Geological setting of retrogressed eclogite and jade in the southern Campbell Range: Preliminary structure and stratigraphy, Frances Lake area (NTS 105H), southeastern Yukon

Fionnuala Devine
Carleton University

Donald C. Murphy[1]
Yukon Geological Survey

Reid Kennedy
University of Calgary

Amy M. Tizzard
University of Victoria

Sharon D. Carr
Carleton University

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ABSTRACT

The southern Campbell Range is underlain by greenschist facies volcaniclastic, epiclastic and sedimentary units of the Tuchitua River and Money Creek formations. Stratigraphy is deformed by at least three syn- to post-Early Permian folding events. Northwest-striking, high-angle faults imbricate the folded metasedimentary package with sheets of serpentinite. These rocks are juxtaposed against basinal rocks of the Fortin Creek group, to the east, along the Jules Creek fault.

Coarse-grained quartz-muscovite schist with lenses of retrogressed eclogite occurs within serpentinite and also in immediate fault contact with greenschist facies Tuchitua River and Money Creek metasedimentary rocks in the western field area. At the King Arctic mine, nephrite jade is the result of metasomatic replacement of Money Creek chert-pebble conglomerate and serpentinite by microcrystalline tremolite-actinolite along late high-angle faults.

RÉSUMÉ

Sous le sud du chaînon Campbell reposent des unités sédimentaires, épiclastiques et volcanoclastiques à faciès des schistes verts des formations de Tuchitua River et de Money Creek. La stratigraphie est déformée par au moins trois plissements du Permien précoce (synchrones à postérieurs). Les failles à direction nord-ouest fortement inclinées imbriquent les roches métasédimentaires plissés avec des lentilles de serpentinite. Ces roches sont juxtaposées à des roches de bassin du groupe de Fortin Creek le long de la faille de Jules Creek.

Le schiste à quartz-muscovite à grain grossier renfermant des lentilles d'éclogite rétromorphisée se trouve au sein d'un mélange de serpentinite et en contact de faille avec les roches métasédimentaires à faciès des schistes verts dans la portion ouest de la zone. À la mine King Arctic, le jade néphritique est le résultat du remplacement métasomatique du conglomérat à cailloux de chert de Money Creek et de la serpentinite par une trémolite-actinolite microcristalline le long de failles tardives à angle fort.

[1]*don.murphy@gov.yk.ca*

INTRODUCTION

The occurrences of eclogite in Yukon-Tanana Terrane (YTT) are important clues to the terrane's Late Paleozoic tectonic development (Erdmer et al., 1998; Erdmer, 1992; Erdmer, 1987; Erdmer and Helmstaedt, 1983). Permian-age eclogites in central Yukon (Fig. 1) can reasonably be interpreted to mark the suture between YTT and North America. However, little is known about eclogites with Mississippian ages in the southern Campbell Range and Stewart Lake areas, Frances Lake map area (NTS 105H). No detailed geological framework has been presented for these occurrences and the reason for their presence near the eastern margin of Yukon-Tanana Terrane remains uncertain. Recently completed compilations of geology and stratigraphy in several regions of Yukon-Tanana Terrane, including the nearby Finlayson Lake area, provide a broad regional geological and tectonic context for the Frances Lake project. The project was initiated with the objective of constraining the geological relationships around the Mississippian-age (Erdmer et al., 1998) southern Campbell Range eclogite locality.

The study area covers the hills of the southern Campbell Range which rise to the west of the Robert Campbell Highway directly north of Tuchitua Junction (Fig. 1). This paper summarizes stratigraphy and structure of the southern Campbell Range and places the eclogite and jade occurrences into a geological framework. It is based on 1:10 000- and 1:20 000-scale geological mapping completed during 2003 in the southwestern corner of the Klatsa River map area (NTS 105H/3).

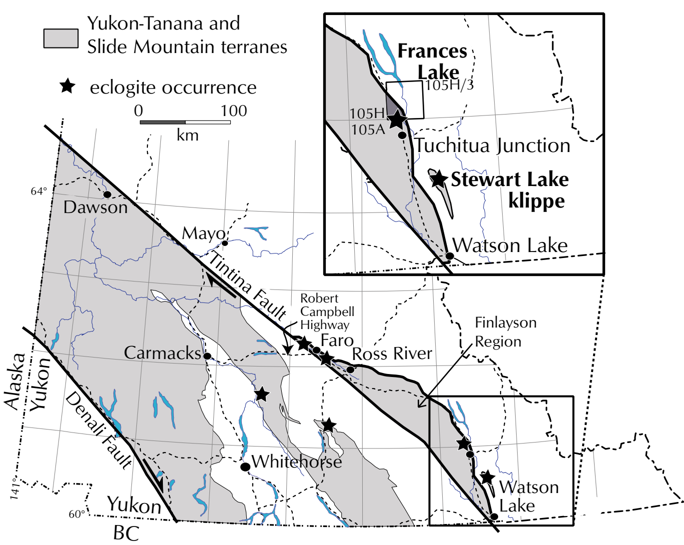

Figure 1. *Southern Campbell Range location map. The southern Campbell Range field area is marked by the shaded southwestern corner of the box outlining 1:50 000-scale NTS map sheet 105H/3. The field area overlies one eclogite occurrence; all others are marked by black stars. The southern Campbell Range and Stewart Lake localities are the only known eclogite occurrences with Mississippian ages in Yukon.*

PREVIOUS WORK

The southern Campbell Range was included in 1:253 440-scale mapping of the Frances Lake map area (105H) by Blusson (1966 a,b, 1967). Mortensen (1983), and Mortensen and Jilson (1985) also included the area in their regional reconnaissance of Yukon-Tanana Terrane (YTT) north of the Tintina Fault. The discovery of volcanogenic massive sulphide (VMS) deposits in the Finlayson region in the mid-1990s increased awareness of the mineral potential of YTT and prompted the initiation of a 1:50 000-scale mapping program of the Finlayson Lake region by the Yukon Geological Survey under the direction of D.C. Murphy. The Klatsa River map area (105H/3) was included in the areas covered during this program (Murphy, 2001). Regional geological compilations which are pertinent to the present study include the federal Targeted Geoscience Initiative (TGI) focused on the Finlayson Lake area in 2001 (Murphy et al., 2002) and studies of correlative rocks elsewhere in Yukon-Tanana Terrane under the NATMAP program (e.g., Colpron et al., 2003).

The coarse-grained metamorphic rocks in the southern Campbell Range were studied by Erdmer et al. (1998) and Creaser et al. (1999) who presented geochronological and geochemical data, respectively, of eclogites in central Yukon. However, the work presented in this paper is the first detailed geological compilation of the southern Campbell Range.

REGIONAL GEOLOGY

Current tectonic models for the development of YTT (e.g., Murphy et al., 2003) describe a western North American marginal crustal fragment which experienced arc growth in the Devonian to Early Permian. This began with eastward-directed subduction of proto-Pacific oceanic crust, and continued again in the middle to Late Permian as the Slide Mountain ocean basin separating the arc from North America closed through westward-directed subduction. In the Early Permian, prior to initiation of closure of the Slide Mountain ocean, the arc was shortened by regional-scale northeast-vergent

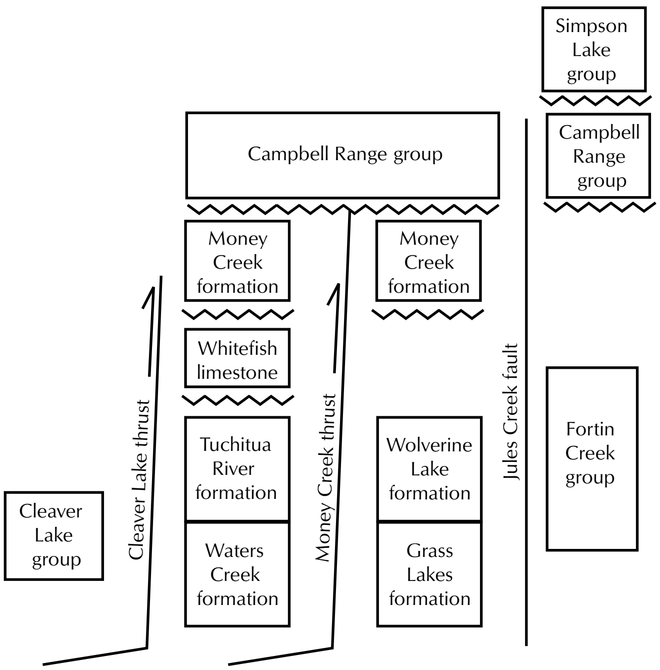

Figure 2. *Schematic stratigraphic diagram showing the fault relationships between different Devono-Mississippian to Early Permian successions in the Finlayson Lake region. Based on Murphy (2004, this volume).*

thrusting. Geology in the Finlayson Lake region shows Early Permian-age displacement along the Money Creek and Cleaver Lake thrusts (Murphy et al., 2003) which resulted in the stacking of Devono-Mississippian successions that formed in different arc environments (Murphy, this volume).

Southwestern Frances Lake map area is underlain primarily by rocks in the hanging wall of the Money Creek thrust fault. The volcanic-dominated Tuchitua River formation rests unconformably on the arc volcanic rocks and metasedimentary rocks of the Waters Creek formation (Fig. 2). Two episodes of plutonism coeval with the Waters Creek and Tuchitua River formations are represented by rocks of the Simpson Range plutonic suite (Mortensen and Jilson, 1985; Murphy, this volume). Together, these rocks represent the transitional arc environment between coeval arc (Cleaver Lake group) and backarc rocks (Wolverine Lake group), now stacked together. Clastic rocks of the Money Creek formation sit unconformably above rocks in different thrust sheets and were likely deposited synchronously with the Early Permian thrust-faulting event.

In the Finlayson Lake region, Early Permian thrusting was succeeded by deposition of the Campbell Range formation and emplacement of associated mafic and ultramafic intrusions. As these rocks occur on both sides of the Jules Creek fault near the eastern margin of YTT, Murphy et al. (2003) have suggested that the Jules Creek fault is a lithospheric-scale transform fault with associated plutonism, active during the Middle to Late Permian closure of the Slide Mountain ocean. The Late Permian and/or Triassic Simpson Lake group (Simpson Lake assemblage of Mortensen et al., 1997, 1999) conglomerate is the forearc, possibly progressive to foreland, sedimentary deposit resulting from Slide Mountain ocean closure. The conglomerate unconformably overlies the Fortin Creek group along the eastern margin of YTT.

A Triassic overlap sequence on YTT and North American rocks constrains the timing of terrane-continent amalgamation. Later crustal shortening in Jurassic to Cretaceous time imbricated YTT, and resulted in motion along the eastern YTT/Slide Mountain-bounding Inconnu thrust fault. This was followed by an extensional faulting event in the Cretaceous.

GEOLOGY OF THE SOUTHERN CAMPBELL RANGE

Three geological domains have been recognized in the southern Campbell Range (Fig. 3a). The break in slope along the east side of the range marks the boundary between the two eastern domains and coincides with the southeast-striking, shallowly west-dipping Jules Creek fault, a reactivated fault with most recent east-vergent thrust motion. To the east are basinal rocks of the Fortin Creek group of Slide Mountain Terrane (Murphy et al., 2002) unconformably overlain by the Late Permian and/or Triassic Simpson Lake group (Mortensen et al., 1997, 1999). To the west are Mississippian arc-derived clastic rocks of the Tuchitua River formation and unconformably overlying basinal deposits of the Early Permian Money Creek formation. The third domain occurs along the western edge of the area where poorly exposed metavolcanic and metaintrusive rocks of the Waters Creek formation and Simpson Range plutonic suite occur in presumed fault contact with adjacent Tuchitua and Money Creek rocks.

At least three early folding and two faulting events deform the Tuchitua River and Money Creek formation rocks. Southeast-striking faults imbricate the metasedimentary rocks with sheets of serpentinite, and dominate the structural pattern of the area (Fig. 3a,b). Serpentinite is host to blocks of locally-derived metasedimentary rocks,

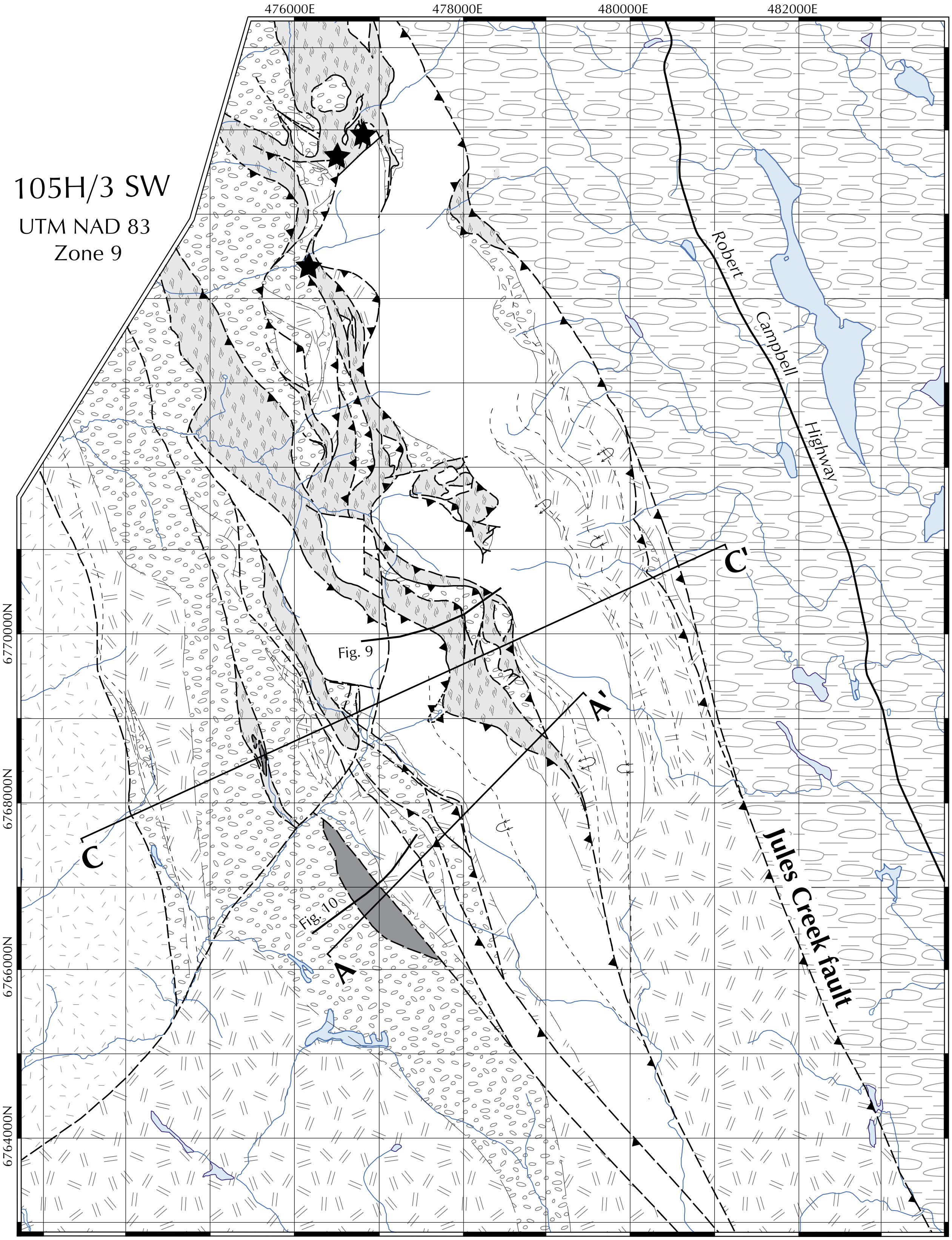

Figure 3a. *Geological map of the southern Campbell Range. The King Arctic jade mine is in the north of the area, where black stars mark nephrite jade occurrences. The locations of ridgelines in Figures 9 and 10 are shown as lines marked Fig. 9 and Fig. 10.*

LEGEND

serpentinite — massive dark to pale green with relict cumulate textures (euhedral bastite) in places.

Yukon-Tanana Terrane | *Jules Creek fault* | *Slide Mountain Terrane*

Mississippian

coarse-grained metamorphic rocks — quartz-muscovite schist with clinozoisite-chlorite symplectic pseudomorphs after garnet and amphibole porphyroblasts; includes lenses of dark green epidote-amphibole metabasite (retrogressed eclogite).

Cleaver Lake thrust

Intrusive Rocks

Mississippian

metagranodiorite and metavolcanic rocks — medium-grained chlorite- and epidote-altered granodiorite and well foliated quartz-phyric chlorite-muscovite schist

Layered Rocks

Permian

Money Creek formation — black to grey chert-pebble conglomerate, blue quartz-eye bearing conglomeratic lithic wacke, carbonaceous phyllite. All metamorphosed to greenschist facies

Mississippian

Tuchitua River formation clastic rocks — homogeneous pale green chert-derived arenite and interbedded fine-grained dark grey argillaceous wacke. Metamorphosed to greenschist facies

Tuchitua River formation — green and pink chert and banded tuffaceous magnetite-bearing green chert with pale grey limestone locally interlayered with tuff. Metamorphosed to greenschist facies

Layered Rocks

Carboniferous?

Fortin Creek (1) and Simpson Lake (2) groups —
(1) pale to dark chert-pebble conglomerate, quartz-arenite and argillite, all commonly vuggy and silicified
(2) polymictic conglomerate and sandstone

Symbols

fault — defined, approximate, assumed, with thrust or reverse motion

geological contact — defined, approximate, assumed

F_3 axial surface trace — overturned antiform, overturned synform

jade occurrence

line of cross-section

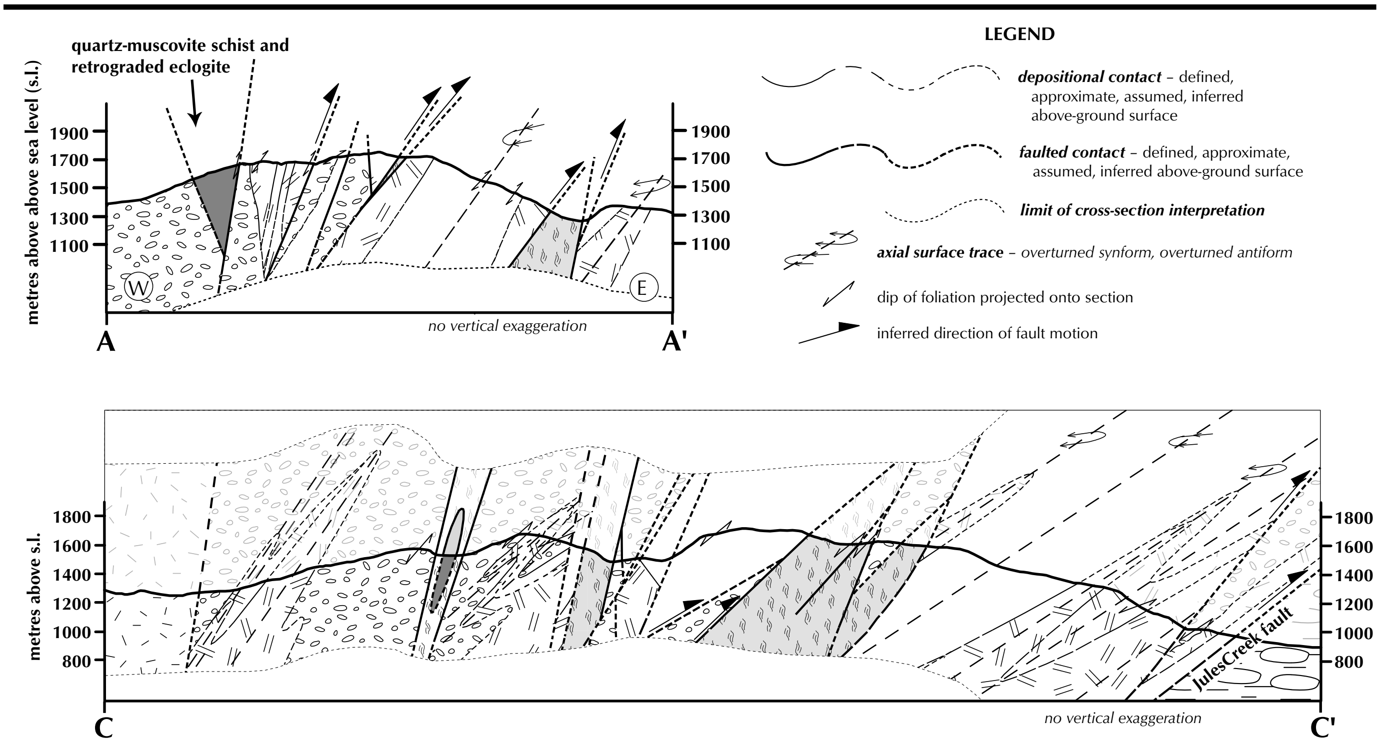

Figure 3b. *Geological cross-sections along lines A-A' and C-C'. The lines of section are shown on Figure 3a. The lightly shaded region above ground surface in cross-section line C-C' represents extrapolated above-surface geology.*

leucogabbro and coarse-grained metamorphic rocks including retrogressed eclogite. With the exception of the retrogressed eclogite and host rocks, all rocks in the area were metamorphosed under greenschist facies metamorphic conditions.

LITHOLOGY

The Tuchitua River formation chert, limestone and clastic rocks and unconformably overlying Money Creek conglomerates and lithic wacke are the most widespread units in the map area; both formations are metamorphosed to greenschist facies (Fig. 4). The Whitefish limestone, which is found above the Tuchitua River formation in other parts of the Finlayson Lake region, is only locally present. Fortin Creek group chert and argillite are found along the eastern side of the map area with minor outcrops of unconformably overlying Simpson Lake group conglomerate. Serpentinite is structurally interleaved with the Tuchitua River and Money Creek metasedimentary rocks and is host to both coarse-grained quartz-muscovite schists with lenses of retrogressed eclogite, and also nephritic jade.

Tuchitua River formation

The Tuchitua River formation is composed dominantly of intermediate volcanic and volcaniclastic rocks with lesser chert and limestone (Murphy, this volume). In the southern Campbell Range, only minor volcaniclastic rocks are present in a package composed of green and pink chert, limestone and an overlying chert-derived clastic package. Volcanic rocks of the lower Tuchitua River formation are not found in the field area but do occur approximately 50 km to the north and northwest. North of the study area near Alligator Lake, at the end of the 99 Mile Creek road, well foliated green lapilli tuff with 1-cm-sized chlorite aggregates along foliation planes (possible altered amphibole crystals) occurs with Tuchitua River formation chert. Chert, limestone and clastic rocks belonging to the Tuchitua River formation are found in the central geological domain in the field area. All units are polydeformed and metamorphosed to greenschist facies, but the following descriptions focus on sedimentary protoliths.

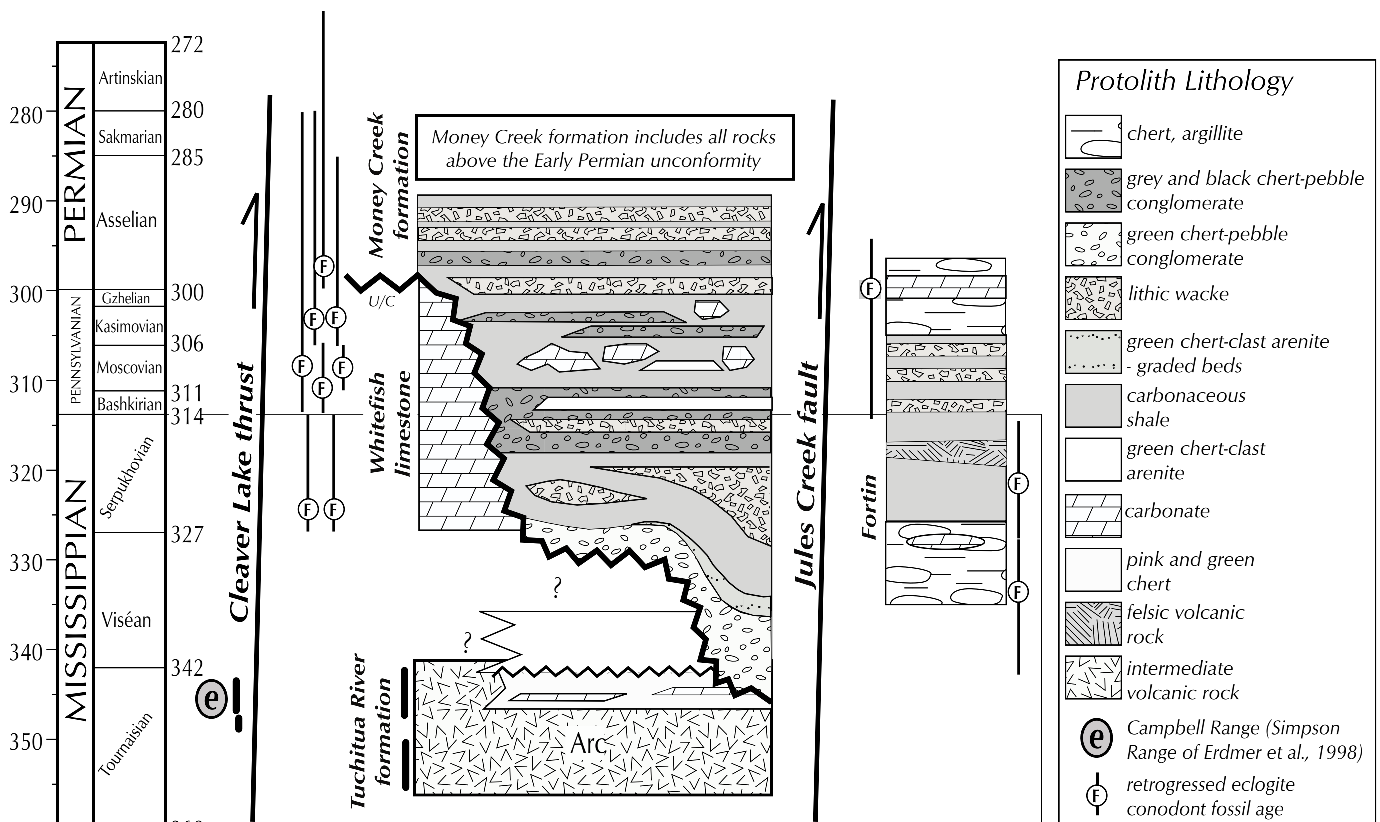

Figure 4. *Stratigraphic and structural relationships in the southern Campbell Range. Fortin Creek stratigraphy and fossil ages are from Murphy and Piercey (1999a,b,c; 2000) and Murphy (2001). E = 344 ± 1 Ma white mica ^{39}Ar-^{40}Ar cooling date on retrogressed eclogite (Erdmer et al., 1998). U/C = unconformity. Time scale after Okulitch (2001).*

Chert and limestone: Chert and limestone are the oldest stratigraphic units of the Tuchitua River formation found in the southern Campbell Range. A lower vari-coloured chert sequence is transitional upwards into limestone, which is overlain by a chert-clastic rock sequence. Relative ages are based on stratigraphic relationships. The entire package has a minimum thickness of 200 m and is bound by the unconformably overlying Tuchitua River clastic rocks.

The stratigraphically lowest chert unit contains interlayered translucent to opaque green, pink and white chert, which has gradational contacts in outcrop; red-pink- and green-dominant regions occur in layers up to 100 m thick. Ribbons 1 to 5 cm thick, with partings of pale green phyllite, are common in the green chert, which varies from highly contorted to relatively undeformed (Fig. 5a). Clastic interbeds are derived from both sedimentary and volcaniclastic sources. Fine-grained quartz-lithic sandstone beds occur within both the green and pink chert sequences. Plagioclase-chlorite lapilli-tuff beds up to 2 cm thick and the local occurrence of pale green phyllite interlayer are indications of volcaniclastic input.

Pale grey-weathering limestone occurs within the upper part of the pink and green chert succession. Siliceous interlayers up to 5 cm thick, with abundant pyrite boxwork, and interlayers of white to pale-green phyllite show the gradational relationship between the chert and the limestone. Carbonate-matrix siliciclastic interlayers with bedding on a cm-scale and crinoid fragments are present locally (Fig. 5b). Recessive-weathering of layers with low clastic content enhances bedding. Along the east side of the map area, the limestone is a discontinuous layer with a minimum thickness of 20 m. Elsewhere, although locally structurally thickened, the limestone is greater than 200 m thick, and is laterally continuous for at least 2 km. This thickness variation is likely due to original depositional variability, however, later structure also cuts the limestone in several places, and therefore only minimum thicknesses have been determined.

Well banded to laminated tuffaceous chert with variable clastic and volcaniclastic content gradationally overlies the pink and green chert (Fig. 5c). This unit is everywhere well banded with high silica content and locally contains pale to bright green opaque feldspar-dominant layers. White, bright yellow-green, and dark green layers are interbedded on a sub-mm- to cm-scale with sub-mm laminations. The pale layers locally have a characteristic black speckled appearance resulting from sub-mm weathering pits within the locally feldspar-

Figure 5. *Tuchitua River formation:* ***(a)*** *green ribbon chert,* ***(b)*** *bedded limestone with disseminated metamorphic chlorite and muscovite,* ***(c)*** *banded to laminated magnetite-bearing green chert.*

dominant tuffaceous matrix. Plagioclase-chlorite lapilli-tuff was sampled from this unit for U-Pb geochronology; results are pending for this work. Magnetite is concentrated in dark green to black chlorite-rich laminae. Pink, green and white chert is locally present and is also locally magnetite-bearing. Concentrated magnetite in this banded chert, along with the approximate late Tournaisian age of this unit, based on stratigraphic relationships with dated Tuchitua River volcaniclastic rocks elsewhere in the Finlayson Lake area (Murphy et al., 2002), supports correlation with siliceous barite-magnetite exhalative rocks above the Wolverine Lake deposit (Yukon MINFILE 2002, 105G 072, Deklerk, 2002). This suggests the presence of a regional hydrothermal system in the early Mississippian.

Clastic rocks: Clastic rocks of the Tuchitua River formation unconformably overlie the chert and limestone units and form the cliffs along the east side of the southern Campbell Range. Original thickness of the unit is at least 250 m, but with structural thickening the unit is up to 750 m thick. Green to dark grey fresh surfaces weather to a characteristic cm-scale 'mottled' texture; this may be due to variable clay content. Medium-grained green chert-clast arenite locally contains opaque sub-rounded to sub-angular white to pale green clasts that range up to pebble size. The unit changes gradationally upwards to fine-grained dark grey argillaceous wacke with the transitional region containing laterally continuous metre- to 10-m-scale interbedded layers of dark grey fine-grained lithic wacke and green chert-clast arenite. Dark grey to black argillite and argillaceous fine-grained wacke with 1-mm- to 1-cm-wide discontinuous green sandstone lenses becomes dominant upsection. The Tuchitua River clastic rocks, derived from immediately underlying Tuchitua River chert, are identified and distinguished from overlying clastic rock units based on clast lithology, widespread occurrence and weathering texture.

Whitefish limestone

The only exposure of the Whitefish limestone (unit Pc of Murphy, 2001) in the study area is a block of marble (25 m by 10 m exposed area) completely enveloped by serpentinite (UTM 478335E, 6771559N). A conodont age of Serpukhovian has been determined from this outcrop in the central field area, which is consistent with the age range of Serpukhovian to early Asselian determined for the unit in its closest in-place occurrence, approximately 50 km to the northwest (Murphy et al., 2002; Poulton et al., 1999). The pale grey- to buff-weathering bioclastic marble is foliated and contains dark grey crinoid fragments up to 2 mm in diameter within a pale grey recrystallized matrix. Orange-weathering diagenetic silica-replacement patches up to 5 cm thick are discontinuous and are concordant with foliation.

Money Creek formation

The Money Creek formation metaclastic rocks (unit 7 of Murphy and Piercey, 1999; unit PPcs of Murphy and Piercey, 2000a; unit Pcl of Murphy, 2001, Murphy, this volume) unconformably overlie the Tuchitua River formation rocks (Fig. 3 and 4). A basal unit derived from immediately underlying Tuchitua River formation chert is overlain, possibly unconformably, by a mixed clastic unit.

Basal conglomerate and sandstone: The basal conglomerate and sandstone of the Money Creek formation occur locally along the contact with underlying Tuchitua River formation rocks. The basal unit varies in thickness from 0 m to approximately 10 m, in part owing to deformation. Distinctive green-granule to -pebble conglomerate is dominated by sub-rounded clasts of green chert with subordinate limestone and pale green to white lithic clasts (Fig. 6a). Graded green chert-clast arenite beds up to 2 cm thick with granule-sized basal clasts occur in close association with the conglomerates and contain the same clast composition. Where the basal unit overlies Tuchitua River limestone, the matrix is commonly calcareous and the conglomerates contain well-rounded chert pebbles up to 2 cm in diameter.

The best exposures of the basal unit occur on hilltops in the northwestern part of the study area where it overlies limestone of the Tuchitua River formation (Fig. 3). Here the basal unit of the Money Creek formation comprises well foliated and lineated conglomerate and sandstone. The contact is an unconformity as clast content of the basal units reflects derivation from immediately underlying Tuchitua River formation chert and limestone. Although structural complexity precludes detailed lateral stratigraphic correlations, the basal conglomerate and sandstone are variable in thickness and are not always present along the unconformity at the top of the Tuchitua River formation, likely as a result of restricted deposition in areas of low paleotopography.

Mixed clastic rocks: Dark coloured clastic rocks of the Money Creek formation with variable clast content locally overlie the basal units. The unit contains dark grey to black rounded chert-pebble conglomerate (Fig. 6b), dark argillaceous chert, black carbonaceous phyllite and lithic

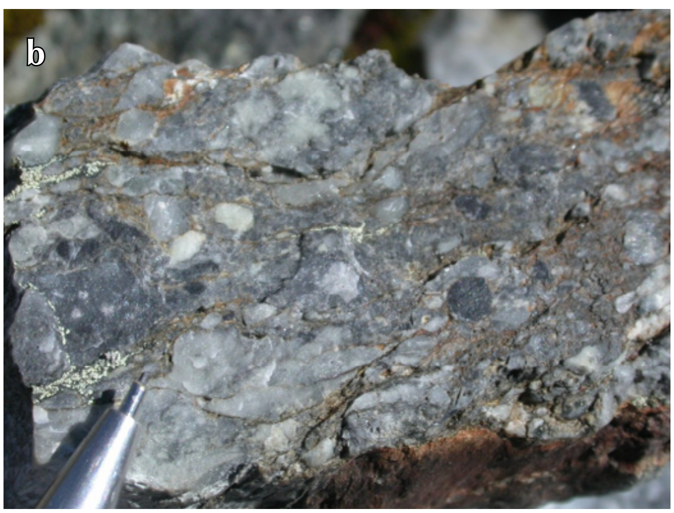

Figure 6. *Money Creek formation:* ***(a)*** *basal green-chert-pebble conglomerate and graded green chert-clast arenite,* ***(b)*** *dark chert-pebble conglomerate.*

wacke commonly with smoky blue quartz-eyes. The unit lacks stratigraphic continuity. Minor green to brown lithic arenite and lithic wacke are found in association with the phyllite and grit and compositionally reflect derivation from rocks of the underlying Tuchitua River formation. Blocks of crinoidal limestone up to 30 m long are found locally, within phyllite. Conodont age data are pending on these blocks, which are presumed to be Whitefish limestone. Limestone block trains in linear outcrop relationship within phyllite are evidence of debris-flow olistostromal deposition of parts of the Money Creek formation.

Fortin Creek group

To the east of the Jules Creek fault (Fig. 3a), in the poorly exposed lowlands on the eastern flanks of the Campbell Range, are rocks of the Fortin Creek group. They were previously known as the Finlayson group (Murphy et al., 2002) and have a regional basinal lithological character. Protolith lithologies of the unit in the field area include grey- to black-chert-pebble conglomerate, rusty-weathering medium-grained quartz-sandstone, and aphanitic rhyolite. All rocks are highly silicified and commonly display open quartz-lined vugs up to 2 cm in diameter. Aphanitic rhyolites display mm-scale flow-banding textures enhanced by later silicification.

Simpson Lake group

Conglomerate of the Permian to Triassic Simpson Lake group (Simpson Lake assemblage of Mortensen et al., 1997, 1999) rests unconformably on the Fortin Creek group. A single outcrop of angular to sub-rounded granule conglomerate containing clasts of ultramafic rock and Fortin Creek chert may be continuous under cover with more extensive exposures to the north. Along the road to the King Arctic jade mine, north of the field area, polymictic conglomerate includes subangular to well rounded clasts of chert, mica schist, quartzite, and various types of sandstone. Eclogite pebbles are found in exposures along the Robert Campbell Highway to the south (Mortensen et al., 1997, 1999).

Waters Creek formation and Simpson Lake plutonic suite

Poorly exposed metaintrusive and metavolcanic rocks occur along the western side of the map area in presumed fault contact with Money Creek formation rocks to the east (Fig. 3a); they include moderately foliated, fine- to medium-grained chloritized muscovite-amphibole granodiorite; chloritized, foliated, coarse-grained quartz-phyric amphibole granite-granodiorite, and well foliated quartz-phyric chlorite-muscovite schist. These rocks spatially and lithologically fit within the Waters Creek formation and Simpson Range plutonic suite (Mortensen and Jilson, 1985; Murphy, this volume) found in other parts of the Finlayson Lake area. A presumed fault contact with Money Creek formation rocks to the east is supported by the linear nature of the contact and the absence of lower Tuchitua River volcanic rocks, which would be present if the transition from Waters Creek formation rocks to upper Tuchitua River chert was stratigraphically intact.

Coarse-grained metamorphic rocks

Two occurrences of coarse-grained metamorphic rocks are found in the western part of the field area, in fault contact to both the east and west with greenschist facies clastic rocks of the Money Creek formation. Coarse-grained quartz-muscovite schist is the dominant lithology with quartz and muscovite content varying on the cm- to m-scale. Green chlorite and clinozoisite symplectic pseudomorphs after garnet and possibly amphibole have subhedral to anhedral shapes and are up to 1.5 cm in diameter (Fig. 7a). In places within the schist, the replaced porphyroblasts occupy up to 50% volume of the rock.

Rare discontinuous carbonate bands up to 10 cm thick, and lenses of very dense, heavy metabasite up to 20 m long and 10 cm to 5 m wide occur within the quartz-muscovite schist, and are concordant with foliation (Fig. 7b). Retrograded garnet porphyroblasts within the metabasite are present, up to 50% by volume, with minor relict garnet bound by fractures which are lined with the retrograde mineral assemblage. The garnet is the last remaining component of the peak metamorphic assemblage. A retrograde mineral assemblage of epidote and pale amphibole occupy the matrix and overprint the retrograded garnet domains. Titanite-rimmed rutile is present as 1- to 2-mm-long red crystals that are abundant in the metabasite only. These rocks have an N-MORB (normal mid-oceanic ridge basalt) geochemical signature (Creaser et al., 1999). White mica is late and interstitial to all other mineral assemblages and has a ^{39}Ar-^{40}Ar age of 344 ± 1Ma (Erdmer et al., 1998), interpreted to represent the cooling age of the unit through 350°C.

The metabasite has previously been interpreted as retrogressed eclogite (Erdmer et al., 1998; Mortensen and Jilson, 1985). We support this conclusion based on the retrograde mineral assemblage, textural similarity to well preserved eclogite, the presence of mafic lenses of basaltic composition within a quartz-muscovite schist host elsewhere in the Yukon-Tanana Terrane (YTT; similar to the Permian-aged eclogites in YTT), and the Mississippian age (Erdmer et al, 1998), which is similar to the age of preserved eclogite to the south in the Stewart Lake klippe (Fig. 1). Field relationships of the two occurrences of quartz-muscovite schist with retrogressed eclogite are discussed later in the paper with implications for tectonic development of YTT.

Serpentinite

Serpentinite in the area is commonly dark green, smooth and well foliated. Cumulate textures are preserved in places with bastite up to 1.5 cm in diameter. Where pale green bastites are preserved in a dark-green matrix, the rocks have a distinctive texture with the appearance of 'lizard-skin'. Local high-magnetite content is a result of olivine breakdown during serpentinization of the ultramafic protolith.

The serpentinite occurs across the map area as sheets with variable thicknesses ranging from less than 1 to

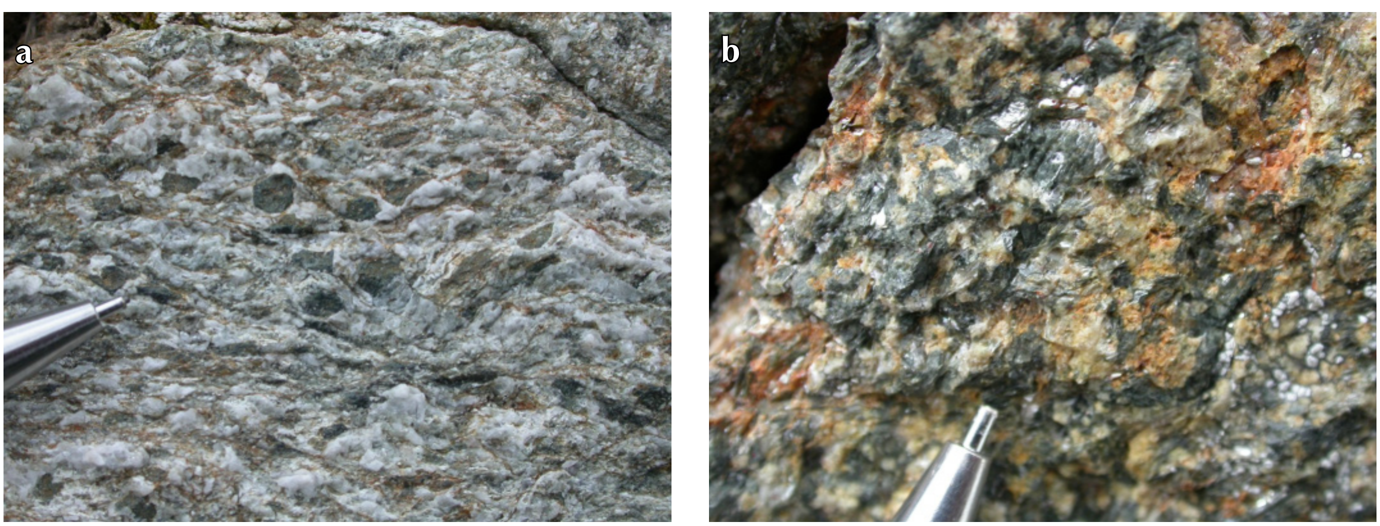

Figure 7. *Coarse-grained metamorphic rocks: **(a)** quartz-muscovite schist with symplectic chlorite and clinozoisite pseudomorphs after garnet porphyroblasts; **(b)** retrogressed eclogite with symplectic chlorite and clinozoisite pseudomorphs after garnet porphyroblasts in an epidote-amphibole matrix with interstitial, late white mica.*

200 m. One-metre-wide zones of talc-schist are developed along sheared contacts between serpentinite and metasedimentary sheets. Locally, the serpentinite contains blocks of various metasedimentary rocks, vari-textured leucogabbro, and coarse-grained quartz-muscovite schist with retrogressed eclogite.

Murphy et al. (2002) mapped similar serpentinite bodies along strike to the north of the field area. The serpentinite to the north is associated with Early Permian mafic volcanic and mafic plutonic rocks that occur on both sides of the Jules Creek fault (D.C. Murphy, pers. comm., 2003). Blocks of leucogabbro associated with the northern serpentinite have U-Pb zircon crystallization ages 274.3 ± 0.5 Ma (Mortensen, 1992) and 273.4 ± 2.1 Ma (D.C. Murphy, pers. comm., 2003). Similar leucogabbro blocks are associated with serpentinite in the east-central field area.

Jade

In the northern field area at the King Arctic mine (Yukon MINFILE 2002, 105H 014, Deklerk, 2002), nephrite jade (microcrystalline tremolite-actinolite) occurs in fault-controlled bands up to 3 m wide. It is located along faulted contacts of serpentinite and basal Money Creek formation chert-pebble conglomerates and sandstones (Fig. 8). The jade is generally heterogenous in colour, varying from white-green to very dark green. Variably foliated aggregates of tremolite-actinolite make up the pure nephrite with inclusions of epidote and bright-green serpentine. Fine-grained white-coloured rock is found associated with the jade occurrences, as blocks within serpentinite and as part of the nephrite package along faults. Macroscopically, this rock is similar to descriptions of white-rock, including rodingite, found associated with some nephrite deposits in British Columbia (e.g., Simandl et al., 2000) but has a mineralogy consisting dominantly of zoisite-clinozoisite, epidote and carbonate. No garnet has been found in petrographic analysis to date.

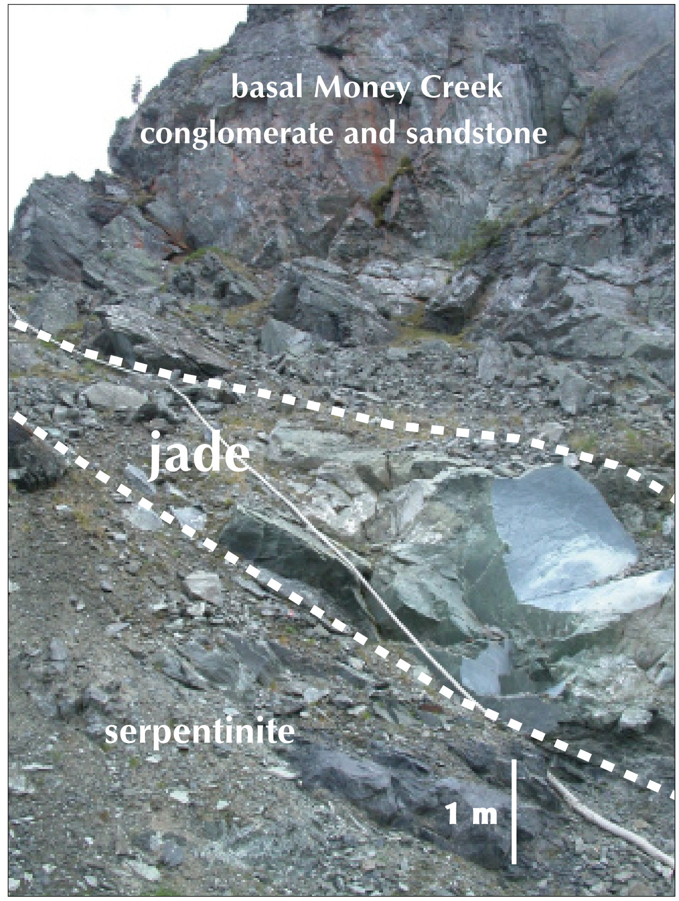

Figure 8. *Jade contacts near the working face at the King Arctic mine. Jade occurs along the faulted contact between serpentinite (below) and Money Creek basal metasedimentary rocks (above).*

STRUCTURE

F_1, F_2 and F_3 folding

The oldest structures in the area are overturned open to tight similar folds of the Tuchitua River and Money Creek formations. Identification of the earliest folding event, F_1, is based on cross-cutting relationships, as structures from this event have been overprinted and reoriented by later structural events. Money Creek formation mixed clastic rocks are folded by F_2 and F_3 folds; however, on the eastern slopes of the southern Campbell Range, the mixed clastic rocks are interpreted to cross-cut previously folded Tuchitua River formation chert and clastic rocks. Similar fold-unconformable relationships are observed elsewhere in the southern Finlayson region (D.C. Murphy, pers. comm., 2003).

F_2 folds are folded by F_3 east-vergent folds and are identified in map pattern although not seen in outcrop (Fig. 3b). In the central part of the field area, Money Creek clastic rocks are wrapped around the fold hinge of an F_2 synform which plunges approximately 50° to the northwest. No S_2 axial planar fabric, that could be distinguished from S_3 structures, was observed in the field area.

D_3 structures are dominant in the rocks through the rest of the field area with F_3 folds of regional scale plunging between 30° to 50° northwest. The dominant foliation in the area strikes southeast with dips between 30° and 60°

southwest, and is axial planar to the F_3 folds. Minor folds in outcrop, most visible in Tuchitua River formation chert, mimic the regional F_3 fold orientation. F_3 strain can be variable; for instance, limestone ranges from relatively undeformed to highly-strained and boudinaged. It is likely that F_3 folds tightened earlier F_1 folds based on the synformal contact of Money Creek formation over an F_3 antiform along the east side of the southern Campbell Range (Fig. 3a).

All three folding events may be progressive with later F_2 and F_3 events having occurred synchronously with Money Creek formation deposition. This fits with tectonic models for YTT which describe northeast-directed shortening in Early Permian time (Murphy et al., 2003).

D_4 faulting

The northwest-southeast structural grain of the area is a result of D_4 reverse (present orientations) faulting. Rocks of the Tuchitua River and Money Creek formations are locally imbricated with serpentinite sheets that range in thickness from absent along the fault plane to up to 150 m (Fig. 9). The fault planes are curviplanar and locally show variations in dip orientation. Foliation parallel to the faults is well developed in the immediate hanging wall and footwall, and evidence of high strain is preserved in 'zebra-striped' mylonitic limestones. Along the boundaries of the serpentinite bodies, talc-schist zones up to 1 m thick are the result of shearing and fluid flow along the contacts with metasedimentary blocks. Slivers and blocks of local metasedimentary rocks are distributed through the serpentinite bodies. Limestone in close proximity to serpentinite commonly contains tremolite and magnetite porphyroblasts, possibly the result of mineralization during low temperature fluid circulation.

The reactivated Jules Creek fault marks the eastern limit of observed D_4 faulting as exposure drops off to the east. The dip of the D_4 faults is variable across the field area, but generally steepens to the west where the two most western serpentinite bodies are bound by near vertical faults. The original orientation and displacement direction along these faults is unknown. However, the fault planes commonly parallel bedding along F_3 fault limbs and, therefore, may originally have been low-angle thrusts controlled by folded bedding in Tuchitua River and Money Creek formation rocks. Regional tectonics suggest motion along these faults to be Jurassic to Cretaceous in age, as shortening of YTT and displacement along the Inconnu thrust occurred during this time (Murphy et al., 2003).

D_5 faulting

A high-angle brittle northeast-striking fault cuts D_4 structures; the trace of the fault curves northward in map view in the western half of the field area (Fig. 3a). The fault trace runs northeast along a valley that separates two parallel ridges. Hematitic silica-rich fault gouge is present along the exposed section of the slightly west-dipping, near-vertical fault. The offset along the fault is on the

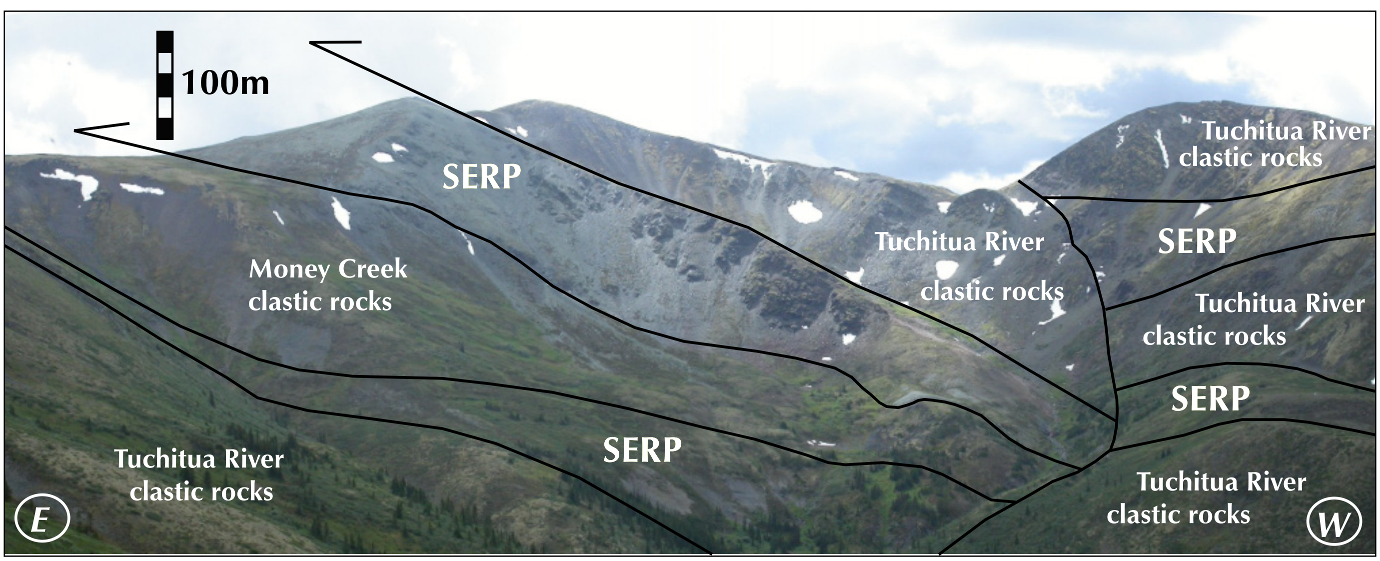

Figure 9. *View south to the southeastern field area along an oblique section through the metasedimentary and serpentinite fault-stacked sequence. The fault plane above the uppermost eastern serpentinite sheet in the photo dips to the southwest. SERP = serpentinite. All contacts are faulted.*

order of hundreds of metres based on the offset of high-angle D_4 faults that are mapped on either side.

Evidence of other late structure is seen as local slickenside preservation along fractures and joints in Money Creek rocks in the southern field area. Fibre-truncation lineations plunge steeply towards the west and preserve evidence of top-down-to-the-west sense of motion. It is not known whether these fabrics are related to the D_5 faulting event or later Cretaceous extension of YTT.

GEOLOGICAL SETTING OF RETROGRADED ECLOGITE

Quartz-muscovite schist ± retrogressed eclogite lenses occurs in two areas separated by the D_5 high-angle fault. The southern occurrence lies at the western edge of good exposure in the field area, well exposed along north- and south-trending spurs off the flanks of a northeast-trending ridge. Coarse-grained quartz-muscovite schist with lenses of retrograded eclogite occurs as a fault-bound block with greenschist facies upper Money Creek metasedimentary rocks on either side (Fig. 10). The eastern bounding fault is near vertical and well constrained, although not exposed. Similarly, to the west, the contact is not exposed and is presumed to be an east-dipping fault based on faulted contact relationships to the north.

The northern eclogite occurrence is roughly along strike from the southern occurrence, across the valley to the north in a low-lying saddle, which is underlain by poorly exposed blocks of quartz-muscovite schist, quartzite and chert. Resistant-weathering mounds up to 50 m long and 10 m wide show quartz-muscovite schist in float. Serpentinite is abundant in the creek gully draining south down the saddle; however, the top of the saddle is underlain by recessive dark argillite. The area is considered to be a fault-bound serpentinite mélange with a variable argillite matrix. Money Creek metasedimentary rocks occur on either side of the saddle in well-exposed cliff and rubbly outcrop.

DISCUSSION

THE ORIGIN OF THE QUARTZ-MUSCOVITE SCHIST, ECLOGITE AND SERPENTINITE

The occurrence of lenses of metabasite within quartz-muscovite schist and also the presence of rounded blocks of a variety of sedimentary and metamorphic rocks within serpentinite mélange in the southern Campbell Range support the formation and exhumation of the coarse-grained metamorphic rocks in a subduction zone. This is the only tectonic environment in which eclogite can be formed and exhumed that is compatible with regional tectonic models. In the Franciscan Complex of California, exhumed forearc subduction zone rocks, eclogite and various metasedimentary rocks occur as blocks within serpentinite- and shale-matrix mélange (Wakabayashi, 1992). Exhumation of intact eclogite facies metasedimentary sequences, now schists, containing

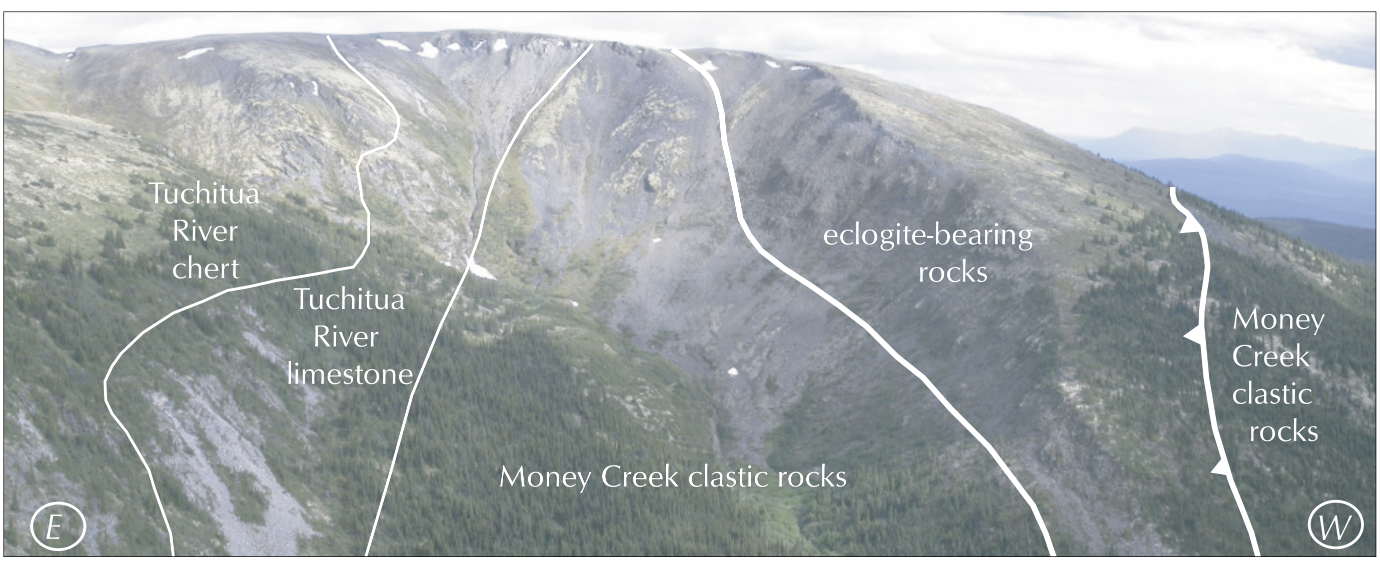

Figure 10. *View south to the southern occurrence of quartz-muscovite schist and retrograded eclogite. Heavy lines denote faulted contacts and thin lines indicate depositional contacts. The distance along the flat part of the ridge is approximately 1.5 km.*

lenses and blocks of eclogite is known from New Caledonia (Ghent et al., 1987). Both eclogite associations are present in the southern Campbell Range.

However, the origin of the serpentinite mélange at the northern occurrence is uncertain. It is possible that at least some of the serpentinite in the field area may be metaintrusive in origin. Regional relationships and age data have led D.C. Murphy (2001; pers. comm., 2003) to suggest that leucogabbro and associated serpentinite and mafic rocks to the north of the southern Campbell Range are a Permian mafic-ultramafic intrusive complex. Is some or all of the serpentinite in the field area part of this intrusive complex and Permian in age? The blocks of coarse-grained schist within serpentinite at the northern occurrence may be due to late (post-Permian) faulting which incorporated blocks of the Mississippian-aged coarse-grained rocks into a Permian-aged host serpentinite. The minimal displacement along the D_4 imbricate faults which placed similar local rock units on either side of serpentinite bodies is more compatible with this altered intrusive model for serpentinite origin. It is significant however that the quartzite blocks at the northern occurrence are not found elsewhere in the region and that the chert blocks are commonly pale in colour unlike dark Money Creek chert found locally. Geochemical study of the serpentinites in the field area will hopefully provide insight into the problem.

Regardless of the origin of the serpentinite mélange, the coarse-grained quartz-muscovite schist with lenses of retrogressed eclogite is foreign to the sedimentary rock units found in the area. These rocks alone provide evidence of a Mississippian-aged subduction zone-related component to the geology of the southern Campbell Range.

Tectonic setting

The presence of Mississippian cooling ages on retrograded eclogite along the eastern edge of Yukon-Tanana Terrane in the Finlayson region, at the southern Campbell Range and Stewart Lake localities, can be explained using current models for Yukon-Tanana Terrane tectonic evolution. The eclogites and associated rocks were formed and exhumed in a west-facing subduction zone along the west side of Yukon-Tanana Terrane in Mississippian-time. Although no date on the timing of peak metamorphism has been determined, using the mid-Mississippian ^{40}Ar-^{39}Ar cooling ages from the southern Campbell Range and Stewart Lake localities (Erdmer et al., 1998) as the age of formation is justified, as global examples show that high-pressure rocks may be exhumed rapidly; age constraints in the French Range of British Columbia show transition of blueschists from peak metamorphic conditions to erosion in potentially as little as 1 million years (Mihalynuk et al., 1999).

Early Permian regional thrust faults have been recognized in the Finlayson region (Murphy et al., 2003; Murphy, this volume). We propose that the eclogite and host rocks were carried from the forearc region along the Cleaver Lake thrust fault, and thrust over inboard arc and backarc rocks into their present position along the eastern margin of Yukon-Tanana Terrane. Folding of the Tuchitua River formation and deposition with progressive folding of the Money Creek formation was likely synchronous with this Early Permian shortening and erosional event. The faulted contacts of the eclogite and host rocks were likely modified by later structural events, including the Jurassic to Cretaceous D_4 event.

THE ORIGIN OF JADE

Jade formed by metasomatic replacement of the chert sand-pebble conglomerate and possibly serpentinite along the D_4 reverse faults that imbricate metasedimentary rocks with serpentinite in the area (Fig. 8). It is possible to see the gradational metasomatic reaction zone in outcrop where the distance from protolith metaconglomerate to serpentinite is approximately 5 m, with an intervening jade seam of approximately 2 m (Fig. 11). Focused fluid flow along the faults likely facilitated the exchange of chemical species between protoliths: Fe, Mg and Ca from the serpentinite, and SiO_2 and Ca from the highly soluble chert-pebble conglomerate. Jade sealed the faulted contacts of the conglomerate and serpentinite implying late syn-faulting jade formation, however it is not possible to determine whether late fault movement was accommodated by shearing in adjacent serpentinite, post-jade formation.

CONCLUSIONS

Early Permian regional shortening of Yukon-Tanana Terrane resulted in polydeformation of Mississippian to Early Permian volcaniclastic and metasedimentary rocks of the Tuchitua River and Money Creek formations. These rocks were imbricated with sheets of serpentinite in the southern Campbell Range, possibly in post-Late Triassic time. Nephrite jade occurs along these imbricate faults, as a result of metasomatic replacement of siliceous

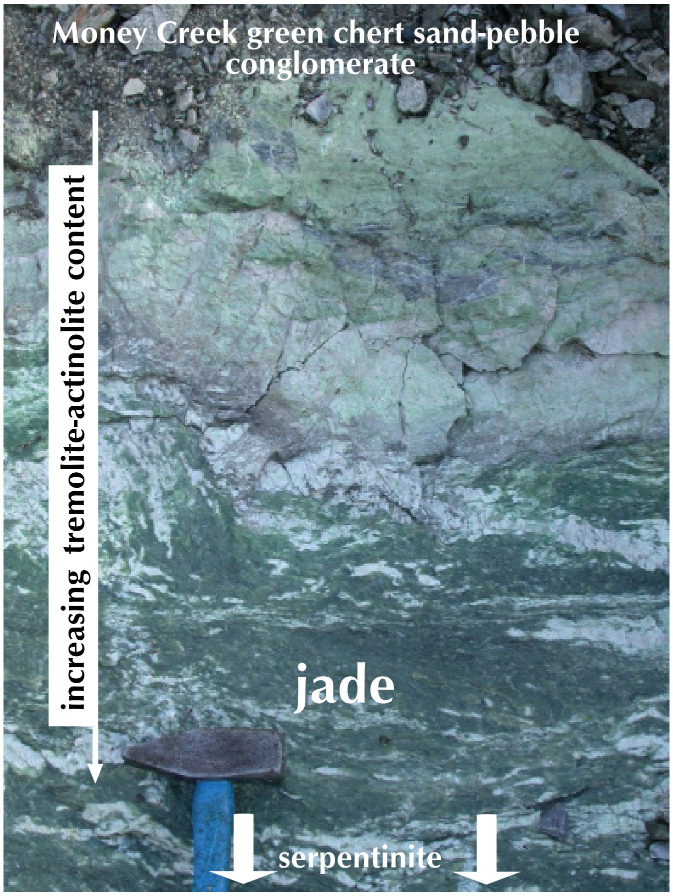

Figure 11. *Nephrite jade contacts in outcrop. Over a distance of approximately 2 m, basal Money Creek chert-clast sandstone and conglomerate is gradationally replaced by nephritic jade. Serpentinite underlies the jade seam. Fluid flow within late high-angle reverse faults facilitated metasomatic replacement of the conglomerate and serpentinite by microcrystalline tremolite-actinolite (nephrite).*

metasedimentary rocks and serpentinite by tremolite-actinolite.

Fault-bounded blocks of quartz-muscovite schist with lenses of Mississippian-age retrograded eclogite occur in the western field area in association with serpentinite-mélange of undetermined origin and are surrounded by greenschist facies metasedimentary rocks. Regional Early Permian thrust faults carried the former high-pressure rocks, from their position above an east-facing arc along the western margin of Yukon-Tanana Terrane, to their present position near the eastern contact with the North American miogeocline.

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REFERENCES

Blusson, S.L., 1966a. Sekwi Mountain, Nahanni, and Frances Lake map-area. *In:* Report of Activities, May to October 1965, S.E. Jenness (ed.), Geological Survey of Canada, Paper 66-1, p. 38-41.

Blusson, S.L., 1966b. Frances Lake, Yukon Territory and District of Mackenzie. Geological Survey of Canada, Map 6-1966, 1:253 440 scale.

Blusson, S.L., 1967. Sekwi Mountain, Nahanni, and Frances Lake map-area. *In:* Report of Activities, Part A: May to October 1966, S.E. Jennes (ed.), Geological Survey of Cananda, Paper 67-1, p. 44-45.

Colpron, M., Murphy, D.C., Nelson, J.L., Roots, C.F., Gladwin, K., Gordey, S.P. and Abbott, J.G., 2003. Yukon Targeted Geoscience Initiative, Part 1: Results of accelerated bedrock mapping in Glenlyon (105L/1-7, 11-14) and northeast Carmacks (115I/9,16) areas, central Yukon. *In:* Yukon Exploration and Geology 2002, D.S. Emond and L.L. Lewis (eds.), Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, p. 85-108.

Creaser, R.A., Goodwin-Bell, J.-A.S. and Erdmer, P., 1999. Geochemical and Nd isotopic constraints for the origin of eclogite protoliths, northern cordillera: implications for the Paleozoic tectonic evolution of the Yukon-Tanana Terrane. Canadian Journal of Earth Sciences, vol. 36, p. 1697-1709.

Deklerk, R. (compiler), 2002. Yukon MINFILE 2002 – A database of mineral occurrences. Frances Lake – 105 H. Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, CD-ROM.

Erdmer, P., 1987. Blueschist and eclogite in mylonitic allochthons, Ross River and Watson Lake areas, southeastern Yukon. Canadian Journal of Earth Sciences, vol. 24, p. 1439-1449.

Erdmer, P., 1992. Eclogitic rocks in the St. Cyr klippe, Yukon, and their tectonic significance. Canadian Journal of Earth Sciences, vol. 29, p. 1296-1304.

Erdmer, P. and Helmstaedt, H., 1983. Eclogite from central Yukon: a record of subduction at the western margin of ancient North America. Canadian Journal of Earth Sciences, vol. 20, p. 1389-1408.

Erdmer, P., Ghent, E.D., Archibald, D.A. and Stout, M.Z., 1998. Paleozoic and Mesozoic high-pressure metamorphism at the margin of ancestral North America in central Yukon. Geological Society of America Bulletin, vol. 110, p. 615-629.

Ghent, E.D., Black, P.M., Brothers, R.N. and Stout, M.Z., 1987. Eclogites and associated albite-epidote-garnet paragneisses between Yambe and Cape Colnett, New Caledonia. Journal of Petrology, vol. 28, p. 627-643.

Mihalynuk, M.G., Erdmer, P., Ghent, E.D., Archibald, D.A., Friedman, R.M., Cordey, F., Johannson, G.G. and Beanish, J., 1999. Age Constraints for Emplacement of the Northern Cache Creek Terrane and Implications of Blueschist Metamorphism. *In:* Geological Fieldwork 1998, British Columbia Ministry of Energy and Mines, Paper 1999-1, p. 127-141.

Mortensen, J.K., 1983. Age and evolution of the Yukon-Tanana Terrane, southeastern Yukon Territory. Unpublished Ph.D. thesis, University of California, Santa Barbara, California, 155 p.

Mortensen, J.K., 1992. New U-Pb ages for the Slide Mountain Terrane in southeastern Yukon Territory. Radiogenic age and isotopic studies, Report 5. Geological Survey of Canada Paper, Report 91-02, p. 167-173.

Mortensen, J.K. and Jilson, G.A., 1985. Evolution of the Yukon-Tanana Terrane: Evidence from southeastern Yukon Territory. Geology, vol. 13, p. 806-810.

Mortensen, J.K., Erdmer, P. and Ghent, E.D., 1997. Westerly-derived Upper Triassic clastic sedimentary rocks in southeastern Yukon: Evidence for Early Mesozoic terrane interaction with the western margin of ancentral North America. *In:* Slave – Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting, Abstracts, F. Cook and P. Erdmer (comps.), Lithoprobe Report No. 56, p. 76.

Mortensen, J.K., Erdmer, P., Piercey, S.J. and Ghent, E.D., 1999. Evidence for Late Triassic terrane accretion in the northern Canadian Cordillera in southeastern Yukon. Geological Survey of Canada/Geological Association of Canada, Terrane Paths 99, Circum-Pacific Terrane Conference, Abstracts and Program, p. 55.

Murphy, D.C., 2001. Yukon-Tanana Terrane in southwestern Frances Lake area (105H/3,4 and 5), southeastern Yukon. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, p. 217-233.

Murphy, D.C., 2004 (this volume). 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). *In:* Yukon Exploration and Geology 2003, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 157-175.

Murphy, D.C., Colpron, M., Roots, C.F., Gordey, S.P. and Abbott, J.G., 2002. Finlayson Lake Targeted Geoscience Initiative (southeastern Yukon), Part 1: Bedrock geology. *In:* Yukon exploration and Geology 2001, D.S. Emond, L.H. Weston and L.L. Lewis (eds.), Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, p. 189-207.

Murphy, D.C., Piercey, S.J., Mortensen, J.K. and Orchard, M.J., 2003. Mid- to Late Paleozoic tectonostratigraphic evolution of Yukon-Tanana Terrane, Finlayson Lake massive sulphide district, southeastern Yukon. *In:* Geological Association of Canada – Mineralogical Association of Canada - Society of Economic Geologists Joint Annual Meeting, Vancouver, British Columbia, Abstracts vol. 28, p. 212, CD-ROM.

Okulitch, A.V., 2001. Geological time chart, 2002. Geological Survey of Canada, Open File 3040.

Poulton, T., Orchard, M.J., Gordey, S.P. and Davenport, P., 1999. Paleontology data set. *In:* Yukon Digital Geology, S.P. Gordey and A.J. Makepeace (comps.), Geological Survey of Canada, Open File D3826 and Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Open File 1999-1(D), 2 CD-ROMs.

Simandl, G.J., Riveros, C.P. and Schiarizza, P., 2000. Nephrite (jade) deposits, Mount Ogden area, central British Columbia (NTS 093N 13W). *In:* Geological Fieldwork 1999, British Columbia Ministry of Energy and Mines, Paper 2000-1, p. 339-347.

Wakabayashi, J., 1992. Nappes, tectonics of oblique plate convergence, and metamorphic evolution related to 140 million years of continuous subduction, Franciscan Complex, California. Journal of Geology, vol. 100, p. 19-40.