Re-evaluating the chronostratigraphic framework for felsic volcanic and intrusive rocks of the Finlayson Lake region, Yukon-Tanana terrane, Yukon

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ABSTRACT

The Finlayson Lake district contains >30 Mt of volcanogenic massive sulphide (VMS) mineralization, but has not been the focus of field-based research since the mid-2000s. We present herein preliminary fieldwork on Yukon-Tanana terrane (YTT) host rocks that are the groundwork for future petrologic, isotopic, and geochronologic studies of the stratigraphy and crustal evolution of the VMS deposits and YTT rocks in the Finlayson Lake region and other peri-Laurentian terranes of the northern Cordillera. During the summer of 2017, we logged seven drill holes that intersected the stratigraphic hanging walls and footwalls of the mafic-hosted Fyre Lake and felsic-hosted Kudz Ze Kayah and GP4F VMS deposits. The stratigraphic results generally reveal finely laminated to bedded mafic or felsic volcaniclastic rocks that are interbedded with clastic rocks or cut by intrusive rocks and reflect changes in depositional environments and tectonomagmatic regimes in the Late Devonian to Early Mississippian.

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INTRODUCTION

The Finlayson Lake district contains >30 Mt of polymetallic (Zn-Pb-Cu-Co-Au-Ag) volcanogenic massive sulphide (VMS) mineralization that has been discovered since the mid-1990s (Hunt, 1997; Peter *et al.*, 2007). Current exploration and development has been focused at the Kudz Ze Kayah Zn-Pb-Cu deposit and has resulted in a NI 43-101 compliant total geological resource of 19.2 Mt at 6.3% Zn, 1.9% Pb, 0.9% Cu, 148 g/t Ag, and 1.4 g/t Au (BMC Minerals Ltd.). Regional mapping and U-Pb ages completed in the late 1990s and early 2000s have defined stratigraphic domains and a tectonostratigraphic framework for the Kudz Ze Kayah and other VMS deposits in the district (Grant, 1997; Murphy and Piercey, 1999a,b; Murphy *et al.*, 2006); however, the petrological relationships and precise timing of sulphide deposition relative to nearby subvolcanic intrusions is not well understood.

Modern, high-precision U-Pb geochronology has been useful in constraining the of age of stratigraphic sequences, timing of mineralization, and relationships between intrusive and extrusive rocks in various VMS deposits worldwide (*e.g.*, Corfu *et al.*, 1989; Barrie *et al.*, 2002; Mortensen *et al.*, 2008; Piercey *et al.*, 2008; Rosa *et al.*, 2009; Eyuboglu *et al.*, 2014; Ross *et al.*, 2014). In addition, more recent studies have combined isotopic geochemistry with mineral-scale petrology to address critical knowledge gaps related to the fertility and prospectivity of mineral belts, and intrinsic parameters of the magmas that supply heat and/or metals to VMS deposits (*e.g.*, Wolverine VMS deposit; Piercey *et al.*, 2017). The integration of modern geochronological and geochemical techniques can also constrain the timing and petrological evolution of VMS-associated rocks, which may be useful to discriminate prospective from less prospective stratigraphic sequences globally (*e.g.*, Piercey, 2011).

In this paper, we provide new stratigraphic data for VMS mineralization in the Finlayson Lake district. This revised stratigraphic framework forms the basis for additional geochronological and lithogeochemical sampling undertaken in 2017. We present a compilation of mainly U-Pb zircon ages from the current geochronological database (Appendix 1) to evaluate the constraints on stratigraphic horizons that host mineralization in the district. This assessment sheds light on the overall paucity of robust U-Pb ages throughout the region, especially those in the Cleaver Lake and Money Creek thrust sheets, and the need for updated ages utilizing modern high-precision chemical abrasion-thermal ionization mass spectrometry (CA-TIMS) U-Pb techniques to better constrain the stratigraphic boundaries for VMS-bearing horizons. We also present new graphic logs from the Fire Lake, Kudz Ze Kayah, and Wind Lake formations, subject of detailed U-Pb sampling in 2017, and describe the research plan for future work in the region.

GEOLOGICAL SETTING

The Finlayson Lake region is an Upper Devonian to Lower Mississippian fault-bounded sliver of the peri-Laurentian Yukon-Tanana and Slide Mountain terranes located in southeastern Yukon (Fig. 1; Tempelman-Kluit, 1979; Mortensen and Jilson, 1985; Murphy *et al.*, 2006). The Yukon-Tanana stratigraphy comprises variably deformed,

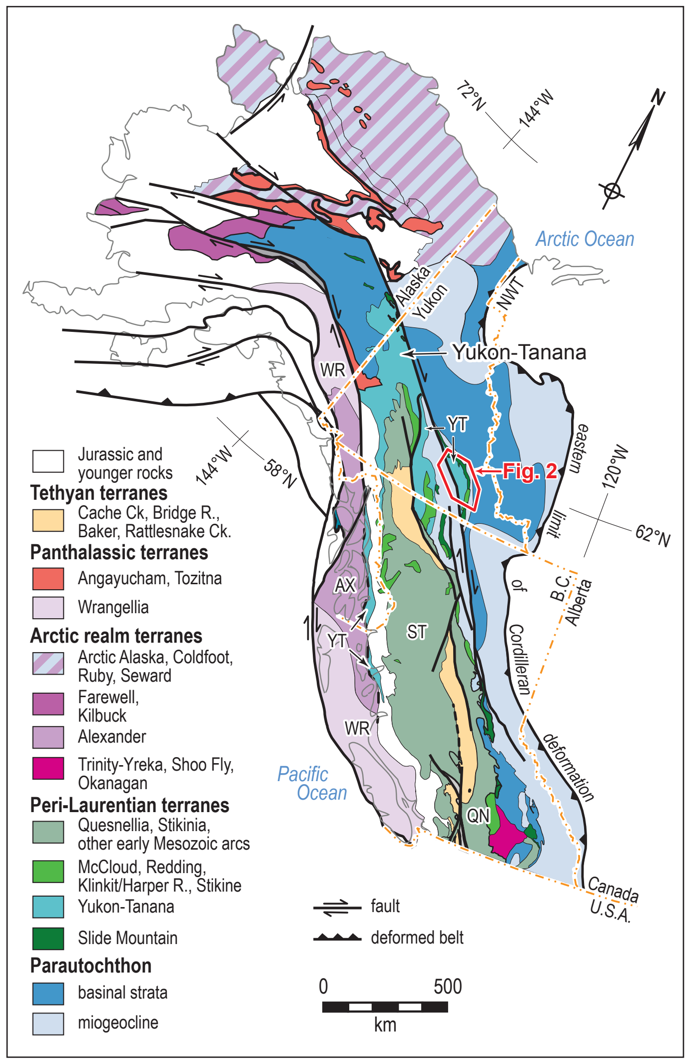

Figure 1. *Terranes of the northern Cordillera in British Columbia, Yukon and Alaska (modified after Colpron and Nelson, 2011). AX = Alexander, QN = Quesnellia, ST = Stikinia, YT = Yukon-Tanana, WR = Wrangellia.*

pervasively metamorphosed, and stratigraphically-intact volcanic, plutonic, and sedimentary rocks that were deposited or intruded above a pre to Late Devonian continental basement (*i.e.*, North River formation and Snowcap assemblage; Colpron *et al.*, 2006; Murphy *et al.*, 2006; Piercey and Colpron, 2009). The Yukon-Tanana rocks are separated from juvenile mafic volcanic rocks and basinal sedimentary rocks of the Slide Mountain terrane by the Jules Creek transform fault (Murphy *et al.*, 2006). The combined Yukon-Tanana and Slide Mountain rocks were thrust onto Laurentian continental margin strata, including Selwyn basin, along the Jurassic-Early Cretaceous Inconnu thrust following final accretion (Figs. 2 and 3; Murphy *et al.*, 2002). Rocks of the Yukon-Tanana terrane presently located in the Finlayson Lake district were subsequently displaced ~430 km south of the main part of the terrane along the Tintina strike-slip dextral fault in the Eocene (Fig. 1; Gabrielse *et al.*, 2006).

Rocks of the Yukon-Tanana terrane in the Finlayson Lake region comprise three fault-bounded stratigraphic successions confined to distinct structural panels: the Cleaver Lake, Money Creek, and Big Campbell thrust sheets, respectively (Figs. 2 and 3). The Cleaver Lake thrust sheet includes Upper Devonian to Lower Mississippian basalt and minor rhyolite, chert, and greywacke of the Cleaver Lake formation, which are intruded by Early Mississippian Simpson Range granitoid rocks and juxtaposed with ultramafic-mafic components from the Money and North klippen (Tempelman-Kluit, 1979; Piercey and Murphy, 2000; Murphy *et al.*, 2006). Rocks in the Money Creek thrust sheet comprise pre-Upper Devonian sedimentary rocks of the North River formation (also basement to the Big Campbell thrust sheet discussed below) that are stratigraphically overlain by predominantly felsic volcanic and deep marine sedimentary rocks of the Waters Creek formation and intruded by Simpson Range granitoid rocks. Intermediate to felsic volcanic, volcaniclastic, and epiclastic rocks of the Tuchitua River formation unconformably overlie the Waters Creek formation (Fig. 3). The Big Campbell thrust sheet contains North River formation metasiliciclastic rocks that precede Upper Devonian volcanism of the Grass Lakes group, which is unconformably overlain by the sedimentary and volcanic rocks of the Lower Mississippian Wolverine Lake group (Figs. 2, 3 and 4). The base of the Grass Lakes group consists of bimodal mafic and lesser felsic volcanic and volcaniclastic rocks of the Fire Lake formation that are associated with ultramafic-mafic rocks. These are overlain by felsic volcanic-volcaniclastic rocks of the Kudz Ze Kayah (KZK) formation, which have been intruded by Late-Devonian-Early Mississippian Grass Lakes granitoid rocks, and mafic volcanic rocks of the Wind Lake formation (Murphy, 1998; Murphy *et al.*, 2006). The Mississippian Wolverine Lake group unconformably overlies the Grass Lakes group and typically includes conglomerate to sandstone and felsic volcanic rocks that are capped by an extensive exhalite horizon and basalt (Figs. 3 and 4; Murphy and Piercey, 1999a, b; Bradshaw *et al.*, 2001, 2008; Murphy *et al.*, 2002).

The Big Campbell thrust sheet is host to most VMS deposits in the district. Mineralization is of variable style and hosted in different stratigraphic packages that reflect the dynamic mid-Paleozoic tectonomagmatic history of the district (Piercey *et al.*, 2001, 2006; Nelson *et al.*, 2006; Peter *et al.*, 2007). The Kudz Ze Kayah Zn-Pb-Cu and GP4F Zn-Pb deposits (Kudz Ze Kayah formation) are hosted by felsic volcanic host rocks of the Kudz Ze Kayah formation, whereas the Fyre Lake Cu-Co-Au and Ice Cu ± Zn deposits are part of mafic-dominated successions (Fire Lake and Campbell Range formations, respectively), and the Wolverine Zn-Pb-Cu-Ag-Au deposit is hosted by the volcano-sedimentary sequence of the Wolverine Lake group, which contains abundant shale and iron formation (Figs. 3 and 4; Piercey *et al.*, 2001, 2016; Sebert *et al.*, 2004; Peter *et al.*, 2007; Bradshaw *et al.*, 2008).

PREVIOUS WORK

LITHOGEOCHEMISTRY AND RADIOGENIC ISOTOPES

A number of studies over the past 30 years have contributed to the growing database of geochemical data in the Finlayson Lake region. The earliest work by Mortensen (1992) and Grant (1997) focused on U-Pb and radiogenic isotopic data for granitoid and other rocks in the district, and both illustrate that continental crustal material played a significant role in the formation of magmatic rocks throughout the region, and that basin sediments contained significant contributions from Precambrian crustal material. Integrated mapping, lithogeochemical, and radiogenic isotopic work on the felsic and mafic rocks in the district was undertaken Piercey (2001). Subsequent investigations of the felsic rocks revealed a distinct divide between typical calc-alkalic, I-type arc rocks and HFSE-REE-enriched, A-type back-arc rocks (Piercey *et al.*, 2001; 2003) that are both interpreted to have extensive crustal contamination from Precambrian basement domains.

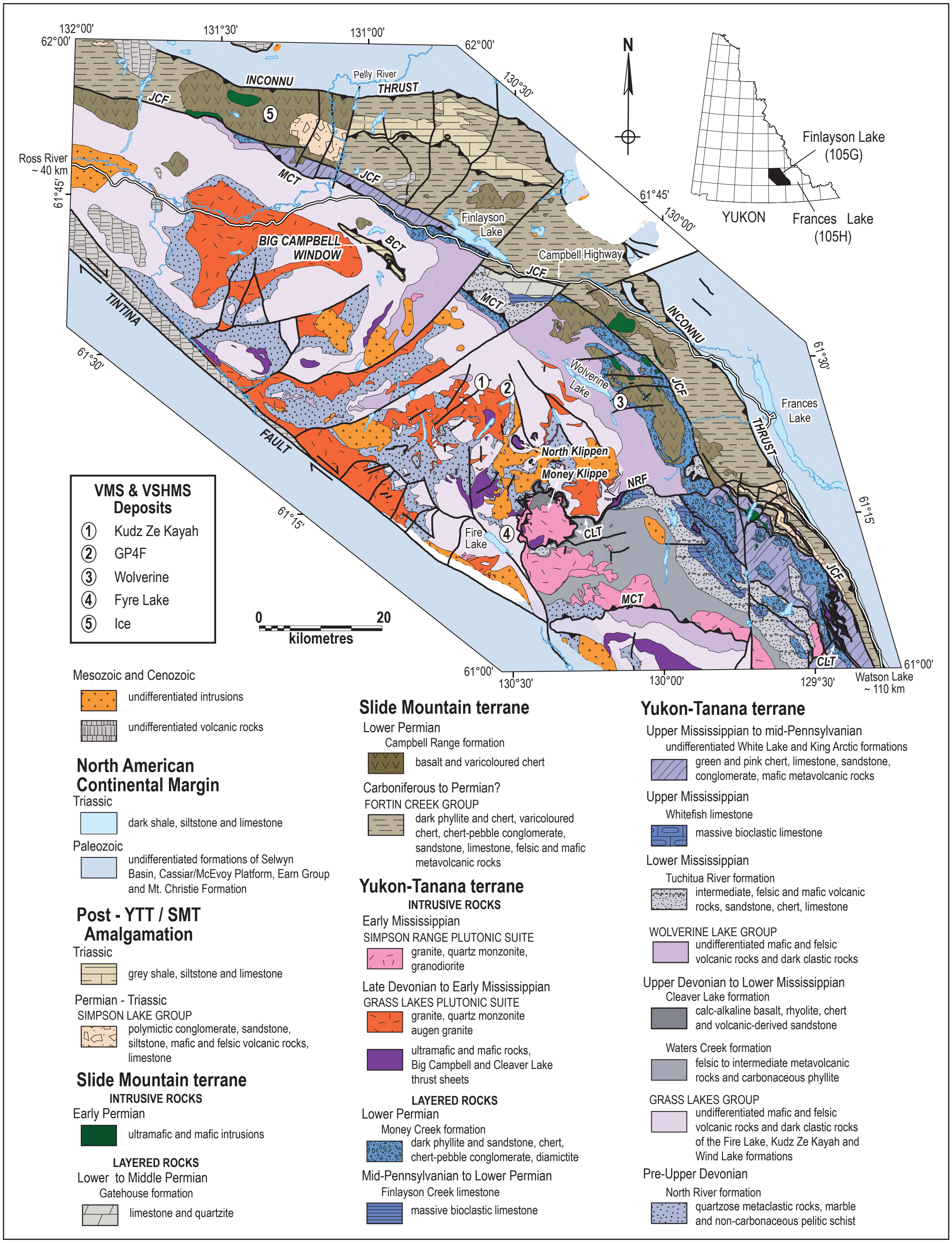

Figure 2. *Regional geologic setting of the Finlayson Lake region, Yukon-Tanana terrane (modified after Murphy et al., 2006). Numbers indicate locations of VMS deposits in the region. BCT=Big Campbell thrust; CLT=Cleaver Lake thrust; JCF=Jules Creek fault; MCT=Money Creek thrust; NRF=North River fault; VMS=volcanogenic massive sulphide; VSHMS=volcanic sediment-hosted massive sulphide.*

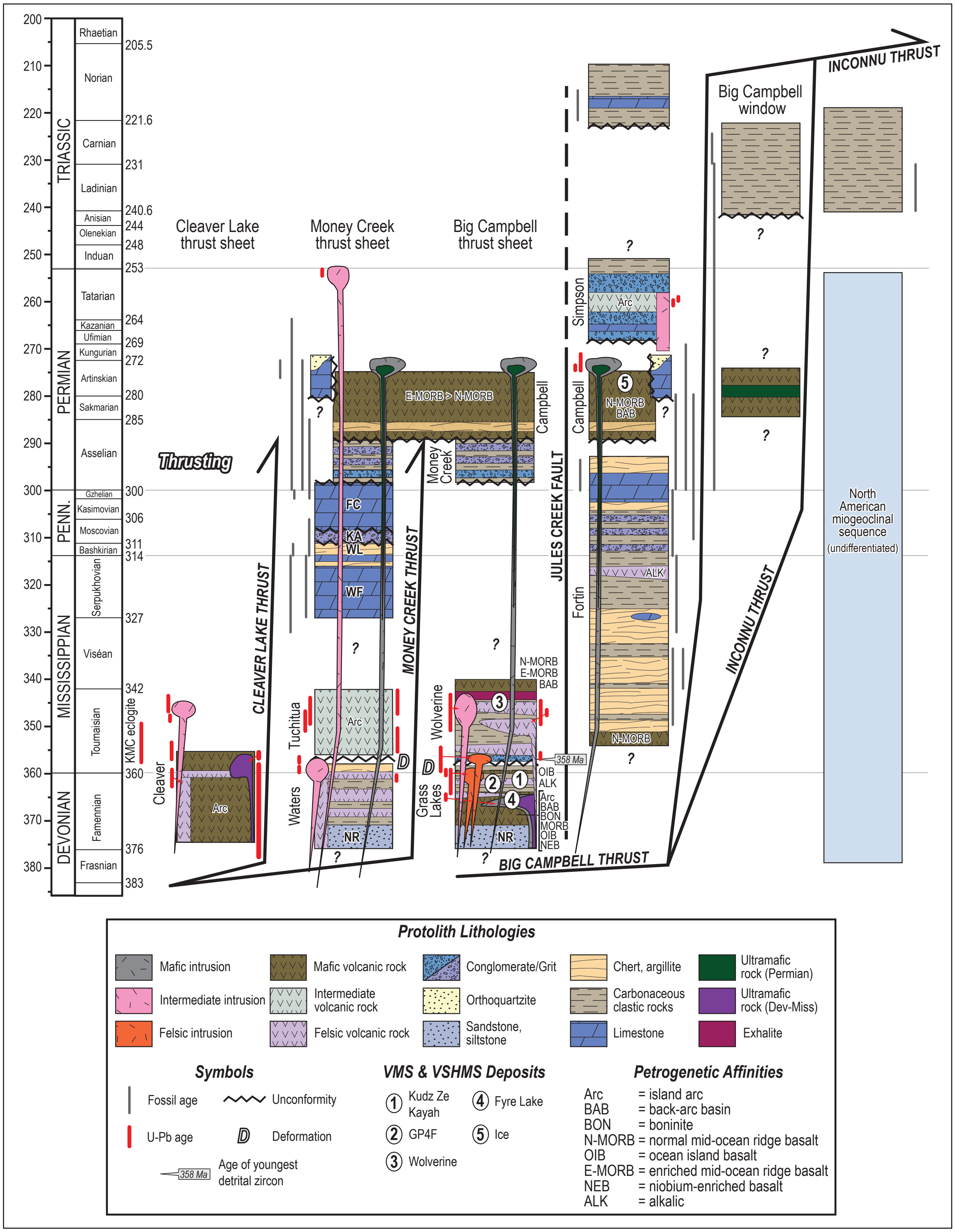

Figure 3. *Composite chronostratigraphic columns for the Finlayson Lake region with locations of VMS prospects, U-Pb zircon and fossil ages, and petrogenetic affinities (modified after Murphy et al., 2006). KMC=Klatsa Metamorphic Complex; NR=North River formation; Dev=Devonian; Miss=Mississippian.*

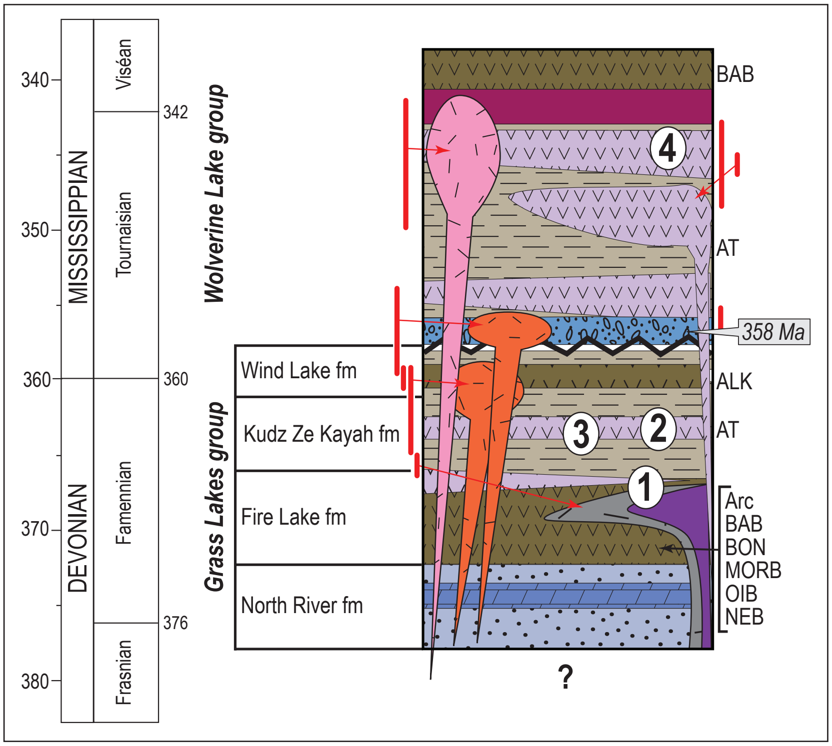

Figure 4. *Stratigraphic column for the Big Campbell thrust sheet (modified after Piercey et al., 2016). Petrogenetic affinity abbreviations as in Figure 3. Existing age constraints are indicated by red bars.*

Associated mafic volcanic rocks in this arc-back-arc setting exhibit petrogenetic affinities of alkalic ocean island basalt (OIB), low-Ti tholeiite to boninite, back-arc basin basalt (BABB), enriched mid-ocean ridge basalt (E-MORB; e.g., Fire Lake formation; Piercey *et al.*, 2002a,b; 2004), enriched and normal mid-ocean ridge basalt (E-, N-MORB) and back-arc basin basalts (BABB; e.g., Wolverine Lake group and Campbell Range basalts, Slide Mountain terrane; Piercey *et al.*, 2002c). The evolved Nd isotopic signature of felsic rocks (*i.e.*, $\varepsilon Nd_{(t)}<0$) in the district indicate significant Precambrian crustal contributions during evolution of the northern Cordillera (Piercey *et al.*, 2001, 2003). Conversely, juvenile isotopic compositions in mafic rocks (*i.e.*, $\varepsilon Nd_{(t)}>0$) represent components of mantle-derived material and shifts in tectonomagmatic affinities; however, these rocks are interpreted as minor additions to a predominantly evolved Cordilleran crust (Piercey *et al.*, 2004, 2012).

U-PB GEOCHRONOLOGY

Numerous studies have presented new geochronological data to constrain the age of stratigraphy in the Finlayson Lake region and its relationship to the rest of the Yukon-Tanana terrane (Mortensen, 1983, 1992, 2004, unpublished data; Grant, 1997; Piercey, 2001; Devine *et al.*, 2006; Murphy *et al.*, 2006; and Piercey *et al.*, 2008; Appendix 1; Fig. 5). While the first U-Pb ages for the Finlayson Lake district illustrated the host rocks were Paleozoic (*ca.* 360-351 Ma; Mortensen, 1983), they are excluded from discussion here for consistency because analyses were completed prior to the introduction of air-abrasion sample preparation (Krogh, 1982). Thirty-seven ages are reported for the Finlayson Lake region; analyses include air abrasion-isotope dilution-thermal ionization mass spectrometry (ID-TIMS) U-Pb zircon (n=33), ID-TIMS U-Pb titanite (n=1), sensitive high-resolution ion microprobe (SHRIMP) U-Pb zircon (n=3), and $^{40}Ar/^{39}Ar$ white mica (n=1) geochronology (Appendix 1; Fig. 5). Ages range from the Early Devonian (*ca.* 375 Ma) to the Late Permian (*ca.* 255 Ma; Figs. 3 and 5). Re-evaluation of these data indicate that the U-Pb analyses only broadly define the age of host stratigraphy and the timing of seafloor VMS formation (Fig. 5). In evaluating historic data, we assigned each age an objective rating (*i.e.*, uncertain, poor, good, moderate, excellent) based on the number of concordant *vs.* discordant fractions, inheritance and Pb-loss reported for these samples (Appendix 1).

Historic samples from the district provide a rough framework for magmatism, volcanism and sedimentation (Appendix 1). In the Big Campbell thrust sheet, these ages provide reasonable constraint for the Wolverine Lake group (*ca.* 356 to 346 Ma) and a possible upper limit of the Fire Lake formation (*ca.* 365 Ma), but do not define critical boundaries for VMS-bearing rocks of the Kudz Ze Kayah formation (Fig. 5). Ages determined for the Money Creek thrust sheet are relatively well-defined with clear breaks between the Waters Creek (*ca.* 360 Ma) and Tuchitua (*ca.* 352 to 347 Ma) formations, with Simpson Lake granitoid rocks intruding the Waters Creek formation at *ca.* 357 Ma. The Cleaver Lake thrust sheet contains the *ca.* 360 to 356 Ma Cleaver Lake formation and two intervals of magmatic activity represented by the Simpson Range plutonic suite (*ca.* 355 Ma and *ca.* 347 Ma). Despite a broad range of U-Pb ages presented here, new age analyses are needed to tighten the constraints on stratigraphic boundaries and timing of mineralization, which will provide an improved framework for future exploration in the district.

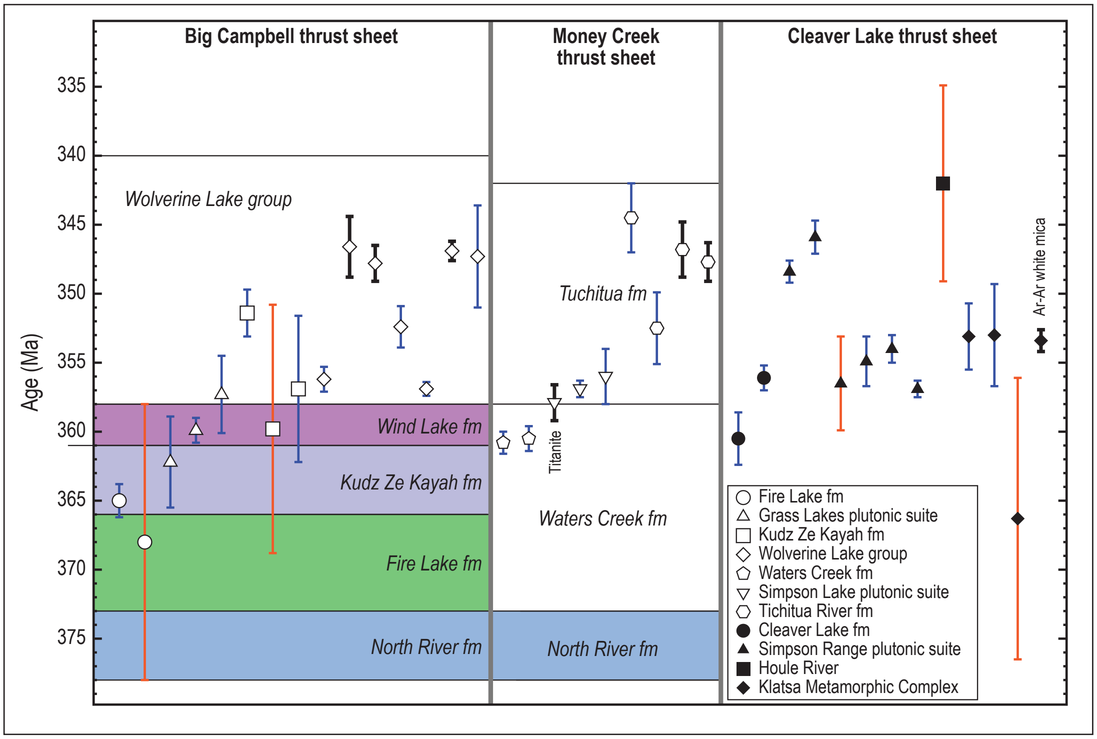

Figure 5. *Compilation of U-Pb zircon geochronology for rocks in the Finlayson Lake region. Ages from Mortensen (1992); Grant (1997); Piercey (2001); Mortensen (2004, unpublished data); Devine et al. (2006); Murphy et al. (2006); and Piercey et al. (2008; as in Appendix 1). Bold, black error bars indicate analyses of excellent quality; blue error bars are of moderate to good quality; and red bars indicate uncertain or poor quality that cannot discriminate between stratigraphic units.*

2017 FIELD STUDIES

The primary goals of the 2017 fieldwork were to map and sample the stratigraphy in the Finlayson Lake region, specifically the Big Campbell thrust sheet and deposit-bearing stratigraphy, for the purposes of: 1) refining the ages of stratigraphic horizons that host VMS deposits; and 2) determining the role of felsic magmatism in crustal growth of the northern Cordillera and, if possible, the formation of VMS deposits in the Yukon-Tanana terrane. Fieldwork was based out of the Kudz Ze Kayah exploration camp (BMC Minerals Ltd., 2017). Focused sampling of outcrop and drill core, combined with detailed stratigraphic logging, was completed on seven drill holes from the Kudz Ze Kayah (n=4), GP4F (n=1), and Fyre Lake (n=2) VMS deposits, with holes that intersected the stratigraphic hanging wall and footwall of each deposit (Figs. 6 and 7). Twelve U-Pb geochronology and 71 lithogeochemistry samples were collected at selected outcrops and from drill core intervals both above and below ore lenses. For the purposes of this paper, we will only discuss the stratigraphic results relevant to sampling for U-Pb geochronology.

STRATIGRAPHY

Grass Lakes group

Fire Lake formation

Two drill holes (FL96-39 and FL97-109) from the Fire Lake formation, where both intersected the Fyre Lake VMS lenses, were logged. Both sections contain a footwall sequence of bedded and variably deformed mafic volcaniclastic rocks (*e.g.*, mafic ash to lapilli tuff) associated with sulphide-magnetite lenses, (*e.g.*, Sebert *et al.* 2004). Drill hole FL96-39 contains two stacked, ~10-15 m sulphide lenses that are separated by ~35 m of mafic tuffaceous rocks with minor felsic material. The stratigraphic hanging wall to the sulphide lenses presents a transition from interbedded argillite, siltstone, and sandstone with mafic tuffaceous rocks grading into a fining-upwards sequence dominated by finely laminated to bedded black, grey, and/or white clastic rocks and argillite interpreted as turbidite deposits (Fig. 6).

Kudz Ze Kayah formation

Outcrop and drill holes from the Kudz Ze Kayah (n=3; K15-299, K15-301, K16-372) and nearby GP4F (n=1; K15-302) VMS deposits are dominated by felsic volcaniclastic rocks and lesser sedimentary rocks, which contrast with the mafic rocks of the Fire Lake (below) and Wind Lake formations (above; Fig. 4). Rocks that comprise the Kudz Ze Kayah deposit are primarily felsic volcaniclastic rocks with crosscutting intermediate to felsic intrusive rocks (rarely they have mafic compositions) throughout the hanging wall and footwall to the Kudz Ze Kayah VMS lenses (e.g., BMC Minerals Ltd., 2017).

The Kudz Ze Kayah deposit is contained within the >500 m thick Kudz Ze Kayah formation, which consists of a deeper footwall of fining-upwards sequences dominated by felsic crystal tuff to lapilli tuff intercalated with either laminated clastic pelitic rocks, felsic tuff with argillite, or rare mafic tuffaceous rocks; locally massive to amygdaloidal felsic volcanic rocks comprise parts of the footwall. In the GP4F deposit, the stratigraphic footwall consists of feldspar-blue quartz-eye crystal tuffs that are interbedded with finely laminated pelitic rocks near the contact with massive sulphides. The immediate hanging wall stratigraphy of the GP4F deposit contains variably lapilli and crystal-rich tuffaceous rocks that are interbedded with finely laminated biotite-calcite-rich pelitic rocks immediately above the GP4F sulphide zone. In the uppermost part of the Kudz Ze Kayah formation, the rocks are dominantly felsic tuffs to lapilli tuffs that dip shallowly to the north and are transitional with overlying mafic tuffs of the overlying Wind Lake formation.

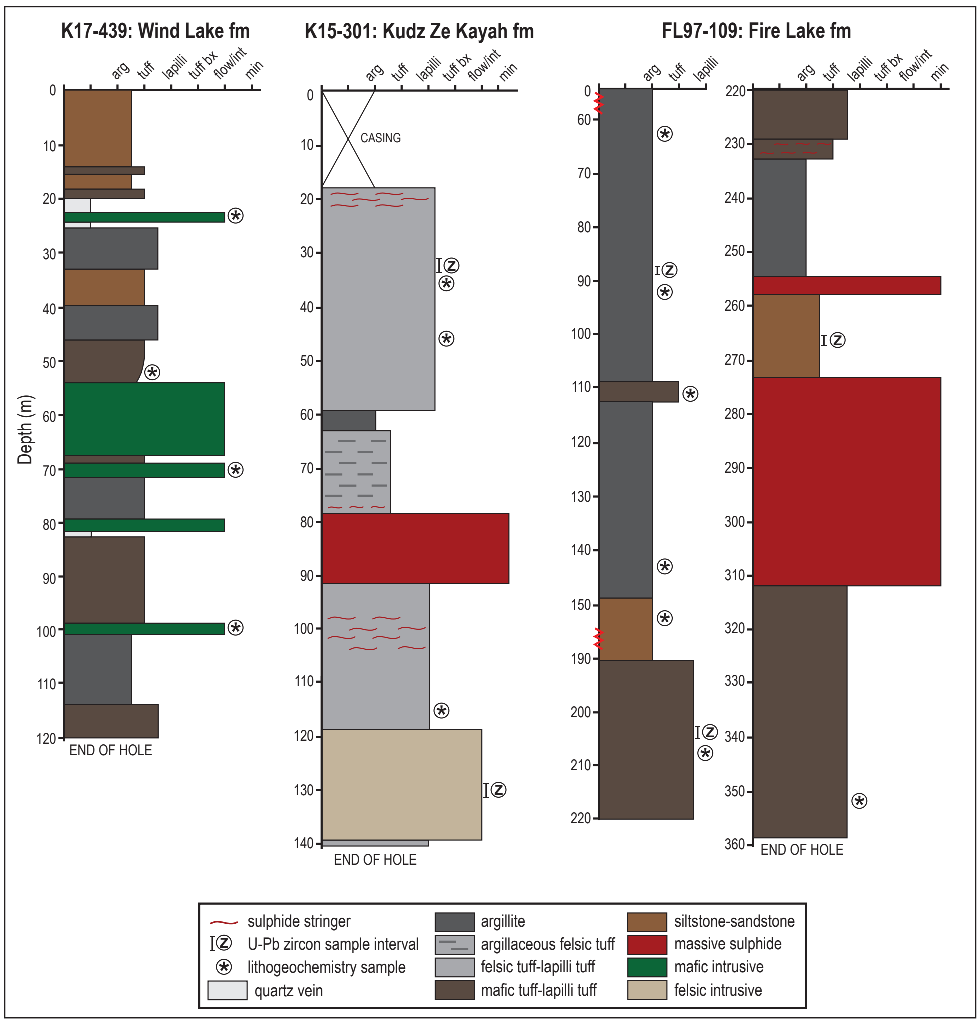

Figure 6. *Detailed stratigraphic logs and sampling locations for three representative drill holes through stratigraphy in the Wind Lake, Kudz Ze Kayah, and Fire Lake formations. Note the change in scale (red zig-zag line) for hole FL97-109, where units of the same lithology were shortened at 0-60 m and 150-190 m. Abbreviations: arg=argillite; bx=breccia; int=intrusion; min=mineralization.*

Both the Kudz Ze Kayah and GP4F deposits are cut by mafic and felsic intrusive rocks (dikes?) that are locally up to 30 m thick; some of the mafic intrusive rocks are potentially correlative with the Wind Lake formation. The lower and upper contacts of the Kudz Ze Kayah formation are cut by intrusive rocks of the Late Devonian-Early Mississippian Grass Lakes plutonic suite, which are shown to have comparable age and geochemical characteristics to rocks of the Kudz Ze Kayah formation (Piercey *et al.*, 2003).

Wind Lake formation

The Wind Lake formation overlies the Kudz Ze Kayah formation and represents a geochemical transition to dominantly mafic volcaniclastic rocks and argillaceous to quartz-rich sedimentary rocks (*e.g.*, Murphy, 1998; Murphy *et al.*, 2006; Fig. 6). Drill hole K17-439 shows dominantly mafic rocks that include interbedded, finely laminated mafic tuffaceous rocks with argillite that transitions uphole to greater abundances of siltstone, wacke, and lesser clastic material intercalated with mafic tuff and argillite (Fig. 6). Abundant biotite-rich mafic intrusive rocks have sharp contacts with tuffaceous rocks (*i.e.*, dikes or sills) and are thickest (~13.5 m) at the transition from mafic volcaniclastic rocks to coarser grained clastic to argillaceous rocks up section in the Wind Lake formation.

Grass Lakes plutonic suite

Rocks of the Late Devonian to Early Mississippian Grass Lakes plutonic suite intrude the entire Grass Lakes group stratigraphy, are texturally heterogeneous, and range from feldspar-quartz augen granites to feldspar-dominant porphyries with minor blue quartz eyes (*e.g.*, Murphy *et al.*, 2006; Figs. 4 and 7d,i). Both varieties are variably foliated and deformed with feldspar crystal modes between 10 and 40 vol.% and that have grain sizes between 2 and 30 mm.

Wolverine Lake group

The lowermost rocks of the Wolverine Lake group crop out approximately 80 m east of Grass Lakes granite outcrops and across an angular unconformity (Murphy and Piercey, 1999b; Murphy *et al.*, 2002). These rocks are strongly foliated quartz and feldspar-bearing felsic rocks (porphyry?) that contain relatively homogenous, 3-5 mm quartz and feldspar crystals (Fig. 7c).

SAMPLE DESCRIPTIONS

Grass Lakes group

Fire Lake formation

Two U-Pb geochronology samples from FL97-109 are sedimentary rocks (sand beds in siltstone, 17MM-043; siltstone between sulphide lenses, 17MM-049; Fig. 7j,l) that will be treated as detrital samples and analyzed using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) techniques, with the potential for follow-up CA-TIMS analyses to constrain maximum depositional ages. Sample 17MM-047 is a siliceous band (tuff?) intercalated with mafic volcaniclastic rocks where CA-TIMS methods will be utilized to constrain the upper limits of sulphide mineralization in the Fyre Lake deposit (Figs. 6 and 7k).

Kudz Ze Kayah formation

Sampling for U-Pb geochronology was restricted to outcrop and holes K15-301 (intersects massive sulphides) and K16-372 (footwall; Figs. 6 and 7b,e-h). A beige, blue quartz-eye felsic volcaniclastic rock (ash to local lapilli tuff) was collected ~5 m below the inferred Wind Lake formation contact to constrain the upper limit and last major phase of felsic volcanism in the hanging wall of the Kudz Ze Kayah formation (17MM-002; Fig. 7b). Approximately 50 m above the massive sulphides, a green to grey, felsic ash to lapilli tuff, with local lapilli stone is interpreted to record the minimum age for mineralization (17MM-031; Figs. 6 and 7e). Three additional intrusive rocks interpreted to cut primary stratigraphy were collected in the footwall of the Kudz Ze Kayah deposit (17MM-034, 17MM-060, and 17MM-061; Fig. 7f-h).

Wind Lake formation

One U-Pb sample (17MM-001) was collected from an outcrop approximately 300 m above the Kudz Ze Kayah contact. Here, a 40-cm section of beige to orange, foliated and locally laminated felsic ash tuff is intercalated with chlorite-rich mafic tuff and interpreted to represent the upper limit of volcanic activity for the Wind Lake formation (Fig. 7a).

Figure 7. *Field photographs of 2017 sampling locations for U-Pb zircon geochronology in the Big Campbell thrust sheet, Finlayson Lake region.* ***(a)*** *17MM-001: Wind Lake formation, felsic ash tuff interbedded with mafic ash tuff ~300 m above contact with Kudz Ze Kayah formation (413749E, 6815933N);* ***(b)*** *17MM-002: Kudz Ze Kayah formation, blue quartz-eye felsic volcaniclastic intercalated with ash tuff, ~ 5 m below the Wind Lake formation contact (413907E, 6815182N);* ***(c)*** *17MM-004: Wolverine Lake group, massive and foliated quartz-feldspar porphyry (429446E, 6812106N);* ***(d)*** *17MM-005: Grass Lakes plutonic suite, foliated and deformed, massive alkali feldspar-quartz augen granite (429291E, 6812095N);* ***(e)*** *17MM-031: Kudz Ze Kayah hanging wall (50 m above massive sulphides), felsic lapilli to ash tuff with local lapilli stone;* ***(f)*** *17MM-034: Kudz Ze Kayah footwall, quartz-sericite altered massive rhyolite intrusive;* ***(g)*** *17MM-060: biotite-chlorite altered mafic dike cross-cutting KZK footwall;* ***(h)*** *17MM-061: quartz-feldspar porphyry with rare blue quartz eyes that cuts KZK footwall;* ***(i)*** *17MM-062: Grass Lakes plutonic suite, quartz-feldspar porphyry;* ***(j)*** *17MM-043: Fyre Lake hanging wall, grey siltstone with intercalated sandy beds;* ***(k)*** *17MM-047: Fire Lake hanging wall, siliceous bands interbedded in mafic tuff; and* ***(l)*** *17MM-049: Fire Lake formation, siltstone between sulphide lenses. Hammer (35 cm) for scale in (a)-(d). Coordinates for specific locations noted in (a)-(d) above are UTM Zone 9N, NAD 83.*

Grass Lakes plutonic suite

Two U-Pb samples were collected from this unit. Sample 17MM-005 is a foliated and deformed to massive alkali feldspar-quartz augen granite from just below the inferred Wolverine Lake group unconformity (Fig. 7d; Murphy and Piercey, 1999b,c). Sample 17MM-062 is a quartz-feldspar porphyry with blue quartz eyes from the base of the Kudz Ze Kayah formation, at 580 m depth in drill hole K16-372 (Fig. 7i).

Wolverine Lake group

U-Pb sample 17MM-004 was collected from outcrop where it is interpreted to be the lowermost, thus oldest, rocks of the Wolverine Lake group (Fig. 7c). This will test the existing detrital zircon data by Murphy *et al*. (2006) which indicated a maximum depositional age of 358 Ma for a basal conglomerate of the Wolverine Lake group (Figs. 3 and 4).

FUTURE RESEARCH

CHEMICAL ABRASION ID-TIMS U-PB ZIRCON GEOCHRONOLOGY

A review of historical U-Pb zircon dates reveals a knowledge gap when defining the chronostratigraphic framework for VMS mineralization in the Finlayson Lake region.

Air abrasion treatment of zircon was the typical sample preparation technique used for these samples from the 1980s to 2000s, a method which removed the U+Th-rich rims of zircon to lessen the effects Pb-loss and produce more concordant and thus geologically significant ages (Krogh, 1982). Recent advances in chemical abrasion techniques (CA-TIMS) have increased our ability to remove high U+Th domains within the internal structure of zircon by thermal annealing and stepwise chemical leaching (Mattinson, 2005). The result is increased precision down to 0.1% (or better) and capability to analyze closed-system zircon with relatively low levels of initial U and Th (Mattinson, 2005; Schmitz and Kuiper, 2013). Utilization of the CA-TIMS method on felsic rocks of the Finlayson Lake region will considerably increase our confidence in the chronostratigraphic framework for mineralization, the timing of mineralization, and the duration of magmatic activity. These results will provide key information that may aid future exploration in the region.

LITHOGEOCHEMISTRY, BULK ROCK AND *IN SITU* HF-ND ISOTOPES

Rocks in the Finlayson Lake region display a wide range of geochemical characteristics and petrogenetic affinities that reflect distinct tectonic regimes during the Late Paleozoic (Piercey *et al*., 2001, 2002a,b, 2003, 2004, 2006, 2012). New drill core, most notably from the ongoing projects of BMC Minerals Ltd. at Kudz Ze Kayah and GP4F, has allowed us to access previously unavailable parts of the Grass Lakes group stratigraphy for ancillary geochemical sampling. A subset of the samples will be analyzed for major and trace element lithogeochemical analysis to properly place these rocks in a petrogenetic context. In addition, whole-rock Hf-Nd radiogenic isotopic analyses will be undertaken to complement existing Nd isotopic data (*e.g.*, Piercey *et al*. 2003). At a smaller scale, we will also begin a comprehensive mineral separation program to remove zircon, monazite, and apatite from select samples for *in situ* laser ablation split stream (LASS) Lu-Hf and U-Pb (zircon) and Sm-Nd and U-Pb (monazite, apatite) isotopic analyses at Memorial University of Newfoundland. Integration of these methods will aim to link new field observations with lithogeochemical and *in situ* analyses to evaluate petrogenetic processes and the intensive parameters of magma generation (*e.g.*, temperature of emplacement, redox state, sulphur budget) and the extent of mantle *vs.* crustal contributions to formation of felsic rocks (both VMS-bearing and barren suites). Isotopic analyses of felsic rocks will provide new insight in evolved magmatism and crustal growth in Paleozoic terranes of the northern Cordillera, and add to the existing regional framework for direct comparison and refinement of tectonic models for the Finlayson Lake region and the Yukon-Tanana terrane.

CONCLUSIONS

1) The level of exposure in the Finlayson Lake region, coupled with stratigraphically controlled drill core, provide exceptional opportunities to study the age and geochemistry of the VMS stratigraphy of the Finlayson Lake region and test existing tectonic and metallogenic models for the district.
2) New high-precision chemical abrasion ID-TIMS U-Pb zircon geochronology is needed to constrain the VMS-bearing and barren stratigraphy, and timing of VMS mineralization in the district.

3) New stratigraphic logging has allowed us to accurately place U-Pb and lithogeochemical samples in stratigraphic context relative to VMS mineralization.

4) Future work will include high-precision U-Pb zircon geochronology, *in situ* and whole-rock radiogenic isotopic techniques, and major and trace element lithogeochemistry to address the petrology of felsic rocks and their relation to crustal growth of the northern Cordillera.

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Appendix 1. *Geochronology compilation from the Finlayson Lake region, Yukon.*

Sample[1]	Thrust Sheet	Unit	Age (Ma)	Error (2σ)	Analysis Comments	Quality	Method[2]	Reference
HD-35	Big Campbell	Fire Lake formation	365	1.2	3-point discordant array	Moderate	ID-TIMS	Murphy et al. (2006)
96DM-065	Big Campbell	Fire Lake formation	366.3	10.2	Highly discordant	Poor	ID-TIMS	Murphy et al. (2006)
98DM-088	Big Campbell	Grass Lakes plutonic suite	362.2	3.3	3-point weighted Pb-Pb of Pb-loss discordia	Moderate	ID-TIMS	Murphy et al. (2006)
GG-19	Big Campbell	Grass Lakes plutonic suite	359.9	0.9	1 concordant fraction; Pb-loss and inheritance	Good	ID-TIMS	Murphy et al. (2006)
96DM-119	Big Campbell	Grass Lakes plutonic suite	357.3	2.8	4-point Pb-loss discordia with Pb-Pb weighted age	Moderate	ID-TIMS	Murphy et al. (2006)
FV-49	Big Campbell	Kudz Ze Kayah formation	351.4	1.7	Uncertain	Uncertain	ID-TIMS	Mortensen, unpublished data (2004)
FV-16	Big Campbell	Kudz Ze Kayah formation	359.8	9	Uncertain	Uncertain	ID-TIMS	Mortensen, unpublished data (2004)
P98-KZK2	Big Campbell	Kudz Ze Kayah formation	356.9	5.3	6-point discordia; Pb-loss and inheritence	Good	ID-TIMS	Piercey (2001)
FV-21	Big Campbell	Wolverine Lake group	356.2	0.9	1 concordant fraction; inheritance in 3 fractions	Good	ID-TIMS	Murphy et al. (2006)
P98-069A	Big Campbell	Wolverine Lake group	346.6	2.2	3 concordant fractions	Excellent	ID-TIMS	Piercey et al. (2008)
WW-00-01	Big Campbell	Wolverine Lake group	347.8	1.3	2 concordant fractions	Excellent	ID-TIMS	Piercey et al. (2008)
Sable	Big Campbell	Wolverine Lake group	352.4	1.5	2 concordant fractions; Pb-loss and inheritance	Moderate	ID-TIMS	Piercey et al. (2008)
Puck	Big Campbell	Wolverine Lake group	356.9	0.5	1 concordant fraction, potential inheritance	Good	ID-TIMS	Piercey et al. (2008)
GP4F-1	Big Campbell	Wolverine Lake group	346.9	0.7	2 concordant fractions; Pb-loss in 4 fractions	Excellent	ID-TIMS	Murphy et al. (2006)
98DM-GDR	Big Campbell	Wolverine Lake group	347.3	3.7	2-point discordia, Pb-Pb weighted age; Pb-loss array	Moderate	ID-TIMS	Murphy et al. (2006)
FV-27	Money Creek	Waters Creek formation	360.8	0.8	3-point discordia; inheritance	Moderate	ID-TIMS	Murphy et al. (2006)
Sample 2	Money Creek	Waters Creek formation	360.5	0.9	5-point discordia; inheritance	Moderate	ID-TIMS	Mortensen (1992)
SL-45*	Money Creek	Simpson Lake plutonic suite	357.9	1.3	2 condordant fractions	Excellent	ID-TIMS	Murphy et al. (2006)
TRP-22	Money Creek	Simpson Lake plutonic suite	356.9	0.6	1 concordant fraction	Good	ID-TIMS	Murphy et al. (2006)
ARG-32	Money Creek	Simpson Lake plutonic suite	356	2.0	4-point Pb-loss discordia with Pb-Pb weighted age	Moderate	ID-TIMS	Mortensen, unpublished data (2004)
01DM-238	Money Creek	Tichitua River formation	344.5	2.5	3-point discordia; inheritance	Moderate	ID-TIMS	Murphy et al. (2006)
PR-21	Money Creek	Tichitua River formation	352.5	2.6	1 concordant fraction	Good	ID-TIMS	Murphy et al. (2006)
03DM-022	Money Creek	Tichitua River formation	346.8	2.0	2 concordant fractions	Excellent	ID-TIMS	Murphy et al. (2006)
03DM-023	Money Creek	Tichitua River formation	347.7	1.4	3 concordant fractions	Excellent	ID-TIMS	Murphy et al. (2006)
QP-30	Cleaver Lake	Unnamed	360.5	1.9	Uncertain	Uncertain	ID-TIMS	Mortensen (1992)
ARG-32	Cleaver Lake	Unnamed	356.1	0.9	Pb-Pb discordia; Pb-loss	Moderate	ID-TIMS	Murphy et al. (2006)
SA-02	Cleaver Lake	Simpson Range plutonic suite	348.4	0.8	3-point lower intercept	Moderate	ID-TIMS	Murphy et al. (2006)
SG94-14	Cleaver Lake	Simpson Range plutonic suite	345.9	1.2	3-point discordia; inheritance	Moderate	ID-TIMS	Grant (1997)
SG94-11	Cleaver Lake	Simpson Range plutonic suite	356.5	3.4	2-point discordia; inheritance	Poor	ID-TIMS	Grant (1997)

Appendix 1 continued.

Sample[1]	Thrust Sheet	Unit	Age (Ma)	Error (2σ)	Analysis Comments	Quality	Method[2]	Reference
SA-28	Cleaver Lake	Simpson Range plutonic suite	354.9	1.8	Pb-Pb discordia; Pb-loss	Moderate	ID-TIMS	Murphy et al. (2006)
TRP-22	Cleaver Lake	Simpson Range plutonic suite	354	1.0	Uncertain	Uncertain	ID-TIMS	Mortensen, unpublished data (2004)
TRP-22	Cleaver Lake	Simpson Range plutonic suite	356.9	0.6	Uncertain	Uncertain	ID-TIMS	Mortensen, unpublished data (2004)
AG-48	Cleaver Lake	Hoole River orthogneiss	342	7.1	Uncertain	Uncertain	ID-TIMS	Mortensen, unpublished data (2004)
03FD039-2	Cleaver Lake	Klatsa Metamorphic Complex	353.1	2.4	Metamorphic overgrowths; inverse isochron; age of metamorphism	Moderate	SHRIMP	Devine et al. (2006)
03FD056-2	Cleaver Lake	Klatsa Metamorphic Complex	353	3.7	Metamorphic overgrowths; inverse isochron; age of metamorphism	Moderate	SHRIMP	Devine et al. (2006)
03FD231-1	Cleaver Lake	Klatsa Metamorphic Complex	368	10	Igneous cores; large errors	Poor	SHRIMP	Devine et al. (2006)
03FD039-2**	Cleaver Lake	Klatsa Metamorphic Complex	353.4	0.79	Ar-Ar white mica; plateau age; exhumation age	Excellent	Laser NG-MS	Devine et al. (2006)

Notes: 1 Analyses are U-Pb zircon geochronology unless noted: *=U-Pb titanite; **=$^{40}Ar/^{39}Ar$ white mica.
2 ID-TIMS = isotope dilution-thermal ionization spectrometry (air abrasion); SHRIMP = sensitive high-resolution ion microprobe; Laser NG-MS = laser noble gas mass spectrometry.