Devonian-Mississippian metavolcanic stratigraphy, massive sulphide potential and structural re-interpretation of Yukon-Tanana Terrane south of the Finlayson Lake massive sulphide district, southeastern Yukon (105G/1, 105H/3,4,5)

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ABSTRACT

Upper Devonian and Lower Mississippian metavolcanic rocks of Yukon-Tanana Terrane in southern Finlayson Lake and Frances Lake map areas occur in three thrust sheets, locally modified by a Cretaceous normal fault. The lower thrust sheet, the Big Campbell sheet, comprises the Upper Devonian to Lower Mississippian metavolcanic stratigraphy that hosts the main volcanic-hosted massive sulphide (VHMS) deposits of the district. Metavolcanic rocks in the middle thrust sheet, the Money Creek sheet, include the Upper Devonian Waters Creek and Early Mississippian Tuchitua River formations. The former comprises primarily felsic metavolcanic rocks and carbonaceous phyllite and is extensively intruded by sheets of comagmatic porphyry. The latter comprises primarily intermediate metavolcanic, volcaniclastic and epiclastic rocks. The upper thrust sheet, the Cleaver Lake sheet, is in part made up of Late Devonian calc-alkaline basalt and rhyolite, the Cleaver Lake formation, and comagmatic felsic to ultramafic plutonic rocks. Of these, the Waters Creek formation and the formations in the Big Campbell sheet have the highest potential to host VHMS deposits.

RÉSUMÉ

Les roches métavolcaniques du Dévonien supérieur et du Mississippien inférieur du terrane de Yukon-Tanana dans le sud des régions cartographiques de Finlayson Lake et de Frances Lake forment trois nappes de charriage, localement modifiées par une faille normale du Crétacé. La nappe basale de Big Campbell comprend les formations métavolcaniques du Dévonien supérieur au Mississippien inférieur où l'on trouve les principaux gisements de sulfures massifs dans des roches volcaniques du district. Les roches métavolcaniques de la nappe intermédiaire, Money Creek, incluent les formations de Waters Creek du Dévonien supérieur et de Tuchitua River du Mississippien précoce. La première se compose principalement de roches métavolcaniques felsiques et de phyllades carbonées et elle est injectée de part en part de nappes de porphyre comagmatique. La dernière se compose principalement de roches métavolcaniques, volcanoclastiques et épiclastiques intermédiaires. La nappe de Cleaver Lake supérieure est, en partie, composée de basalte et de rhyolite calco-alcalins du Dévonien tardif, de la formation de Cleaver Lake et de roches plutoniques felsiques à ultramafiques comagmatiques. La formation de Waters Creek et les formations de la nappe de Big Campbell offrent le potentiel le plus élevé de receler des gîtes de sulfures massifs dans des roches volcaniques.

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INTRODUCTION

Recent work in the Finlayson Lake massive sulphide district of southeastern Yukon (FLD; Fig. 1) has established the geological settings of the volcanic-hosted massive sulphide (VHMS) deposits that define the district (Murphy et al., 2002, Fig. 2, 3). With the exception of the Ice deposit which is hosted by basalt of the Permian Campbell Range formation[1], the deposits of the FLD (Fyre Lake, Kudz Ze Kayah, GP4F and Wolverine) are hosted in Upper Devonian and Lower Mississippian metavolcanic rocks of the Grass Lakes and Wolverine Lake groups. These prospective stratigraphic units have geochemical signatures indicating deposition in an extensional setting in the back-arc region of a magmatic arc built primarily on sialic basement (Piercey, 2001; Piercey et al., 2000a,b, 2001, 2002, 2003). These units occur in the structurally deepest part of the imbricated Yukon-Tanana Terrane, in the footwall of the Money Creek thrust, an Early Permian thrust fault with greater than 35 km of northeast-directed displacement (Murphy and Piercey, 2000a,b; Murphy et al., 2003).

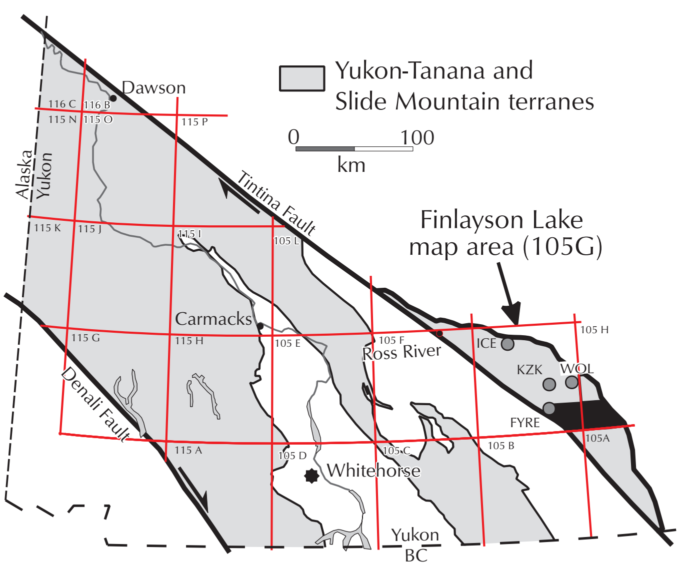


Figure 1. *Distribution of Yukon-Tanana and Slide Mountain terranes in Yukon. Area of interest south of the Finlayson Lake massive sulphide district is indicated in black. Locations of Ice (ICE), Kudz Ze Kayah (KZK), Fyre Lake (FYRE) and Woverine (WOL) volcanic-hosted massive sulphide deposits are shown with small circles.*

Devonian and Mississippian volcanic rocks also occur south of the FLD in both the hanging wall and footwall of the Money Creek thrust (Murphy and Piercey, 2000a,b), but their character and distribution have not yet been fully documented and their potential to host VHMS deposits has not been evaluated. Fieldwork in 2003 was focused on the southern part of Finlayson Lake (105G/1) and Frances Lake map areas (105H/4) in order to document the nature of these rocks and their relationships to other rocks in the area. In the process of mapping in this area, new insights into the age and geometry of faults within Yukon-Tanana Terrane were also gained. In this paper, the nature of the metavolcanic successions south of the FLD is described, a new interpretation of the age and geometry of the major intra-terrane faults of Yukon-Tanana Terrane is presented, and a preliminary evaluation of the geological setting and potential to host VHMS deposits of the metavolcanic rocks in this area is made.

YUKON-TANANA TERRANE, FINLAYSON LAKE MASSIVE SULPHIDE DISTRICT: AN UPDATE

The most recent interpretation of the extent of Yukon-Tanana Terrane (YTT) in the Finlayson Lake massive sulphide district (FLD) is shown in Figure 2. This interpretation differs from previous interpretations (Murphy et al., 2002, 2003) in three main ways. First of all, owing to their basinal character and lithological similarity to parts of the Sylvester Allochthon of Slide Mountain Terrane (Nelson, 1993), the rocks of the Fortin Creek group (Finlayson succession of Murphy et al., 2002) have been re-interpreted as belonging to Slide Mountain Terrane. Secondly, the Lower Permian Campbell Range formation and affiliated mafic and ultramafic plutonic rocks, deposited/intruded on/into both YTT and the Fortin Creek group, are interpreted as the magmatic products associated with 'leaky' transform displacement on the Jules Creek fault, the fault juxtaposing the two terranes. Hence, they represent an overlap assemblage on the two terranes, and an onlap of the ocean floor environment typical of Slide Mountain Terrane onto YTT. Therefore, they have been assigned to the Slide Mountain Assemblage, rather than the Slide Mountain Terrane. Thirdly, owing to their lithological similarity to the Campbell Range formation, and their uncertain pre-Triassic relationships to surrounding rocks of YTT, the pre-Triassic mafic volcanic rocks and ultramafic rocks in the structural window in Big Campbell Creek have been assigned to Slide Mountain Terrane.

[1]Informal stratigraphic nomenclature used herein will be defined in upcoming bulletin.

In this new interpretation, rocks belonging to YTT in the FLD comprise all the rocks older than the Lower Permian Campbell Range formation south and west of the Jules Creek fault (Fig. 2). These rocks have been subdivided into several fault- and unconformity-bound metasedimentary and metavolcanic successions and affiliated metaplutonic suites (Fig. 3, Murphy et al., 2002, 2003). The structurally deepest rocks, and those that host the majority of the VHMS deposits of the district, are in the Big Campbell thrust sheet, bound below by the Big Campbell thrust, and above by the Money Creek thrust. These include the Upper Devonian and older Grass Lakes group and affiliated metaplutonic rocks, and the unconformably overlying Lower Mississippian Wolverine Lake group and affiliated metaplutonic rocks. The unconformably overlying Lower Permian Money Creek formation, previously considered to overlie and therefore post-date the Money Creek thrust (Murphy et al., 2002, 2003), is now inferred to have been offset by the thrust based on a re-interpretation of its geometry. Rocks in the hanging wall of the Money Creek thrust include metavolcanic and metaplutonic rocks coeval with those of the footwall but primarily of intermediate composition, Upper Mississippian to Lower Permian limestone, and

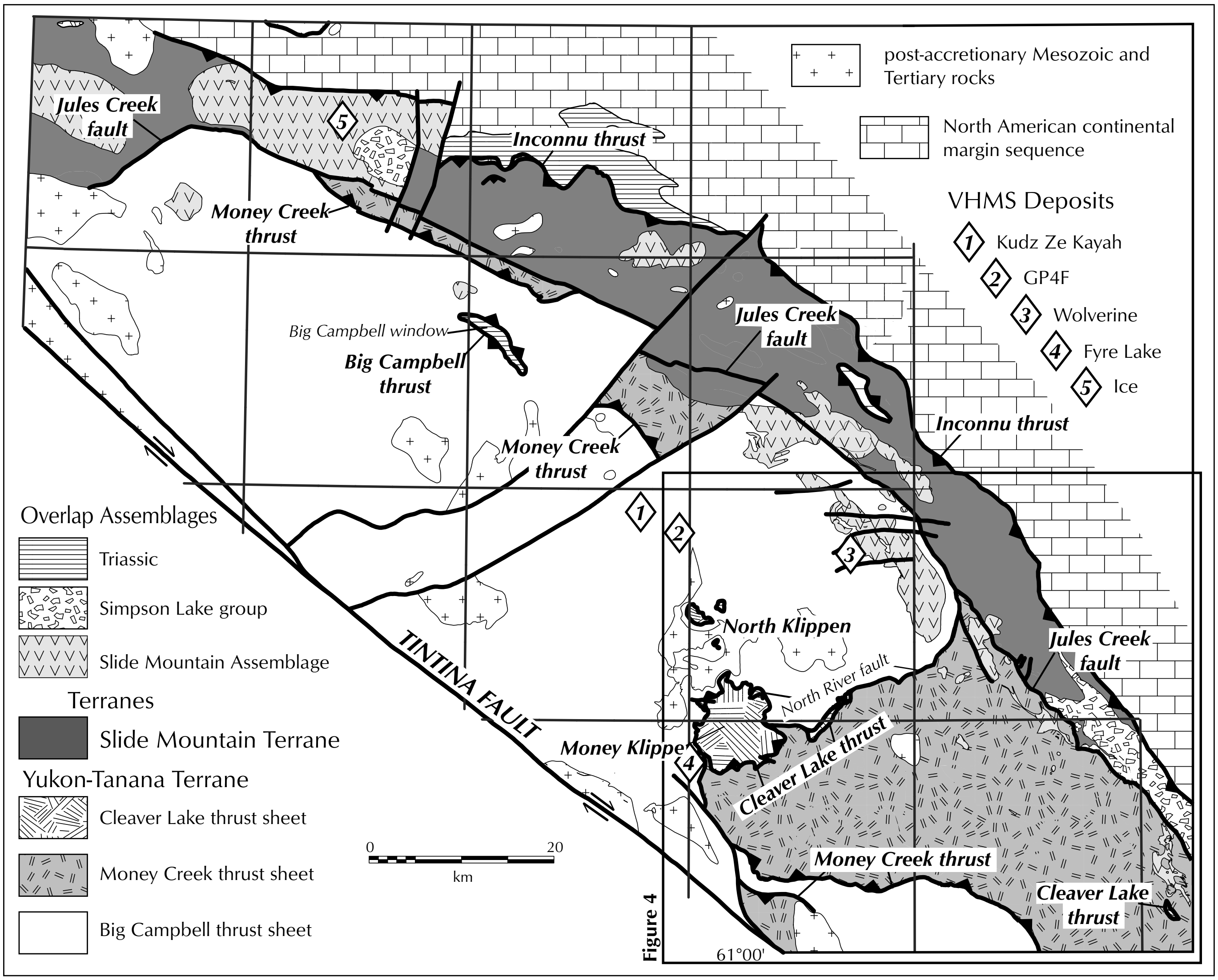


Figure 2. *Terranes and assemblages of the Finlayson Lake massive sulphide district. Yukon-Tanana Terrane is subdivided into its component thrust sheets, the lowest Big Campbell thrust sheet in the hanging wall of the post-Late Triassic Big Campbell thrust, the middle, Money Creek thrust sheet and the upper, Cleaver Lake thrust sheet, the latter two having formed in the Early Permian. Big Campbell window comprises both Triassic clastic rocks and mafic and ultramafic rocks of Slide Mountain Terrane; the area of these latter rocks is too small to portray at the scale of this map.*

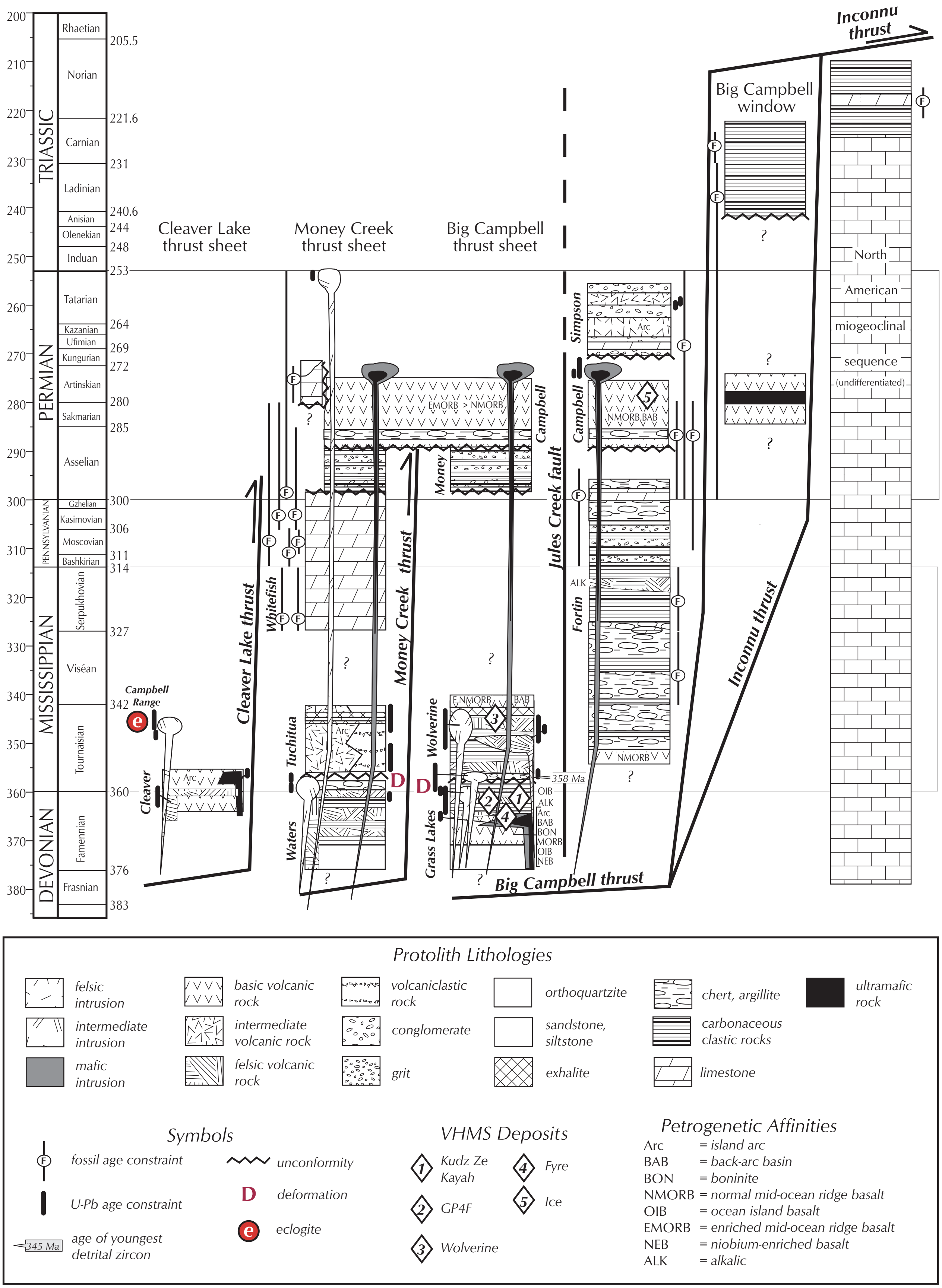


Figure 3. *Caption on facing page.*

Lower Permian carbonaceous clastic rocks and chert of the Money Creek formation. Murphy and Piercey (2000a,b) also included in the Money Creek thrust sheet undeformed Devonian basalt and rhyolite (Piercey and Murphy, 2000, part of Tuchitua succession of Murphy and Piercey, 2000a, b), comagmatic felsic to ultramafic plutonic rocks, and an early Mississippian pluton that lay above a fault inferred by them to be a minor backthrust within the Money Creek thrust sheet. However, as there are no rocks of equivalent composition in the Money Creek thrust sheet, their basal fault is now considered to be a structurally higher thrust fault, herein called the Cleaver Lake thrust.

GEOLOGY OF SOUTHEASTERN FINLAYSON LAKE AND SOUTH-WESTERN FRANCES LAKE MAP AREAS

The southern part of Finlayson Lake and Frances Lake areas is underlain primarily by pre-Upper Devonian to Lower Mississippian metavolcanic and metasedimentary rocks of the Big Campbell thrust sheet; and pre-Upper Devonian to Lower Permian metasedimentary and metavolcanic rocks, and Late Devonian and Early Mississippian metaplutonic rocks of the Money Creek thrust sheet (Figs. 2, 4). In addition a smaller part of the area is underlain by the Cleaver Lake thrust sheet comprising Upper Devonian volcanic and subvolcanic intrusive rocks, Early Mississippian plutonic rocks and two small bodies of coarse-grained metamorphic rocks interpreted as retrograded eclogite (Erdmer et al., 1998; see Devine et al., this volume). Cross-cutting plutons of Jurassic and Cretaceous age occur in the southern and central parts of the area.

BIG CAMPBELL THRUST SHEET

The same stratigraphic units that occur in the core of the FLD emerge to the south from beneath the Money Creek thrust sheet in Waters Creek map area (NTS 105G/1). The oldest rocks are quartz-rich psammite (meta-sandstone), meta-pelite and marble of the pre-Upper Devonian North River formation (unit 1 of Murphy, 1997; Murphy, 1998; unit Dq of Murphy and Piercey, 2000a; Murphy et al., 2001). The North River formation is overlain by the Fire Lake formation (unit 2 of Murphy, 1997; Murphy, 1998; unit DMF of Murphy and Piercey, 2000a; unit DF of Murphy et al., 2001), which consists primarily of chloritic phyllite or schist, and lesser carbonaceous phyllite or schist, and muscovite-quartz phyllite or schist of felsic volcanic protolith. The lower part of the Fire Lake formation in this area comprises a greater than 200-m-thick member of locally amygdaloidal felsic metavolcanic rock (muscovite-quartz schist). As in the FLD, mafic and variably serpentinized ultramafic metaplutonic rocks are spatially associated with the Fire Lake formation; in this area a several hundred-metre-thick sheet lies within the upper part of the formation. The Fire Lake formation is overlain by carbonaceous phyllite or schist, muscovite-quartz phyllite or schist (felsic metavolcanic rocks, locally amygdaloidal), rare light grey marble, and quartzofeldspathic metasandstone of the Kudz Ze Kayah formation (unit 3 of Murphy, 1997; Murphy, 1998; unit MK of Murphy and Piercey, 2000a; unit DK of Murphy et al., 2001). The youngest unit in the Big Campbell thrust sheet in this area is a several hundred-metre-thick succession of quartzofeldspathic grit and pebble conglomerate with lesser carbonaceous phyllite and locally amygdaloidal metarhyolite. This unit correlates with the lithologically similar basal clastic unit of the Wolverine Lake group which unconformably overlies the Grass Lakes group in the core of the FLD (unit 5l of Murphy and Piercey, 1999; unit CWcl of Murphy and Piercey, 2000a; unit MWcl of Murphy et al., 2001). The less highly strained nature of the basal clastic unit of the Wolverine Lake group in this area also suggests that the basal contact is an unconformity.

Figure 3. *(preceding page) Stratigraphic and structural summary diagram for Yukon-Tanana and Slide Mountain terranes, Finlayson Lake massive sulphide district. Time scale from Okulitch (2002). U-Pb geochronological data from Mortensen (1992), Breitsprecher et al. (2002), J.K. Mortensen, pers. comm., 1996-2003. Biochronological data from M.J. Orchard, pers. comm., 1997-2003 and Poulton et al. (2003).*

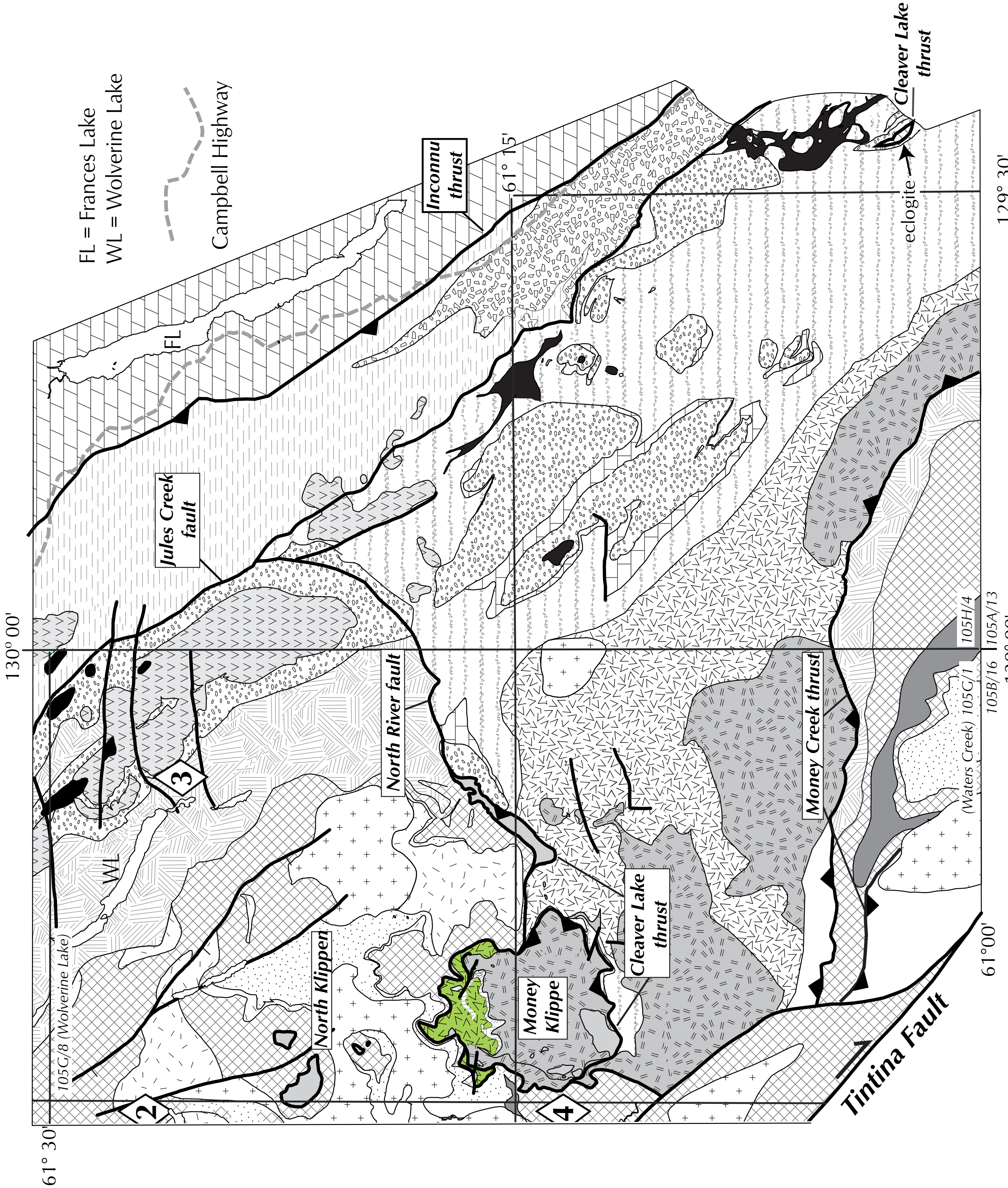


Figure 4. *Caption and legend on facing page.*

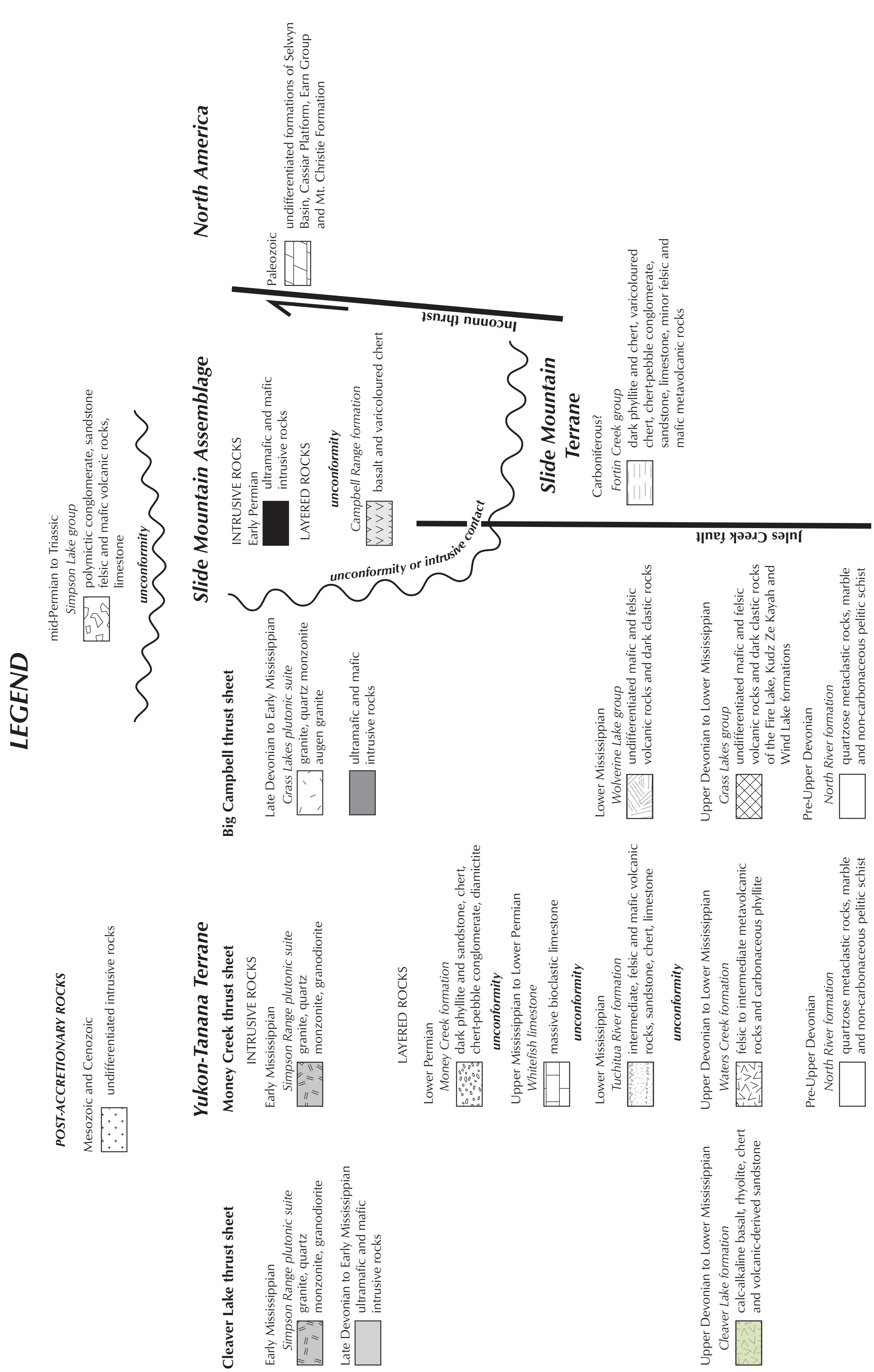


Figure 4. ***(a)*** *Geological map of southeastern Finlayson Lake map area and southwestern Frances Lake map area (on facing page);* ***(b)*** *Legend for 5a.*

MONEY CREEK THRUST SHEET

The oldest rock unit in the Money Creek thrust sheet, directly overlying the thrust in Waters Creek map area (105G/1), consists of quartz-rich psammite, metapelite and lesser marble, calcareous schist or calc-silicate rock (Fig. 5). This unit is lithologically identical to the North River formation in the footwall and is therefore correlated with it. As in the footwall, the stratigraphic base of the unit is not exposed in the area; its top is marked by the first appearance of rock of metavolcanic character or carbonaceous phyllite.

The North River formation is overlain sharply by the Upper Devonian Waters Creek formation, a succession of primarily felsic quartz-, feldspar- and locally hornblende-

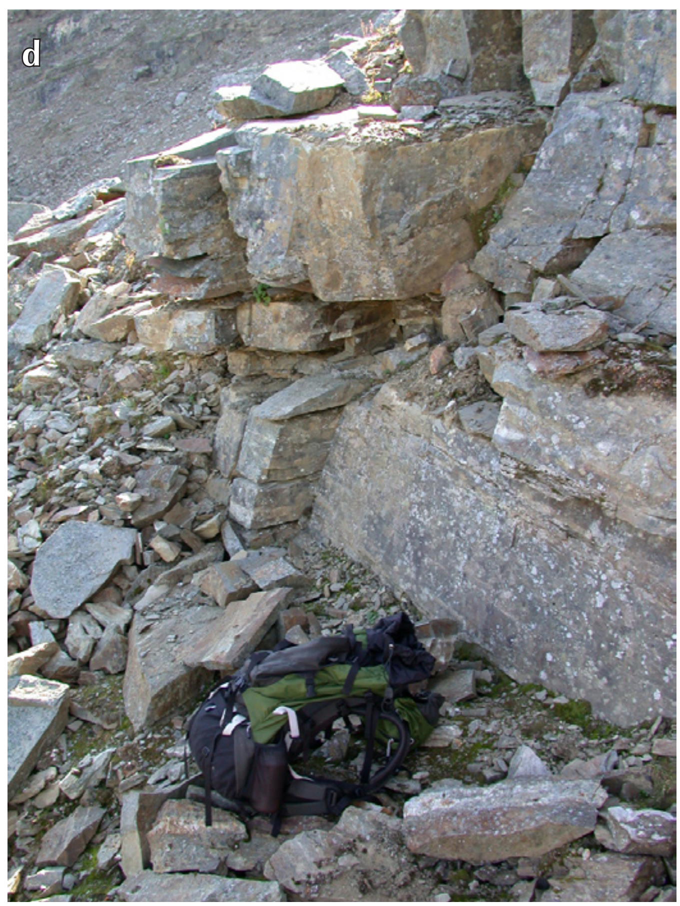
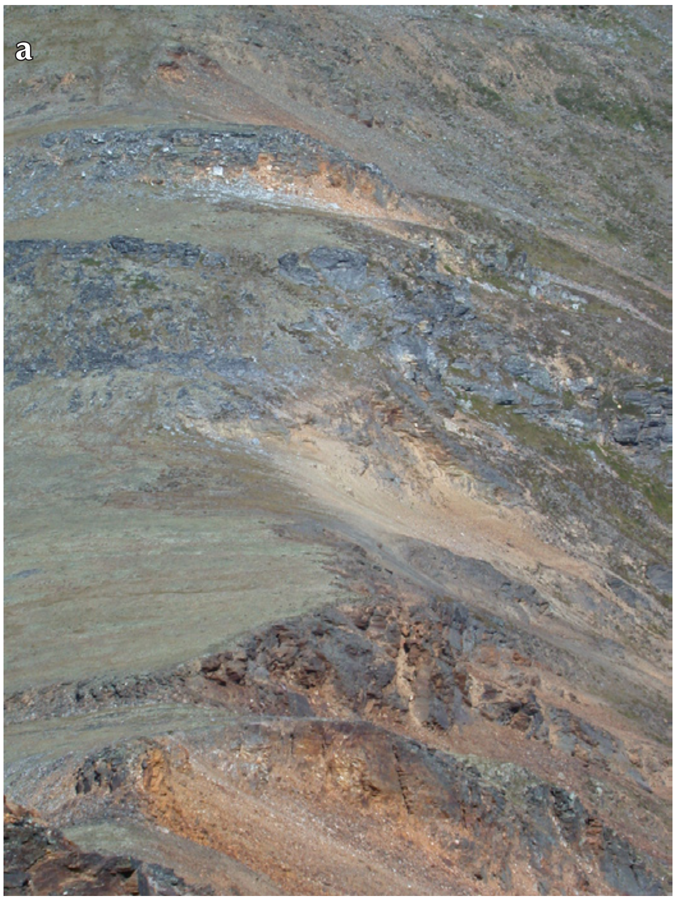


Figure 5. *North River formation:* ***(a)*** *lineated and foliated calcareous and non-calcareous quartz psammite, light-coloured layer in centre is about 4 cm thick;* ***(b)*** *isoclinally folded grey marble layer, pen for scale at top of photo;* ***(c)*** *garnet-diopside skarn in marble near contact with intrusion of Simpson Range plutonic suite;* ***(d)*** *slabby quartz psammite, pack for scale.*

phyric metavolcanic rocks, carbonaceous phyllite and locally, bedded barite, quartzite and quartz-pebble metaconglomerate (Fig. 6). The top of the Waters Creek formation comprises thinly laminated dark grey, white, salmon and pale green chert. Massive greenstone occurs locally in the upper part of the formation. The age of the Waters Creek formation is constrained by a ca. 360 Ma U-Pb date on a felsic metavolcanic rock in the upper part of the unit (Mortensen, 1992; Breitsprecher et al., 2002).

The Waters Creek formation is overlain by the Early Mississippian Tuchitua River formation, a succession of metamorphosed, primarily intermediate volcanic, volcaniclastic and epiclastic rocks with lesser chert and limestone (Fig. 7). The Tuchitua River formation sits on



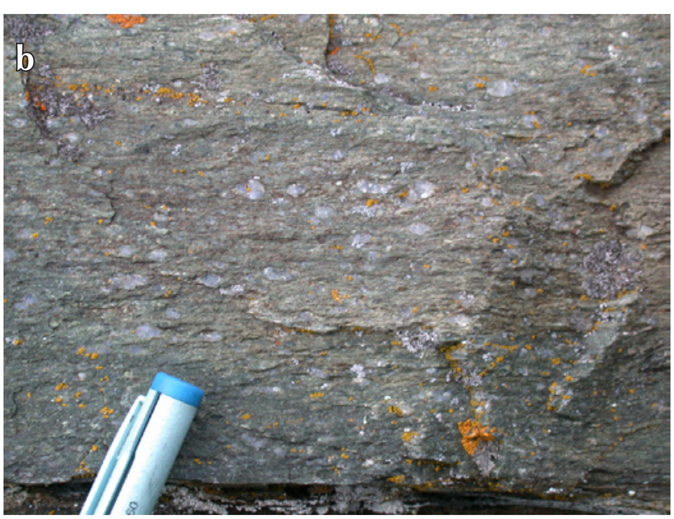


Figure 6. *Waters Creek formation:* ***(a)*** *intercalated carbonaceous phyllite, muscovite-quartz phyllite of felsic metavolcanic protolith and quartzite (light-coloured outcrops near far end of ridge);* ***(b)*** *quartz-feldspar meta-porphyry intercalated with rusty muscovite-quartz phyllite, Py occurrence (Yukon MINFILE 2003, 105G 083, Deklerk, 2003);* ***(c)*** *banded pale green, white and black chert near top of Waters Creek formation;* ***(d)*** *bedded barite, Akhurst occurrence (Yukon MINFILE 2003, 105G 083, Deklerk, 2003).*

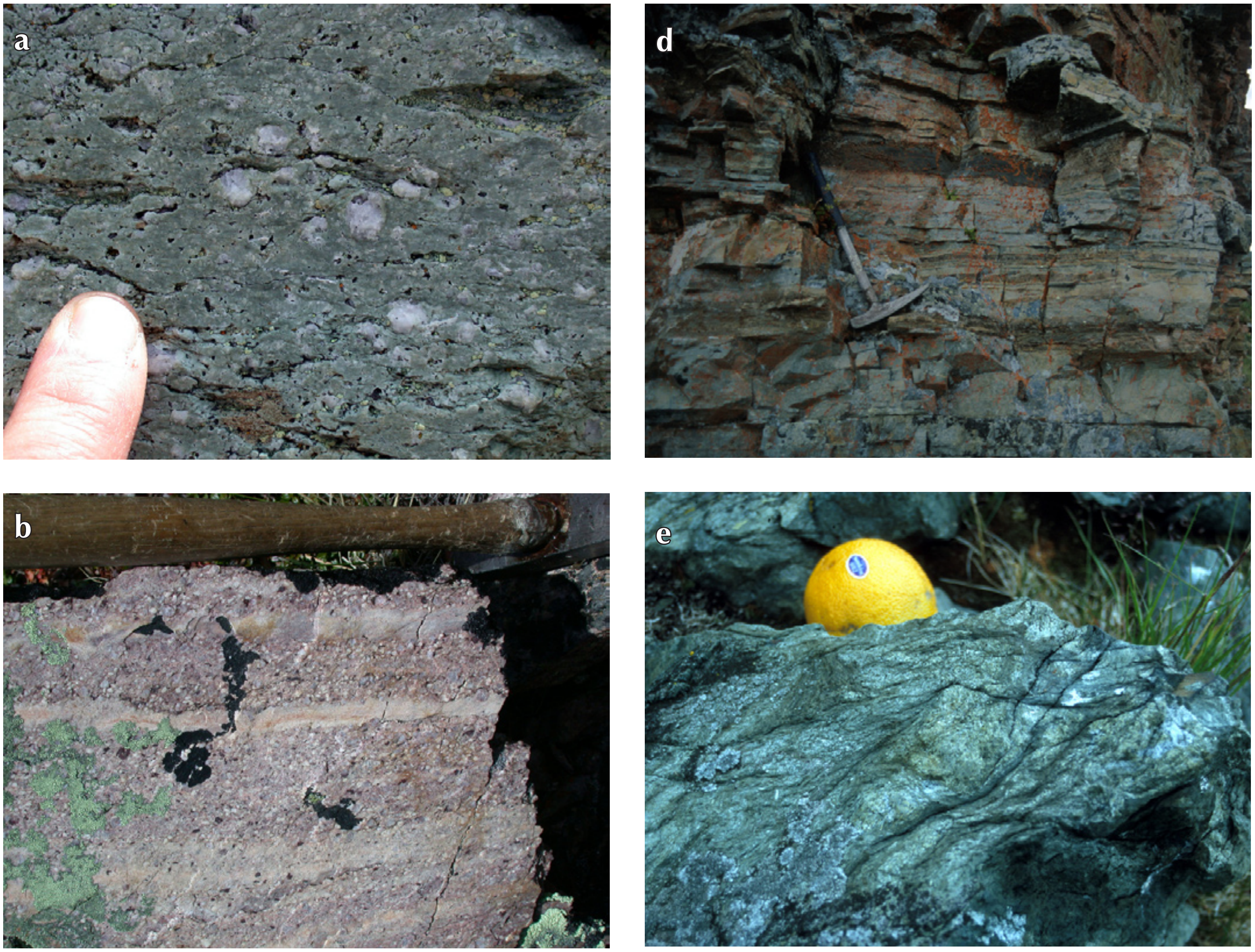


Figure 7. *Tuchitua River formation:* ***(a)*** *quartz-feldspar porphyry flow;* ***(b)*** *bedded volcanogenic epiclastic rocks, light-coloured beds are about 3 cm thick;* ***(c)*** *rhyodacitic crystal-lithic tuff breccia;* ***(d)*** *banded pale green magnetite-bearing chert and grey (dark bands) limestone;* ***(e)*** *foliated intermediate to mafic metavolcanic rock (orange for scale).*

top of different parts of the Waters Creek formation in different areas, suggesting that its basal contact is an unconformity, an interpretation further supported by the less highly strained nature of the overlying rocks. The age of the Tuchitua River formation is constrained by a ca. 354 Ma U-Pb date on rhyodacitic tuff breccia (Mortensen, 1992; Breitsprecher et al., 2002).

Two different episodes of hornblende-phyric plutonism are recorded in the Money Creek thrust sheet; owing to their similar metaluminous compositions, plutons of both episodes have been included in the Simpson Range plutonic suite (Mortensen and Jilson, 1985). Intercalated with both the North River and Waters Creek formations are metre-scale and thicker (to greater than a hundred-metre-thick) sheets of strongly foliated, locally potassium feldspar-megacrystic hornblende-quartz meta-porphyry (Fig. 8a,b). These sheets are lithologically similar to a pluton of foliated hornblende quartz monzonite to granodiorite that lies above the Money Creek thrust in west-central Waters Creek map area, and likely are sills and/or dykes that emanated from it. The porphyritic character of the intrusive rocks and their lithological similarity with the Waters Creek metavolcanic rocks suggests that the plutonic rocks are shallow subvolcanic intrusions. If so, then the age of the first plutonic episode is also ca. 360 Ma. The second plutonic episode is represented by discordant, weakly to unfoliated hornblende quartz monzonite plutons such as the Tuchitua River pluton (Fig. 8c,d,e), which are lithologically similar and possibly comagmatic with dacitic to rhyodacitic flows and tuffs of the Tuchitua River formation. The weakly to unstrained and discordant nature of the intrusions belonging to the second episode suggests that it, like the Tuchitua River formation, followed deformation of the Waters Creek formation and affiliated metaplutonic rocks. The age of the second plutonic episode is constrained by ca. 357 Ma U-Pb date on the Tuchitua River pluton (Mortensen, 1992; Breitsprecher et al., 2002).

The Late Devonian-Early Mississippian volcanic and plutonic rocks of the Money Creek thrust sheet are overlain by a thick and laterally persistent bioclastic limestone unit called the Whitefish limestone (unit Pc of Murphy, 2001). Conodont collections from the Whitefish limestone throughout the region indicate an Late Mississippian to Early Pennsylvanian/Early Permian age range for the unit (M.J. Orchard, pers. comm., 1997-2003; Poulton et al., 2003), implying a depositional hiatus between the youngest underlying rocks of the Tuchitua River formation and the base of the Whitefish limestone. The local occurrence of cobble conglomerate at its base and the observation that the Whitefish limestone is locally deposited on the Waters Creek formation implies that its basal contact is an unconformity.

The Whitefish limestone and underlying rocks are in turn unconformably overlain by the Money Creek formation (unit 7 of Murphy and Piercey, 1999; unit PPcs of Murphy and Piercey, 2000a; unit Pcl of Murphy et al., 2001), a poorly organized succession of carbonaceous phyllite, dark grey to black chert, chert-pebble conglomerate, quartzofeldspathic sandstone to pebble conglomerate and locally, matrix-supported diamictite. The age of the Money Creek formation is indirectly constrained by the Upper Pennsylvanian/Lower Permian age of the youngest conodont collection from the Whitefish limestone and the Lower Permian age of the Campbell Range formation which locally overlies it in the FLD.

CLEAVER LAKE THRUST SHEET

The Cleaver Lake thrust refers to the oft-photographed fault underlying what previous workers referred to as the Simpson Allochthon of the Money Klippe (Tempelman-Kluit, 1979; Erdmer, 1985). It exhibits older-over-younger relationships along its full map trace with Devonian and Mississippian rocks overlying Lower Permian rocks. The fault has been traced from its intersection with a younger low-angle normal fault east of Fire Lake, eastwardly to a second intersection with the normal fault in the Money Creek valley (Figs. 2, 4). Outliers of rocks of the thrust sheet are found to the north (North Klippen of Tempelman-Kluit, 1979), but their lower boundary is the younger low-angle normal fault, not the Cleaver Lake thrust.

In the Money Klippe, the Cleaver Lake thrust sheet comprises unstrained Devonian volcanic and volcaniclastic rocks of the Cleaver Lake formation, their subvolcanic intrusions, as well as a cross-cutting Early Mississippian intrusion of the Simpson Range plutonic suite. The Cleaver Lake formation comprises calc-alkalic pillow basalt, related volcaniclastic breccias and lesser vesicular rhyolite flows (Piercey and Murphy, 2000, Fig. 9). Minor graded epiclastic sandstone, shale and rare chert also occur in the formation. Quartz porphyritic rocks with a geochemical signature identical to the rhyolite locally intrude the basalt; these show magma-mingling textures with diabase dykes having a geochemical signature identical to the basalt (Piercey and Murphy, 2000). These observations suggest that basalt, rhyolite, quartz porphyry and diabase are broadly coeval. Their absolute ages are

Figure 8. *Simpson Range plutonic suite, older episode:* ***(a)*** *weakly foliated potassium feldspar-megacrystic hornblende-phyric augen granodiorite to quartz monzonite;* ***(b)*** *more strongly foliated version of 8a. Simpson Range plutonic suite, younger episode;* ***(c)*** *hornblende-quartz-feldspar porphyritic dyke near Tuchitua River pluton (end of marker for scale);* ***(d)*** *unfoliated potassium feldspar megacrystic granodiorite phase of the Tuchitua River pluton;* ***(e)*** *equigranular granodiorite to quartz monzonite of the Tuchitua River pluton.*

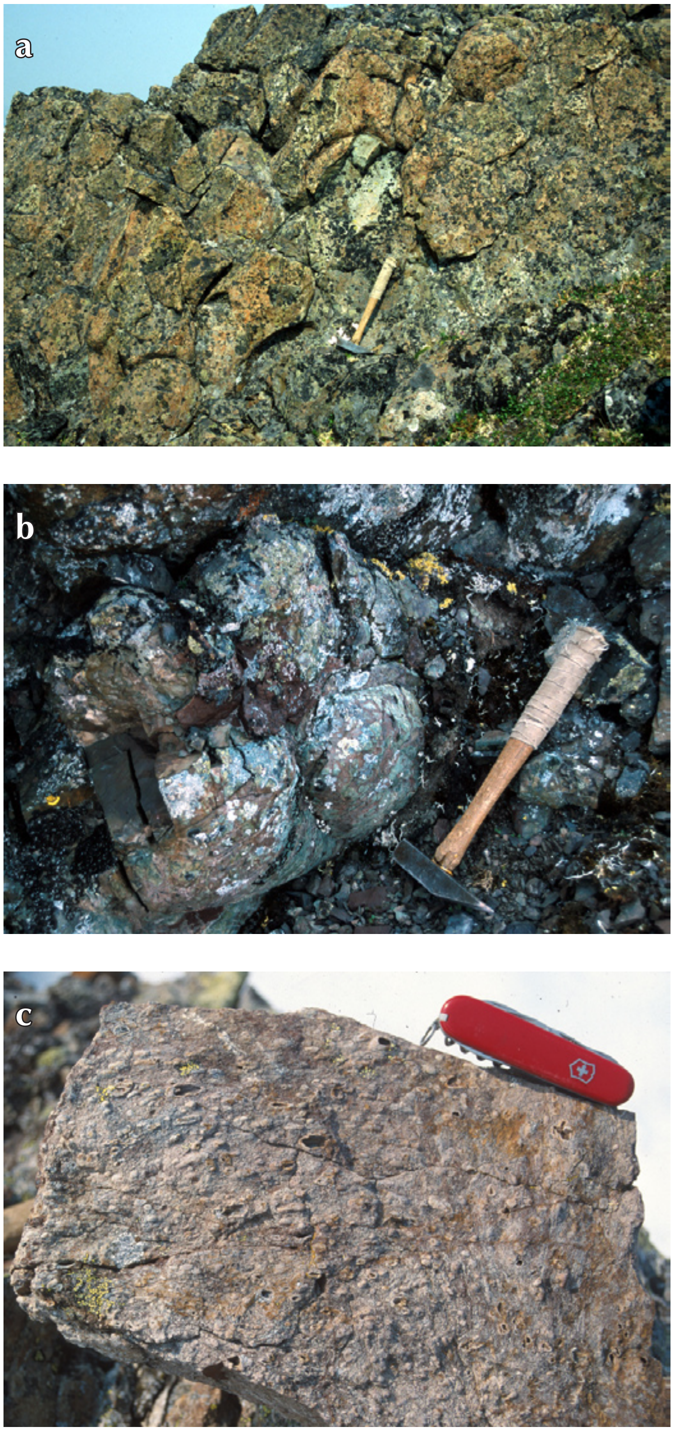


Figure 9. *Cleaver Lake thrust sheet, Cleaver Lake formation: **(a)** pillow basalt; **(b)** closeup of base of pillow basalt; **(c)** amygdaloidal rhyolite; **(d)** graded volcanogenic greywacke, top to right; **(e)** cliff of gabbro and serpentinized ultramafic rock underlying basalt and rhyolite on skyline to right*

constrained by a ca. 360 Ma U-Pb date on a quartz porphyry intrusion (Mortensen, 1992b). Gabbro and variably serpentinized ultramafic plutonic rocks (main rock type of North Klippen; Figs. 2, 4) that underlie the volcanic rocks are also interpreted as comagmatic products; a ca. 356 Ma U-Pb date was obtained from one gabbroic body (Mortensen, 1992a; Breitsprecher et al., 2002). All of these rocks are intruded by an extensive body of hornblende-biotite quartz monzonite and granite of the Simpson Range plutonic suite (Mortensen and Jilson, 1985). A ca. 348 Ma U-Pb age determination (Mortensen, 1992a; Breitsprecher et al., 2002) shows that it is one of the youngest bodies of the suite.

Two small isolated bodies of coarse-grained metamorphic rocks inferred to be retrogressed eclogite (Erdmer et al., 1998; see Devine et al., this volume; Figs. 3, 4) are also included in the Cleaver Lake thrust sheet. This interpretation is based on their structural position above the lower part of the Lower Permian Money Creek formation which is the same stratigraphic level followed by the Cleaver Lake thrust under the Money Klippe. The combined presence of volcanic and plutonic rocks with a volcanic arc geochemical signature, and rocks that formed in a coeval Devono-Mississippian subduction zone suggests that the Cleaver Lake thrust sheet, before erosional dissection, contained the Devono-Mississippian transition from arc to forearc environments.

GEOMETRY AND AGES OF FAULTING IN THE FLD

Throughout most of Waters Creek map area (105G/1) the Cleaver Lake and Money Creek thrusts are defined by the older-over-younger relationships described above and have a consistent stacking order above the rocks of the Big Campbell Creek thrust sheet. However, to the north in Wolverine Lake map area (105G/8), at the North Klippen and along the northern edge of the Money Klippe, rocks of the Cleaver Lake thrust sheet sit directly on the Kudz Ze Kayah formation of the Grass Lakes group that, to the south, lie in the footwall of the Money Creek thrust. In these places, younger rocks are faulted over older rocks and the intervening Money Creek thrust sheet is missing.

The younger-over-older relationship and unusual stacking order in Wolverine Lake map area are best explained by the presence of a low-angle normal fault along which the upper thrust sheet is down-dropped to rest above the rocks of the Big Campbell thrust sheet (Fig. 10). The trace of this normal fault, herein called the North River fault (Figs. 2, 4), extends eastwardly from the North River valley along what Murphy and Piercey (2000a,b) previously considered the trace of the Money Creek thrust. It continues down the valley of Money Creek where it likely intersects one of the poorly understood northwest-trending faults in the area. Along its trace it juxtaposes younger rocks of the Cleaver Lake and Money Creek thrust sheets against older rocks of the Big Campbell Creek thrust sheet. In Money Creek, it juxtaposes Lower Permian Money Creek formation of the Money Creek thrust sheet against the same formation, but in the Big Campbell Creek thrust sheet. Also, with the exception of the North Klippen, everywhere along its trace rocks in the hanging wall of the North River fault, the rocks dip moderately to the north, likely reflecting the original hanging wall cut-off angle.

The timing of displacement on the Money Creek and Cleaver Lake thrusts is constrained by the youngest age of footwall rocks and the oldest age of rocks or structures that cross-cut the faults. Lower Permian rocks of the Money Creek formation occur in the immediate footwall of both thrusts locally. Thrusting thus post-dates the Lower Permian Money Creek formation. The Lower Permian Campbell Range formation and spatially associated mafic and ultramafic plutonic rocks overlie or are intruded into both the hanging wall and footwall of the Money Creek thrust, suggesting that the Money Creek thrust pre-dated them. The Money Creek thrust is therefore an Early Permian fault. Although inferred to be part of the same Early Permian thrust system, the age of displacement on the Cleaver Lake thrust is less tightly constrained; its lower age limit is mid-Cretaceous, the inferred age of the North River normal fault cutting the thrust.

A Cretaceous age for the North River fault is suggested by the distribution of Cretaceous cooling ages with respect to the fault. Rocks in the footwall of the North River fault are characterized by mid-Cretaceous U-Pb ages on titanite (Breitsprecher et al., 2002) and $^{40}Ar/^{39}Ar$ cooling ages of biotite and hornblende (Villeneuve and Murphy, unpublished data). These rocks were ductily deformed prior to and during the emplacement of mid-Cretaceous granite. In contrast, rocks in the hanging wall lack Cretaceous granite, and are characterized by older (Mississippian) K/Ar and U-Pb titanite ages (Breitsprecher et al., 2002). The contrast in metamorphic and cooling ages across the fault suggests that the fault accommodated the uplift and cooling of the footwall, and hence is mid-Cretaceous in age.

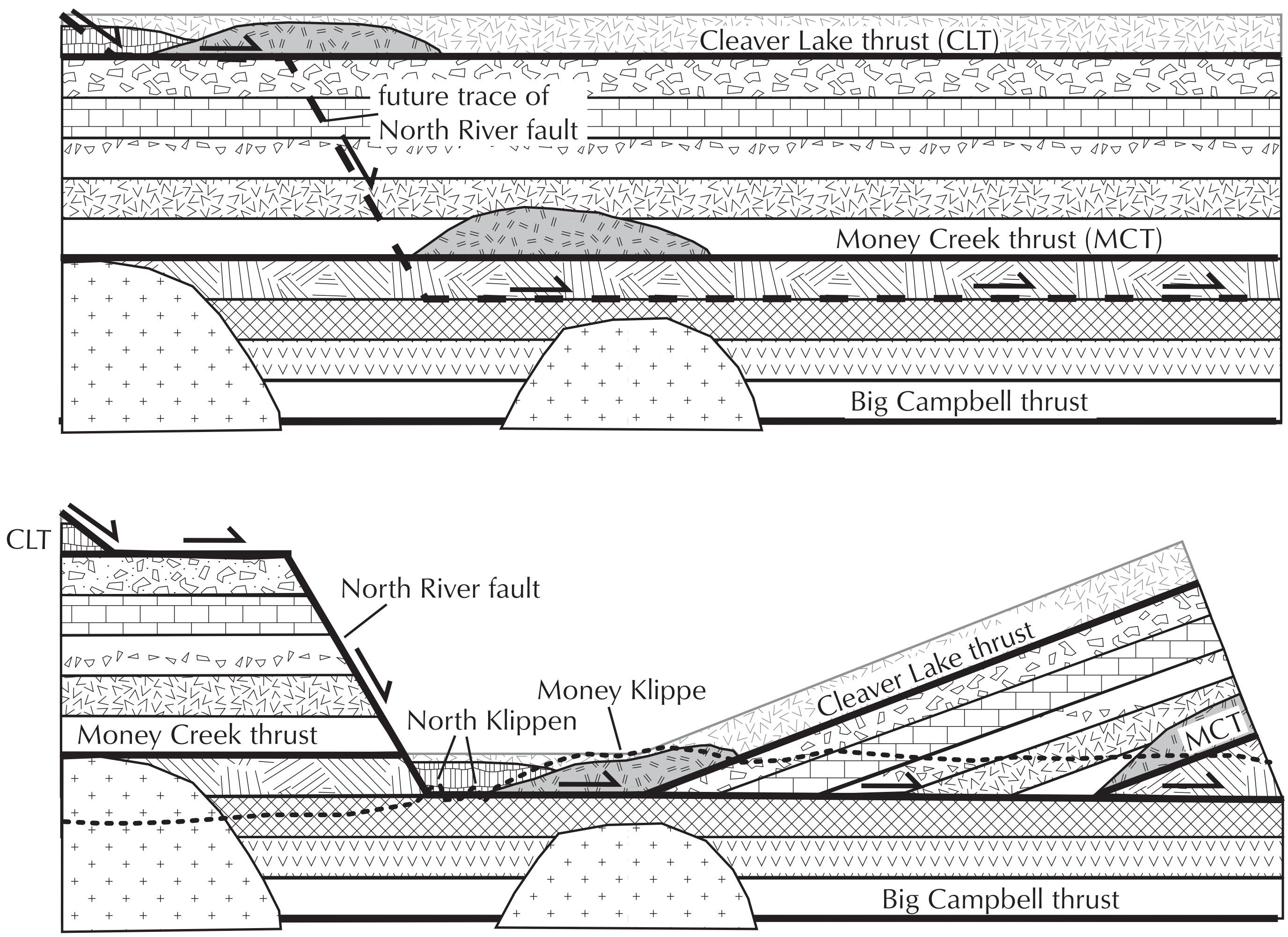


Figure 10. *Schematic cross-section illustrating how displacement on the stair-step trajectory North River normal fault down-drops the Cleaver Lake thrust sheet and juxtaposes it with the Big Campbell thrust sheet. Section broadly north-south and extending from north of the North Klippen to the southern part of 105G/1 (Fig. 4). Dotted line indicates schematic topographic profile. Patterns as in Figure 4.*

VOLCANIC-HOSTED MASSIVE SULPHIDE (VHMS) DEPOSIT POTENTIAL SOUTH OF THE FINLAYSON LAKE MASSIVE SULPHIDE DISTRICT (FLD)

The geological settings determined for the known deposits of the FLD provide models with which to evaluate the potential for VHMS deposits south of the FLD. Key features common to all the geological settings of the deposits include interbedded carbonaceous metasedimentary rocks in the metavolcanic-metasedimentary successions hosting the deposits, geological features indicating the presence of synvolcanic faults (Murphy and Piercey, 2000a,b), and voluminous comagmatic subvolcanic plutonic rocks near the deposits. The former indicates anoxic basinal bottom waters, key to the concentration of metal species and preservation of deposits (e.g., Bradshaw, 2003; Bradshaw et al., 2003a,b), and the latter provide conduits to focus hydrothermal fluids and the heat source to drive the hydrothermal cells, respectively. Coherent amygdaloidal felsic metavolcanic rocks as found at the Kudz Ze Kayah deposit are second-order indicators of proximity to volcanic vents/structures.

Two of the Devono-Mississippian volcanic successions south of the core area of the FLD have characteristics similar to those that host the deposits. First of all, the Grass Lakes group in the southern Waters Creek map area (105G/1) resembles the Grass Lakes group in the core of the FLD. Chloritic phyllite (mafic metavolcanic rock) of the Fire Lake formation is intercalated with carbonaceous phyllite and associated with voluminous amounts of comagmatic mafic and ultramafic metaplutonic rock (gabbro and variably serpentinized ultramafic rocks). Felsic metavolcanic rocks at the base of the Fire Lake formation are locally amygdaloidal and altered, suggesting proximity to a feeder zone. Amygdaloidal and altered felsic metavolcanic rocks also occur in overlying rocks of the Kudz Ze Kayah formation and Wolverine Lake group, but these units differ from their equivalents in the core of the FLD in the smaller amount of metavolcanic rock and subvolcanic intrusions. Secondly, with the exception of the hornblende-phyric composition of its felsic metavolcanic rocks, the Waters Creek formation in NTS 105G/1 and 105H/4 resembles the Kudz Ze Kayah formation near the Kudz Ze Kayah deposit in 105G/7. In this area, massive feature-less felsic (and lesser intermediate to mafic) metavolcanic rocks of the Waters Creek formation are intercalated with carbonaceous phyllite and porphyritic volcaniclastic rocks, and are intruded by sheets of locally megacrystic quartz-feldspar porphyry. A larger body of granodiorite of similar composition to the metavolcanic rocks is likely the subvolcanic feeder to both the metavolcanic rocks and sheets of porphyry. Signs of VHMS mineralization in the Waters Creek formation include disseminated to semi-massive pyrite, chalcopyrite and sphalerite in altered felsic flow rocks (e.g., Py and Ellen Creek, Yukon MINFILE 105G 083 and 135, respectively (Deklerk, 2003); Fig. 11). Bedded barite, barite veins, and local manganese staining attest to locally exhalative hydrothermal activity.

The other two Devonian to Mississippian metavolcanic successions in this area, the Cleaver Lake and the Tuchitua River formations, have little in common with the rocks that host the deposits in the FLD, and hence have little potential to host the associated types of VHMS deposits (Fyre, basalt-pelagic sediment-dominated, other felsic-siliciclastic sediment-dominated types of Franklin et al., 1999). However, as about 80% of the world's VHMS deposits occur in volcanic arc-related successions (Franklin et al., 1999), the mineral potential of these two arc and/or forearc successions can not be overlooked. Centres of magmatic activity associated with the Tuchitua River formation, identified by coherent flow rocks and

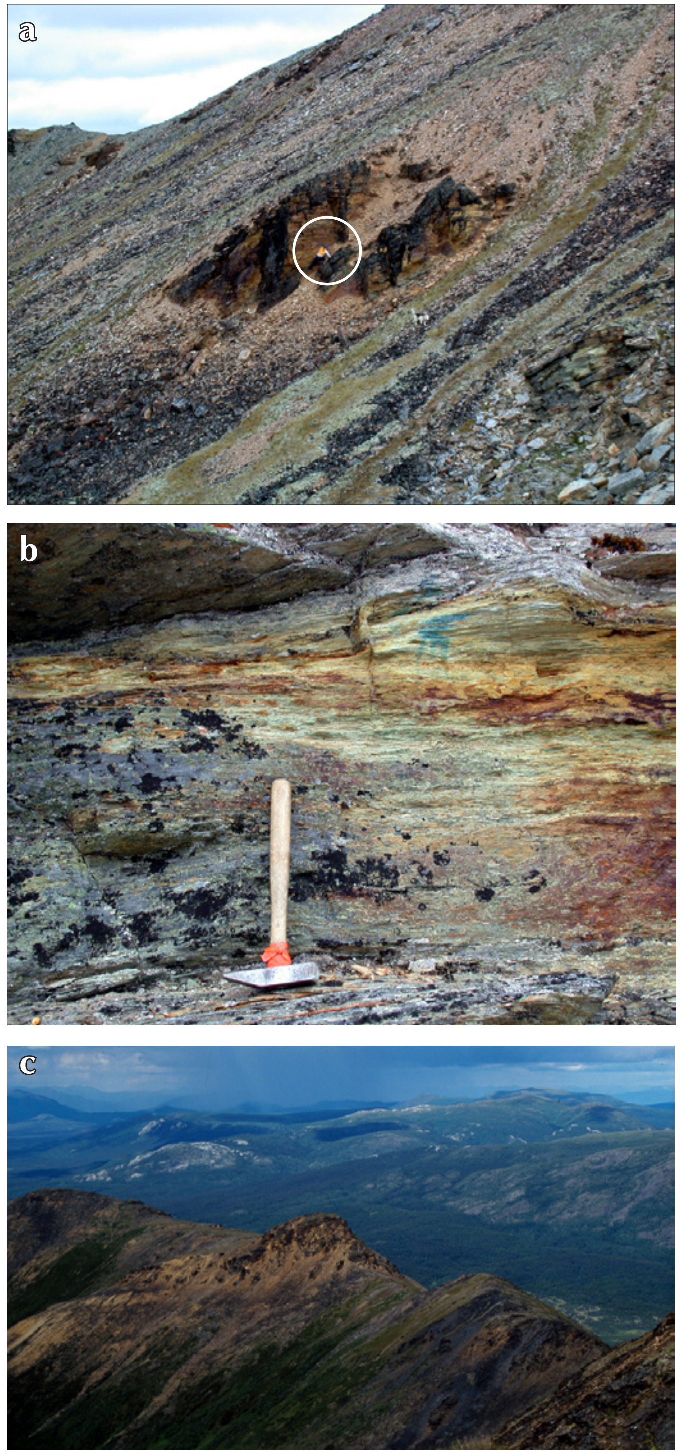


Figure 11. (a) *Rusty altered felsic metavolcanic rocks, Waters Creek formation near Ellen Creek occurrence (Yukon MINFILE 2003, 105G 135, Deklerk, 2003; person in centre for scale);* ***(b)*** *rusty, malachite-stained felsic metavolcanic rocks, Ellen Creek occurrence;* ***(c)*** *view of knob of rusty, altered felsic metavolcanic rocks with barite veins, Kneil occurrence (Yukon MINFILE 2003, 105H 080, Deklerk, 2003).*

large subvolcanic intrusions (Tuchitua River and Hasselberg Lake plutons), occur in southern Frances Lake map area and extend to the south into Watson Lake and Wolf Lake areas. Signs of hydrothermal activity in the Tuchitua River formation include laterally extensive magnetite-bearing pink, green and tan chert — which may be coeval (see Devine et al., this volume) with the siliceous barite-magnetite exhalite in the hanging wall of the Wolverine deposit (Bradshaw et al., 2003a) — and local members of altered felsic metavolcanic rock. The Cleaver Lake formation in the Money Klippe directly overlies coeval felsic to ultramafic mafic subvolcanic intrusions and therefore may be a preserved magmatic centre. However, the only mineral occurrences reported from the Money Klippe comprise jade formed near the faulted base of the klippe (Lady Lee, Yukon MINFILE 2003, 105G 114) and Reid (Yukon MINFILE 2003, 105G 039), a silver-copper-lead-zinc vein cutting basalt and underlying quartz porphyry (Deklerk, 2003). The volcanic character of these rocks has only been recently recognized (Piercey and Murphy, 2000), so the lack of mineral occurrences within this succession may have more to do with a lack of prospecting for VHMS targets in the area.

All of the Devonian and Mississippian volcanic successions described in this report track to the south and east out of the Finlayson and Frances Lake map areas into the less explored western part of Watson Lake map area and the northeastern corner of Wolf Lake map area. Although there has been little recent mapping in these areas, they contain rocks with significant potential to host VHMS mineralization.

CONCLUSIONS

1. The structure of Yukon-Tanana Terrane in and around the Finlayson Lake massive sulphide district has been re-interpreted to include a higher level thrust sheet, the Cleaver Lake thrust sheet. This thrust sheet includes outliers of both Devonian and Mississippian arc rocks, and rocks that formed in a Devono-Mississippian subduction complex; hence, it likely preserved the Devono-Mississippian arc to forearc transition before erosional dissection.
2. Much of what had previously been inferred to be the trace of the Money Creek thrust is now inferred to be a Cretaceous normal fault, the North River fault. This fault explains how rocks of the structurally high Cleaver Lake thrust sheet came to sit on top of the structurally low Big Campbell thrust sheet.
3. Devonian and Mississippian metavolcanic rocks south of the core area of the Finlayson Lake massive sulphide district have many characteristics in common with the rocks hosting the mineral deposits in the district. These similarities attest to the potential for more deposits to be found in this area and in western Watson Lake and northeastern Wolf Lake areas to the south.

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