat nature of most of the region is a reflectance of the horizontal to gently dipping sedimentary bedrock. The region is poorly drained, secondary streams are not deeply incised, and organic deposits in the form of fens and bogs abound. The physiography of northern Alberta consists of a number of uplands such as the Buffalo Head Hills, Cameron Hills, Caribou Mountains, and Clear Hills separated by broad lowlands with major drainages such as the Peace and Hay rivers (Pettapiece, 1986). These rivers are part of the Mackenzie River drainage basin which empties into the Beaufort Sea.

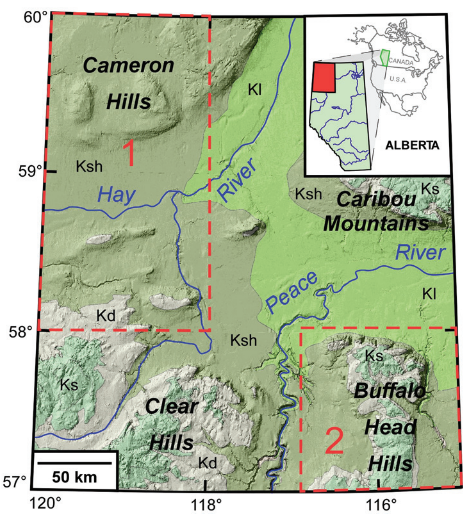

Figure 1: Physiography and bedrock geology of northwest Alberta in which the glacial sediment survey (1) and the stream survey (2) were undertaken. Cretaceous bedrock units listed from oldest to youngest (after Hamilton et al., 1998): Loon River Formation (Kl), Shaftesbury Formation (Ksh), Dunvegan Formation (Kd) and Smoky Group (Ks). The Loon River and Shaftesbury formations occur within the upper part of the Fort St. John Group.

The underlying bedrock in these regions are a Cretaceous succession of nearly horizontal and poorly indurated marine shales of the Fort St. John Group (Loon River and Shaftesbury formations) and Smoky Group, which are separated by deltaic to marine sandstones of the Dunvegan Formation (Green et al., 1970; Okulitch, 2006). The transition from Lower to Upper Cretaceous strata occurs within the Shaftesbury Formation.

Northern Alberta is covered by an extensive cover of unconsolidated glacial and nonglacial sediments which greatly varies in thickness from 0 to 450 m (e.g., Pawlowicz et al., 2005; 2007). These sediments were deposited during glacial and interglacial periods of the Quaternary. For the most part, the surficial materials and present-day landforms are a result of the last glacial event, the Late Wisconsin (25 000 to 10 000 radiocarbon years before present). Ice derived from the Keewatin Sector of the Laurentide Ice Sheet flowed west and southwest across the area towards the Rocky Mountains. Ice retreated from the study area between 12 000 and 11 000 radiocarbon years before present (Dyke, 2004), at which time extensive glacial lakes developed over the lowland regions as a result of damming of the eastward drainage by the retreating glaciers. Consequently, glacial lake sediments overlie till in the lower portions of the Hay and Peace River drainage basins.

METHODS

The survey methodology and results described in this paper were conducted as separate subprojects within the collaborative AGS and GSC project. The glacial sediment sampling survey was completed during the course of surficial mapping in northwest Alberta. The stream survey was conducted as part of the National Geochemical Reconnaissance (NGR) survey in the Buffalo Head Hills.

Glacial sediment sampling survey

Bulk sediment samples (~30 kg) of predominantly till (but also included a few glaciofluvial samples) were collected. Samples were collected from the C soil-horizon (>1 m depth) from road exposures, natural bluffs, hand-dug pits, and borrow or sump pits dug for road construction or oil and gas drilling operations.

Samples were sent for heavy mineral and gold grain analyses to a commercial laboratory to provide a preliminary overview of the mineral potential for the region. The heavy mineral fraction was isolated in a two step process involving a shaking table and heavy liquids (specific gravity of 3.2). Kimberlite indicator minerals, gold grains and other heavy minerals such as metamorphosed/magmatic massive sulphide indicator minerals were identified from the 0.25 – 2 mm sand-sized fraction under binocular microscopes by staff mineralogists at the laboratory. The silt and clay-sized fraction (<0.063 mm or –250 mesh) was separated by dry sieving at the Alberta Geological Survey. Duplicate and analytical standard samples were introduced, and then the material was sent to a commercial laboratory for analyses. Three analyses were conducted on the <0.063 mm sized fractions: 1) 15 g sub-samples were submitted for inductively coupled plasma mass spectrometry (ICP-MS) analysis for a suite of 37 minor elements following an aqua regia digestion, 2) 0.2 g sub-samples were analyzed for major elements by ICP emission spectrometry (ICP-ES) and 3) for minor elements by ICP-MS both after a LiBO2 fusion and dilute nitric acid digestion. Detailed field sampling methods, laboratory procedures for heavy mineral separation and identification, and quality control and reproducibility are described in Plouffe et al. (2006).

Stream waters and sediments sampling survey

Analytical data for stream waters and stream sediments in the Buffalo Head Hills were obtained by the GSC and the AGS during National Geochemical Reconnaissance (NGR) survey activities from 2001 to 2005 (Friske et al., 2003; McCurdy et al., 2004; Prior et al., 2005a; McCurdy et al., 2006). Samples were collected for heavy mineral analyses (including the recovery of kimberlite indicator minerals), stream sediment (silt) geochemical analyses and stream water analyses using acidified and non-acidified samples. Only the ICP-MS trace element results for acidified stream water and silt samples from the northern and central part of the survey areas are discussed below.

Water samples were collected in mid-channel, from flowing water where possible, at planned sampling densities of 1 sample per 25 km^2 to 1 sample per 12.5 km^2. The 125 ml field samples were filtered within 24 hours of collection through single-use 0.45-µm filter units attached to 50-ml or 60-ml sterile plastic syringes. After 50 ml of water was filtered into new 60-ml bottles, the remainder was used for the determination of pH and conductivity before being discarded. Using a pipettor with disposable plastic tips, 0.5 ml of 16M nitric acid (HNO3) was added to filtered water samples. The water samples were analyzed by ICP-MS for trace elements at the GSC laboratories in Ottawa.

Silt samples, which commonly include very fine-grained to fine-grained sand and may contain clay, were collected from active stream channels at a planned sampling density of 1 sample per 12.5 km^2. The silt samples were shipped to a commercial laboratory where they were air-dried at temperatures below 40ºC and sieved through an 80-mesh (177 µm) screen. For each sample, one gram of <80 mesh material was leached with 6 ml of HCl, HNO3, and distilled, deionized water, in equal volume proportions, at 95° C for one hour. The sample solution was diluted with deionized water to 20 ml and analysed by ICP-MS. Additional information regarding sample collection, preparation, analysis and quality control are presented in McCurdy et al. (2006).

RESULTS

The impetus of these surveys was to provide background information and stimulate exploration for diamonds and other commodities in northern Alberta. There are 48 known kimberlite pipes in northern Alberta and potential for additional discoveries associated with several unexplained anomalies (Dufresne et al., 1996; Prior et al., 2005b; 2006a). However, of particular significance, and the focus of this paper is the discovery of a sphalerite dispersal train in northwest Alberta and elevated zinc values in stream waters and sediments, associated with low pH values, in the northern Buffalo Head Hills.

Northwest Alberta survey results

Heavy mineral analysis of 70 glacial sediment samples in northwestern Alberta have resulted in the discovery of a dispersal train containing anomalous concentrations of sand-sized sphalerite grains with traces of galena (Plouffe et al., 2006). The strongest anomaly comes from a single 34 kg till sample which yielded >1000 sphalerite grains in the 0.25-0.5 mm size fraction (Figure 2). Most of the recovered sphalerite has a dark grey to black colour; rare grains are orange to honey sphalerite. The grains exhibit angular to sub-angular edges and a few are glacially polished (Figure 3). The size of this mineralogical anomaly extends over an area of approximately 1200 km^2. One to four grains of galena were reported in some of the till samples obtained from the anomalous region. The galena grains are angular to sub-angular.

Matrix (<0.063 mm) geochemistry of the till samples collected in the survey area show that till samples with high sphalerite content in the sand-sized fraction did not yield high zinc concentrations in the silt and clay-sized fraction. Regional zinc concentrations in till are slightly elevated in a broad band oriented NE-SW extending subparallel to the Great Slave Shear Zone.

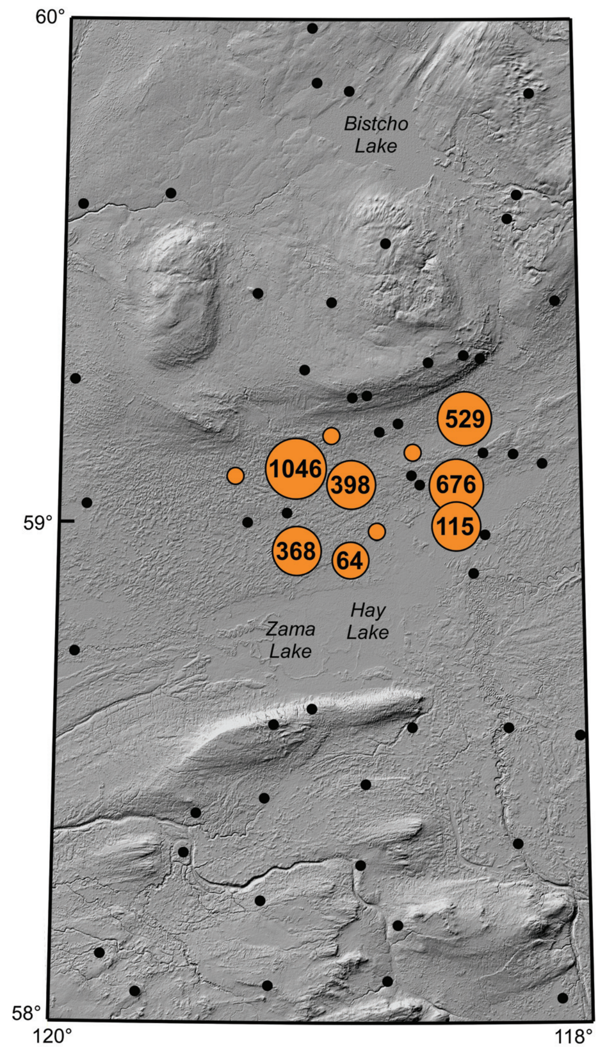

Figure 2: Number of sphalerite grains recovered from glacial sediments, normalized to 30 kg sample weights, plotted on Space Shuttle radar (SRTM) generated digital elevation model. Small orange circles represent a single grain count, and small black circles indicate samples with no recovered sphalerite.

Fifteen sphalerite grains were submitted for electron microprobe analyses (Plouffe et al., 2007). The average composition of the sphalerite is 33.4 wt % S, 65.4 wt % Zn, 0.7 wt % Fe and 0.43 wt % Cd with traces amounts (0.3 to 0.1 wt %) of Cu, Ag, Se, and In. Compared to the composition of sphalerite at Pine Point (Kyle, 1981), sphalerite from this study contains on average lower levels of Pb and Fe coupled with higher Cd concentrations. Furthermore, sphalerite color from the Pine Point deposit varies from tan, yellow, light red-brown, dark red-brown to dark brown (Kyle, 1981). In contrast, the majority of sphalerite grains recovered from northwestern Alberta till are dark grey.

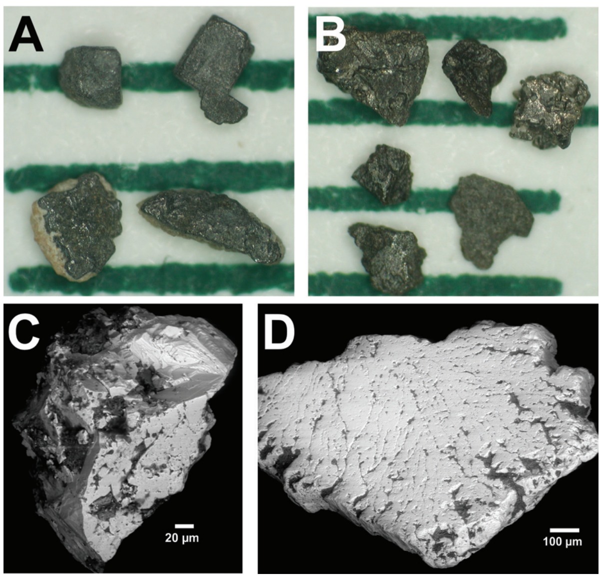

Figure 3: Photomicrographs of the galena and sphalerite grains recovered from glacial sediments; 1 mm line-spacing in images A and B. A) galena grains (note cubic crystal structure in some grains); B) dark grey to black zinc-rich sphalerite; C) scanning electron microscope (SEM) image of an angular sphalerite grain; D) SEM image of a sphalerite grain with a glacially faceted surface and fine striations.

Glacial dispersal and ice-flow history

The sphalerite anomaly is not thought to be derived from the world class Pine Point deposit located on the south shore of Great Slave Lake, about 330 km to the northeast. The survey area was inundated by ice emanating from the Keewatin Sector of the Laurentide Ice Sheet during Late Wisconsin glaciation. At the onset of glaciation, topographically confined lobes of ice advanced into the region. At glacial maximum, ice flowed westward across the region towards the Rocky Mountains (Figure 4) where it abutted the Cordilleran Ice Sheet and became deflected north and south along the mountain front. The Zama Lake area lies east of this north-south flow divide. The significance of this is that during glacial maximum, ice trajectories across the Pine Point ore deposit would have traveled north of the Cameron Hills, well north of the Zama Lake sphalerite anomaly (yellow star, Figure 4). Extensive fluted and otherwise glacially-sculpted terrain (smaller arrows, Figure 4) exhibit a number of crosscutting, and at times topographically confined flows (Smith et al., 2005). Many of these streamlined landforms formed during deglaciation when the ice sheet retreated as a series of lobes. Similarly, during initial ice advance, at the onset of the last glaciation, topographically confined lobes advanced across the region. Thus, it is possible that material from the Pine Point region was transported for short distances towards Zama Lake during either early or late stages of the last glaciation. However, sphalerite minerals were recovered from basal till sampled from >3 m depth, suggesting it was deposited during full glacial, as opposed to deglacial time.

Buffalo Head Hills survey results

Strongly anomalous zinc values in water occur in several streams values are also strongly elevated in stream waters of the northern Buffalo Head draining the northern flank of the Buffalo Head Hills (Figure 5). The maximum value is 1002 ppb Zn whereas the median zinc value is 1.0 ppb. Copper, nickel, lead, cadmium and cobalt Hills, and some of which are markedly acidic with pH values as low as 3.3 (Friske et al., 2003; McCurdy et al., 2004; Prior et al, 2005a; McCurdy et al., 2006).

Silt samples collected from streams flanking the northern Buffalo Head Hills tend to contain elevated amounts of nickel, copper, zinc, cadmium, molybdenum, silver, mercury, lead and, to a lesser extent, barium (Prior et al, 2005; McCurdy et al., 2006). The degree of enrichment in the silts tends to be much less pronounced than in the waters. For example, the maximum zinc value in silt is 157 ppm compared to a median of 58 ppm Zn.

CONCLUSION

The source of the sphalerite and galena grains in till remain unknown. Mineral colour, composition, surficial mapping and ice-flow studies in the region indicate that it is unlikely that the sphalerite-bearing till is the product of long-distance glacial transport from the Pine Point Mississippi Valley Type Zn-Pb deposits on the southern shore of Great Slave Lake, Northwest Territories. Aside from the regional ice-flow history, there are several factors that argue against the sphalerite anomalies being the product of long-distance glacial transport, comminution, and deposition of erratic material from the Pine Point area, and instead favour a proximal bedrock source. First, sphalerite grains were recovered from basal lodgement till sampled at >3 m depth, which most likely reflects a proximal source because drift thickness is relatively thin (Pawlowicz et al., 2005; 2007). Second, the seven sample sites with high sphalerite grain counts (and four with lesser concentrations) are situated within a geographically restricted area north of Zama Lake. Third, geochemical analyses of the silt and clay-sized fraction of the tills does not reveal proportionally elevated concentrations of lead and zinc,

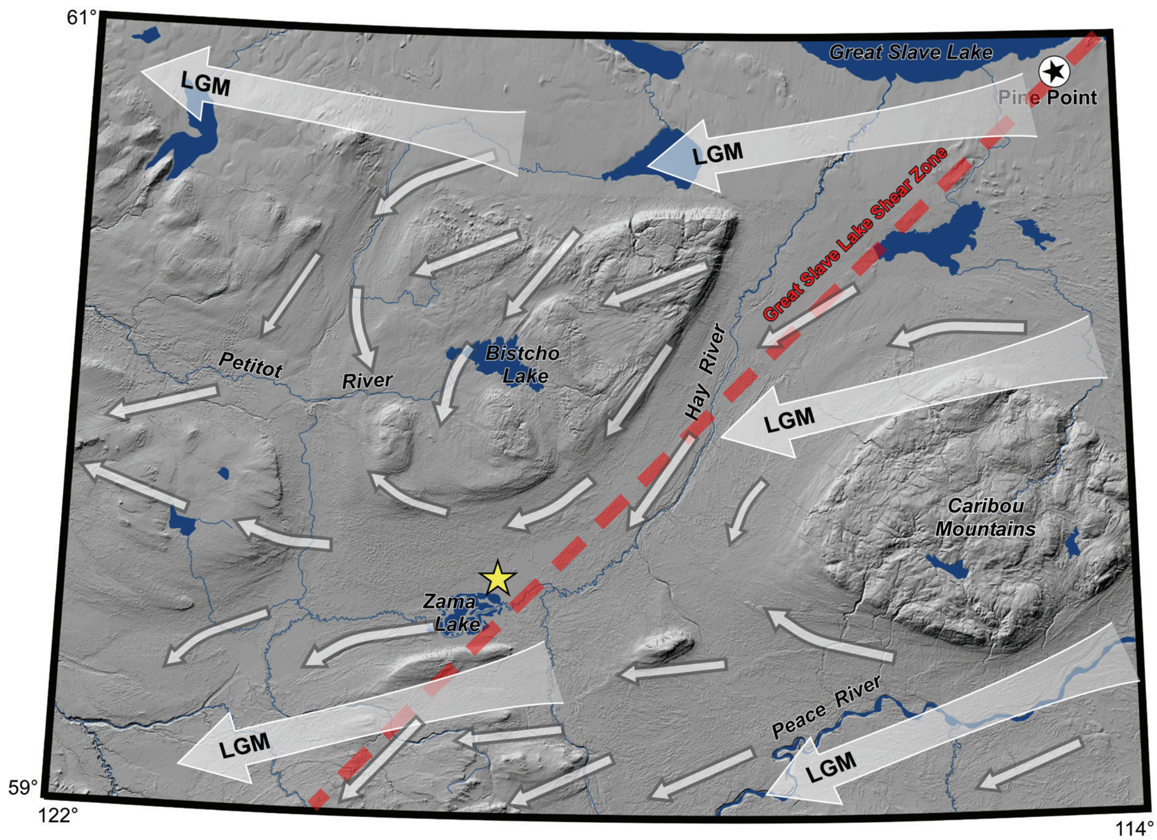

Figure 4: Late Wisconsin regional ice-flow history for northwest Alberta derived from recent surficial mapping depicted on SRTM generated digital elevation model. The large arrows indicate ice flow during last glacial maximum (LGM) and small arrows indicate younger, late glacial ice-flow trajectories.

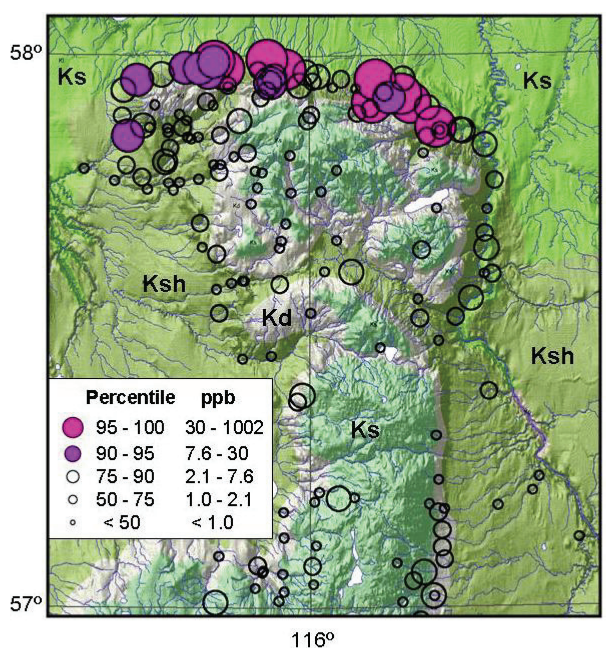

Figure 5: Zinc content of stream water in the northern and central Buffalo Head Hills. See Figure 1 for formation names.

suggesting that glacial comminution of sand-sized sphalerite and galena has been limited. Fourth, close examination of the mineral grains shows that some grains have strong primary crystal structure and subangular to angular morphologies which would not have likely survived extensive glacial erosion and transport (Figure 3). Lastly, the sphalerite grains have dissimilar optical and chemical properties than the ore studied at Pine Point by Kyle (1981).

Conjecture that the sphalerite grains found in the glacial sediment survey do not represent long-distance transport of erratic material and instead were eroded from an unknown proximal bedrock source suggest that we have identified a potential for zinc mineralization in the Cretaceous shale bedrock. The anomaly is situated in close proximity to the Great Slave Lake Shear Zone (Burwash et al., 1994). Recent research on lead and zinc in formation waters (Hitchon, 2006) concluded that exploration should focus on these shear zones and faults, up which geothermal fluids might have migrated. Future Pb and S isotopic analyses of the galena and sphalerite grains may resolve their provenance, and shed further light on mineral potential in the study area.

The geological setting associated with acidic, zinc-rich stream waters of the northern Buffalo Head Hills indicates that the source of these anomalies lies within the Cretaceous Shaftesbury Formation. Additional elements that are enriched in water and/or silt from northern Buffalo Head Hills streams include nickel, copper, cadmium, molybdenum, silver, mercury and lead. These results are consistent with rock geochemical data for both the Loon River and Shaftesbury formations that identify zones enriched in zinc (up to 0.1% Zn) and other elements within both formations (Dufresne et al., 2001; Prior et al., 2006b).

Both the till heavy mineral results and the stream water and sediment geochemical results highlight the potential for the discovery of one or more zinc-rich base metal deposits hosted within Cretaceous shale of northwestern Alberta.

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