Finlayson project: Geological evolution of Yukon-Tanana Terrane and its relationship to Campbell Range belt, northern Wolverine Lake map area, southeastern Yukon

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ABSTRACT

Geological mapping in Wolverine Lake area has outlined new Yukon-Tanana Terrane stratigraphy, constrained the stratigraphic position of the Wolverine Lake volcanogenic massive sulphide (VMS) deposit, and clarified the relationship of Yukon-Tanana Terrane to the Campbell Range belt. Yukon-Tanana Terrane comprises two stratigraphic successions separated by an angular unconformity. Beneath the unconformity are polydeformed felsic and mafic meta-volcanic rocks, carbonaceous meta-clastic rocks, marble and granitic orthogneiss. The Kudz Ze Kayah VMS deposit occurs in felsic meta-volcanic rocks of this sequence. Yukon-Tanana Terrane rocks above the unconformity are deformed by only one phase of deformation and consist primarily of carbonaceous meta-clastic rocks and quartz- and feldspar-phyric felsic meta-volcanic rocks. The Wolverine VMS deposit occurs in this succession, associated with siliceous exhalite and baritic magnetite iron formation. Meta-basalt of the Campbell Range belt, included previously in Slide Mountain Terrane, overlies the upper succession of Yukon-Tanana Terrane with sharp contact. This contact has been observed at several localities and it appears depositional. There is no evidence that it is a terrane boundary fault.

RÉSUMÉ

La cartographie géologique de la région du lac Wolverine a permis l'ébauche d'une nouvelle stratigraphie pour le terrane de Yukon-Tanana (TYT), la détermination de la position stratigraphique du gîte sulphures massifs volcanogènes (SMV) Wolverine Lake et l'éclaircissement de la relation entre le TYT et la zone de la chaîne Campbell. Le TYT comprend deux successions stratigraphiques séparées par une discordance angulaire. Sous la discordance, se trouvent des roches métavolcaniques felsiques et mafiques, des roches métaclastiques carbonées, du marbre et un orthogneiss granitique. Toutes ces roches sont polydéformées. Le gîte SMV Kudz Ze Kayah se trouve dans les roches métavolcaniques felsiques de cette séquence. Les roches du TYT au-dessus de la discordance ne sont déformées que par une seule phase de déformation et consistent principalement de roches métaclastiques carbonées et de roches métavolcanofelsiques à quartz et feldspath porphyriques. Le gîte SMV Wolverine Lake se trouve dans cette succession, associé à une formation d'exhalite siliceuse et de magnétite barytinique. Le métabasalte de la zone de la chaîne Campbell, antérieurement inclus dans le terrane de Slide Mountain, recouvre la succession supérieure du TYT le long d'un contact franc. Ce contact a été observé en plusieurs endroits et semble stratigraphique. Il n'y a aucune indication à l'effet qu'il s'agisse d'une faille limitant un terrane.

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INTRODUCTION

Located south of the Campbell Highway in the heart of the Finlayson Lake massive sulphide district, Wolverine Lake map area (105G/8) is a key area in the understanding of Yukon-Tanana Terrane and the geological setting of its massive sulphide deposits (Fig. 1). The area hosts the Expatriate Resources/Atna Resources' Wolverine deposit (> 6 million tonnes at 1.33% Cu, 1.55% Pb, 12.66% Zn, 370 g/t Ag, 1.76 g/t Au; Tucker et al., 1997) and several other occurrences of massive and semi-massive sulphides. Cominco Ltd.'s Kudz Ze Kayah deposit (13 million tonnes at 1.00% Cu, 1.3% Pb, 5.5% Zn, 125 g/t Ag, 1.2 g/t Au; Schultze, 1996) lies about 5 km along strike, west of the western boundary of the map area. Mapping of Wolverine Lake area provides the opportunity to evaluate the geological setting of the Wolverine deposit and other occurrences and to compare with that of the Kudz Ze Kayah deposit in adjacent Grass Lakes map area recently mapped by Murphy (1997, 1998). More specifically, are the two deposits hosted by the same stratigraphic unit (as proposed by Hunt, 1997, 1998a,b; and Murphy, 1998)? In addition, the northern part of Wolverine Lake area is underlain by rocks of the Campbell Range belt which have been correlated with Slide Mountain Terrane (see Plint and Gordon, 1997 for a recent summary). The correlation with Slide Mountain Terrane implies that the contact of the Campbell Range succession with Yukon-Tanana Terrane is a terrane-boundary fault. Although a fault has been inferred by previous workers, this fault has not been described nor is it required by the ages of the rocks in contact. Detailed mapping in northern Wolverine Lake area provides an opportunity to examine this important contact.

In this paper and an open file map (Murphy and Piercey, 1998), we report on the results of seven weeks of geological mapping in northern Wolverine Lake map area. We conclude that Yukon-Tanana Terrane in this area comprises two stratigraphic successions separated by a previously unrecognized angular unconformity. The lower succession is made up of rocks that were deformed, metamorphosed and intruded by Early Mississippian granitic orthogneiss before the deposition of the

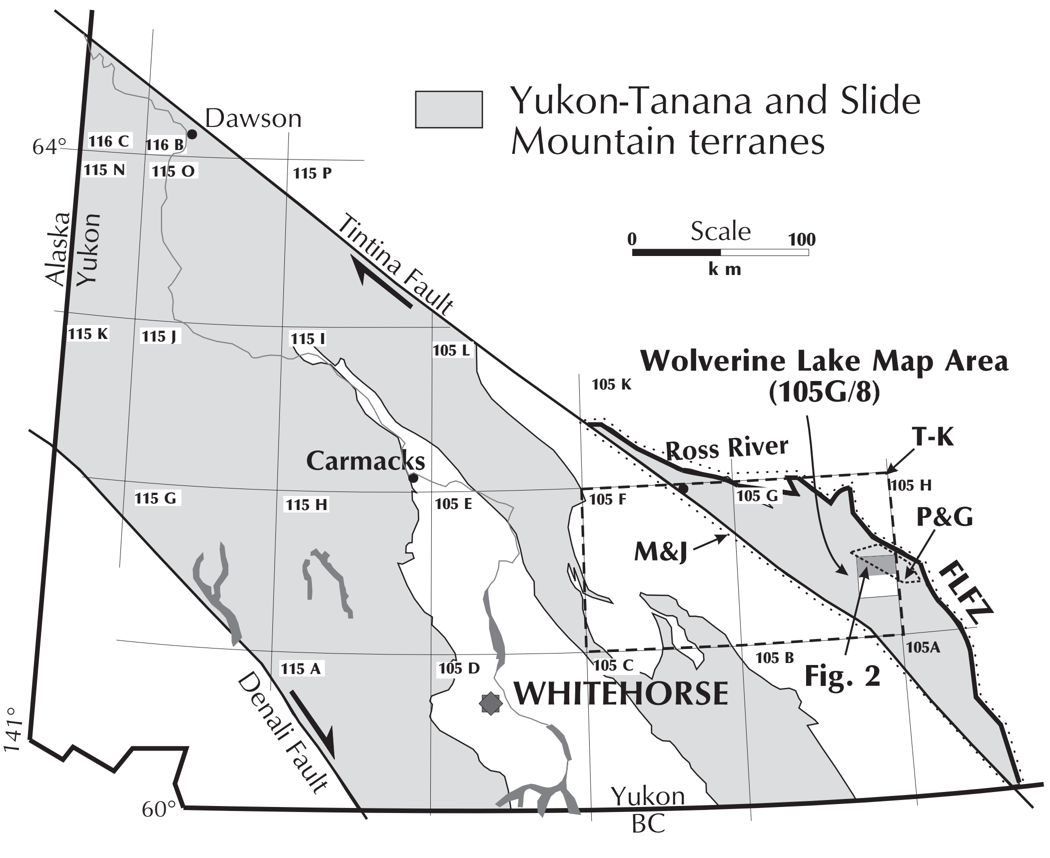

Figure 1. *Location of Wolverine Lake map area with respect to the distribution of Yukon-Tanana and Slide Mountain terranes in Yukon (modified from Wheeler and McFeely, 1991). Mesozoic plutons and metamorphic complexes are not differentiated. Areas discussed by Tempelman-Kluit (1977, 1979), Mortensen and Jilson (1985) and Plint and Gordon (1997) are outlined [T-K (long dashes), M&J (dotted), P&G (short dashes), respectively]. FLFZ = Finlayson Lake fault zone*

upper succession. Massive sulphide deposits occur in both successions: the Kudz Ze Kayah deposit occurs in polydeformed rocks below the unconformity and the Wolverine deposit occurs in singly deformed rocks above the unconformity, hence their host units do not correlate. Secondly, in mapping the contact between the upper succession of Yukon-Tanana Terrane and Upper Paleozoic meta-basalt of the Campbell Range belt, a contact previously considered to be part of the terrane-bounding Finlayson Lake fault zone, we found no evidence of faulting and conclude that the contact is stratigraphic. It therefore cannot be a terrane boundary and Campbell Range belt must be considered in the context of the evolution of Yukon-Tanana Terrane, not as an unrelated geological element.

PREVIOUS WORK

The geology of Wolverine Lake area was initially mapped at a scale of 1"=4 mi. by Wheeler et al. (1960) and subsequently at 1:250 000 scale by Tempelman-Kluit (1977). Emphasizing the highly deformed nature of Yukon-Tanana Terrane, Tempelman-Kluit (1979) expanded this regional geological framework into a comprehensive model for the tectonic evolution of the North American continental margin. In this model, rocks of Wolverine Lake map area were included in three allochthonous sheets (siliceous cataclasite of Nisutlin Allochthon, plutonic cataclasite of Simpson Allochthon, and sheared basalt, gabbro, serpentinite of Anvil Allochthon). Nisutlin Allochthon is described by Tempelman-Kluit (1979, p. 8) as “muscovite-quartz blastomylonite and mylonite with interfoliated phyllonitic slate and chlorite schist” which grade laterally into “weakly sheared or protoclastic feldspathic quartz-granule grit and sandstone with interbedded slate” presumed to be the protolith for much of the Nisutlin Allochthon. “Dark slate and fragmental volcanics of intermediate composition” and crinoidal limestone were recognizable locally and were thought to be the protoliths for more highly sheared chlorite schist, phyllonitic slate and flaser marble. In Tempelman-Kluit’s view, all original stratigraphic character and relationships were obliterated during deformation. The Nisutlin Allochthon was interpreted as tectonic mélange made up of “synorogenic clastic rocks and remnants of crustal fragments” (Tempelman-Kluit, 1979, p. 21) that were deformed and imbricated with similarly disrupted Anvil and Simpson allochthons during Early Mesozoic subduction southwestward beneath the Intermontane Belt. Rare occurrences of eclogite were offered as further evidence of a subduction zone setting for the deformation of Yukon-Tanana Terrane. The imbricated assemblage was subsequently thrust onto rocks of the outer North American continental margin in the Early Cretaceous.

In contrast to Tempelman-Kluit’s “mélange” interpretation for Yukon-Tanana Terrane in this area, Mortensen (1983), Mortensen and Jilson (1985) and Mortensen (1992) recognized a stratigraphic succession and presented an alternative model for the evolution of the terrane. They subdivided the metamorphic rocks into three regionally mappable units, and in Mortensen and Jilson (1985, p. 808) described them as follows: the lower unit consists of “quartz-mica-garnet schist, micaceous feldspathic quartzite, and near the top, calcite marble and calcareous schist.” The middle unit consists of “dark gray to black siliceous phyllite to quartzite, locally with medium gray calcareous phyllite toward its base” interlayered with “abundant mafic metavolcanic and lesser felsic metavolcanic rocks” and, toward the top, “abundant chloritic quartz grits, locally with bluish opalescent quartz granules.” Late Devonian to mid-Mississippian U-Pb ages were obtained from felsic meta-volcanic rocks of the middle unit. The upper unit is “a package of white carbonate and quartzite that is at least in part Early Pennsylvanian to Early Permian in age [conodont ages, Tempelman-Kluit, 1979; M. Orchard, 1984, pers. comm.]” Three suites of variably deformed Devono-Mississippian granitic rocks were also recognized throughout the area, with evidence of intrusive contacts. In Mortensen and others’ view, Yukon-Tanana Terrane in the Finlayson Lake area consists of a mid-Paleozoic magmatic arc, its continental crustal basement, and overlying Upper Paleozoic platformal rocks. The continental magmatic arc represented by the Permian Klondike Schist documented in Mortensen (1990, 1992) was, and is as yet, unrecognized in the Finlayson Lake area. This assemblage was initially intensely deformed and metamorphosed in the Permian or Triassic on the basis of deformed and metamorphosed clasts in nearby Norian conglomerate. Subsequently, between Late Triassic and mid-Cretaceous time, the terrane was imbricated by thrusting with the Norian clastic rocks and with meta-basalt, mafic and ultramafic meta-plutonic rock, chert and argillite of Slide Mountain Terrane (Campbell Range belt and other isolated occurrences, all previously included in Anvil Allochthon of Tempelman-Kluit, 1979; see also Mortensen, 1992). Finally, by mid-Cretaceous time, this composite entity was joined with rocks of the North American continental margin by displacement along the Finlayson Lake fault zone, a steep structure that Mortensen and Jilson (1985) inferred to be transpressive in nature (Fig. 1).

Plint (1995) and Plint and Gordon (1995, 1996, 1997) mapped part of Wolverine Lake map area in their study of the rocks of the Campbell Range belt, its relationship to Yukon-Tanana Terrane, and the implications of this relationship for the evolution of the Finlayson Lake Fault Zone. Using lithostratigraphic and chronostratigraphic arguments, they affirmed previous correlations of rocks of the Campbell Range belt with Slide Mountain Terrane. Secondly, they inferred that meta-basalt of the Campbell Range formed in a oceanic (marginal?) basin on the basis of trace element data. Thirdly, they interpreted the contacts of Campbell Range belt with both Yukon-Tanana Terrane on the west and rocks inferred to be of North American affinity on the east as oppositely vergent thrust faults. Finally, they proposed that the Finlayson Lake fault zone, rather than being a steep fault zone, is part of an originally northeast-vergent thrust system that was subsequently modified by southwest-directed thrusts and folds.

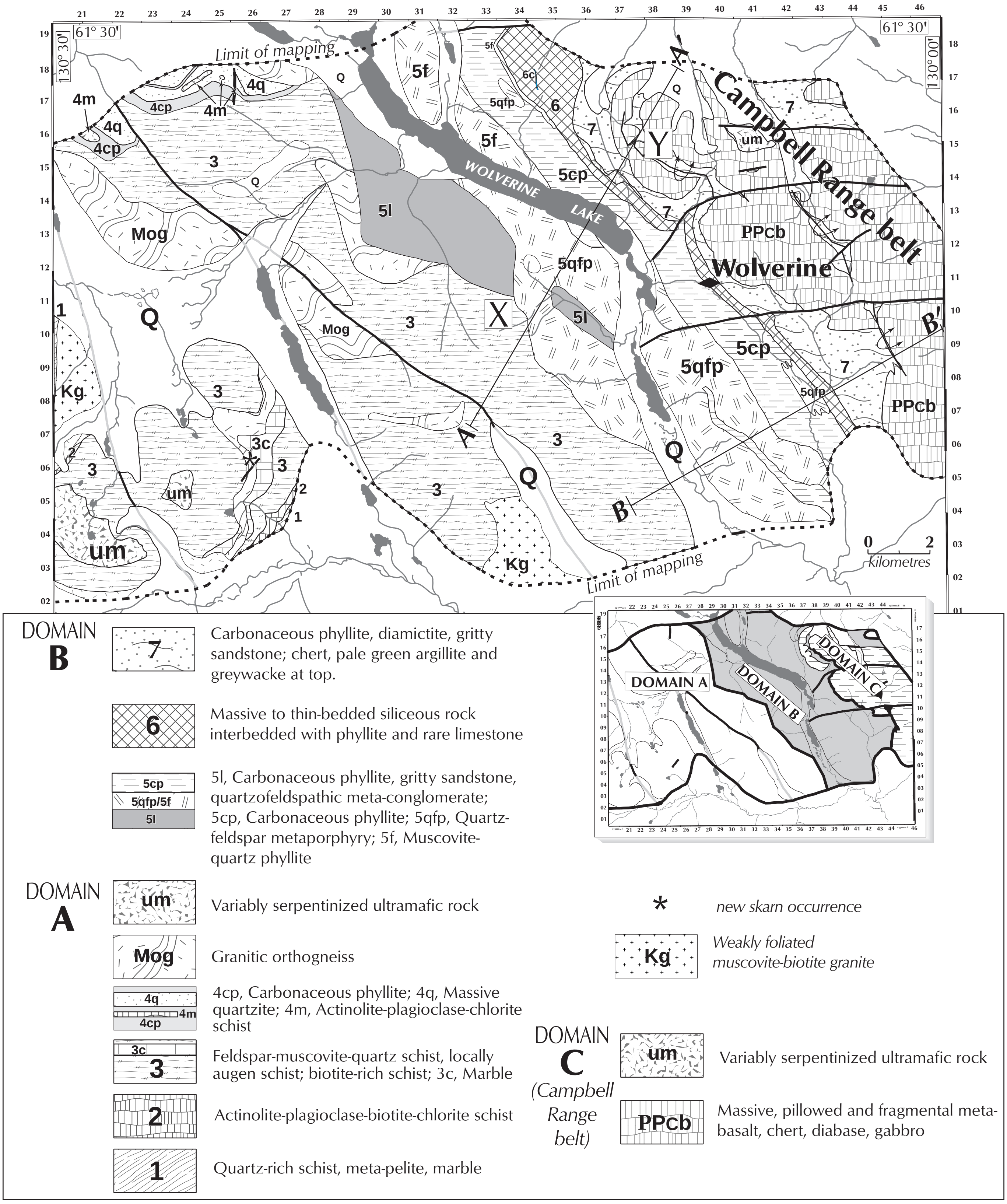

***Figure 2**. Geological map of northern Wolverine Lake area. Inset map shows distribution of domains discussed in text. X and Y are locations where critical relationships between domains were observed (see text). A-A′ and B-B′ are lines of cross sections shown in Fig. 16.*

In the most recent phase of investigation of Yukon-Tanana Terrane in this area, the Grass Lakes area (105G/7) was mapped at 1:50 000 scale by Murphy and Timmerman (1997a,b) and Murphy (1997, 1998), and parts of neighbouring areas were mapped by Hunt and Murphy (1998). They affirmed the stratigraphically intact nature of Yukon-Tanana Terrane in this area as proposed by Mortensen and Jilson (1985) and Mortensen (1992), subdivided these authors' lower and middle units into 4 mappable units, and placed the syngenetic massive sulphide deposits into this stratigraphic framework. Furthermore, the authors speculated/concluded that:

1) quartz-feldspar meta-conglomerate in unit 4 marks an unconformity reflecting the uplift and erosion of Early Mississippian granitic rocks and their host rocks;
2) some of the mafic and ultramafic rocks in the area, considered by previous workers to be thrust slices, are intrusions, based on their three-dimensional form and lack of evidence for a basal thrust; and
3) the strain zone beneath the Money Klippe near Fire Lake may be a sheared intrusive contact rather than a large-displacement thrust fault, based on the intrusive nature of many of the contacts in the klippe and the similarity of the rocks in the klippe with the rocks beneath the strain zone.

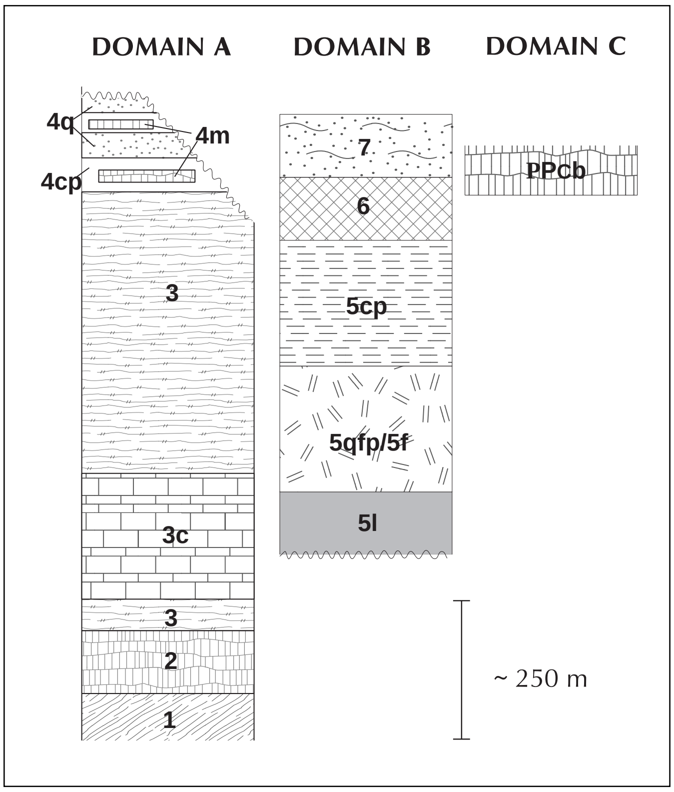

***Figure 3**. Stratigraphic columns from each of three domains discussed in text. Patterns as in Figure 2.*

This report, in describing rocks immediately east of Grass Lakes map area, extends the area of stratigraphic and structural control from the Grass Lakes area and presents new conclusions on stratigraphically higher parts of Yukon-Tanana Terrane.

GEOLOGY OF NORTHERN WOLVERINE LAKE MAP AREA

The deformed and metamorphosed rocks of northern Wolverine Lake map area can be subdivided into three domains on structural and lithostratigraphic grounds (Fig. 2, 3). Domain A is underlain by the east-northeast striking succession of rocks mapped in Grass Lakes map area (units 1-4 and Early Mississippian orthogneiss of Murphy, 1997, 1998) which extends into Wolverine Lake map area. Domain B consists of a northwest-striking, northeast-dipping succession of rocks that truncates and overlies Domain A on the east, and lacks Early Mississippian orthogneiss. Domain C comprises the northwest-striking rocks of the Campbell Range belt which lie above the rocks of Domain B.

DOMAIN A

Domain A is largely underlain by felsic schist of unit 3 of Murphy (1997, 1998) with some exposure of units 1, 2, Mississippian orthogneiss, ultramafic rock, and Cretaceous granite (Fig. 3). Unit 1 occurs in two locations, between the western edge of the map area and the western contact of the nearby Cretaceous granite, and at the southern edge of the area mapped. It consists of tan- to brown-weathering muscovite-quartz[1] schist, locally with quartzofeldspathic grit(?) layers, quartz-muscovite-biotite schist, and lesser marble. Unit 2 also occurs in the same two areas where it comprises pale to medium green, weakly calcareous actinolite-plagioclase-biotite-chlorite schist.

Unit 3 is a heterogeneous unit made up of both meta-sedimentary and meta-volcanic rocks. Light grey weathering, grey and tan to brown biotite-muscovite-feldspar-quartz schist (Fig. 4a), commonly with mm- to cm-scale feldspar augen (Fig. 4b) is the dominant rock type. Locally, the matrix of these rocks is creamy white, fine-grained and siliceous. Biotite-rich quartz-feldspar-calcite-biotite schist ("biotitite," Fig. 4c) is commonly interfoliated with augen schist. Intervals of meta-sedimentary rock punctuate the dominantly felsic schist succession. These include calcareous quartz psammite and siliceous carbonaceous schist and quartzite, locally with soft, pale pink to rusty quartz-muscovite schist and magnetite-bearing semi-massive sulphide layers and lenses ("iron formation," Fig. 4d); and marble (Fig. 4e). The latter is locally thick enough to map as a separate unit 3c (Fig. 2, 3). Pale to medium green actinolite-quartz-plagioclase-biotite-chlorite schist similar to unit 2 also occurs locally in unit 3. Mortensen (1992)

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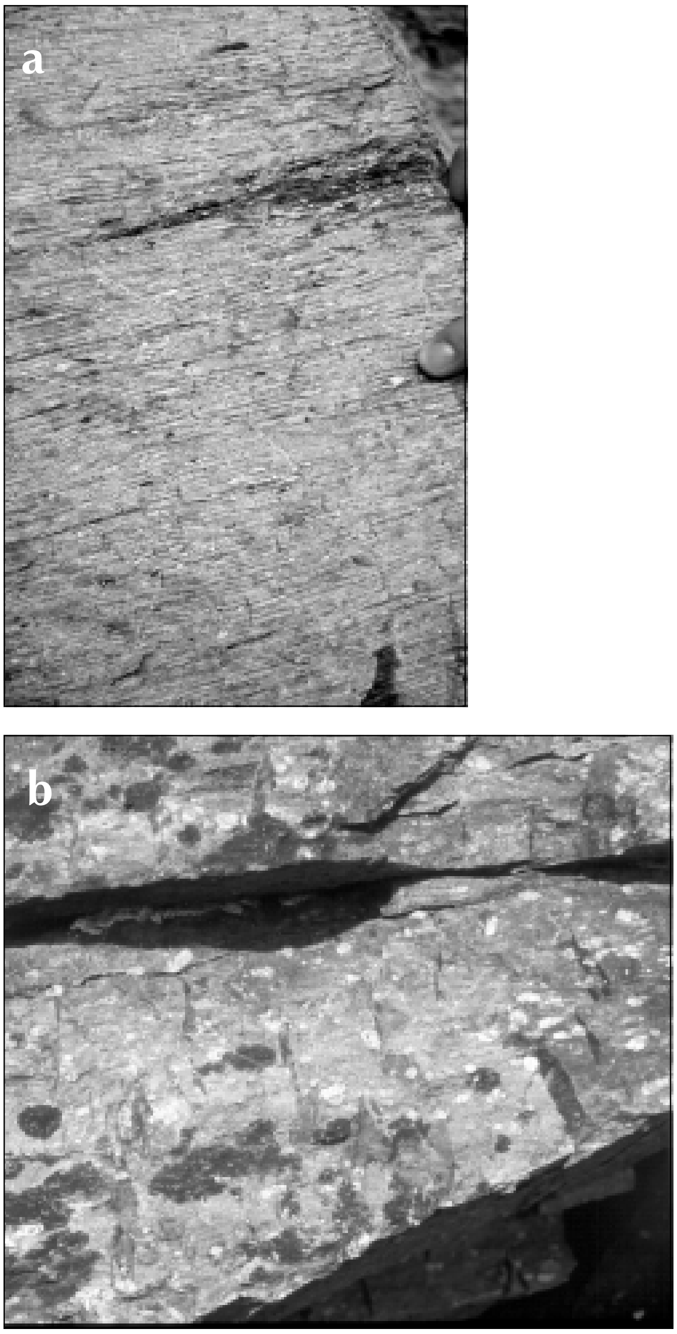
[1] Mineral descriptors of rock types are listed in order of increasing abundance.

reported Late Devonian-Early Mississippian U-Pb age determinations for similar rocks throughout Yukon-Tanana Terrane northeast of the Tintina Fault.

In the southwestern part of the area, beneath the ultramafic bodies capping the prominent peaks, the felsic and carbonaceous rocks are organized into thinning and fining upward cycles (Fig. 5). Each cycle is characterized by fine- to coarse-grained augen schist at the base and a meta-sedimentary top comprising siliceous carbonaceous schist, calcareous psammite and/or marble. In the uppermost cycles, the meta-sedimentary component predominates and consists mainly of siliceous carbonaceous phyllite, pale, locally rusty magnetite-bearing quartz-muscovite schist, and layers and lenses of magnetite-bearing semi-massive sulphide.

The fining and thinning upward cycles described above are overlain by a sheet of variably serpentinized ultramafic rock,



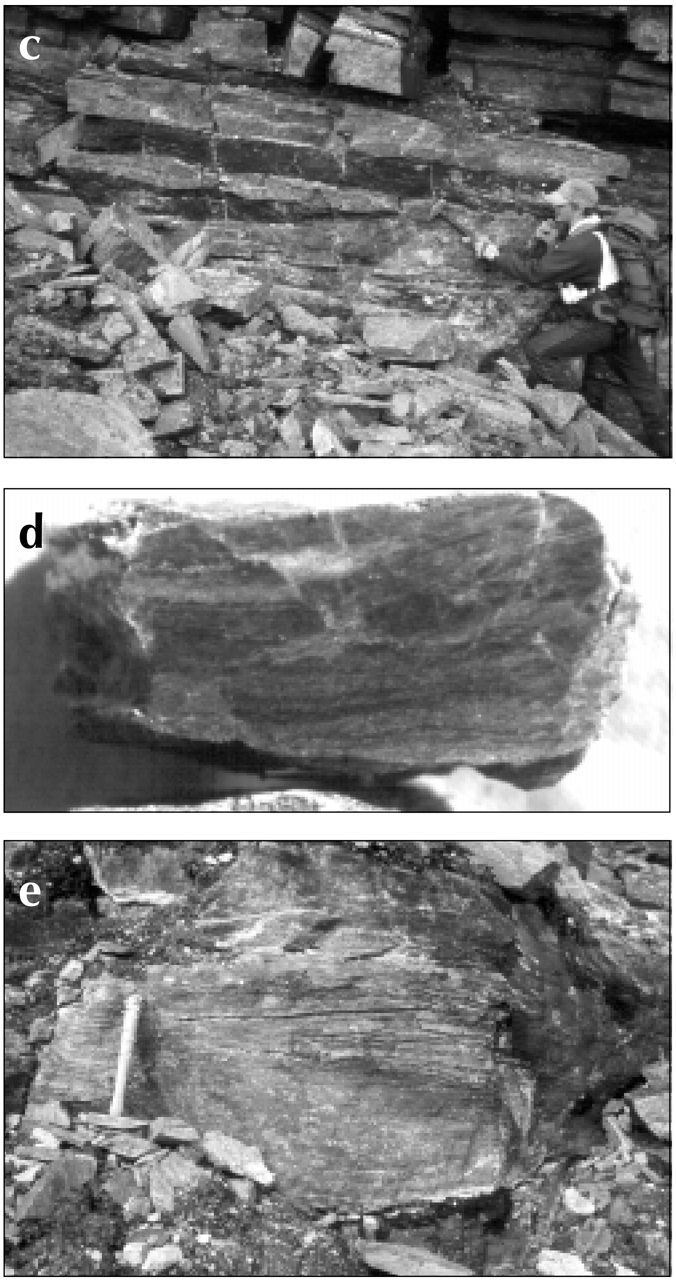


***Figure 4**. Unit 3: **a)** biotite-muscovite-feldspar-quartz schist with mm- to cm-scale feldspar augen; **b)** coarse feldspar augen biotite-muscovite-feldspar-quartz schist; **c)** biotite-rich quartz-feldspar-calcite-biotite schist (“biotitite;” dark layers) interlayered with felsic shist as in 4a; **d)** mangane,e zoisite-magnetite-pyrite ± sphalerite layer in carbonaceous schist near top of unit 3; **e)** unit 3c: coarse-grained grey marble and boudinaged calc-silicate layers.*

hence their stratigraphic position in unit 3 is unknown. However, a similar upward increase in siliceous carbonaceous phyllite occurs at the stratigraphic top of unit 3 in the northwestern part of the area. In this area, unit 3 feldspar augen muscovite-quartz schist is overlain by siliceous carbonaceous phyllite, with lesser pale quartz-muscovite schist, chlorite schist, greenstone, and massive quartzite of unit 4. Chlorite schist of unit 4 resembles unit 2 but is more massive (greenstone). The quartzite unit in the northwest corner of the map area is unique in the area in that it is massive to thick-bedded, ranges in colour from mottled grey/white, to pink and purple and occurs in a mappable thickness (greater than 300 m thick in cross section). This quartzite unit has been traced for over 5 km, defining the east-northeast strike of the strata. It disappears into the Wolverine Lake valley and doesn't re-appear along strike to the east.

Bodies of coarse-grained equigranular granitic orthogneiss occur throughout Domain A (Fig. 6). These are similar to Grass Lakes orthogneiss in Grass Lakes map area to the west. They also resemble feldspar-augen meta-volcanic schist that occurs in the same area in unit 3. These two meta-igneous rock types are distinguished by the grain size of the matrix: if the quartz-rich matrix is coarse-grained and massive, then the rock is inferred to be meta-plutonic (unit Mog); if fine-grained and schistose, then the rock is inferred to be either a porphyritic meta-volcanic or a high-level, meta-plutonic rock. The intrusive nature of these bodies is attested to by the local occurrence of skarn near contacts with calcareous host rocks and the increase in number of metre-scale bodies of granitic orthogneiss toward the contact with the larger bodies.

***Figure 5**. Thinning and fining upward cycles at top of unit 3.*

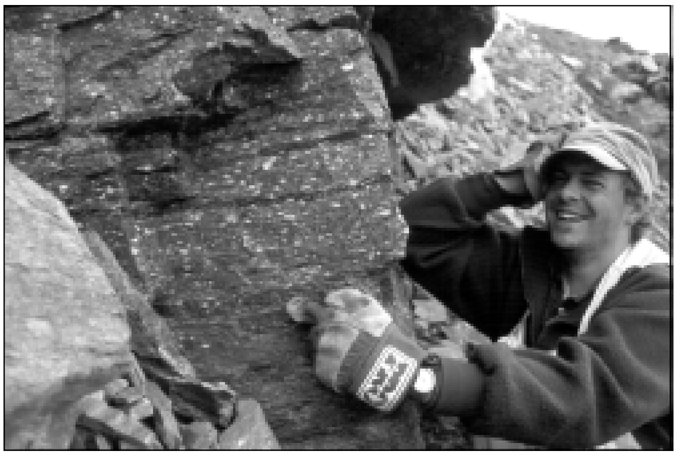


***Figure 6**. Coarse-grained equigranular granitic orthogneiss in central part of area.*

Dun- to chocolate brown-weathered, dark green to black, variably serpentinized ultramafic rocks, previously considered to be part of Anvil Allochthon or Slide Mountain Terrane (North Klippen of Tempelman-Kluit, 1979), cap the two prominent peaks in the western part of the map area (Fig. 2). Ultramafic rock is typically massive, unfoliated and cut by serpentine-filled fractures/veins. Fish-scale serpentinite is rarely observed and likely indicates small-displacement fault zones. Relic coarse-grained (cm-scale and larger) crystals of a blocky mineral phase, probably orthopyroxene, occur locally. Magnetite is a common constituent of these rocks; they have strong magnetic signatures on aeromagnetic maps (DMTS, 1961; GSC, 1998). In the westernmost of the two peaks, the contact with underlying rocks of unit 3 is sharp and well exposed in several places (Fig. 7). At these exposures, unit 3 is very hard and finely but strongly foliated and lineated, fine-grained felsic schist with a distinct maroon cast. Ultramafic rock above the contact is fractured but not more than elsewhere. Even with good exposure, it is not clear if the contact is a fault or a deformed intrusive contact.

The mapped area includes part of two weakly foliated granite plutons, both in Domain A. The eastern side of a northwardly-elongate batholith occurs in the western part of the map area.

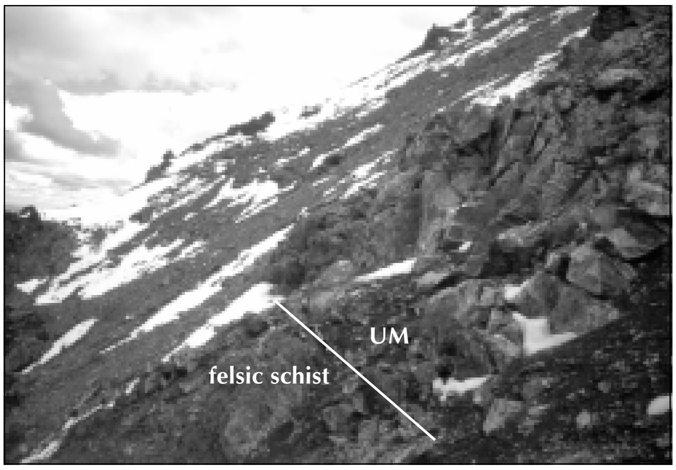


***Figure 7**. Contact between ultramafic rocks capping peak in western part of map area and hard, fine-grained muscovite-quartz schist of unit 3.*

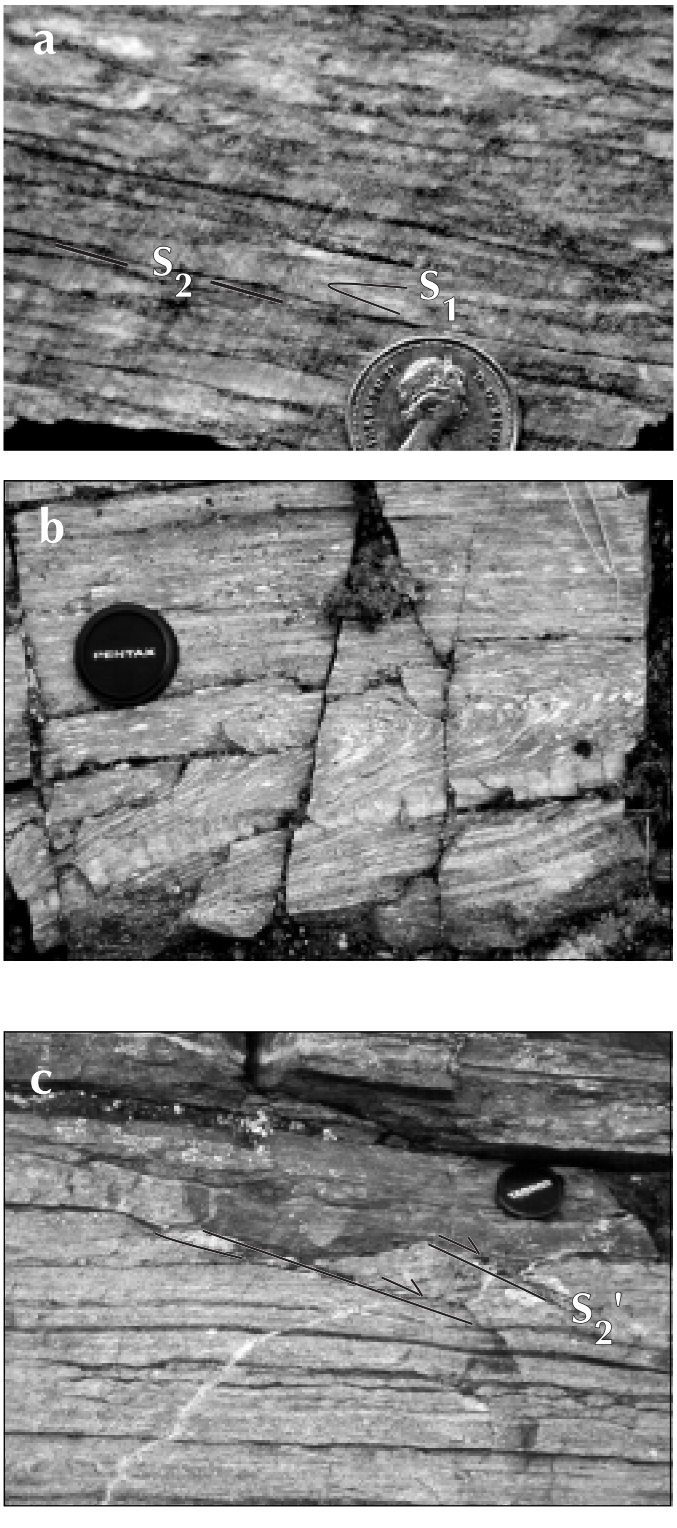


Figure 8. ***a)*** *Doubly foliated rocks of Domain A;* ***b)*** *folded foliations;* ***c)*** *view to east of outcrop face parallel to lineation and perpendicular to foliation showing shear bands with top-to-south vergence.*

The second is an incompletely mapped granite pluton in the southern part of the map area. Both bodies are weakly foliated, medium- to coarse-grained, tourmaline-bearing muscovite-biotite granite. Although weakly foliated, they truncate the main foliation in the country rocks, and dykes emanating from the larger bodies are folded; both observations suggest late syn-kinematic intrusion with respect to the prominent foliation in the country rock. Country rock adjacent to the contact is recrystallized. Mid-Cretaceous U-Pb ages have been determined for both of these bodies (110-113 Ma, J. Mortensen, pers. comm., 1996).

Rocks of Domain A host two kinds of mineral occurrences, volcanic-hosted massive sulphide mineralization and skarn. The Kudz Ze Kayah volcanic-hosted massive sulphide deposit (Yukon Minfile 105G 117) and other occurrences of this type of mineralization (Pack, 105G 032; Cobb, Overtime claims) occupy a stratigraphic position near the top of unit 3 in Grass Lakes map area. The same stratigraphic interval in Wolverine Lake map area is marked by felsic schist and carbonaceous phyllite which locally includes black-weathered, pyrolusite-coated, foliated green manganese zoisite-magnetite-pyrite ± sphalerite ± galena-bearing rock (Goal Net I target of Expatriate Resources). In eastern Grass Lakes map area, skarn showings occur on Expatriate Resources' Goon claims where marble is in contact with Early Mississippian orthogneiss, and at the Myda occurrence (#105G 071) where the same marble is in contact with a Cretaceous granite. In Wolverine Lake map area, we located a previously unreported skarn showing at the contact between an Early Mississippian sill and unit 3c (Fig. 2).

The layered metamorphic rocks and most bodies of Early Mississippian orthogneiss of Domain A show evidence for two profound phases of penetrative deformation followed by later upright, open folding and high-angle faulting. In any given outcrop, two foliations are typically visible. The first, S1, is typically inclined in microlithon domains between the prominent folia of the other, (S2; Fig. 8a). Tight to isoclinal, generally south- or southwest-vergent folds occur locally; these typically fold S1 and have S2 for an axial-planar fabric (Fig. 8b). S2 is deflected sigmoidally by S2´ shear bands with top to the south displacement, parallel to a prominent quartz-rodding and mineral-streaking lineation, (L2; Fig. 8c). Shear bands both deflect and are asymptotic to S2, implying that they formed during the same deformation (D2).

Late folds and faults are indicated by systematic changes in orientation of S2 (Fig. 9). In area 1 of Fig. 9, changes in orientation of S2 define a structural basin beneath the western ultramafic body. Across Domain A in an east-west direction, S2 changes from northeast-striking, northwest-dipping to northwest-striking and northeast-dipping around north-northwest-striking axial surfaces (areas 2 and 3, Fig. 9). The transitions locally coincide with high-angle north-northwest-striking faults.

In spite of the late folding of S2, the structural and stratigraphic grain of Domain A is broadly east-northeast striking. Within a kilometre of Domain B, the structural grain changes to northwestwardly striking, sub-parallel to that of Domain B. The stratigraphic grain, however, must still be inclined to that of Domain B because the westernmost unit of Domain B is next to different units of Domain A in different parts of the map area (Fig. 2).

DOMAIN B

The east-northeast striking stratigraphic succession of Domain A is truncated to the east by the northwest-striking, northeast-dipping strata of Domain B (Fig. 2). For reasons outlined in a separate upcoming section, the contact between the Domain A and B is interpreted as an angular unconformity for part of its extent and as an intrusive contact for the remainder.

The lowest stratigraphic unit of Domain B is unit 5, which consists of a lower member of carbonaceous phyllite and grey gritty quartzofeldspathic meta-sandstone with variable amounts of quartzofeldspathic meta-conglomerate (unit 5l, Fig. 10a), and an upper member comprising laterally and vertically variable amounts of quartz-feldspar meta-porphyry (5qfp, Fig. 10b); muscovite-quartz phyllite (5f); grey, locally gritty, sandstone with glassy black quartz and argillite clasts; and carbonaceous phyllite (5cp, Fig. 10c). Unit 5l is typically overlain by quartz-feldspar meta-porphyry except south-southwest of Wolverine Lake (location X on Fig. 2). Here, quartz-feldspar meta-porphyry both overlies and underlies unit 5l, and is in direct contact with felsic schist of unit 3. This relationship is further discussed in the section on contacts between the domains.

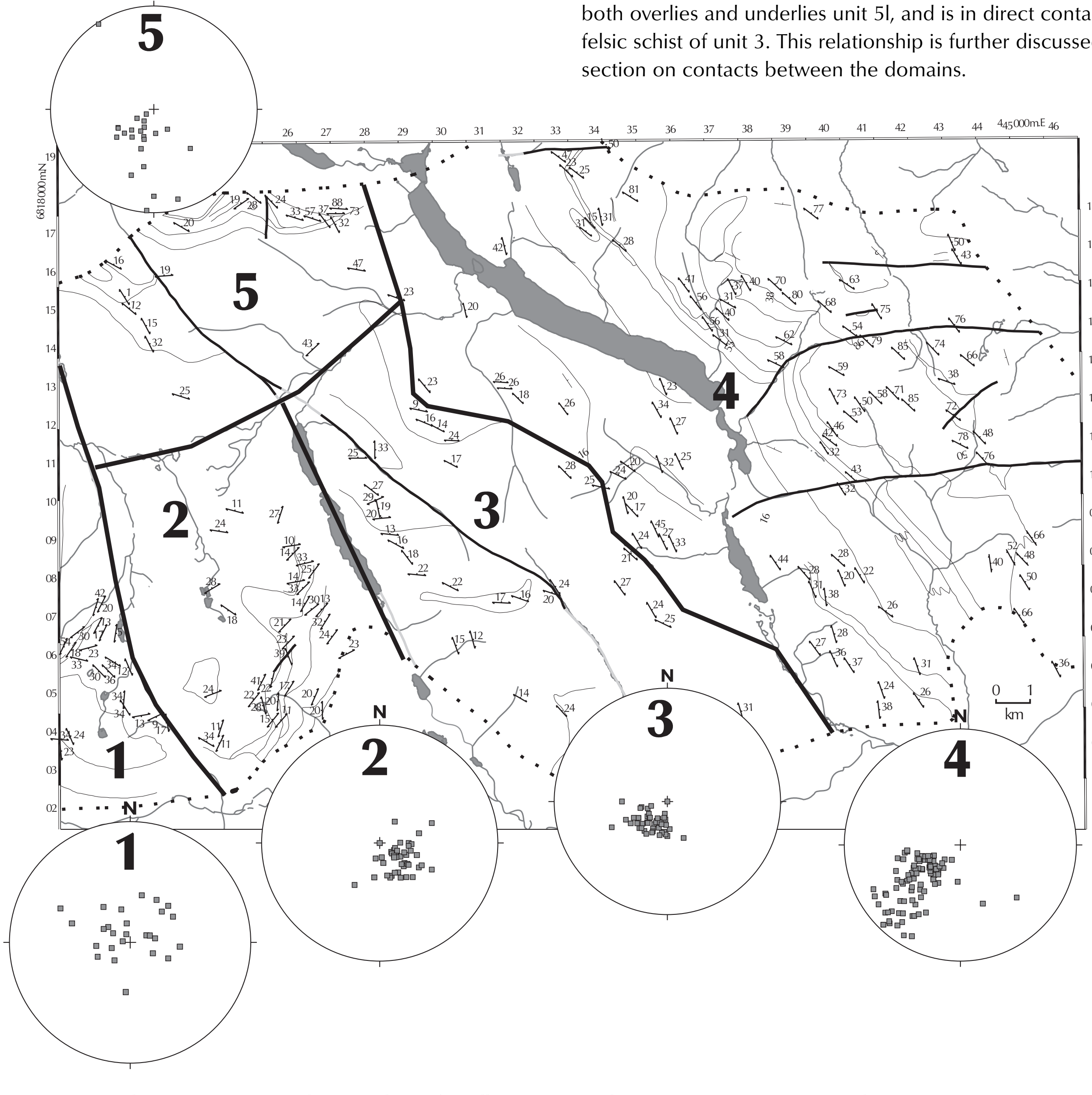


Figure 9. Structural measurements and stereoplots of S2 illustrating its change in orientation across the map area.

Conformably overlying unit 5 is a thin but laterally persistent unit consisting primarily of cream to tan siliceous rock and barite-magnetite iron formation interbedded with lesser amounts of muscovite-quartz phyllite and carbonaceous phyllite (unit 6). At the base of unit 6, the siliceous rock is massive to thick-bedded, locally characterized by boxwork pyrite and interbedded with tan muscovite-quartz phyllite (Fig. 11a). Upsection, bed thickness decreases to cm- and mm-scale and interbedded phyllite becomes grey (Fig. 11b, c). A metre-scale brown marble band occurs in the upper part of the unit.

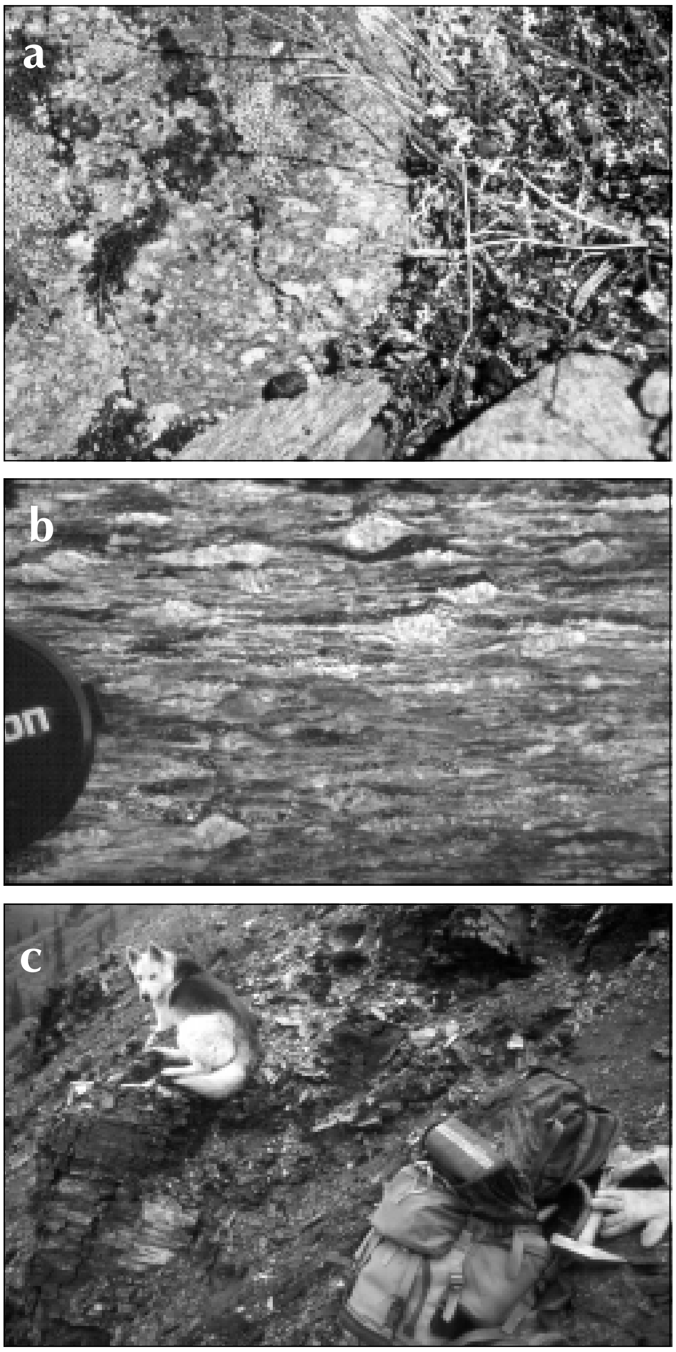


***Figure 10**. **a)** Unit 5l: quartzofeldspathic meta-conglomerate; **b)** Unit 5qfp: quartz-feldspar meta-porphyry. Note shear bands. View is to the east and surface is parallel to lineation so hanging wall transport is to the south; **c)** Unit 5cp: carbonaceous phyllite and grey quartz meta-sandstone.*

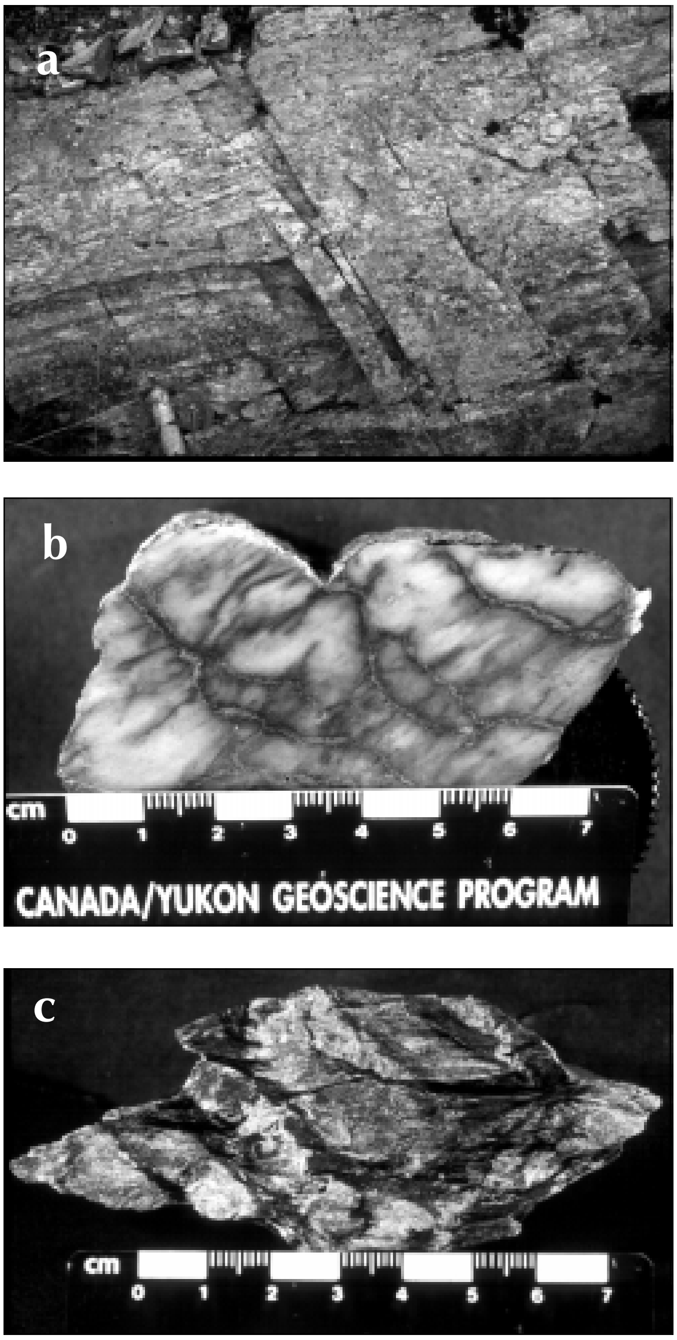


***Figure 11**. Unit 6: **a)** cream to tan siliceous rock with barite-magnetite iron formation; **b)** cm-scale beds of siliceous rock with lesser mm-scale beds of muscovite-quartz phyllite; **c)** cm-scale beds of siliceous rock with subequal amounts of cm-scale beds of carbonaceous phyllite*

Unit 7 comprises carbonaceous phyllite and grey, locally gritty meta-sandstone with lesser amounts of chloritic phyllite and diamictite. The diamictite is a matrix-supported conglomerate made up of isolated centimetre- to decimetre-scale clasts of felsic and mafic meta-volcanic rock and quartz-pebble meta-conglomerate in a matrix of carbonaceous phyllite (Fig. 12a). Grey ribbon chert (Fig. 12b), greywacke with shale chips, coarse-grained limestone, and pale green, fine-grained siliceous argillite occur toward the top (Fig. 12c). These latter rock types are interbedded in rare outcrops with breccias made up of basalt clasts.

Rocks of Domain B host volcanic-hosted massive sulphide mineralization. The Wolverine massive sulphide deposit (Yukon Minfile 105G 072) and nearby mineralized zones (Fisher, Lynx, Sable) occur near the contact between units 5 and 6 (Fig. 2). The spatial association of unit 6 with this belt of volcanic-hosted massive sulphide mineralization and its association with barite-magnetite iron formation suggests that the siliceous layers of unit 6 are of exhalite origin.

In comparison to those of Domain A, rocks of Domain B are less deformed and bedding and other primary structures are more readily recognized. Like Domain A, Domain B rocks are foliated, lineated, folded by southwest-vergent folds and locally deformed by late kink folds and crenulations of the foliation. The prominent foliation affecting Domain B (S1) is a curviplanar pressure-solution foliation that is defined by finely spaced seams of concentrated micas and insoluble residue in phyllite layers, and more coarsely spaced seams of mica/insoluble residue in more siliceous layers (see Fig. 11b, c). The foliation is axial-planar to outcrop- and larger-scale, open to tight, upright to southwest-overturned folds that have a first-order southwest-vergence. The axial-planar relationship is especially evident at the higher stratigraphic and structural level of unit 6 and 7 where foliation and bedding are typically at a relatively large angle (Fig. 12b) and their intersection produces an intersection lineation that parallels the hinges of these folds. At the stratigraphic level of unit 5, bedding/compositional layering and foliation are sub-parallel and folds are tight to isoclinal, both of which suggest a downward increase in strain. Foliation surfaces at this level are characterized by a quartz-rodding lineation that trends southerly; shear bands in quartz-feldspar meta-porphyry at this level suggest hanging wall transport to the south, parallel to the lineation (Fig. 10b). At the stratigraphic level of unit 5, the character of the structural fabric resembles that of the second phase of deformation in Domain A, with one important difference. Although Domain B rocks have not yet been examined in thin section, the pressure-solution foliation looks to be the first foliation in the rock and does not appear to be a crenulation of an earlier fabric as observed in Domain A.

DOMAIN C (CAMPBELL RANGE BELT)

Lying above unit 7 of Domain B is a folded yet gently dipping sheet of meta-basalt, argillite, chert, diabase, gabbro and serpentinized ultramafic rock of Domain C (Campbell Range

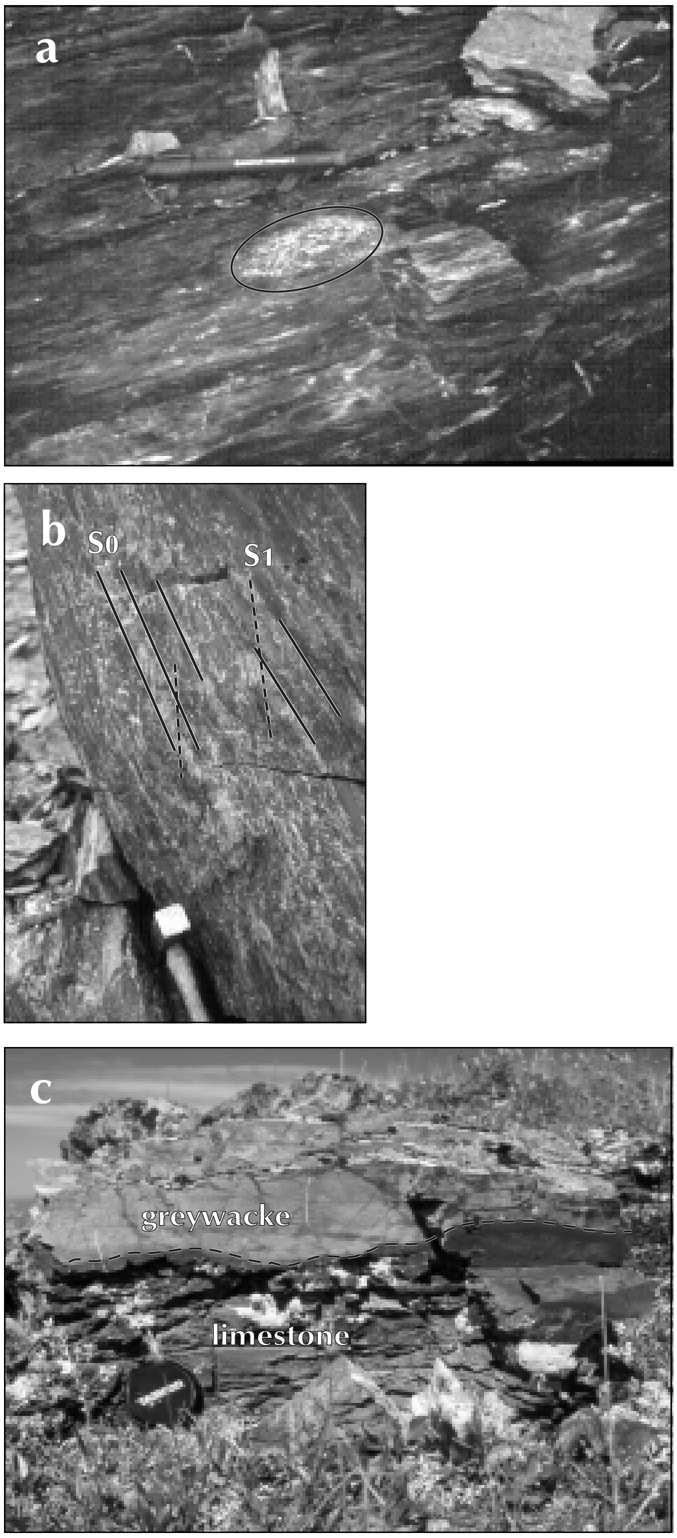


***Figure 12**. Unit 7: **a)** diamictite, clast of quartz-pebble meta conglomerate outlined; **b)** beds of chert in silicous argillite (bedding, So, indicated). View is to the southeast and cleavage-bedding relationship indicates that outcrop is on the southwestern limb of anticline; **c)** limestone and greywacke.*

belt of Mortensen and Jilson, 1985; Mortensen, 1992; Plint and Gordon, 1997; units PPCb and um of Fig. 2). As will be discussed in an upcoming section, the contact between Domains B and C is inferred to be depositional.

Massive meta-basalt is the dominant rock type with pillowed and fragmental varieties occurring locally (Figs. 13a, b). Massive basalt is generally dark green to black, variably foliated and locally marked by magnetite-bearing reddish jasperoidal silica and pale green epidote-quartz veins. Decimetre- to metre-scale pillows are locally well preserved and indicate that with the exception of short overturned limbs of southwest-vergent folds, the sequence is generally upright. Fragmental meta-basalt is light reddish brown and variably foliated and lineated. These fine- to coarse-grained monomictic breccias consist of angular basalt fragments and carbonate or chlorite cement. Polymictic breccias elsewhere in the Campbell Range were described by Plint and Gordon (1997).

Less common rock types in the Campbell Range include maroon or green silty and siliceous argillite, chert, and mafic and ultramafic meta-plutonic rocks. Plint and Gordon (1997) described interbeds of radiolarian chert in meta-basalt from which they obtained a mid-Pennsylvanian to Early Permian age (identification by T. Harms). Mafic meta-plutonic rocks with fine- to medium-grained diabasic texture occur throughout the Campbell Range belt; although no contacts were observed, Plint and Gordon (1997) reported intrusive relationships. Aeromagnetically prominent bodies of serpentinized ultramafic rock occur in the northeastern part of the area. The contacts aren't exposed although scaly foliated serpentinite occurs near the southern margin of one body implying a locally faulted contact (Fig. 14).

No mineral occurrences are known in Domain C in northern Wolverine Lake map area. Magnetite-bearing jasperoidal silica occurs locally and rusty, pyritic zones occur along late east-striking normal faults. Campbell Range meta-basalt hosts the Money occurrence just outside the map area to the east, and Expatriate Resources' Ice deposit occurs about 90 km along strike to the northwest in basaltic rocks possibly correlative to the Campbell Range basalt (Hunt, 1998a).

Domain C has a similar structural style to Domain B. Fragmental and pillowed meta-basalt are foliated and lineated with fragmental rocks showing a stronger degree of fabric development. Foliation and lineation are axial-planar to open to tight, upright to southwest-overturned, southwest-vergent folds that occur in both Domain B and C, and fold the contact between the two domains (Fig. 15). A synclinal keel of meta-basalt at the western edge of the belt is more strongly foliated than the eastern part of the belt (Figs. 2, 15, location Y), probably owing to the tightness of the folding (see Discussion). Steep, east-striking normal faults cut both Domain B and C.

NATURE OF CONTACTS BETWEEN THE DOMAINS

Figure 16 summarizes our interpretation of the contacts between the domains. The contact between Domains A and B is inferred to be an angular unconformity where between unit 5l

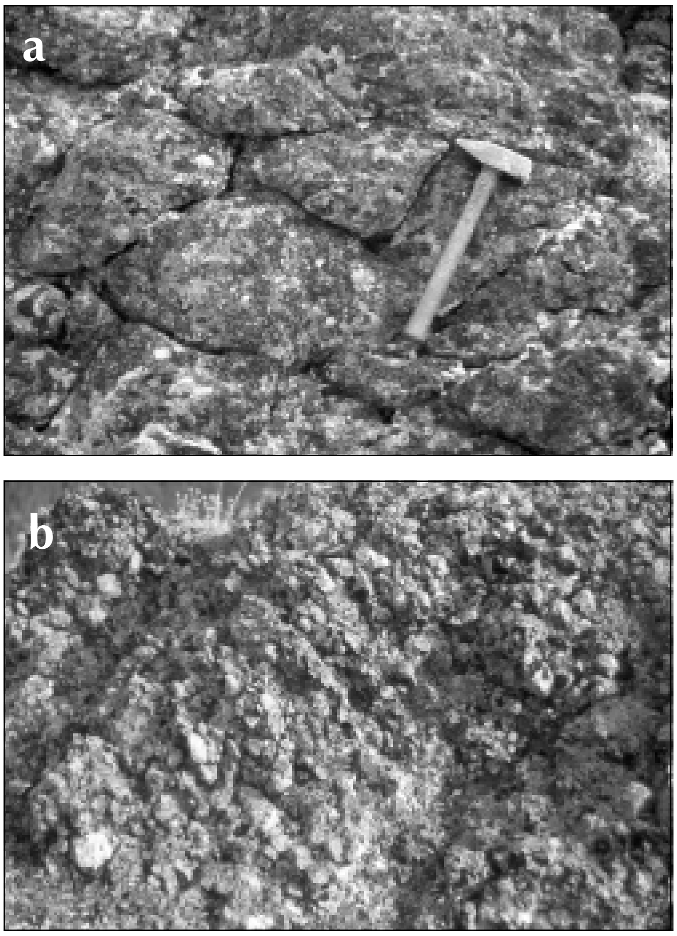


Figure 13. Campbell Range meta-basalt: ***a)*** *pillowed,* ***b)*** *fragmental.*

Figure 14. Scaly foliated serpentinite near contact of ultramafic rocks and massive meta-basalt in Campbell Range belt.

and underlying rocks, and a deformed intrusive contact where between unit 5qfp and unit 3. The contact between Domains B and C is interpreted as a conformable depositional contact.

Three lines of evidence support the interpretation of an angular unconformity beneath unit 5l. First of all, unit 5l, the lowest unit of Domain B, comprises quartzofeldspathic meta-conglomerate in its lower part. Locally, feldspar clasts in the conglomerates are cm-sized and angular, and detrital zircons are euhedral (J. Mortensen, pers. comm., 1998), implying a local source. The coarse-grained meta-plutonic rocks of Domain A are obvious candidates for a local source. If so, then Domain A must have been uplifted and eroded to the extent that meta-plutonic rocks within it were exposed before the deposition of unit 5l. Secondly, rocks of Domain A are more highly deformed than Domain B and possibly have undergone an additional phase of deformation. Where the contact can be constrained to within a few metres, the change is abrupt, yet no structural features there indicate a fault or shear zone boundary. If depositional, then the underlying rocks must have been intruded, deformed, intruded again, uplifted and eroded before the deposition of unit 5l. This sequence is supported by preliminary geochronological data on two weakly foliated yet discordant intrusions in Domain A, originally thought to be Cretaceous, which yielded Early Mississippian ages (J. Mortensen, pers. comm., 1998). Thirdly, an angular discordance between Domain A and Domain B is required by two observations: 1) unit 5l rests upon different units of Domain A, and 2) there is a general discordance in strike between the domains such that strata of Domain A strike into the basal unit of Domain B.

The interpretation that the contact between unit 3 and unit 5qfp is a deformed intrusive contact is based on geological relationships south-southwest of Wolverine Lake (location X on Fig. 2). Here, quartz-feldspar meta-porphyry both overlies and underlies unit 5l, and quartz-feldspar meta-porphyry, with a single foliation, is in direct contact with polydeformed felsic schist of unit 3. A reasonable explanation for this relationship is that where unit 5qfp lies beneath unit 5l, it is a subvolcanic feeder to the meta-porphyries that overlie unit 5l, and the contact between unit 3 and unit 5qfp is intrusive. In this interpretation, where unit 5qfp underlies unit 5l, the contact between the two would also have to be intrusive.

The contact between Domains B and C is inferred to be depositional. First of all, the top of unit 7 includes pale green siliceous phyllite and meta-sandstone as well as some of the rock types of the Campbell Range belt such as thin-bedded chert and rare fragmental meta-basalt with carbonate cement. The occurrence of these rock types at the top of unit 7 suggests a transitional contact with Campbell Range meta-basalt. Secondly, the contact exhibits no structural evidence of a fault or shear zone. The base of the sheet of Campbell Range meta-basalt has been observed with relatively good exposure both along strike and across strike in anticlinal hinge zones (Figs. 2, 15). Everywhere along this contact, the meta-basalt sits above the transitional-looking upper part of unit 7, and there are no increases in the amount of fracturing or strength of foliation, slickensides or gouge. Meta-basalt and unit 7 are folded conformably around first-order upright to southwestwardly overturned, southwest-vergent folds with a gently dipping enveloping surface (Fig. 15).

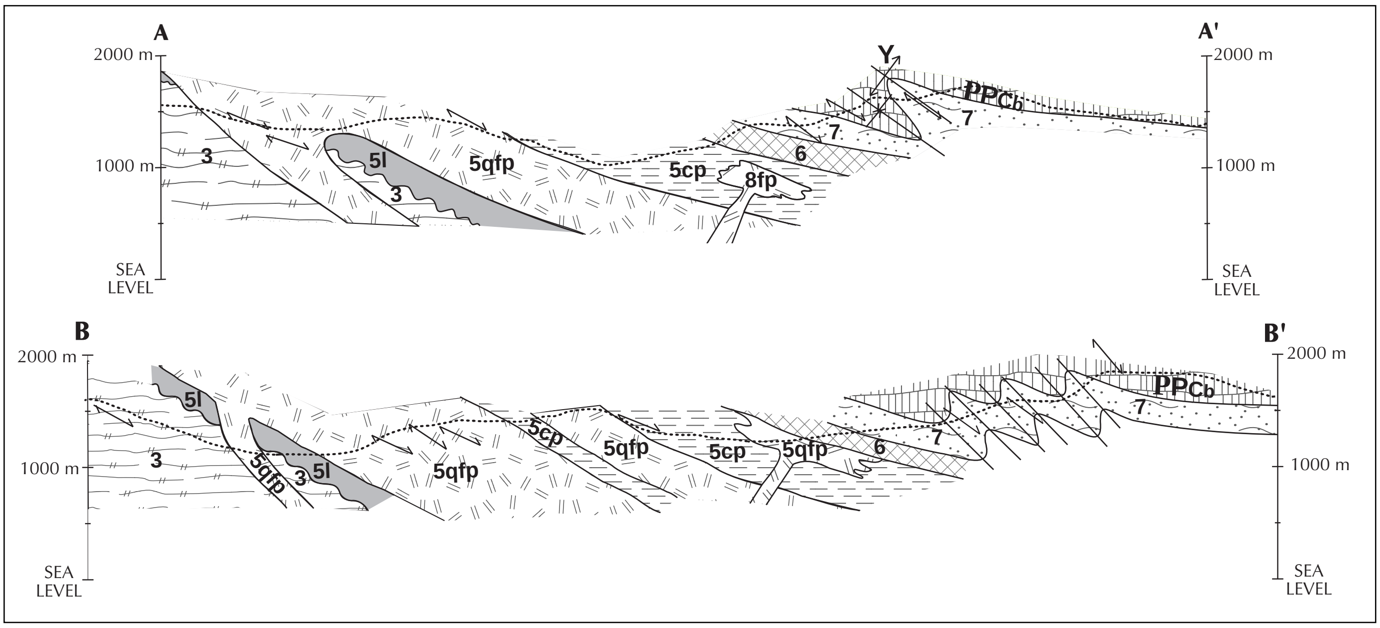


***Figure 15**. Cross sections of northern Wolverine Lake map area. Location and legend are as in Fig. 2. The unconformable contact between units 3 and 5l, the intrusive contact between units 3 and 5qfp, and the contact between unit 7 and PPCb (Campbell Range belt) are discussed in the text.*

DISCUSSION

We have presented evidence for a previously unrecognized angular unconformity in Yukon-Tanana Terrane, an unconformity that marks the completion of an episode of deformation, metamorphism, plutonism and uplift. The unconformity is broadly Early Mississippian in age, based on relatively imprecise Early Mississippian U-Pb ages of late-kinematic meta-plutonic rocks below the unconformity and quartz-feldspar meta-porphyry above the unconformity (J. Mortensen, pers. comm., 1998). The unconformity's short time gap indicated by the geochronological data and the apparently rapid restoration of continental magmatic arc activity after the unconformity imply that it may only be a local intra-arc feature. However, nearby Stewart Lake and Simpson Range eclogites also have Early Mississippian mica cooling ages (Erdmer et al., 1998), permitting the possibility of a linkage between the tectonic activity indicated by the unconformity, and the formation and exhumation of the eclogites. If it is of regional extent and significance, this unconformity may be a useful feature in correlating between widely separated areas of Yukon-Tanana Terrane. Further work is needed to determine the regional extent of Early Mississippian tectonism and its significance.

Secondly, our new work shows that the strata hosting the Wolverine and Kudz Ze Kayah massive sulphide deposits are different. The Wolverine deposit occurs in Domain B above the unconformity and Kudz Ze Kayah, below, in Domain A. This distinction explains the differences in stratigraphic, structural, metamorphic and geochemical character that have been noted by geologists who have visited both deposits. It also adds another stratigraphic horizon to the growing list of horizons known to host VMS deposits in Yukon-Tanana Terrane.

Thirdly, our location of the contact between unit 7 and meta-basalt of the Campbell Range belt, and our interpretation of it as depositional, differ from previous interpretations. Tempelman-Kluit (1977, 1979) located the contact of Anvil Allochthon (Wolverine Klippen=Campbell Range belt) at approximately the same place as our study but interpreted it as a thrust fault. He shows the Anvil Allochthon as a gently dipping sheet capping topographically high areas, with low-lying rocks belonging to the underlying Yukon-Tanana Terrane. Mortensen and Jilson (1985) located the basal contact of rocks of the Campbell Range belt northeast of where we placed it and interpreted it as a synformally folded thrust fault. Furthermore, they interpreted topographically low outcrops of meta-chert, argillite, lesser felsic and mafic meta-volcanic rocks, and serpentinite surrounded by the main body of Campbell Range meta-basalt as a klippe lying above the meta-basalt. Similarly, Plint and Gordon (1997) located the basal contact of rocks of the Campbell Range belt northeast of where we located it, but not as far to the northeast as Mortensen and Jilson (1985), and interpreted the low-lying meta-chert and argillite unit as a structurally overlying klippe.

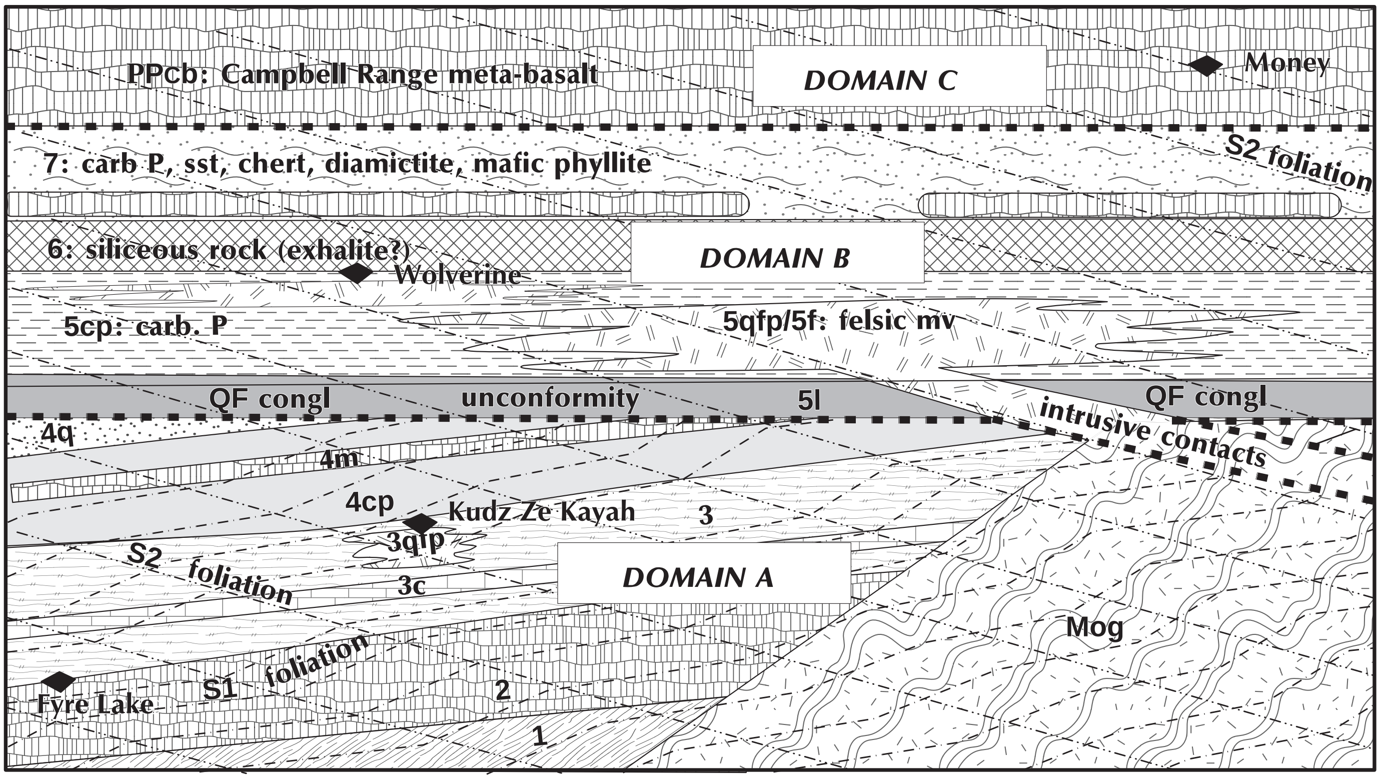


***Figure 16**. Schematic cross section summarizing structural and stratigraphic relationships between the domains. See text for discussion.*

Instead of a single synformally folded thrust, however, they proposed that the southwestern boundary of the belt was a southwest-vergent thrust fault and the northeastern boundary was an older northeast-vergent thrust fault.

In examining where previous workers located the faulted base of Campbell Range belt/Anvil Allochthon, we observe similar rocks on both sides, differing only in the state of strain. For example, Plint and Gordon (1997) map the faulted base of the Campbell Range belt through locality Y in Fig. 2. Northeast of their fault trace are typical weakly strained massive and fragmental meta-basalt of the Campbell Range belt and conformably underlying pale green siliceous argillite and meta-chert, carbonaceous phyllite and grey gritty greywacke with argillite chips. However, southwest of the trace, strongly foliated, pillowed and fragmental meta-basalt that is geochemically identical to Campbell Range meta-basalt (Plint and Gordon, 1997; Piercey et al., this volume) occurs in a synclinal keel enclosed by carbonaceous phyllite, meta-chert, green siliceous argillite and gritty meta-sandstone of unit 7. The syncline is defined by changes in orientation of the basal contact of the meta-basalt and changes in vergence of minor structures (second- and third-order folds, and cleavage-bedding relationships). Our structural and stratigraphic observations at this locality are more consistent with the interpretation that the conformable base of the meta-basalt is deformed into a tight, northwest-trending, southwest-overturned, southwest-vergent anticline-syncline pair, rather than being faulted (section A-A', Fig. 15).

We agree with Tempelman-Kluit's (1977) interpretation that the topographically low rocks that Mortensen and Jilson (1985) and Plint and Gordon (1997) included in klippe above the Campbell Range meta-basalt actually physically underlie the meta-basalt. The contact between the Campbell Range meta-basalt and unit 7 is folded around upright to overturned, northwest-trending, southwest-vergent folds. Isolated exposures of unit 7 occur at about the same elevation along axial-surface traces of adjacent first-order anticlines, suggesting that the enveloping surface of these folds dips subhorizontally in the map area. With such an orientation, the basal contact of the meta-basalt would project to the north above the low-lying rocks. Although these rocks have not yet been examined, their description resembles that of units 5, 6 and 7 which is what would be expected to underlie the meta-basalt. Hence, our working hypothesis is that the low-lying rocks are units 5, 6, and 7 occurring in a topographic window through the meta-basalt.

If our interpretation that the Campbell Range meta-basalt depositionally overlies Yukon-Tanana Terrane is correct, then this contact marks a profound shift in the tectonic evolution of the Yukon-Tanana crustal block. Rocks of Yukon-Tanana Terrane below this contact represent a mid-Paleozoic continental magmatic arc (Mortensen and Jilson, 1985; Mortensen, 1992). Rocks above this contact formed in an oceanic or marginal basin setting. This transition which occurred sometime in the Pennsylvanian or Permian can be explained in many ways, none of which can be reasonably constrained with current information. This and other questions will be addressed by future research.

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