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R.C. Paulen[1], A. Plouffe[1], S. Paradis[2], and I.R. Smith[3]

[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario
[2] Geological Survey of Canada, 9860 West Saanich Road, Sidney, British Columbia
[3] Geological Survey of Canada, 3303 – 33rd Street NW, Calgary, Alberta

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ABSTRACT

This report presents the analytical data from Pb and S isotope analyses from sphalerite and galena grains recovered from bulk till samples collected from the north-central sector of the Zama Lake (NTS 84L) and south-central sector of the Bistcho Lake (NTS 84M) map sheets, northwest Alberta. The main objective of the isotope analyses is to evaluate if the Pine Point Mississippi Valley-type (MVT) deposit could be a potential source for the sphalerite and galena grains recovered in till. Results indicate that the sphalerite grains recovered from the till have a Pb isotopic composition identical to ore samples from other occurrences along the Great Slave Lake Shear Zone. Results from the S isotope analyses indicate that the source of sphalerite and galena in the till is not from the Pine Point MVT deposit, but from a local source situated along the Great Slave Lake Shear Zone. The source of the sphalerite and galena remains undiscovered but it could be from a sedimentary hosted zinc occurrence.

INTRODUCTION

In 2003 and 2004, the Alberta Geological Survey (AGS) and the Geological Survey of Canada (GSC) conducted bulk glacial sediment sampling of the Zama Lake and Bistcho Lake map sheets (National Topographic System (NTS) 84L and 84M, respectively) of northwest Alberta. This work was undertaken as a collaborative project between the Alberta Geological Survey and the Geological Survey of Canada with the aim of assessing the regional occurrence of kimberlite indicator minerals (KIMs) in glacial sediments. An unforeseen result of this survey was the discovery of anomalous concentrations of sphalerite grains with secondary galena in several of the bulk till samples (Plouffe et al., 2006a, 2008). Dark grey to black, angular, brittle grains of sphalerite were found in high concentrations (>100 grains) in seven till samples from this region; one till sample had 1047 sphalerite grains (normalized to 30 kg sample weight). Trace amounts of galena grains were recovered in association with the sphalerite grains. Plouffe et al. (2007) reported on the trace element chemistry of these sphalerite grains and noted some differences, mainly Fe and Cd contents, between those grains discovered in the northwest Alberta till samples and sphalerite chemistry reported at the nearest Pb-Zn deposits, the Pine Point Mississippi Valley-type deposits (Kyle, 1981).

The purpose of this report is to present the analytical data from the isotopic analyses conducted on the galena and sphalerite grains recovered from till samples in northwest Alberta, where a large sphalerite dispersal train extending over 4000 km^2 was identified (Plouffe et al., 2006a, 2008). The main objective of the isotopic analyses was to evaluate if the Pine Point deposit, that occurs up-ice of the anomalous till samples, could be a potential source of the sphalerite and minor galena grains recovered in till. Results were reported in Paulen et al. (2011), which concluded that Pine Point was not the source of abundant sphalerite and minor galena grains in till in northwest Alberta and that the source of those minerals in till remains undiscovered, possibly in Cretaceous bedrock (Paulen et al., 2007).

Regional setting

The study area for the 2003 and 2004 sample surveys includes the national topographic system (NTS) map sheets 84L (Zama Lake) and 84M (Bistcho Lake) of northwest Alberta (Figure 1). The sphalerite and galena grains were recovered from till samples collected in the northern portion of NTS 84L and southern portion of NTS 84M. This region lies within the Fort Nelson Lowlands of the Alberta Plateau physiographic region (Bostock, 1967), which is a region of subdued to flat relief with an elevation varying from 350 to 750 m above sea level (asl). The region is poorly drained, secondary streams are not deeply incised, and organic deposits in the form of fens and bogs abound.

Geology

The bedrock and stratigraphy of the Cretaceous and Paleozoic rocks are part of the northern Western Canada Sedimentary Basin (WCSB). The uppermost bedrock in northwest Alberta consists of 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, separated by deltaic to marine sandstones of the Dunvegan Formation (Hamilton et al., 1998; Okulitch, 2006; Figure 1). The regional basement is the Paleoproterozoic Hottah terrane (Hoffman, 1989; Gehrels and Ross, 1998). A large structural feature, the Great Slave Lake Shear Zone (GSLSZ) cuts across

the study area (Eaton & Hope, 2003; Figure 1). Bedrock outcrops are rare and are dominantly present in meltwater channels, along modern stream valleys, and on hilltops.

The stratigraphy of the Paleozoic rocks of the WCSB has been documented in details by several authors (Ricketts, 1989; Price, 1994; Eaton et al., 1999) and is therefore not reviewed here. Middle to Late Devonian carbonate rocks of the Upper Keg River Member (or Pine Point Group) and Sulphur Point Formation within the Presqu'ile barrier, Muskeg Formation of the back-barrier, Buffalo River Formation of the fore-barrier, and Watt Mountain and Slave Point formations on top of the barrier host stratabound and stratiform Zn-Pb occurrences and deposits, such as the Pine Point Mississippi Valley-type (MVT) deposit (Hannigan, 2007; Paradis et al., 2006). Host rocks for Zn-Pb MVT mineralization in northern Alberta and southern NWT are carbonates within a miogeoclinal succession consisting of open marine platformal carbonates, basinal shales, and restricted evaporitic sediments (Rice and Lonnee, 2006).

Northwest Alberta is mantled by an extensive cover of unconsolidated glacial and nonglacial sediments of varying thicknesses from 0 to 450 m (Pawlowicz et al., 2005a; 2005b; 2007a; 2007b). During the Late Wisconsin, the Keewatin-sourced Laurentide Ice Sheet flowed west and southwest across northern Alberta towards the Rocky Mountains (Smith et al., 2005a; Paulen et al., 2007). The details of the ice-flow history are depicted on the recently published surficial geology maps of this region (Kowalchuk et al., 2006; Paulen et al., 2005a,b, 2006a,b; Plouffe et al., 2004, 2006b; Smith et al., 2005b, 2007) and summarized in Paulen et al. (2007, 2011)

METHODS

Bulk sediment samples (~30 kg) of till (n=63) and glaciofluvial sediments (n=7) were collected in C soil-horizon (>1 m depth) from hand-dug pits, natural bluffs, and man-made exposures. Samples underwent heavy mineral separation (SG $\geq$3.2 g/cm^3) using a shaking table and heavy liquid separation. Heavy indicator minerals were visually identified and picked from the sand-sized fraction (0.25 – 2.00 mm). Sample locations and detailed sample processing methods are described in Plouffe et al. (2006, 2008).

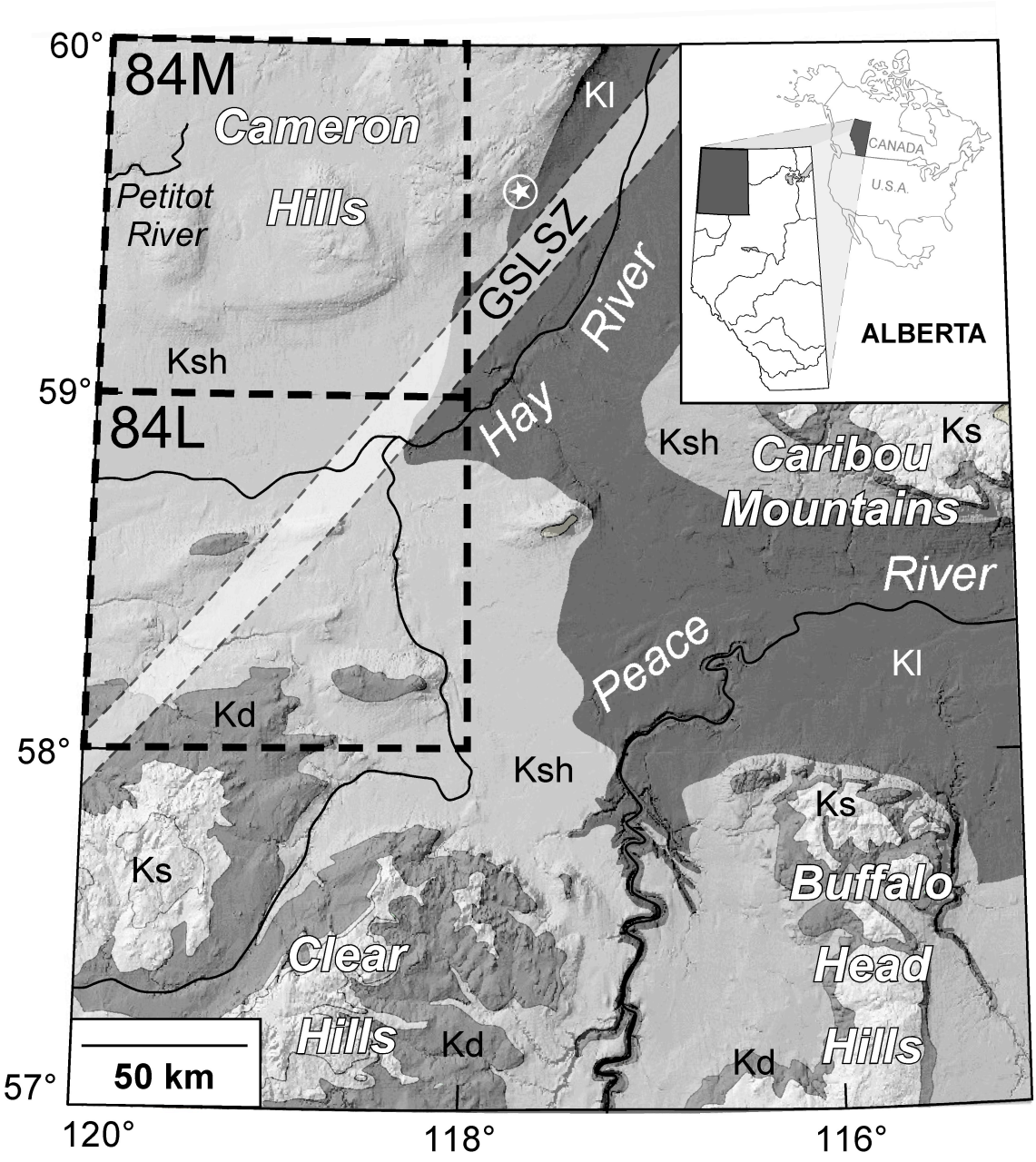

Figure 1. Physiography and bedrock geology of northwest Alberta where the till sampling survey (NTS sheets 84M and 84L) was undertaken. Cretaceous bedrock units listed from oldest to youngest (after Hamilton et al., 1998): Loon River Formation (Kl), Shaftesbury Formation (Ksh), Dunvegan Formation (Kd) and Smoky Group (Ks); the Steen River impact structure is shown as the white circled star. The Great Slave Lake Shear Zone (GSLSZ), projected to surface (Eaton & Hope, 2003), is shown as a white zone outlined by two black dashed lines.

Isotopic analyses of Pb were conducted on galena (n=10) and sphalerite grains (n=2) at the Department of Earth Sciences, Carleton University (Appendix A) utilizing techniques described by Cousens (1996). The grains were powdered and dissolved in 50% hydrofluoric acid – 12N nitric acid, then attacked with 8N nitric acid and finally 6N hydrochloric acid. The residue was taken up in 1N hydrobromic acid for Pb separation. Pb was separated using 1N hydrobromic acid to elute other elements and 6N hydrochloric acid to elute Pb. The collected Pb solution was dried, redissolved in 1N hydrobromic acid, and the above procedure was repeated with a small volume resin bed. Samples were loaded onto single Re filaments with phosphoric acid and silica gel, and were analyzed in a Thermo-Finnigan TRITON mass spectrometer. All mass spectrometer runs were corrected for fractionation using NIST SRM981. The average ratios measured for SRM981 are $^{206}Pb/^{204}Pb = 16.892 + .010$, $^{207}Pb/^{204}Pb = 15.431 + .013$, and $^{208}Pb/^{204}Pb = 36.512 + .038$ (2 standard deviations of the mean), based on 20 runs between April 2005 and November 2006. Subsequent fractionation correction is based on the values of Todt et al. (1984). Isotopic results are reported in conventional per mil notation (‰).

Sulphur isotope analyses (n=15) were performed on sphalerite powders made from grains selected from the 0.25 to 0.5 mm fraction, at the Department of Earth Sciences, University of Ottawa. Samples are weighed into tin capsules with tungstic oxide and then loaded into a Costech elemental analyser to be flash combusted at 1800°C. Released gases are carried by helium through the elemental analyser to be cleaned and separated. SO_2 gas is carried into the DeltaPlus isotope ratio mass spectrometer for analysis. Analytical precision is +/-0.2 per mil (2 standard deviation). Isotopic results are reported in conventional per mil notation (‰).

RESULTS

Lead isotope analyses of sphalerite and galena from till samples are listed in Appendix B and plotted on Figure 2. The average 'crustal evolution curve' of Stacey and Kramers (1975) and the 'shale curve' of Godwin and Sinclair (1982), a growth curve unique to the ancient western margin of North America, are shown for comparison. The 'shale curve' was constructed using the Pb values from galena in SEDEX deposits with well constrained ages within basinal sedimentary sequences of the Canadian Cordillera and

ranging in age from middle Proterozoic to Mississippian. This curve models the isotopic evolution of the upper crustal Pb in the source regions for clastic sedimentary rocks within the North American miogeocline.

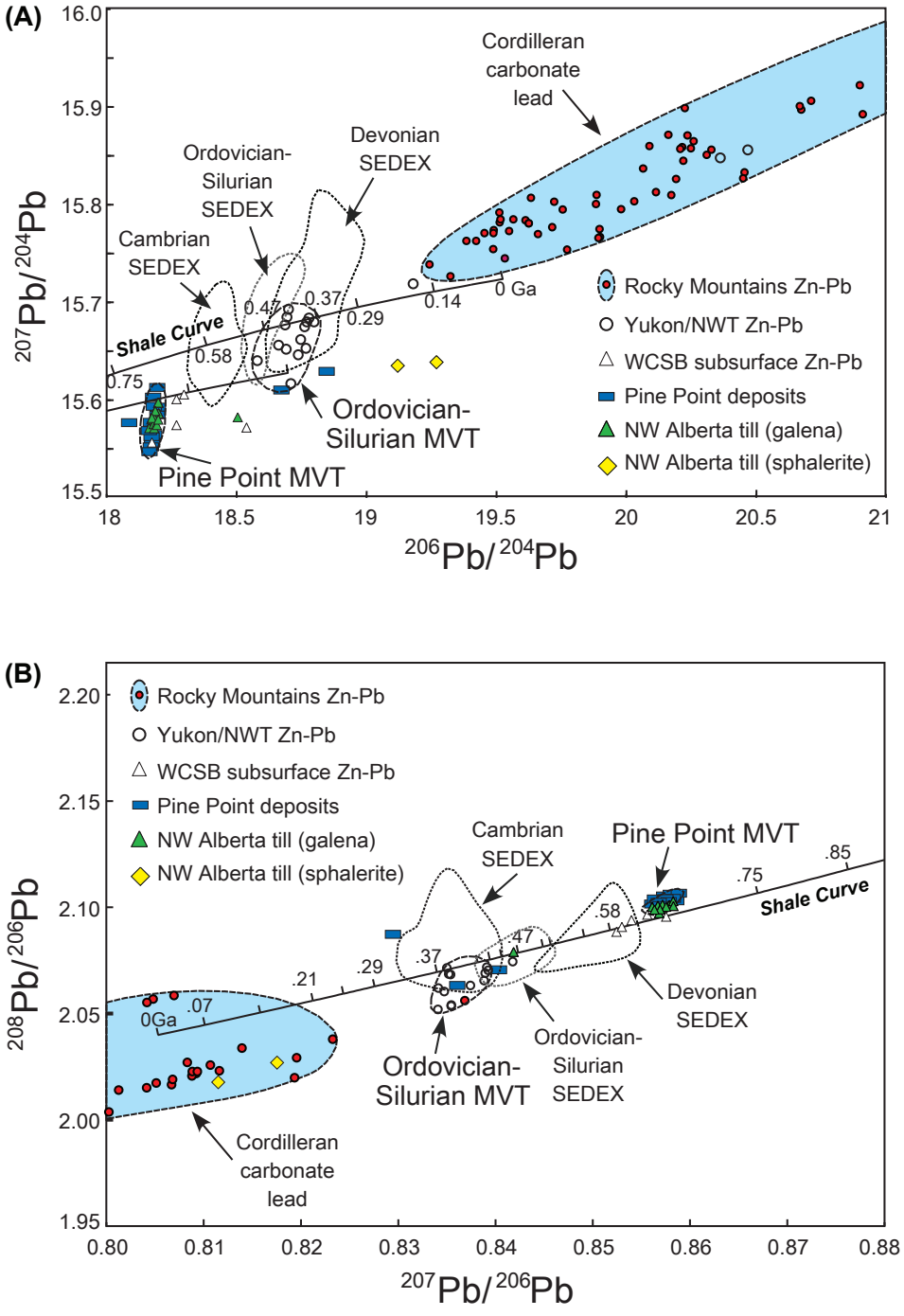

Figure 2. Lead isotopic data for galena and sphalerite grains from selected till samples collected in northwest Alberta (grey diamonds and triangles) compared with ore samples from the Pine Point district (black rectangles; Cumming et al., 1990; Paradis et al., 2006). The data are plotted in reference to the "shale curve" (upper) of Godwin and Sinclair (1982) and the average "crustal evolution curve" (lower) of Stacey and Kramers (1975). These plots include data from the Rocky Mountains Zn-Pb deposits hosted in Devonian-Mississippian carbonates (Godwin et al., 1982; Morrow & Cumming 1982; Nelson et al., 2002; Paradis et al., 2006), Zn-Pb deposits in Yukon and Northwest Territories (NWT) hosted in Ordovician-Silurian carbonates (Godwin et al., 1982), and Zn-Pb occurrences of the Western Canada Sedimentary Basin (WCSB) hosted in subsurface Devonian carbonates (Paradis et al., 2006). Cambrian, Ordovician-Silurian, and Devonian SEDEX deposits of the Selwyn Basin and Kechika Trough (Godwin et al., 1988) are plotted for reference (from Paulen et al., 2011). (A) $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$. (B) $^{208}Pb/^{206}Pb$ versus $^{207}Pb/^{206}Pb$.

Of the ten galena grains recovered from the two till samples, nine plot as one population which exhibits very small variations in $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{206}Pb$. These nine galena grains plot within the 'Pine Point lead' cluster that includes data from the Pine Point orebodies (Cumming et al., 1990), other Zn-Pb occurrences in the Pine Point district (Paradis et al., 2006), and subsurface sulphide occurrences in drill cores from carbonate sequences of the Western Canada Sedimentary Basin located along the GSLSZ. Recent data from Oviatt (2013) are not included in this comparison, but galena from till and bedrock samples studied by Oviatt (2013) have the same isotopic signature of the Pine Point mine site. A single galena grain has a higher $^{206}Pb/^{204}Pb$ and plots below the 'shale curve' (Fig. 2a). The two sphalerite grains analyzed for Pb isotopes plot below the 'shale curve' away from the 'crustal evolution curve'. They have higher $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ values than the galena grains (Fig. 2a) and on the $^{208}Pb/^{206}Pb$ versus $^{207}Pb/^{206}Pb$ plots, the two sphalerite grains plot within the 'Cordilleran carbonate lead' field (Fig. 2b). The Pb in the sphalerite may come from a different reservoir than the Pb in the galena or the Pb in both minerals comes from different mineralizing events. The 'Pine Point Pb' isotopic signature is quite distinctive. It shows remarkable homogeneity, with $^{206}Pb/^{204}Pb$ values in a narrow range of +18.167 to +18.189 ‰, indicating either a homogeneous source or a thorough mixing of Pb during extraction, transport, and

precipitation (Cumming et al., 1990; Paradis et al., 2006). Modelling of U and Pb concentrations and ratios suggest a depleted lower crustal source consistent with Pb derivation from basement rocks (Nelson et al., 2002; Paradis et al., 2006).

Sphalerite grains recovered from the 10 till samples displays a range of $\delta^{34}S$ values between -14.1 to -6.0‰ with a mean value of -9.0‰ (Appendix C). The low values are different than those reported for Mississippi Valley-type deposits in the northern and southern Cordillera, which are dominantly much heavier (Fig. 3). Sulphur isotope values from the Pine Point deposits range from +12.2 to +27.0‰ (Evans et al., 1968; Sasaki & Krouse, 1969; Paradis et al., 2006). $\delta^{34}S$ values in sphalerite grains recovered from the dispersal train vary from -14.1 to -6.0‰ (Fig. 3) and are clearly lower than at Pine Point. These negative values may reflect the incorporation of isotopically light H_2S (aq) derived from the oxidation of the sulphide- bearing solution.

SUMMARY

A full interpretation and discussion of the results are presented in Paulen et al. (2011). Lead and S isotopic composition of sphalerite and galena grains recovered from till samples in northwest Alberta serve to demonstrate that the 4000 km^2 sphalerite dispersal train in that region is not derived from the Pine Point Mississippi Valley-type Zn-Pb deposits located 330 km to the northeast, but rather, is interpreted to be the result of glacial erosion of undiscovered proximal Zn mineralization hosted in the Cretaceous sedimentary bedrock. More specifically, the Pb isotopic values of the galena recovered from the till in northwest Alberta are identical to those from the Pine Point district and other occurrences along the GSLSZ providing a direct link between the undiscovered mineralization and this structural break. On the other hand, the $\delta^{34}S$ values determined on sphalerite grains recovered from till in northwest Alberta are lower than measured in the mineralization at Pine Point, indicating that the sphalerite grains recovered from the till samples are not derived from Pine Point.

Isotopic fingerprinting of indicator minerals is a relatively new, powerful exploration tool to help determine provenance of indicator minerals grains. Other isotopic work, such as age dating, is a relatively new technique to assist in deciphering past glacial flow

trajectories and to ultimately delineate the provenance of erratics and mineral grains (e.g., Plouffe et al., 2011).

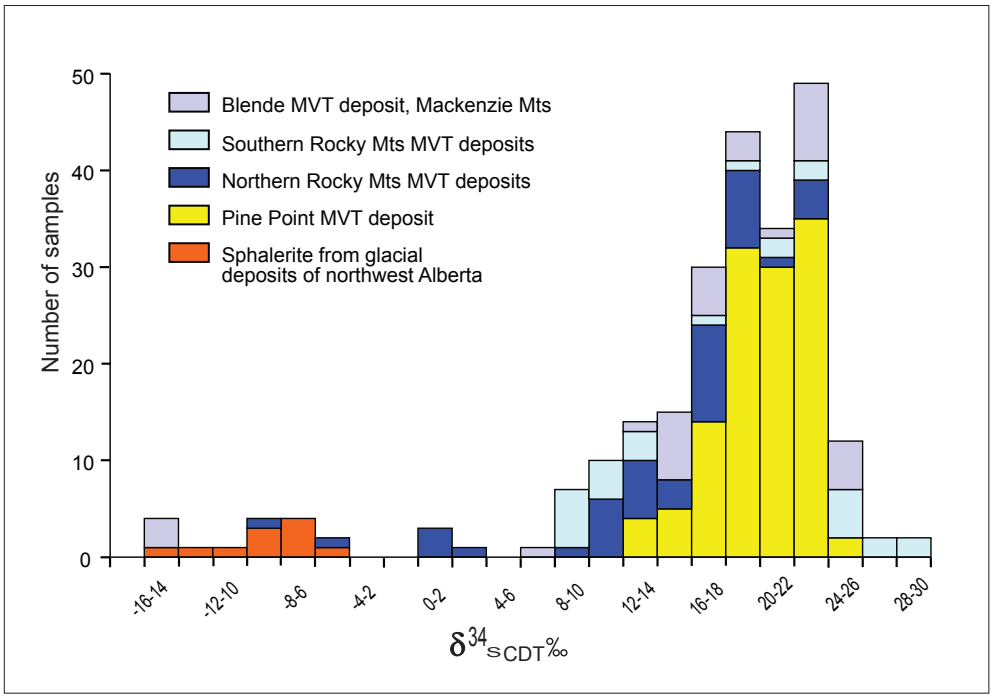

Figure 3. Histogram of $\delta^{34}S$ values for sphalerite grains from NW Alberta till samples (orange), the Pine Point Pb-Zn deposit (yellow) and other Pb-Zn deposits in the Rocky and Mackenzie mountains (from Paradis et al., 2006).

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