Testing the Relationship between the Cottonbelt Lead-Zinc Deposit and the Carbonatite-Syenite Province of the Frenchman Cap Dome Area, Southeastern British Columbia (NTS 082M/06, 07, 10)

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Introduction

This paper is an introduction to the lead author's Ph.D. research on the relationship between the Cottonbelt Pb-Zn deposit and the carbonatite-syenite province of the Frenchman Cap dome area in southeastern British Columbia (BC) that will be undertaken during the next 1–2 years. This paper presents the study's background information, as analytical results are not yet available. The overall goal of the study is to address an age conundrum between the extrusive Mount Grace carbonatite (MGC) and the Cottonbelt Pb-Zn deposit in southeastern BC. The specific objectives are to obtain and compare ^{207}Pb/^{204}Pb and ^{206}Pb/^{204}Pb ratios of regional intrusive units with those of the Cottonbelt deposit. The Pb in the Cottonbelt deposit may have come from Cambrian miogeoclinal sediments, a lower crust–upper mantle source or a mixture of the two.

Regional Geology

The MGC and the Cottonbelt deposit occur as thin, laterally discontinuous stratabound layers in the Monashee Mountains, northwest of Revelstoke, on the northwest flank of the Frenchman Cap dome (Figures 1, 2; Höy and Kwong, 1986; Höy, 1987; Pell, 1994). Both layers have been traced and projected for at least 5 km along the strike of an east-verging fold nappe named the Mount Grace syncline (Figures 1, 2). The MGC and Cottonbelt layers occur on the northeastern overturned limb of the Mount Grace syncline (Figures 1, 2). A similar mineralized layer appears on the southwest upright limb of the syncline, where it is referred to as the McLeod and Complex showings. These may represent the same depositional system (Figures 1, 2).

The MGC and the Cottonbelt deposit occur in the Monashee Complex (MC). The MC is the deepest exposed structural level in the southern Omineca belt; it includes exposed basement rocks in the Frenchman Cap dome in the north and the Thor-Odin dome in the south, bounded by the Selkirk parautochthonous terrane in the west and the Columbia River fault in the east (Figure 1; Okulitch, 1984; Parrish and Scammell, 1988; Johnson, 1994). The MC consists of basement migmatitic paragneiss and granitoid orthogneiss of Paleoproterozoic age and basal quartzite overlain by metasedimentary cover rocks of Paleozoic age (Crowley 1997; Kuiper et al., 2014). In the Jurassic, allochthonous terranes amalgamated and were thrust and obducted over the North American margin (Brown et al., 1993), resulting in tectonic transport of parautochthonous sequences of the outer margin (e.g., Selkirk allochthon) and culminating in maximal crustal thickening and regional uplift during the mid-Cretaceous (Brown et al., 1986).

The uppermost MC rocks, the Monashee cover sequence, consist of quartzite, pelitic schist, silicate gneiss, calcsilicate gneiss and marble, all of which unconformably overlie basement paragneiss and orthogneiss of probable Proterozoic age (Reesor and Moore, 1971; Armstrong and Ward, 1991; Parkinson, 1991; Crowley, 1997). The base of the Monashee cover sequence sedimentary package contains a laterally extensive quartzite of variable thickness and purity with local crossbedding and grading, providing the only top-up indicators (Höy, 1987). The quartzite underlies a sequence of dominantly calcareous and pelitic schists with minor amphibolite, impure quartzite and quartz-feldspar-biotite gneiss interlayers. Topping this is a thinly bedded unit of interlayered calcsilicate gneiss, kyanite and sillimanite schist and gneiss, calcitic and dolomitic marble, amphibolite and thin scapolite-rich marble layers; this section hosts the MGC and the Cottonbelt deposit.

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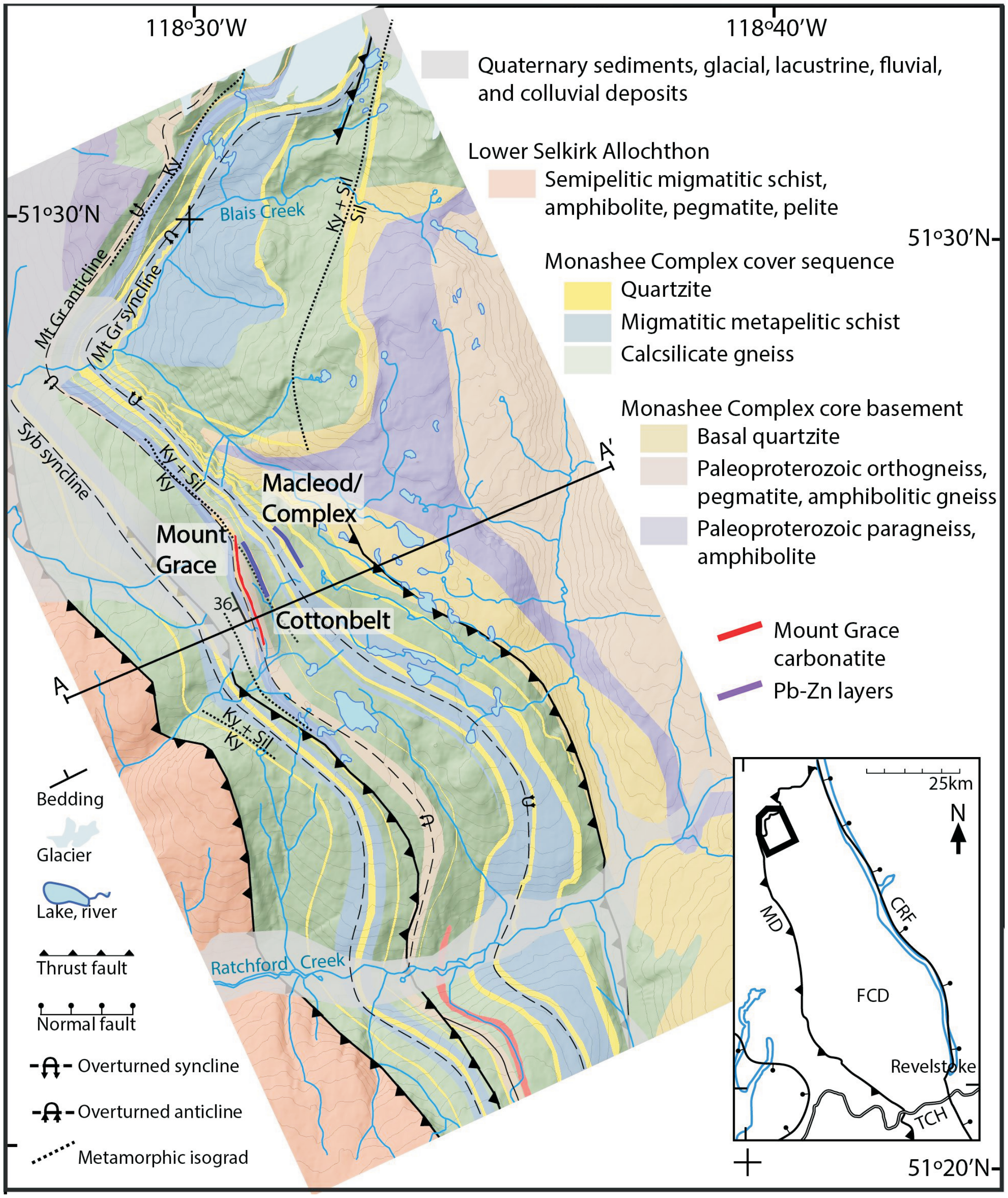

Figure 1. Generalized geology of the northwest flank of the Frenchman Cap dome, showing regional geology, Mount Grace carbonatite, Cottonbelt and Macleod/Complex Pb-Zn layers, structural features and metamorphic isograds (modified from Wheeler, 1965; McMillan, 1970; Höy & McMillan, 1979; Brown, 1980; Pell, 1994; Crowley, 1997; Journeay et al., 2000a, b; Lund, 2008; Millonig et al., 2012; Gervais, 2019). Abbreviations: CRF, Columbia River fault; FCD, Frenchman Cap dome; MD, Monashee Décollement; Ky, kyanite; Mt Gr, Mount Grace; Sil, sillimanite; TCH, Trans Canada Highway.

Previous authors have interpreted the sedimentary package of the Monashee cover sequence to represent a transgressive marine sequence deposited on a low-relief basement complex (McMillan, 1973; Höy and McMillan, 1979; Höy and Kwong, 1986). Coarse fluvial sandstone, conglomerate and perhaps marine sands overlying a regional unconformity pass upward into fine-grained, calcareous muds and siltstones, likely deposited on extensive tidal flats. The tremendous lateral extent of a metasedimentary marble unit and its relative purity (with trace amounts of scapolite), as well as its stratigraphic relationship in a package with quartzites and schists, is consistent with the deposition of marine carbonate on a flat, stable continental shelf (Höy, 1987). A more recent study of the metasedimentary marble unit (Dzikowski et al., 2014) assesses the low Sr contents and their positive correlation with CaO to be consistent with a non-

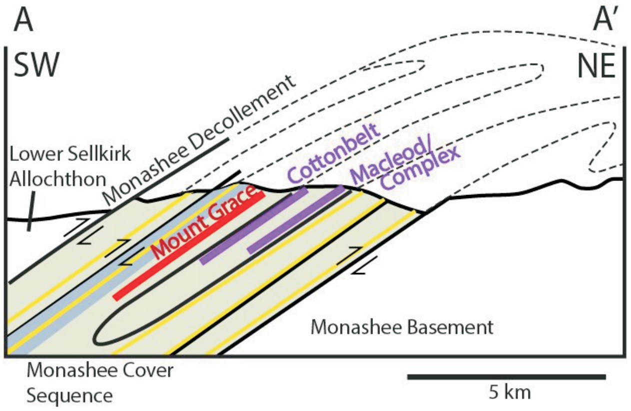

Figure 2. Generalized cross-section (A-A′ in Figure 1) showing the structural relationship between the Mount Grace carbonatite and the Cottonbelt and Macleod/Complex strata.

evaporitic origin, and the isotopic, major- and trace-element composition of the marble to correspond with shales or marls derived from platform sediments.

Mount Grace Carbonatite

The MGC is a deformed, recrystallized, lithic clast–bearing impure marble (Figure 3). Previous authors inferred an extrusive origin for the carbonatite based on a lack of fenitized margins, an abundance of included lithic clasts and the deposit's tremendous lateral extent (Figure 1; Höy and Kwong, 1986). In the field, the MGC is recognized by its unusual pale to medium brown weathering colour; prominent matrix grains of dark brown phlogopite, colourless apatite and black (weathered) amphibole crystals; and the widespread occurrence of white, matrix-supported, lithic clasts (Figure 3a). The deposit commonly contains one main, thick (up to 5 m) layer of tuff breccia interbedded with finer grained, lithic clast–poor, massive or laminated carbonatite layers (Figure 3a). The MGC layer averages 2–4 m in thickness and locally narrows to less than a metre (Pell, 1994). The original thickness of the MGC is unknown, as it was likely thinned in the limbs of the major folds.

Cottonbelt Pb-Zn Layer

Cottonbelt is a sulphide-magnetite layer, 15 cm to approximately 3 m thick, that has been traced or projected for approximately 4 km along strike (Figures 1 and 3b). The Cottonbelt consists predominantly of thickly banded to massive olivine-, pyroxene-, amphibole- and carbonate-bearing calcsilicate gneiss with variable amounts of sphalerite, galena and magnetite. The mineralized zones occur as thick beds, occasionally with thin interbedded layers of metasedimentary marble, calcsilicate gneiss or pelitic schist (Figure 3b). The marble layers contain disseminated sphalerite, galena and trace amounts of pyrrhotite and magnetite. The depositional environment of the Cottonbelt deposit was through sedimentary deposition on the seafloor.

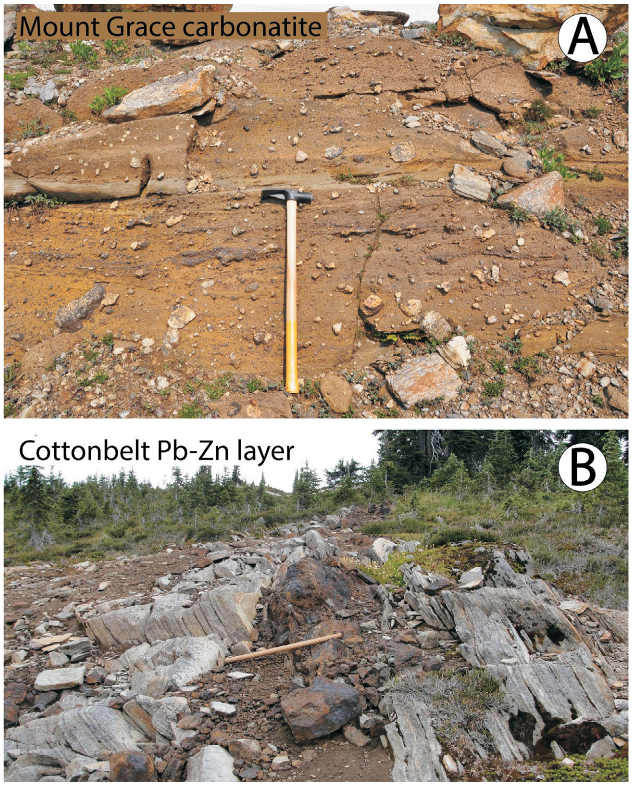

Figure 3. Field photos displaying **a)** the main tuff breccia units of the Mount Grace carbonatite, and **b)** the Cottonbelt sphalerite-galena-magnetite mineralization within the metasedimentary marble. 75 cm GeoTool for scale.

A synsedimentary origin for Cottonbelt is indicated by the crude to finely bedded nature, the large lateral extent, the association with chert of probable exhalative origin and the presence of disseminated sulphides in the associated marble.

Justification of Methodology

The absolute age of the Mount Grace carbonatite is currently in dispute. Millonig et al. (2012) analyzed 28 zircons from the MGC that yielded U-Pb and Th-Pb (from zircons with low U contents) weighted mean ages of ca. 360 Ma, interpreted as its eruptive age. Zircon U-Pb dating by Parrish (1995) of the intrusive Three Valley Gap (TVG) carbonatite, located approximately 20 km southeast of the MGC, yielded a similar age of ca. 360 Ma and may represent the intrusive equivalent to the MGC. Millonig et al. (2012) also dated zircons from the Trident River syenite, located approximately 30 km northeast of the MGC, at ca. 360 Ma. Kuiper et al. (2014) identified a detrital zircon grain from regional pelitic schist (that hosts the MGC) with a zircon U-Pb age of 357 Ma and a CA-TIMS age of 396 Ma. The Devonian age for the MGC conflicts with the Cambrian-Pb model age that Höy and Godwin (1988) assigned to the Cottonbelt Pb-Zn magnetite layer, which structurally and probably stratigraphically overlies the MGC (Höy, 1987; Pell, 1994). The Cottonbelt galena Pb model age uses Pb isotopic comparison with values on the Shale Curve of Godwin and Sinclair (1982), which was developed based on galena-bearing SEDEX deposits within strata of the Canadian Cordilleran miogeocline.

The ^{207}Pb/^{204}Pb vs. ^{206}Pb/^{204}Pb ratios of K-feldspar (from syenite), pyrite and pyrrhotite (from carbonatite) and galena (from Cottonbelt) will be plotted, along with reference terrestrial Pb-growth curves (Stacey and Kramers, 1975) to determine if the nearby carbonatites and syenites played a role in Cottonbelt mineralization, which would discredit the model age. Due to the abundance of xenolithic material and the fine-grained nature of only trace amounts of sulphides in the Mount Grace carbonatite, it was not possible to separate enough suitable grains for Pb isotopic analysis from this rock type. However, an overlap or mixing trend in Pb isotopes between Cottonbelt galena and regional magmatic units would still discredit an upper crustal Pb source.

The study will obtain and compare Pb isotopes from the Trident River and Three Valley Gap syenite feldspars and Three Valley Gap carbonatite sulphides (pyrite and pyrrhotite) to test if magmatic activity contributed to Cottonbelt mineralization. Common Pb is any Pb incorporated into a mineral or rock during formation; this signature reflects the primary Pb composition of the source, and the common Pb isotopic ratio is the product of the fractionation history of the source material (Zametzer et al., 2022). Minerals such as feldspars and sulphides incorporate very little initial U in their structure, meaning minimal Pb isotopic evolution after crystallization (Woodhead, 2009; Flowerdew et al., 2012). Similarly, the original Pb isotopic ratios in Pb ore galena (PbS) inform on the source and timing of metal deposits (Doe and Stacey 1974; Huston et al., 2014). The Pb-isotope compositions of some 'conformable' stratabound Pb-Zn ore deposits can be accounted for by a growth curve from the formation of the Earth to the known emplacement age of dated ores (Stanton and Russell, 1959). The resulting model age for undated ore deposits is an apparent age calculated from measured isotopic abundances (Stanton and Russell, 1959). The Holmes-Houtermans Pb-growth curve model assumes a chemically closed environment and a single-stage system (Houtermans 1946; Holmes 1946, 1947, 1949). The Stacey and Kramers (1975) model for the evolution of terrestrial Pb involves two stages. Godwin and Sinclair (1982) expanded on the Stacey and Kramers (1975) model by constructing a three-stage growth curve that represents the Pb isotopic evolution of sediments deposited on the western margin of North America that were derived primarily from upper crustal rocks derived from erosion of the western Canadian Shield (Figure 3; Godwin et al., 1988; Nelson, 1991; Mortensen et al., 2006).

Andrew et al. (1984) plotted galena-Pb from Pb deposits in southeastern BC (Figure 3) on the shale-growth curve of Godwin and Sinclair (1982). Lead data from Pb-Zn deposits that plot off the shale curve in steep linear arrays represent mixing lines between two Pb sources: upper continental crust represented by the Shale Curve and another source more depleted in U with a low μ (^{238}U/^{204}Pb) value from the lower crust/upper mantle batholith (Nelson batholith; Figure 3). Lead data that plot off the Shale Curve and overlap with Ag-rich veins from the Nelson batholith indicate that the Pb deposit is also related to the nearby intrusion rather than being syngenetic (Figure 3). Höy and Godwin (1988) plotted Pb-isotope ratios of galena from the Cottonbelt deposit on the Shale Curve of Godwin and Sinclair (1982) to infer an Early Cambrian model age (Figure 3).

Höy (2002) noted the unusual metal content of the Cottonbelt deposit compared to more typical sedimentary-exhalative (SEDEX) deposits, involving a magnetite host and skarn mineralogy, with high overall Fe-Mn-Pb contents that may require a magmatic input generating hydrothermal fluids similar to a volcanogenic massive sulphide (VMS) deposit (Figure 4). Dusel-Bacon et al. (2012) noted the overlap of Pb-isotope compositions between sulphides from the Bonnifield VMS deposit in east-central Alaska with those of feldspars from nearby Late Devonian to Early Mississippian felsic igneous rocks, indicating a common source for the Pb in both minerals and a syngenetic origin for the deposit (Figure 5).

Lead isotopes for this study will be measured on an Element II High Resolution ICP-MS (HR-ICP-MS, Thermo Scientific) at The University of British Columbia's Pacific Centre for Isotopic and Geochemical Research. Solution MC-ICP-MS was chosen because high precision (<0.5% 2σ) is critical, but the spatial resolution (i.e., LA-ICP-MS) is less important. The ^{207}Pb/^{204}Pb and ^{206}Pb/^{204}Pb errors of <0.5% (2σ) produce Shale Curve model Pb ages with errors generally less than 0.05 m.y., sufficient for determining isotopic overlap.

Expected Outcomes and Impact

This study will plot Pb-isotope ratios and their corresponding analytical errors (displayed as 2σ) from Trident River syenite feldspar, Three Valley Gap syenite feldspar, Three Valley Gap carbonatite pyrite and pyrrhotite, and Cottonbelt galena on a Pb-Pb plot, along with the Stacey-Kramers Curve (Stacey and Kramers, 1975) and the Shale Curve (Godwin and Sinclair, 1982). Overlapping Pb isotopes may indicate that one (or two) magmatic events played a role in Cottonbelt mineralization. Any mixing trends (similar to results from Andrew et al., 1984) may indicate that both upper crustal miogeoclinal sediments and magmatic fluids affected Cottonbelt mineralization. Either scenario would also preclude using a terrestrial growth curve to date the

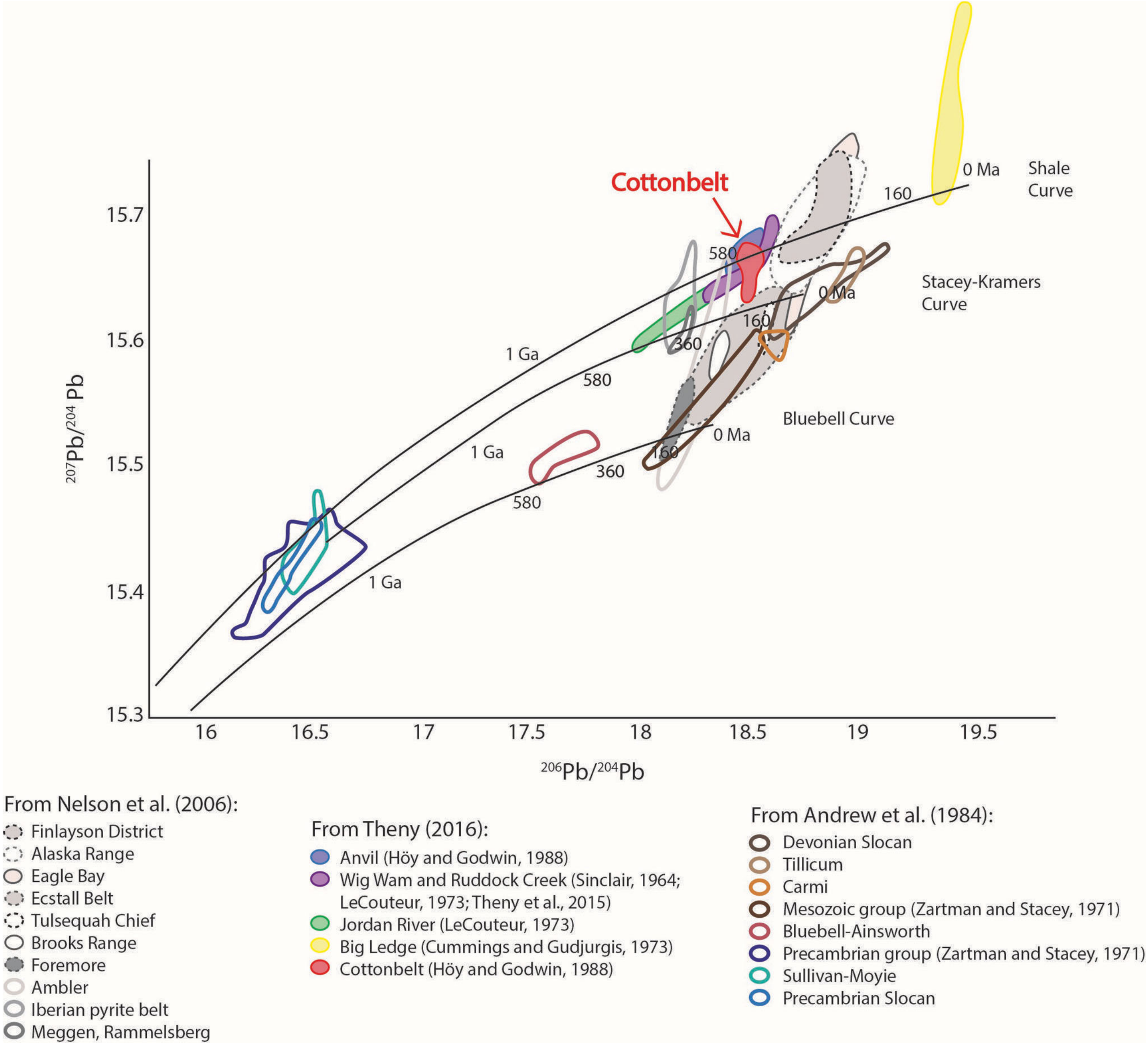

Figure 4. Lead isotopic data for sulphide minerals from sedimentary exhalative (SEDEX)–type deposits and K-feldspar from granitic intrusions (after Sinclair, 1964; Stacey and Kramers, 1975; Godwin et al., 1988; Nelson, 1991; Mortensen et al., 2006; Nelson et al., 2006; Theny, 2016).

Cottonbelt deposit. If there are no isotopic overlaps, then additional studies will be needed to address the age problem of an underlying Devonian pyroclastic carbonatite and overlying Cambrian SEDEX deposit (such as isotopic resetting in the Devonian carbonatite zircons or the presence of an unconformity between the two deposits).

This study illustrates the importance of having a local frame of reference to interpret Pb data and provide a method for dating epigenetic and syngenetic or penecontemporaneous mineralization in the Omineca crystalline belt. Determining accurate age estimates and a potential genetic relationship for the extrusive Mount Grace carbonatite and the Cottonbelt deposit will also have important implications for paleotectonics, as both deposit types indicate rifting. In addition, any influence by carbonatite magmatism on Cottonbelt mineralization would be a world first and any influence by alkaline magmatism would be unique. Only a handful of volcanogenic massive sulphide deposits are associated with peralkaline magmatic rocks and all of these examples (e.g., Cottonbelt) occurred in the Devonian–Mississippian age range on the paleo–western margin of Laurentia (Mortensen & Godwin, 1982; Gibson et al., 1999; Dusel-Bacon et al., 2012).

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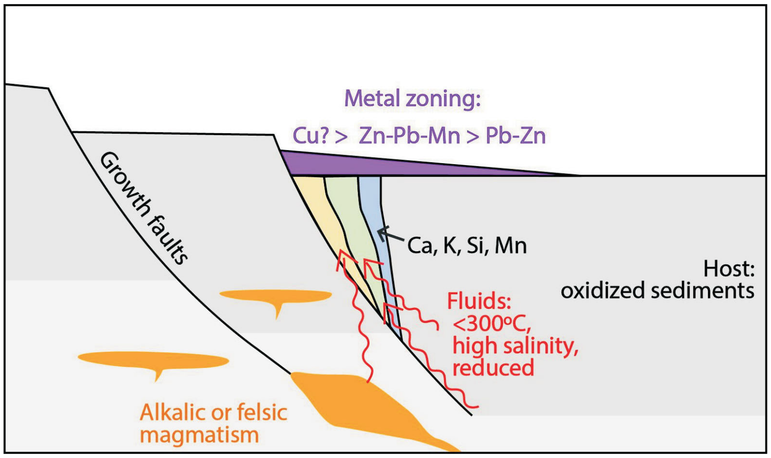

Figure 5. Schematic model of the Cottonbelt deposit (modified from Höy, 2002).

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