GEOLOGICAL FIELDWORK

Syn-mineralization faults and their re-activation, Finlayson Lake massive sulphide district, Yukon-Tanana Terrane, southeastern Yukon[1]

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ABSTRACT

Although deformed and metamorphosed, the strata hosting volcanogenic massive sulphide deposits in the Finlayson Lake district retain characteristics that suggest the influence of syn-depositional faults near the deposits. The Fyre Lake deposit occurs within a mafic schist unit near where notable changes in thickness, rock type and amount of comagmatic metaplutonic rocks occur. These changes occur across a north-northwest-striking corridor along which deposits and prospects in the overlying felsic metavolcanic schist are distributed (including Kudz Ze Kayah). Syn-volcanic, syn-mineralization faulting would explain the association of these deposits with the observed changes in host rock characteristics. Using similar arguments, syn-mineralization faults have been inferred on the Hat Trick property southwest of Fire Lake, as well as in Pennsylvanian and Permian rocks of the Campbell Range succession. Finally, stratigraphic differences between coeval rocks in the hanging wall and footwall of the Money Creek thrust imply that the thrust may have re-activated a syn-depositional structure. The regions of hanging wall and footwall cut-offs of the Money Creek thrust would therefore be considered as highly prospective for massive sulphide deposits.

RÉSUMÉ

Bien qu'elles soient affectées par la déformation et le métamorphisme régionaux, les strates contenant les gisements de sulfures massifs volcanogènes de la ceinture de Finlayson Lake préservent encore des indices de l'influence de failles synvolcaniques près des gisements. Le gisement de Fyre Lake est situé dans une zone caractérisée par des variations important en épaisseur, en lithologies, et en quantité de roches métaplutoniques comagmatiques. Ces changements se produisent le long d'un corridor d'orientation nord-nord-ouest, où l'on retrouve des gisements et des indices minéralisés au sein des roches métavolcaniques felsiques susjacentes (incluant le gisement de Kudz Ze Kayah). La formation de failles synvolcaniques et synminéralisation expliquerait la corrélation entre ces gisements et les changements reconnus dans les roches encaissantes. De mêmes, la présence de failles synminéralisation sont inférées sur la propriété Hat Trick, au sud-ouest de Fire Lake, et dans les roches d'âge Pennsylvanien et Permien de la succession de Campbell Range. Finalement, les différences stratigraphiques entre les roches contemporaines dans le toit et le mur du chevauchement de Money Creek suggèrent fortement que ce chevauchement a réactivé une structure synvolcanique. Par conséquent, les régions où le chevauchement de Money Creek recoupe les strates, à la fois dans le toit et le mur de cette faille, doivent être considérées comme très prometteuses pour la découverte de gisements de sulfures massifs.

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INTRODUCTION

As emphasized in Nelson (1997), an empirical spatial relationship between syngenetic volcanic-associated massive sulphide deposits (VMS) and syn-volcanic faults has been documented in many mature VMS districts (e.g., Noranda, Setterfield et al., 1995) and from studies of modern seafloor hydrothermal systems (e.g., Middle Valley, Goodfellow and Franklin, 1993). Such a relationship underscores the importance of the early identification of these structures for exploration in frontier areas. However, even in the least deformed areas, syn-volcanic faults are subtle features and are typically identified only after detailed mapping and facies analysis of volcanic rock sequences are completed around known deposits (e.g., Gibson et al., 1999). Finding syn-volcanic faults, or their zones of influence, in highly deformed and metamorphosed regions may be an insurmountable challenge.

In spite of the potential difficulty of finding syn-volcanic faults in deformed regions, a number of the criteria that have been used to identify them in pristine areas may have broader application in more highly deformed areas. Gibson et al. (1999) summarized criteria that have been used in recognizing syn-volcanic faults in less deformed areas. These include: 1) localized concentrations of dykes or apophyses of syn-volcanic intrusions; 2) intensification of discordant hydrothermal alteration and/or abrupt change in type of alteration; 3) abrupt change(s) in thickness(es) of pyroclastic, volcaniclastic or sedimentary units; 4) the offset of a volcanic rock unit with subsequent units not being offset; and 5) localized monolithic to heterolithic coarse breccia deposits. Of these, criteria 1), 3), 4) and 5) may not be obscured to any great extent by deformation and metamorphism, and are potentially useful even where rocks are highly deformed. Furthermore, these features may have an influence on subsequent deformation. Stratigraphic perturbations such as thickness/facies changes may provide the nuclei for later folds, and syn-depositional faults may be suitably oriented to be re-activated as thrust faults during later shortening. Hence, structures that appear to be post-depositional must be scrutinized carefully for indications that they may have been controlled by syn-depositional features.

In this paper, we present evidence of syn-volcanic faulting from the Finlayson Lake massive sulphide district of southeastern Yukon, an emerging VMS district hosted in variably deformed and metamorphosed mid- to Upper Paleozoic rocks of Yukon-Tanana Terrane (Mortensen, 1992; Murphy, 1998; Murphy and Piercey, 1999; Figs. 1, 2). We show that the deposits at Fyre Lake and Kudz Ze Kayah, as well as other areas of mineralization, are distributed along a trend that spatially coincides with fundamental changes in the host volcano-sedimentary succession and spatially associated meta-plutonic rocks. Using the criteria listed above, these changes are interpreted in terms of syn-volcanic faulting. We present evidence that the Money prospect, located in less deformed rocks of the Campbell Range belt, occurs along a syn-volcanic structure marked by a pronounced facies change and a localized concentration of co-magmatic intrusions. We describe stratigraphic and structural relationships from the Hat Trick prospect, southwest of Fire Lake that suggest the presence of a syn-volcanic fault that influenced later deformation. Finally, we describe the Money Creek thrust, a newly defined regional-scale

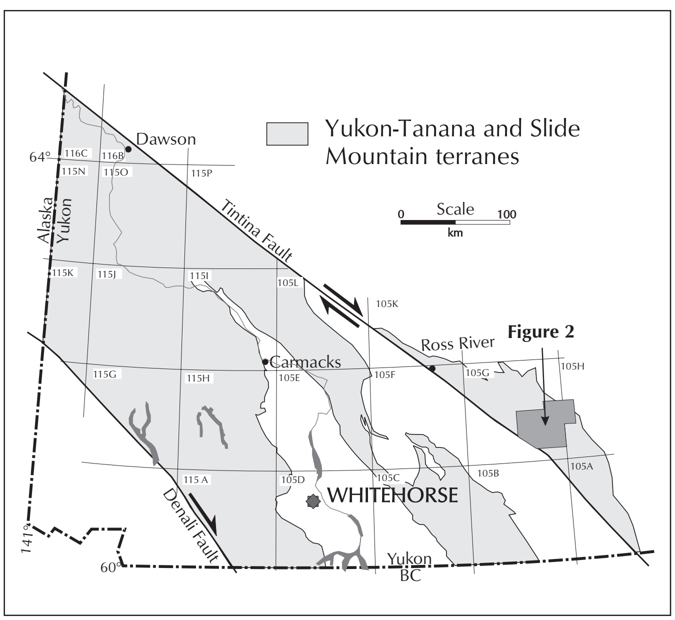


Figure 1. *Location of the study area with respect to the distribution of Yukon-Tanana and Slide Mountain terranes in the Yukon (modified from Wheeler and McFeely, 1991). Mesozoic plutons and metamorphic complexes are not differentiated.*

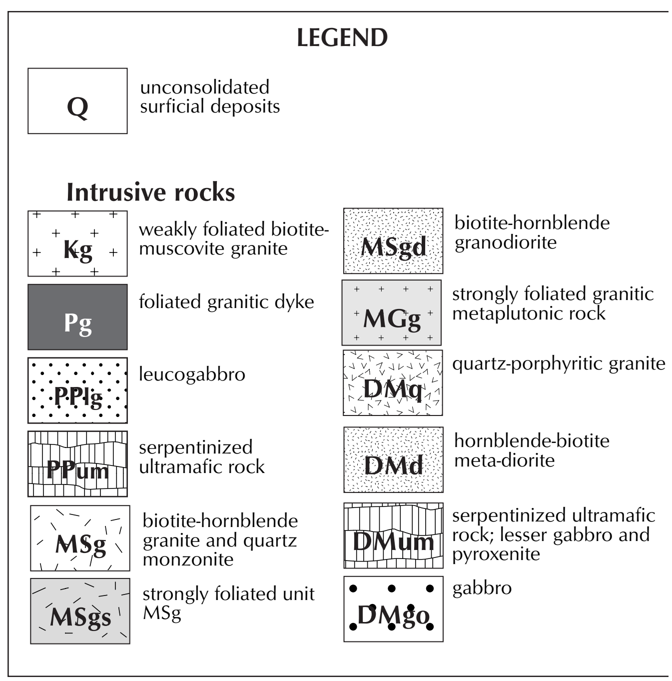
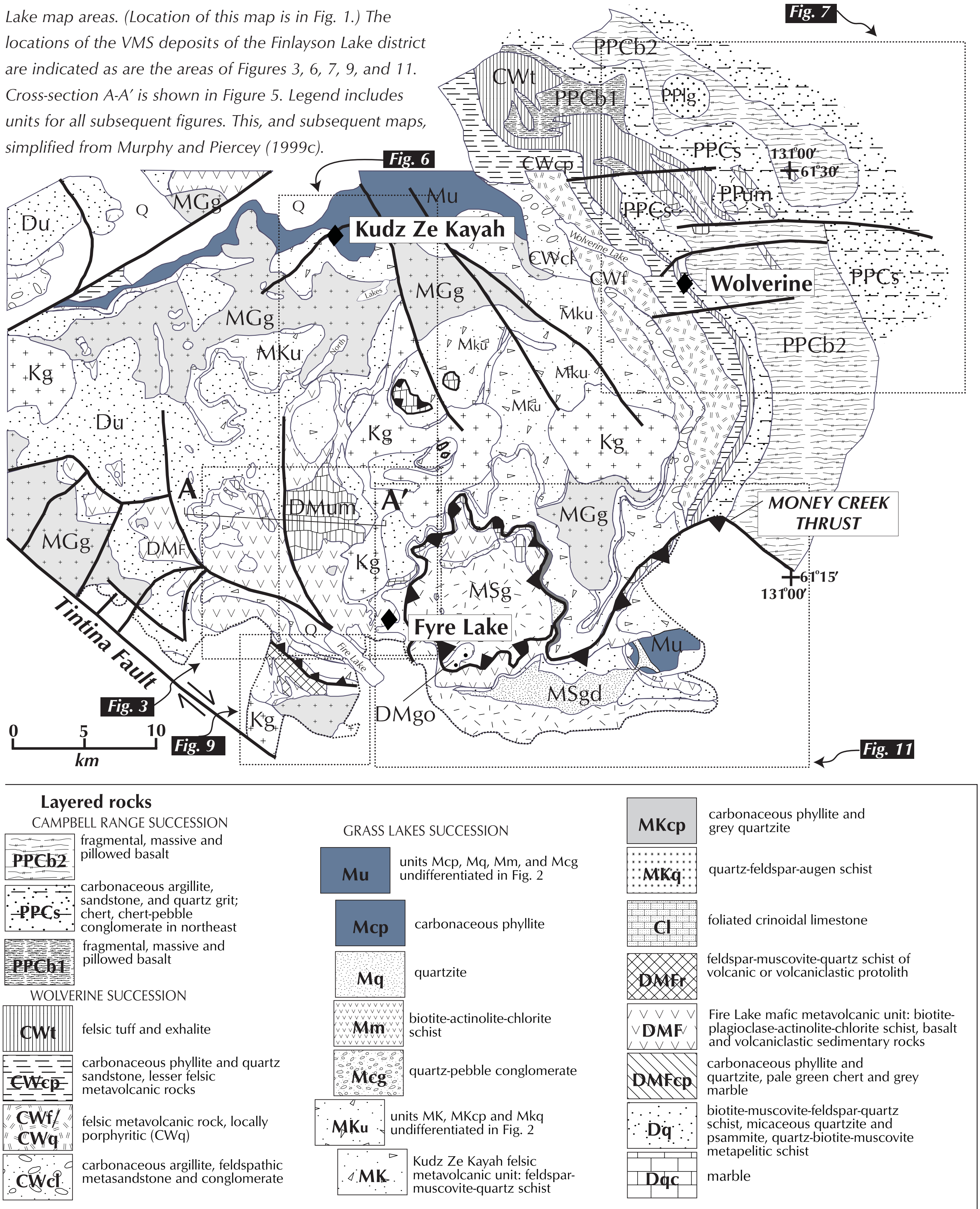


Figure 2. *Geological map of parts of Finlayson and Frances Lake map areas. (Location of this map is in Fig. 1.) The locations of the VMS deposits of the Finlayson Lake district are indicated as are the areas of Figures 3, 6, 7, 9, and 11. Cross-section A-A′ is shown in Figure 5. Legend includes units for all subsequent figures. This, and subsequent maps, simplified from Murphy and Piercey (1999c).*



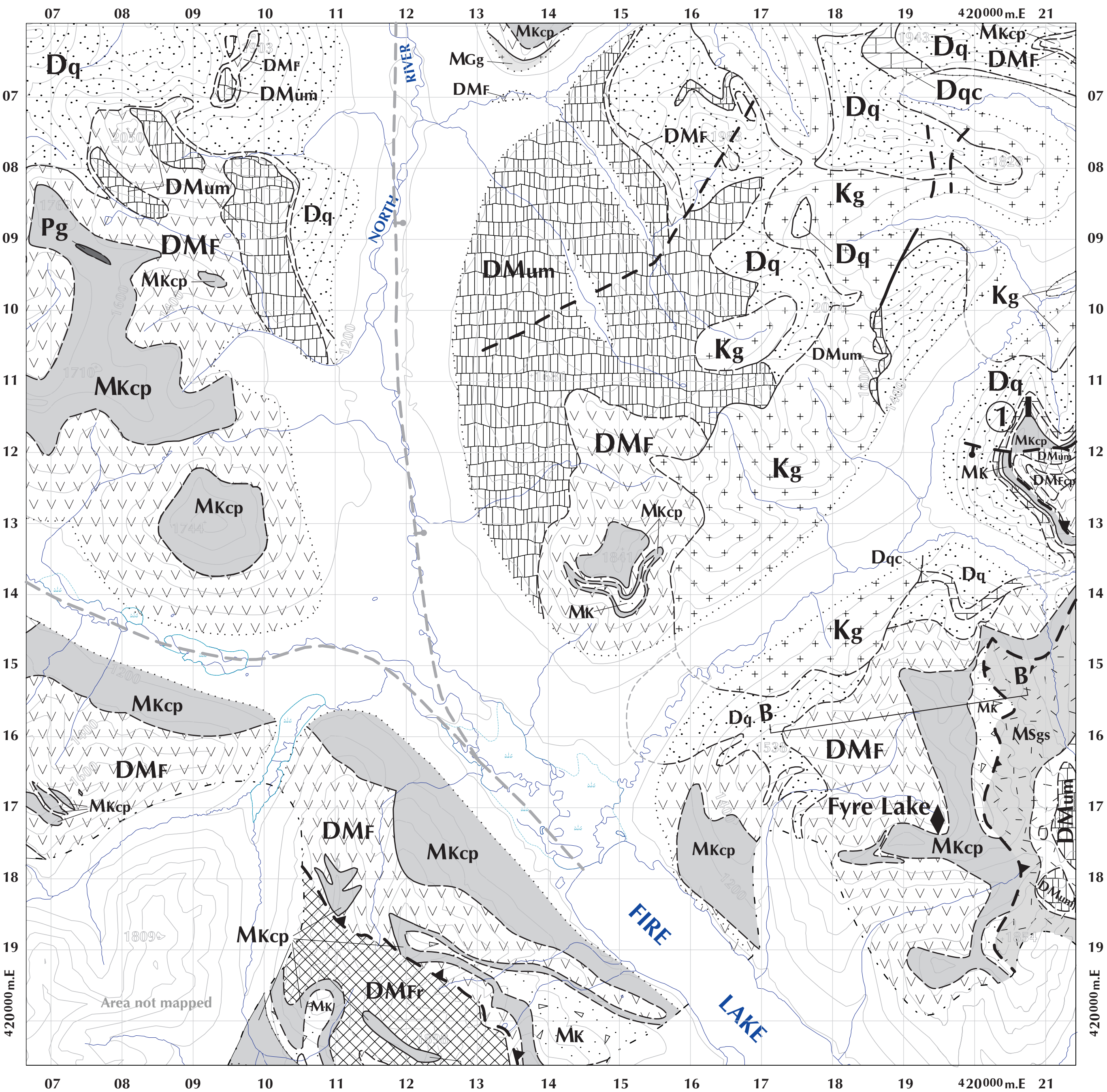


Figure 3. Geological map of the area around the Fyre Lake Cu-Co-Au VMS deposit. Location and legend in Figure 2. Cross-section B-B′ is shown in Figure 4. Location 1, discussed in text, is indicated by the dark bar. Grid lines are spaced 1 km apart.

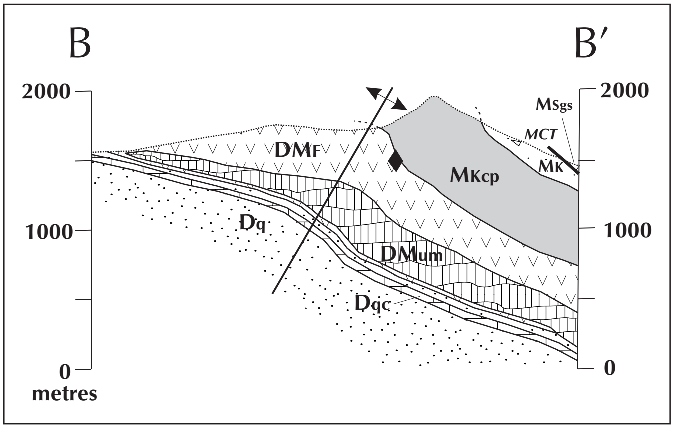


Figure 4. *Cross-section along line B-B′ in Figure 3, about 1.5 km north of the Fyre Lake deposit. The stratigraphic level of the Fyre Lake deposit is indicated by the diamond symbol. At the deposit, the upper part of unit DMF comprises a significant amount of carbonaceous schist and felsic schist of volcanic and volcaniclastic protolith. See text for discussion. The mafic and ultramafic metaplutonic rocks are projected into the line of section from north of the section line. MCT, Money Creek thrust. Legend as in Figure 2.*

thrust fault that juxtaposes coeval, although subtly different, stratigraphic sections and interpret it as a re-activated syn-depositional fault.

FYRE LAKE – KUDZ ZE KAYAH TREND

The characteristics of the host rocks around the Fyre Lake deposit (Pacific Ridge Resources Ltd., 15.4 million tonne preliminary resource containing 8.2 million tonnes, 2.1% Cu, 0.11% Co, 0.73 g/t Au; Yukon Minfile, 1997, 105G 034) satisfy most of the criteria for the presence of a syn-volcanic fault. Regional mapping has shown that the Fyre Lake deposit is spatially associated with profound changes in the nature and thickness of the host Upper Devonian to Lower Mississippian Fire Lake mafic schist unit (Murphy, 1998; Murphy and Piercey, 1999b, c; unit DMF, Figs. 2 and 3). Four kilometres northeast of the deposit (Location 1, Fig. 3), the Fire Lake unit comprises about 40 m of biotite-actinolite-chlorite schist. Near the deposit, the unit is nearly 800 m thick (section B-B′, Fig. 4). At the deposit, unit DMF is at least this thick (the bottom was not intersected in drill holes). It includes 5 to over 200 m of felsic schist of volcanic and volcaniclastic protolith, and siliceous carbonaceous phyllite (quartz-chlorite mica schist of Blanchflower et al., 1997; transition zone of Foreman, 1998; psammitic schist and felsic metavolcanic rocks of Sebert and Hunt, 1999). Massive sulphide mineralization occurs in the upper part of the unit just below the base of the overlying carbonaceous schist, the same carbonaceous schist that overlies the section 4 km to the northeast.

The changes in the thickness and nature of the mafic metavolcanic host rocks of the Fire Lake deposit also coincide with a change in the amount of mafic and ultramafic metaplutonic rocks spatially associated with the host schist. No mafic and ultramafic metaplutonic rocks are found in or near the unit 4 km northeast of the deposit (except in the hanging wall of the Money Creek thrust, discussed later). However, 2 km north of the deposit, over 100 m of massively serpentinized ultramafic rock (meta-peridotite), massive coarse-grained amphibolite (meta-pyroxenite) and coarse-grained actinolite-plagioclase-chlorite schist (meta-gabbro) occur at the base of the unit, directly overlying the marble-quartz psammite unit. On the ridge directly north of the deposit, meta-gabbro makes up about 10% of the mafic schist unit.

Mafic and ultramafic meta-plutonic rocks in southeastern Grass Lakes map area (105G/7, Fig. 2, Murphy, 1997), north-northwest along strike of the Fyre Lake deposit, show characteristics and relationships that suggest they are sills that flowed from dykes lying along the trend of thickness changes in unit DMF. These rocks occur primarily in an approximately 600-m-thick sheet lying near the base of unit DMF (section A-A′, Figs. 2, 5). The sheet tapers to zero thickness over a 6 km horizontal distance westwardly across the North River valley and over a 4 km horizontal distance eastwardly. In addition, to the east, smaller bodies of ultramafic rock occur at different levels within the muscovite-quartz psammite unit (unit Dq) under the mafic schist. East of the Cretaceous granite in this area, bodies of ultramafic rock occur in the lower part of unit Dq, below the calcareous member Dqc. West of the granite, at approximately

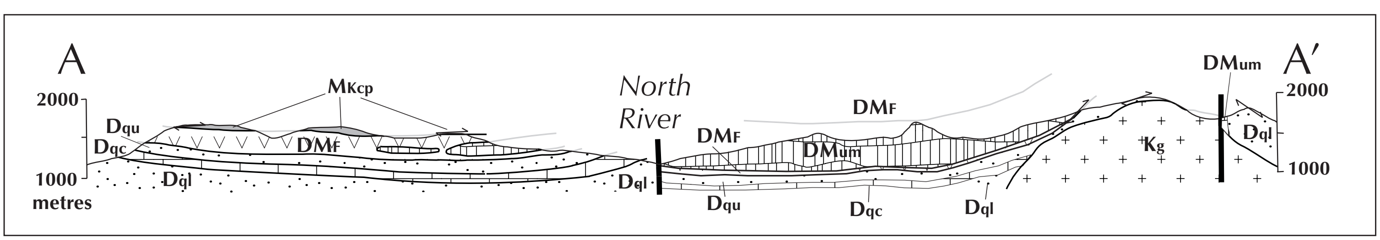


Figure 5. *Cross-section along line A-A′ shown in Figure 2. Legend as in Figure 2. Thickness of unit Dqc east of the North River is not known with certainty. The lower and upper parts of unit Dq are indicated as units Dql and Dqu, respectively.*

the same structural level, ultramafic rocks occur in the part of unit Dq above the calcareous member. These occurrences of ultramafic rock below unit DMF are unusual, observed only in one other place in the area shown in Figure 2, and are interpreted as dykes feeding the stratabound sheet within the overlying mafic schist unit. Furthermore, as two different stratigraphic levels of unit Dq are juxtaposed at the same structural level on either side of the Cretaceous granite, these dykes likely intruded along a fault.

Regionally, the changes identified above occur across a north-northwest-trending corridor that can be traced from the Fyre Lake deposit into east-central Grass Lakes map area and as far north as the large body of Grass Lakes granitic meta-plutonic rock (Fig. 6). The Pack prospect (Yukon Minfile, 1997, 105G 032) occurs along this trend, and occurrences on the OVERTIME, COBB, NHL and GOAL NET properties occur just off the trend both to the east and west. All of these showings occur in or just above the Kudz Ze Kayah felsic metavolcanic unit (MK), the unit that stratigraphically overlies the Fire Lake unit (DMF). Lying directly along this trend, across the Grass Lakes metaplutonic body, is Cominco Ltd.'s Kudz Ze Kayah deposit (>13 million tonne mineable reserve, 1.0% Cu, 1.3% Pb, 5.5% Zn, 123 g/t Ag, 1.2 g/t Au; Yukon Minfile, 1997, 105G 117). The spatial association of prospects and deposits in unit MK, with the projected trace of the Fyre Lake structure, implies that this feature may have controlled hydrothermal fluid flow during the deposition of unit MK.

CAMPBELL RANGE BELT

Pennsylvanian-Permian basalt, chert, and carbonaceous metaclastic rocks of the Campbell Range belt are the youngest stratified rocks of Yukon-Tanana Terrane in the Finlayson Lake area. They represent the culmination of the transition from arc-rifting or back-arc extension to oceanic or back-arc marginal basin magmatism and sedimentation (Plint and Gordon, 1997; Piercey et al., 1999; Figs. 2 and 7). The stratigraphic succession of the Campbell Range belt comprises a lower unit composed primarily of fragmental, pillowed and massive basalt and lesser argillite and chert; a heterogeneous middle unit composed of carbonaceous argillite, quartz sandstone, chert, chert-pebble conglomerate, discontinuous bodies of limestone, and diamictite; and an upper unit similar to the lower one (Murphy and Piercey, 1998, 1999a, b). Diabase, gabbro, leucogabbro and ultramafic rocks intrude all levels of the succession.

Two features of the Campbell Range belt imply the presence of syn-volcanic faults active during the formation of the basin. First of all, the middle heterogeneous sedimentary unit undergoes a facies change from one side of the Campbell Range to the other, over a horizontal distance of about 10 km (Fig. 8). On the southwest side, unit PPCs passes upward from a basal diamictite into carbonaceous phyllite and sandstone with glassy black

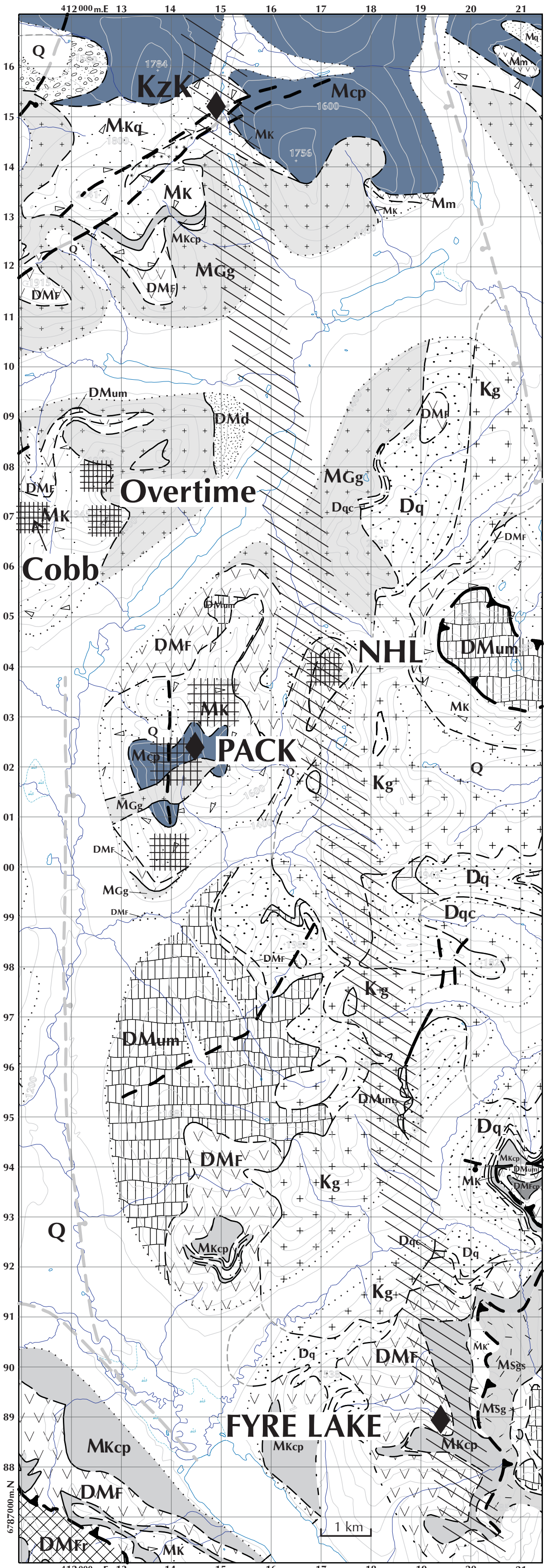


Figure 6. caption on next page.

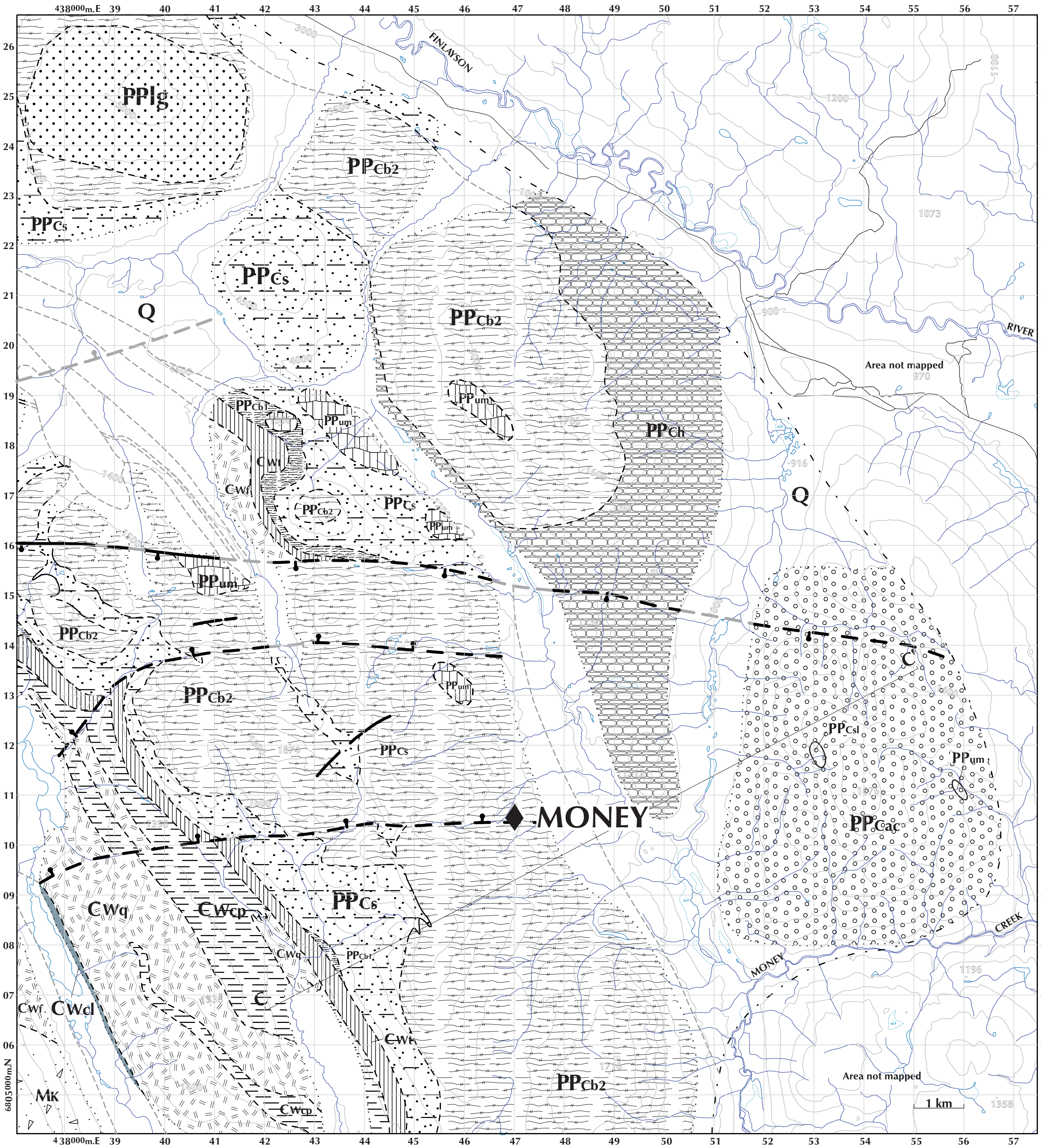


Figure 7. Geological map of the Campbell Range. Cross-section C-C′ is shown in Figure 8. Location and legend in Figure 2, except for PPCcc and PPCch, which are discussed in the text. Grid lines are spaced 1 km apart.

Figure 6, opposite. Geological map of the area between the Fyre Lake and Kudz Ze Kayah (KZK) VMS deposits showing the locations of VMS prospects and gossanous areas (grid pattern). The trend of the inferred syn-volcanic fault discussed in the text is indicated by the diagonal ruled pattern. Location and legend in Figure 2. Grid lines are spaced 1 km apart.

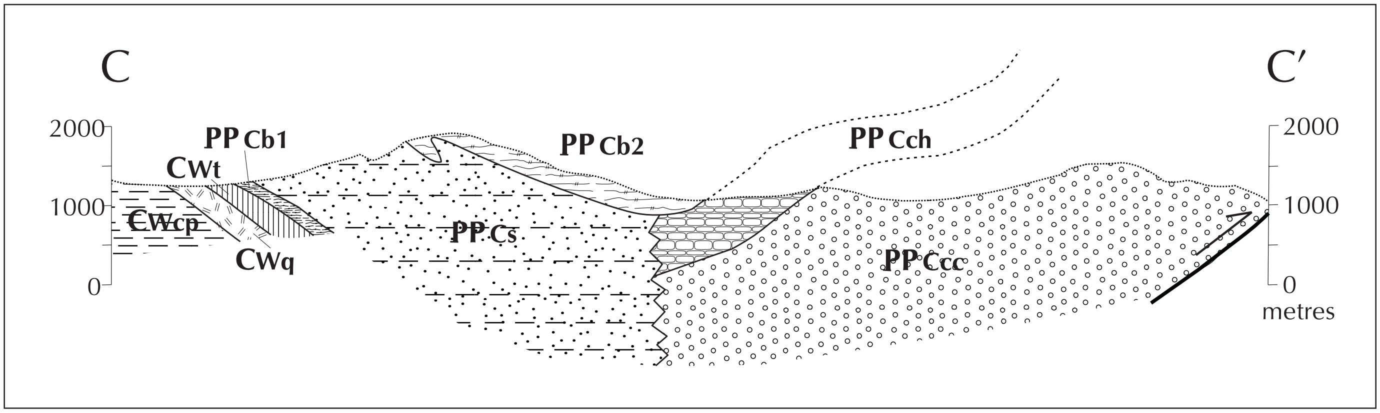


Figure 8. Cross-section across Campbell Range along line C-C′ in Figure 7. Legend as in Figure 2. In this figure, unit PPCs, on the northeast side of the Campbell Range, is subdivided into a lower unit PPCcc and an upper unit PPCch. See text for discussion.

quartz grains, and finally into greywacke and chert in the uppermost part of the unit. On the northeast side of the range, the middle unit comprises two chert- and argillite-dominated subdivisions. The basal subdivision (unit PPCcc in Fig. 8) consists of carbonaceous argillite, dark chert, rare sandstone or greywacke with glassy black quartz grains, and chert-pebble conglomerate. The upper subdivision (unit PPCch in Fig. 8) consists of thin-bedded maroon, green and tan chert and argillite. The lateral facies change between unit PPCs and units PPCcc/PPCch is not exposed in the map area. Secondly, the approximate location of this facies change is marked by a concentration of northwestwardly elongate bodies of mafic and ultramafic metaplutonic rocks, intruding all the units but mainly the upper basalt unit. The spatial association of a dramatic facies change, along with a concentration of potential feeders to the basalts, suggests the presence of a syn-volcanic fault (Gibson et al., 1999).

Few massive sulphide occurrences have been discovered in the Campbell Range belt, but those that have been found occur along or near the trace of the proposed fault. The Money prospect (Yukon Minfile, 1997, 105H 078; Baknes, M., in Hunt et al., 1997) occurs in the upper basalt along this trace. Anomalously high Cu values have been found on Cominco Ltd.'s STRIKE claims along this trend (Mann and Mortensen, this volume). Although there is little detailed geological control along strike, it should be noted that 70 km to the northwest, Expatriate Resources' Ice deposit (about 4.5 million tonnes of 1.48% Cu and minor Au, Ag and Co credits; Yukon Minfile, 1997, 105G 118) occurs in a basalt-rich succession similar to the upper basalt of the Campbell Range belt (Hunt, 1998a, b, 1999), near large bodies of ultramafic rock (see Tempelman-Kluit, 1977). Between the Campbell Range belt and the Ice deposit lies a poorly exposed corridor of greenstone, mafic and ultramafic intrusive rocks, dark argillite and chert-pebble conglomerate, and discontinuous pods of limestone (Tempelman-Kluit, 1977; Mortensen and Jilson, 1985). As has been inferred in the Campbell Range belt, this corridor may host the trace of syn-basinal faults and should be considered to have significant mineral potential for Ice-type deposits. Similar rocks also lie along strike to the southeast of the Money prospect, extending the corridor of high mineral potential in that direction.

HAT TRICK PROPERTY

At Expatriate Resources' Hat Trick property (Fig. 9), both stratigraphic and structural features are evidence for syn-volcanic, syn-mineralization faulting. The property is underlain by two coeval yet different stratigraphic sections separated by a steep, north-dipping fault (Fig. 10). North of the fault, biotite-actinolite-chlorite schist of the Fire Lake mafic meta-volcanic unit (unit DMF) passes upward into siliceous and carbonaceous schist (unit MKcp) with upwardly increasing amounts of quartz-muscovite schist (felsic metavolcanic rock, unit MK). South of the fault, a thick section of locally gossanous and highly altered magnetite-bearing felsic schist, massive siliceous rock, and lesser mafic and carbonaceous schist (unit DMFR) occurs between unit DMF and the carbonaceous schist of unit MKcp. The presence of the thick felsic schist section between units DMF and MKcp south of the fault is reminiscent of the lateral change of unit DMF at the Fyre Lake deposit and is attributed to the presence of a syn-volcanic fault. The fault between the two sections dips to the north and was initially inferred to be a southwest-directed thrust fault. However, the small thrust-sense offset of the top of unit DMF, combined with the stratigraphic difference across the fault, suggest that it is better interpreted as an originally steep, south-dipping, syn-volcanic fault that rotated through the vertical and was possibly re-activated during Cretaceous southwest-directed deformation.

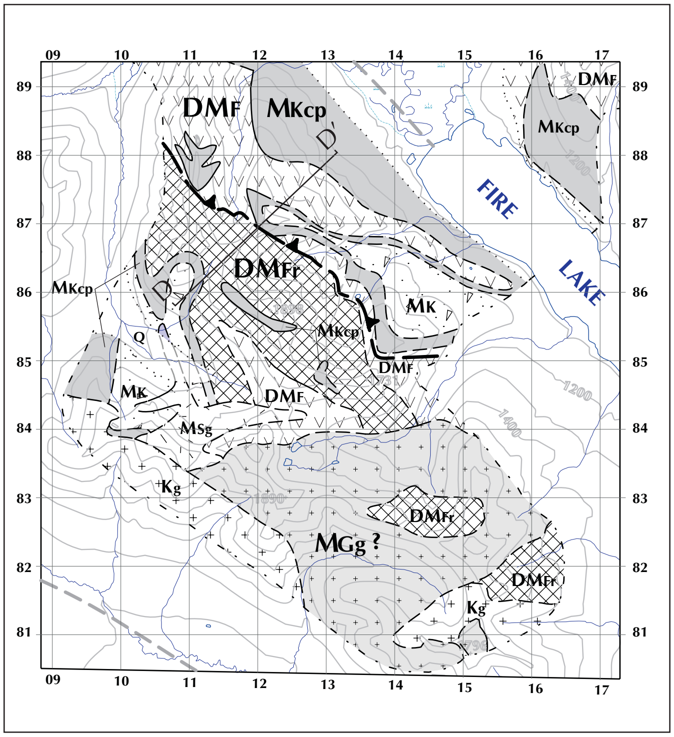


Figure 9. *Geological map of part of Expatriate Resources' Hat Trick property, southwest of Fire Lake. Cross-section D-D′ shown in Figure 10. Location and legend in Figure 2. Grid lines are spaced 1 km apart.*

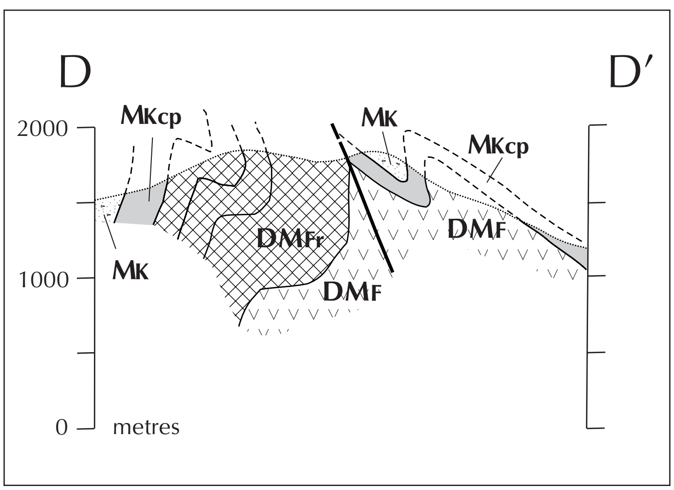


Figure 10. *Cross-section along line D-D′ in Figure 9. Form lines in unit DMFr indicate altered and mineralized horizons. Legend as in Figure 2.*

MONEY CREEK THRUST

The Money Creek thrust (Figs. 2 and 11) is interpreted as another example of a fault that was active during the evolution of Yukon-Tanana volcanism and that was re-activated as a thrust fault during Late Paleozoic or Mesozoic shortening. The stratified rocks of the Money Creek thrust sheet were previously included in the Money and North Klippe and considered to be allochthonous and unrelated to footwall rocks (Tempelman-Kluit, 1979; Erdmer, 1985; Mortensen and Jilson, 1985; Mortensen, 1992b). More recently, Hunt and Murphy (1998), Murphy and Piercey (1999b, c), and Piercey and Murphy (this volume), have shown that the stratified rocks of the thrust sheet resemble rocks in the immediately underlying footwall, both in composition and succession (Fig. 12). Furthermore, U-Pb geochronological constraints (Mortensen, 1992a, b; Grant, 1997; Mortensen, pers. comm., 1996-1999) affirm that the successions are coeval.

Although similar and coeval, there are important differences between the hanging wall and footwall of the Money Creek thrust. These include: 1) the quartz-rich metaclastic rocks in unit Dq of the thrust sheet are primarily quartzite, whereas in the footwall, they are primarily micaceous quartz psammite; 2) both basalt (unit DMF) and rhyolite (unit DMFr) of the thrust sheet are locally subaerial, while coeval rocks of the footwall are intercalated mainly with carbonaceous argillite, implying a basinal setting; 3) a laterally continuous, eastwardly thickening fossiliferous limestone with a shallow water conodont form (Orchard, M., GSC Microfossil Report MJO-1997-14 on sample collected by D. Rhodes) occurs in the thrust sheet and is absent in the footwall; 4) bedded barite occurs in unit MK within the thrust sheet and has not been observed in the footwall; and 5) plutonic rocks in the thrust sheet are hornblende-bearing granodiorite and granite in contrast to the primarily peraluminous granitic meta-plutonic rocks of the footwall (see below). Taken together, these differences suggest that the rocks of the Money Creek thrust sheet may have formed in a different, possibly higher-standing, crustal block than the rocks of the footwall. In such a scenario, the Money Creek thrust may simply be a thrust re-activation of the structure that separated the different crustal blocks in Devonian and Mississippian time.

If a re-activated feature, the areas near the hanging wall and footwall cut-offs would be likely sites for syngenetic mineralization. Bedded barite, altered pyritic felsic metavolcanic rocks, and an altered and locally malachite-stained hornblende granodiorite occur on Cominco Ltd.'s EXPO claims which lie about 10 km behind the leading edge of the thrust. The footwall cut-off has probably been offset along the Tintina Fault. The thrust sheet overlies the same footwall unit (MK) almost to the Tintina Fault (Fig. 2). However, as hornblende-bearing granitic meta-plutonic rocks similar to those in the Money Creek thrust sheet appear in the footwall near the Tintina Fault (Figs. 2 and 9), the footwall cut-off may not have been far to the south or

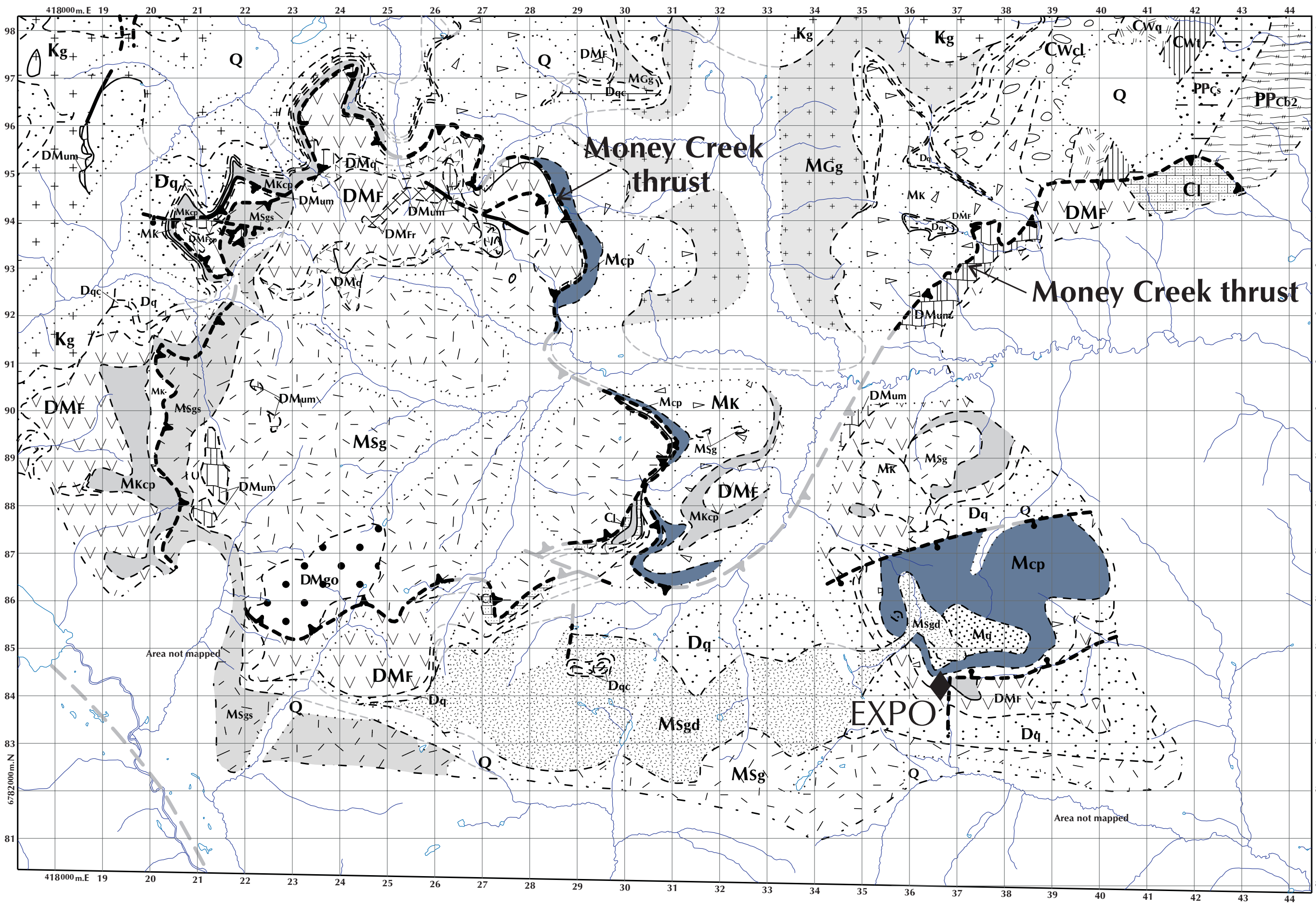


Figure 11. *Geological map of parts of Wolverine Lake (105G/8) and Waters Creek (105G/1) map areas showing the Money Creek thrust sheet and its footwall. Location and legend in Figure 2. Grid lines are spaced 1 km apart.*

southwest. If so, the region of the footwall cut-off may currently be just southwest of the Tintina Fault near Dawson City.

Structural fabrics in the deformation zone immediately above the fault, indicate that the Money Creek thrust sheet was thrust towards the north-northeast. Its displacement was at least 30 km based on the amount of overlap of the footwall by the hanging wall.

SUMMARY

Several lines of evidence suggest that syngenetic mineralization in the Finlayson Lake massive sulphide belt, as in other VMS districts, was focussed along syn-volcanic faults. Although the host rocks are deformed and metamorphosed, the trends of these structures can be estimated, primarily by looking for concentrations of comagmatic intrusions. These trends define corridors of high potential for new discoveries.

ACKNOWLEDGEMENTS

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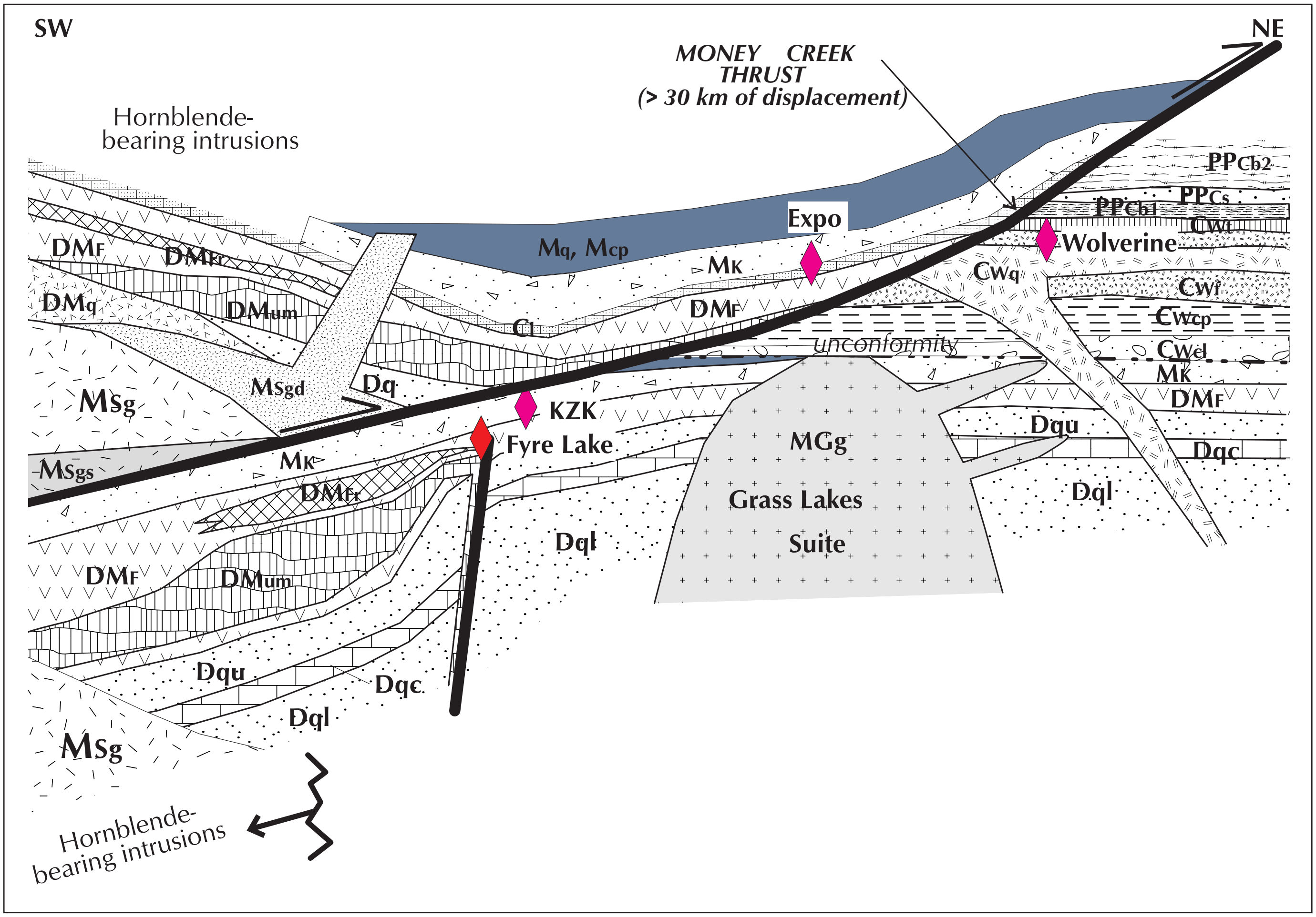

Figure 12. Schematic northeast-southwest cross-section summarizing the stratigraphy and intrusive rocks in the hanging wall and footwall of the Money Creek thrust sheet. Legend as in Figure 2. The appearance of hornblende-bearing granitic meta-plutonic rocks in the footwall near the Tintina Fault is indicated schematically by the jagged vertical line. KZK = Kudz Ze Kayah.

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