# The Ruddock Creek Zn-Pb deposit: Constraining the timing of deposition of the metalliferous Windermere Supergroup, Northern Monashee Mountains, Southern British Columbia

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## Introduction

The Ruddock Creek Property (Figs. 1-5) is situated within the northern Monashee Mountains. It is interpreted to reside within the base of the Selkirk allochthon, in the immediate hanging wall of the Monashee décollement, a crustal-scale, Mesozoic to Eocene thrust-sense shear zone (Read and Brown, 1981; Journeay, 1986; Brown et al., 1992; Gibson et al., 1999; Crowley et al., 2001). In this region, crustal thickening resulted in polyphase deformation and in at least three deformation events and two prograde metamorphic events.

The metasedimentary rocks at the Ruddock Creek property are thought to belong to the Windermere Supergroup (Fig. 1.), a stratigraphic succession in the North American Cordillera interpreted to have been originally deposited along the newly rifted margin of Laurentia during Neoproterozoic time (Ross et al., 1989; Ross, 1991; Link et al., 1993).

The southern Canadian Cordillera hosts a number of stratabound Zn-Pb deposits that may be related to Ruddock Creek (Fyles, 1970; Höy, 2000). Ages of these deposits are poorly constrained (Höy and Godwin, 1989). Determining the age of the host stratigraphy at Ruddock Creek may resolve if these deposits are time correlative and genetically related and help place them in the context of other deposits along the Cordillera.

## Main Objectives

(1) Constraining the age of deposit formation and characterize the deposit by evaluating the genetic relationship between several mineralized zones.

(2) Refine the Ruddock Creek property structural history through structural analysis and mapping at 1:10 000 scale to test the hypothesis that the deposit is within an overturned synform, and dismembered pieces of the deposit occur in the attenuated and transposed limbs.

(3) Relate the deposit to the metallogenic evolution of the Cordillera

## Methods

Detrital zircon data were obtained from 13 samples within and around the Ruddock Creek property **(Figs. 2, 3 and 4)**. Samples include:

- 7 psammites, +/- garnet
- 3 quartzites
- 2 pelites, +/- sillimanite, +/- garnet
- 1 very siliceous calcsilicate

Zircon grains were analyzed at Boise State University by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) using a ThermoElectron X-Series II quadrupole ICPMS and New Wave Research UP-213 Nd:YAG UV (213 nm) laser ablation system. In-house analytical protocols, standard materials, and data reduction software were used for acquisition and calibration of U-Pb dates and a suite of high field strength elements (HFSE) and rare earth elements (REE).

Zircon was ablated with a laser spot of 25 µm or 30 µm wide using fluence and pulse rates of 5 J/cm$^2$ and 10 Hz, respectively, during a 45 second analysis (15 sec gas blank, 30 sec ablation) that excavated a pit ~25 µm deep.

The Pb isotopic compositions of single grains of galena, pyrite and pyrrhotite were analyzed by TIMS at the Boise State University Isotope Geology Laboratory in an attempt to directly constrain the age of formation of the Ruddock Creek Zn-Pb deposit (Figs. 4 and 6). Samples include:

- Galena from the E and Creek Zones
- Galena and pyrite from the Quartz exhalite horizon
- Galena and pyrrhotite from the V Zone

Purified Pb and U from single dissolved grains of galena, pyrite and pyrrhotite were loaded together with a silica gel–phosphoric acid emitter solution on single Re filaments. The Pb and U isotopic compositions were measured sequentially as Pb+ ions or UO2+ ions on a mass spectrometer.Purified Pb and U from single dissolved grains of galena, pyrite and pyrrhotite are loaded together with a silica gel – phosphoric acid emitter solution on single Re filaments. Pb and U isotopic compositions are measured sequentially as Pb+ ions or UO2+ ions on a mass spectrometer.

## Geological setting

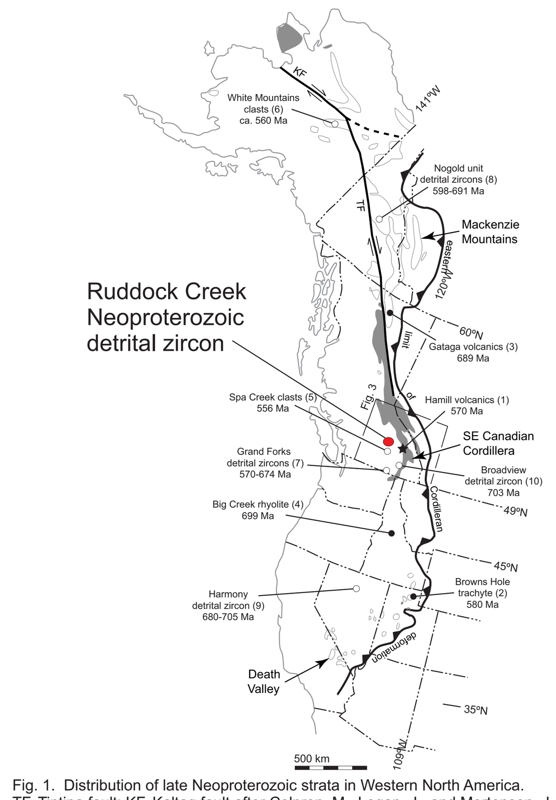

Fig. 1. Distribution of late Neoproterozoic strata in Western North America. TF, Tintina fault; KF, Kaltag fault after Colpron, M., Logan, J., and Mortensen, J. (2002)

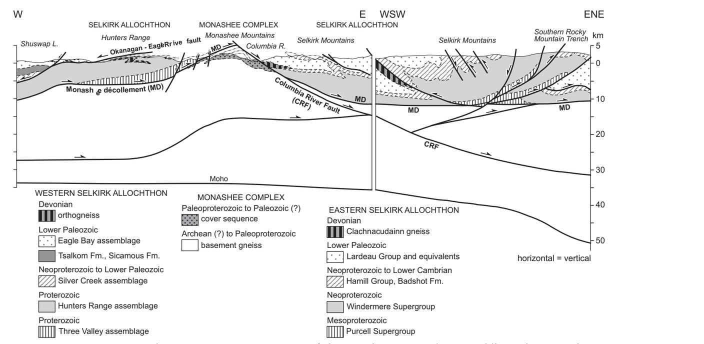


Fig.3. Crustal cross section across part of the southern Canadian Cordillera showing the major structures that bound the Selkirk allochthon and Monashee complex (from Crowley et al. JSG 2001, modified after Johnson & Brown, 1996; line of section shown in Fig. 2)

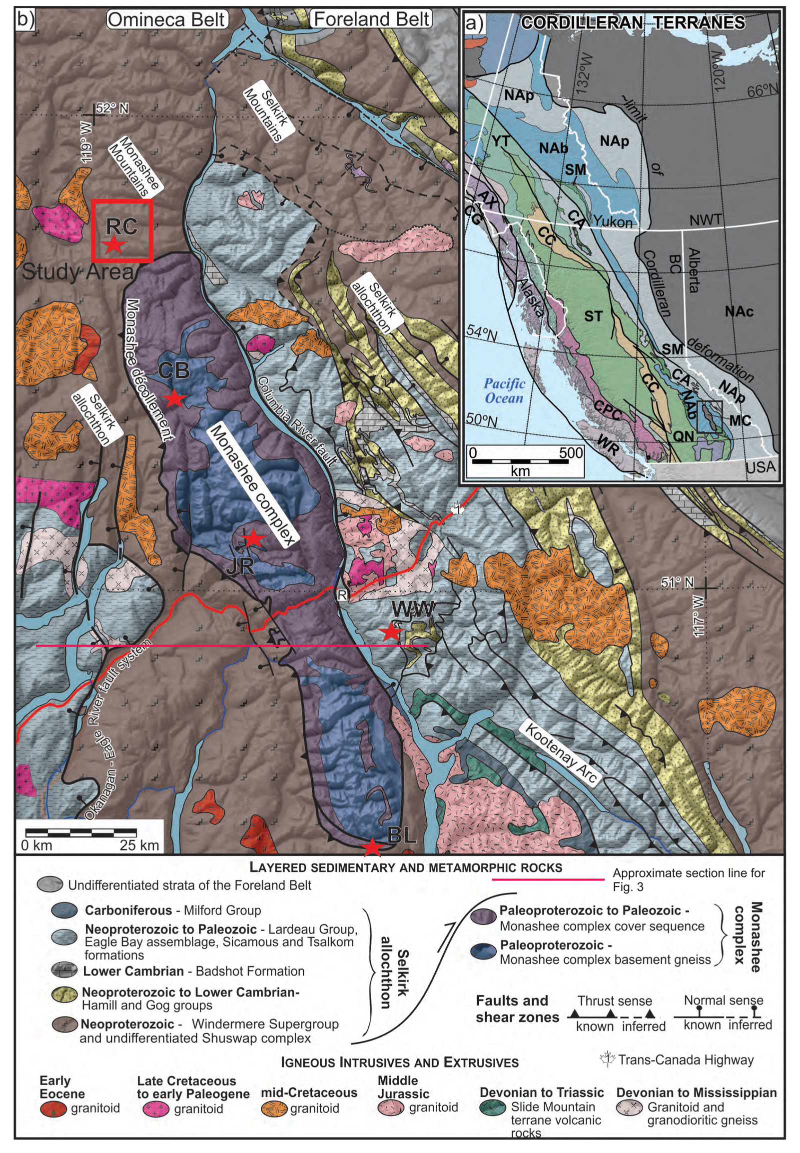


Fig.2. Location of the study area and regional geology. (a) Cordilleran terrane map after Colpron and Nelson, 2011. (b) Tectonic assemblage map, southeastern Omineca belt (after Wheeler and McFeely, 1991 and Gibson et al., 2008), showing lithologic units of autochthonous Monashee complex (North American basement) and overlying Selkirk allochthon. Towns: G = Golden; R = Revelstoke. Terranes: AX = Alexander; BR = Bridge river; CA = Cassiar; CC = Cache Creek; CG = Chugach; CPC = Coast plutonic complex; MC = Monashee complex; NAb = North American basinal; NAc = North American craton & cover; NAp = North American platform; OK = Okanagan; QN = Quesnellia; SM = Slide Mountain; ST = Stikinia; YT = Yukon-Tanana; WR = Wrangellia. Red stars indicate location of major Pb-Zn deposits in the region: BL = Big Ledge; CB = Cottonbelt; JR = Jordan River; RC = Ruddock Creek (this study; see Fig. 3,4); WW = Wigwam

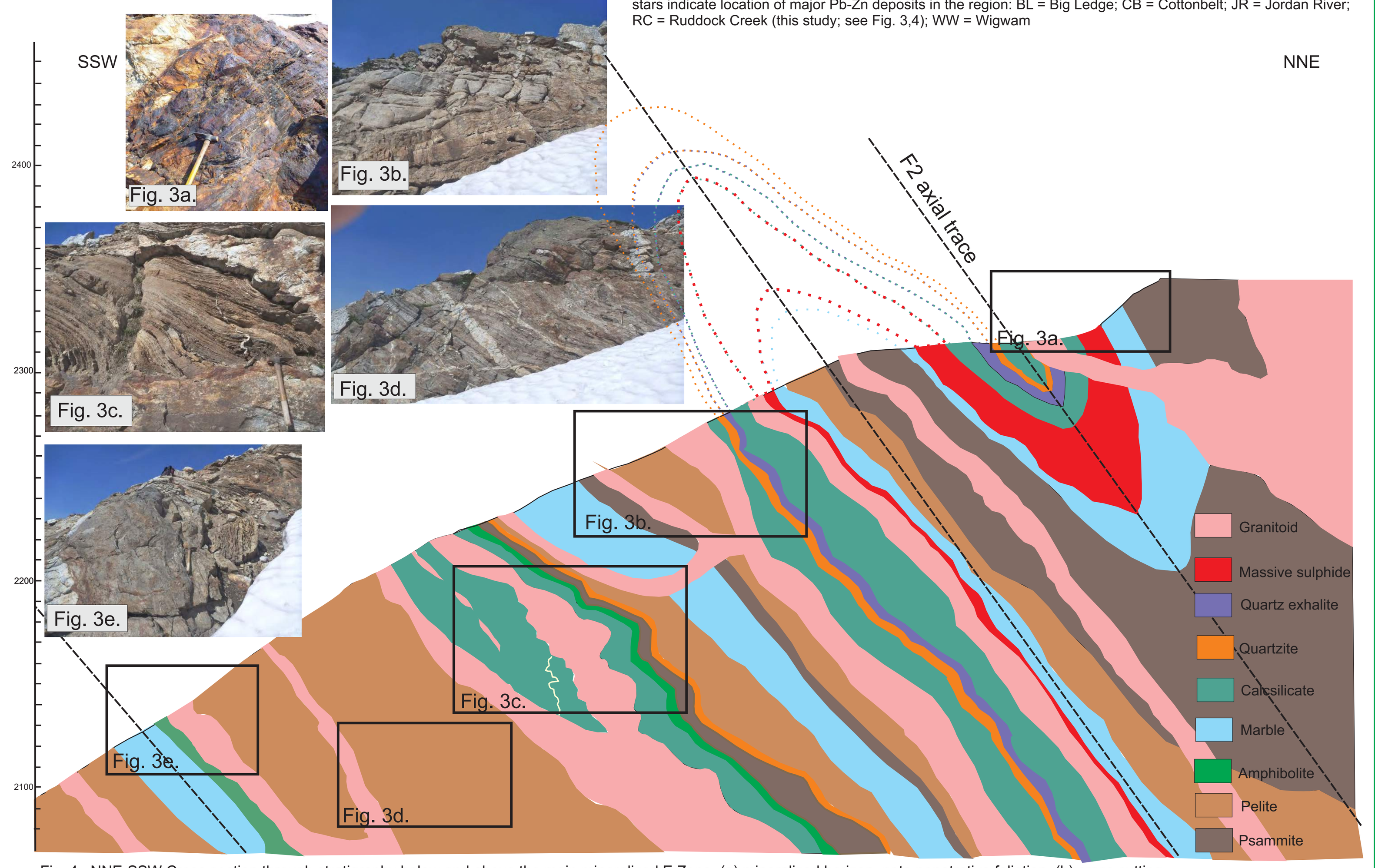


Fig. 4. NNE-SSW Cross section through stratigraphy below and above the main mineralized E Zone. (a) mineralized horizon, note penetrative foliation. (b) cross cutting relationship of metasedimentary units and granitoids. (c)F3 folded granitoid, St synchronous boudins. (d) cross cut psammite. (e) meta-volcanics? overlying marble.

## Property Geology

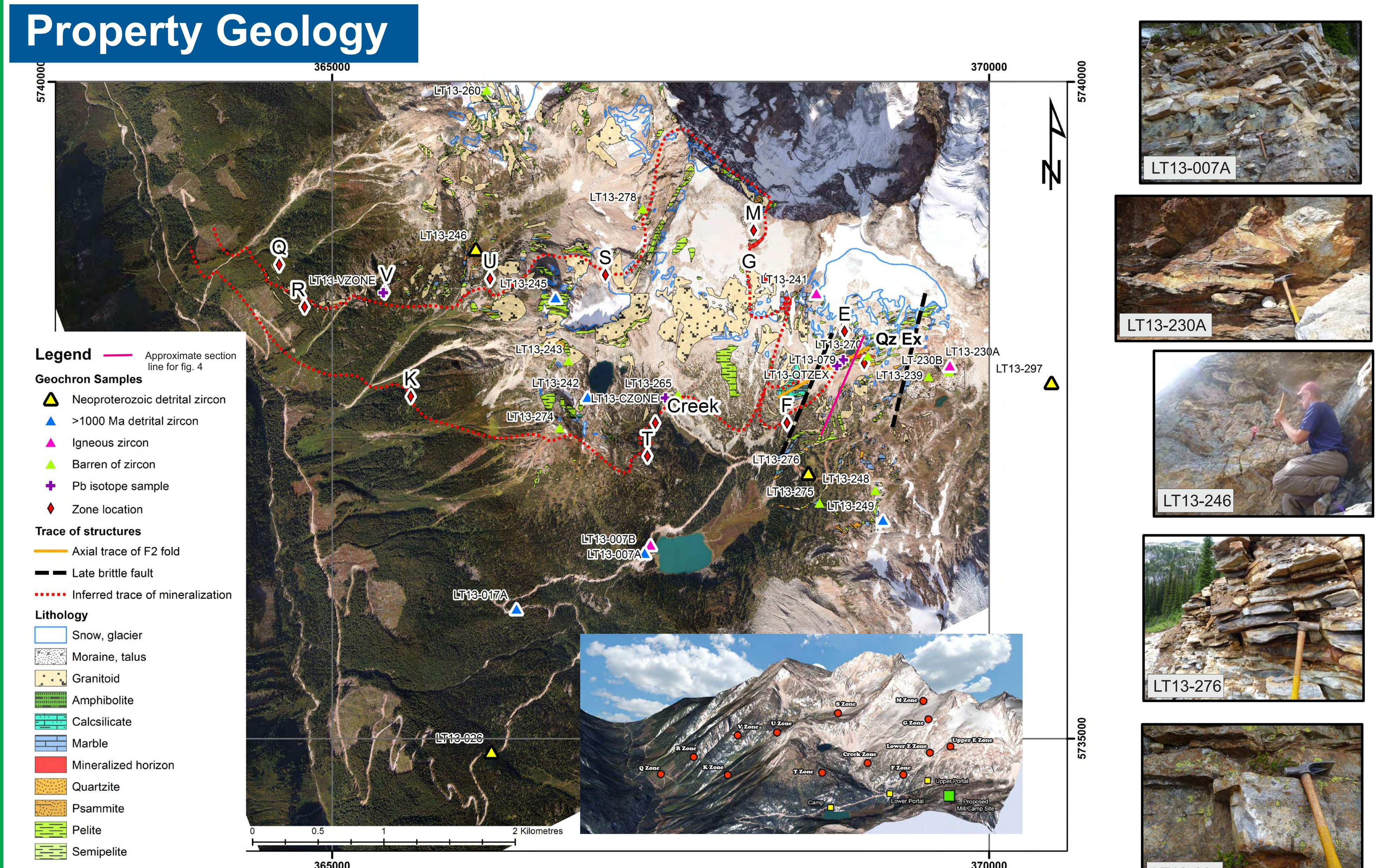


Fig. 5. Plan map of the Ruddock Creek property. Section line from fig.4. in yellow. Trace of mineralized horizon in dashed red. Samples taken for U-Pb dates represented by triangles. Samples taken for Pb isotopic analysis represented by purple crosses. Photographs on the right represent a selection of geochronological samples.

## U-Pb and Pb-Pb dates

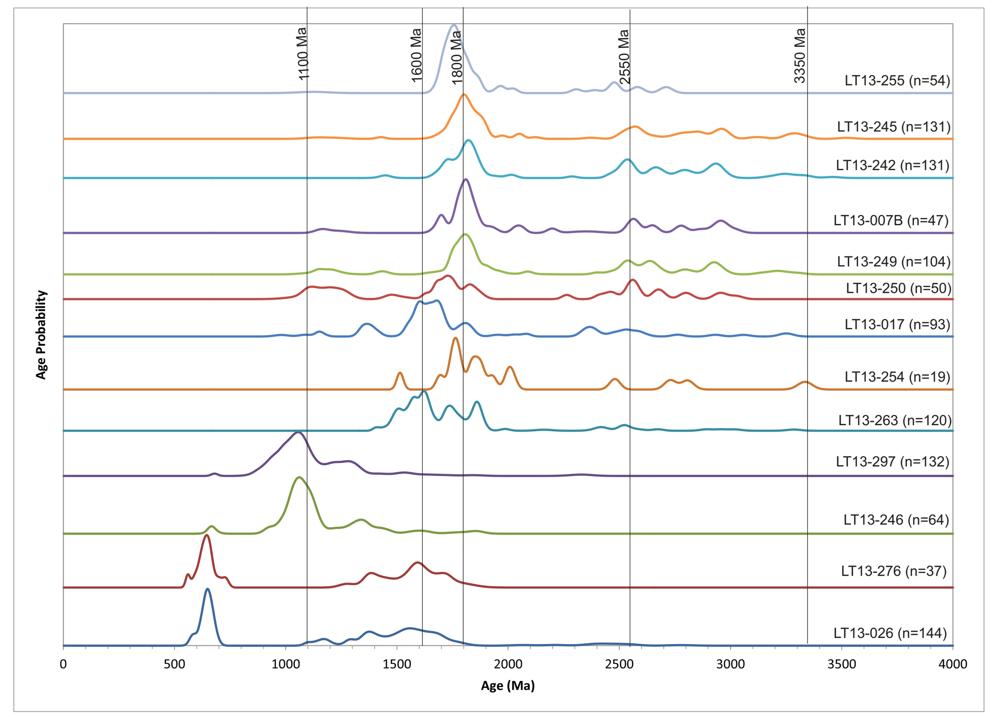


Fig. 6. Normalized probability plot of 12 detrital zircon samples. Samples are group together based on similar probability peaks.

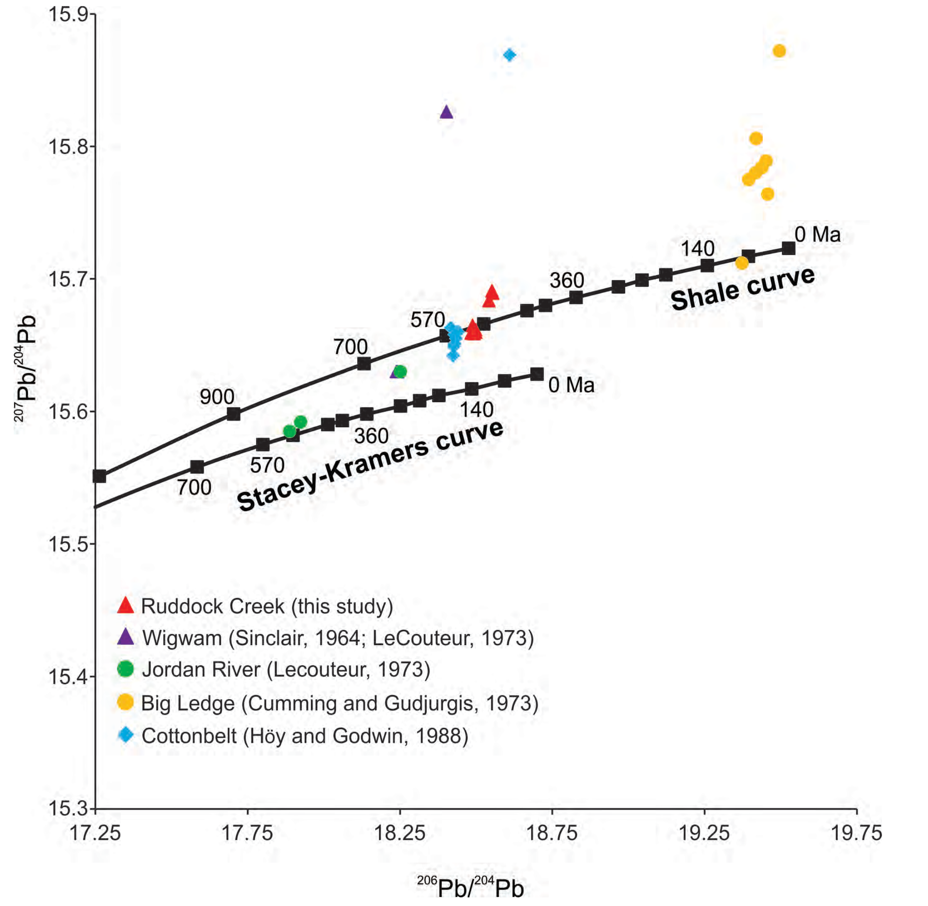


Fig. 7. Lead isotopic data for sulphides from MVT, SEDEX, and Vein deposits (after Nelson et al., 1991; Mortensen et al., 2006). The Ruddock Creek deposit data (red triangles) plot on and above the shale curve at approximately 525 Ma.

## Deformation Events

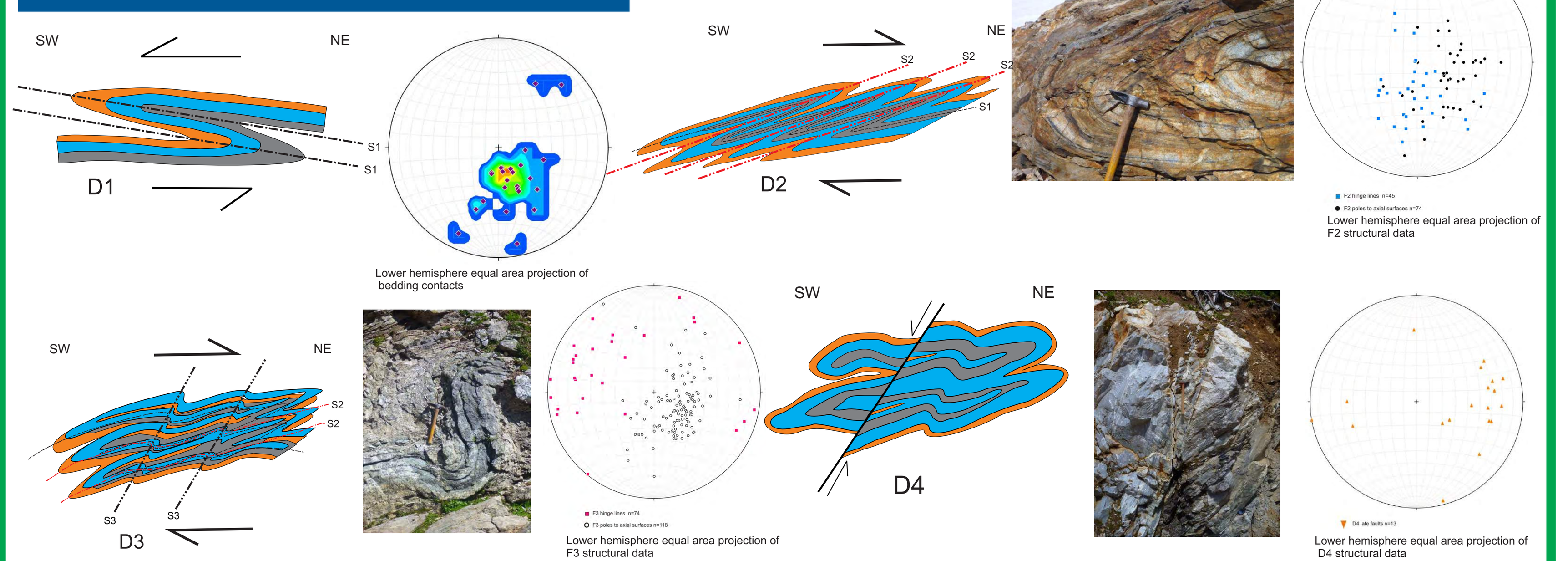


Fig 8. Deformation events that have affected the Ruddock Creek deposit. (a) Cartoon representation of the first phase of deformation (D1), SW-vergent kilometre-scale nappe folds (F1). F1 folds seen at property scale as rootless folds in the penetrative foliation. (b) Cartoon representation of the second phase of deformation (D2), characterized by overturned NE-vergent isoclinal folds that are shown in the photo. (c) Cartoon representation of the third phase of deformation (D3) that includes refolding of F2 folds into more open 'buckle' folds seen in the photo.(d) Cartoon representation of the fourth phase of deformation (D4), which consists of late brittle faults with minor observable offset (m's to 10's m)

## CL images

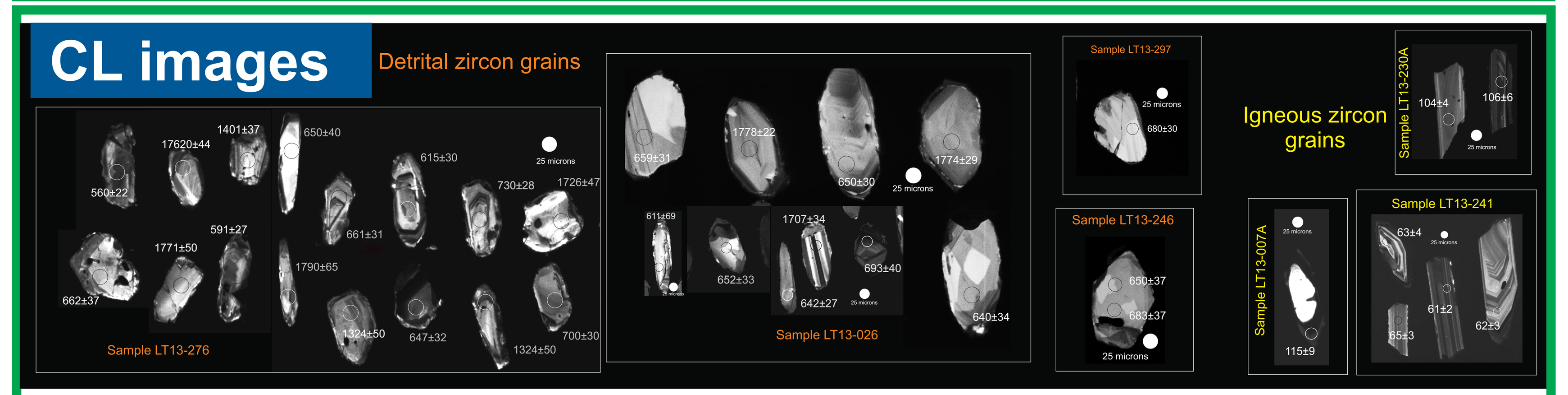


Fig. 9. Cathod luminesence images of detrital zircon grains from geochronological samples that yielded Neoproterozoic ages and igneous zircon ages.

## Key Findings and Future Work

The detrital zircon population from this study shows a temporal dichotomy. Four samples yielded a younger population of Neoproterozoic dates of ca. 650 Ma, with one analysis as young as 560 Ma, and older grains that include promnent peaks at ca. 1100 Ma and the typical Laurentian signatures with Meso- to Paleoproterozoic peaks at ca. 1500, 1700, 1800 and 2500 Ma. These data are consistent with the host lithologies of the Ruddock Creek deposit being part of the Windermere Supergroup, an interpretation previously made but never fully proven (Scammell, 1993). Furthermore, the age of the deposition of the Windermere Supergroup at this location may be no older than ca. 560 Ma, although this is based on a single age that needs to be further investigated. The 207Pb/204Pb model age of ca. 525 Ma provided by plotting the Pb isotopic data on the shale curve supports previous interpretations that the Ruddock Creek mineralized horizon was deposited syngenetically with the metasedimentary host rocks (Fyles, 1970; Scammell, 1993; Höy, 2001).

Two new showings were identified during mapping. The S Zone represents an extension of the upper limb of the overturned, recumbent D2 fold that controls the map-scale geometry and the K Zone represents an extension of the lower limb. These two new showings have helped confirm the working hypothesis that the geometry of the mineralized horizon, which serves nicely as a marker unit, is controlled by a map-scale Type-3 fold interference pattern (Fig.5). All the mineralized showings (E, F, G, T, U, Creek, Q, R, S, and K) (Fig.5) appear to be confined to a stratigraphic interval associated with the calc-silicate gneiss. These map patterns, confirmed by the two new showings, suggest that there are prospective targets yet to be found on the property within the tectonically thickened hinges of F2 folds to the west of the main E zone.

The complicated structural history of the Ruddock Creek deposit makes detailed structural mapping essential for determining its geological history and evaluating its economic potential. Within the Selkirk allochthon, the first phase of deformation (D1) is of kilometre-scale southwest-vergent folds. The second phase of folding overturned the first phase and produced a penetrative transposition foliation and is characterized by northeast-vergent isoclinal folds. Development of the regional transposition foliation and subsequent overprint by D3 deformation took place from 136 to 57 Ma (Scammell, 1993), which correlates with the timing put forward in this research. Map patterns observed during this research have suggested that the mineralized horizon has been subjected to all these phases of deformation. The fact that the deposit has been metamorphosed to upper amphibolite facies and polydeformed makes it very difficult to say with confidence what model the deposit would best fit. Based on the observations and data that were collected, the Ruddock Creek deposit seems to most closely fit that of a Broken Hill–type SEDEX deposit (Höy, 2001). Knowing the age and type of model that best characterizes the deposit could help with future exploration for similar deposits, possibly even along the length of the Cordillera. The presence of the Ruddock Creek deposit within the Windermere Supergroup suggests that this succession of rocks is a viable exploration target.

Future work for the project includes the creation of a detailed geological map, possibly more detrital zircon analyses and Sm-Nd and Rb-Sr analyses of the mineralized horizon with hopes of further constraining the time of ore genesis. Very few well defined ages have been produced for highly metamorphosed SEDEX-type deposits. Provided that the Sm-Nd and Rb-Sr isotopic systems have not been disrupted at the Ruddock Creek property, elucidating a Sm-Nd and Rb-Sr isochron could prove to be very instructive. Both sphalerite and fluorite from the main mineralized zone, the E zone, will be analysed. Not only could this method of dating the mineralization help constrain the genetic model for ore deposition at Ruddock Creek but it could also possibly provide a feasible method for dating highly metamorphosed SEDEX-type deposits.

The work included in this project is part of the senior author's master's thesis, which should be completed this summer.

## Acknowledgements

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