'Alpine-type' ultramafic rocks of the Kluane metamorphic assemblage, southwest Yukon: Oceanic crust fragments of a late Mesozoic back-arc basin along the northern Coast Belt

Jochen E. Mezger
Department of Earth and Atmospheric Sciences, University of Alberta[1]

Mezger, J.E., 2000. 'Alpine-type' ultramafic rocks of the Kluane metamorphic assemblage, southwest Yukon: Oceanic crust fragments of a late Mesozoic back-arc basin along the northern Coast Belt. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 127-138.

ABSTRACT

Mica-quartz schist and olivine serpentinites form the Kluane metamorphic assemblage, a 150-km-long belt that is wedged between the Yukon-Tanana Terrane and the Insular Superterrane in the northern Coast Belt. The olivine serpentinites are serpentinized dunites that occur as lens-shaped bodies, interlayered along strike, with the mica-quartz schist. The larger ultramafic bodies developed a foliation and shear sense that is similarly oriented to those in the adjacent schist, suggesting 'Alpine-type' emplacement. Tectonic juxtaposition of schist and ultramafic rocks occurred during collapse and subduction of a back-arc basin underneath the North American continental margin in the Late Cretaceous. Oxygen isotope analyses point to values similar to known ophiolitic serpentinites. The ultramafic rocks are interpreted to be part of an oceanic crust that formed topographic highs during subduction and were subsequently sheared off and tectonically interleaved with metasedimentary rocks during the accretionary process.

RÉSUMÉ

Des schistes à mica-quartz et des serpentinites à olivine forment l'assemblage métamorphique de Kluane; une ceinture de 150 km de long que l'on retrouve entre le terrane de Yukon-Tanana et le superterrane Insulaire, dans la partie septentrionale de la chaîne Côtière. Les serpentinites à olivine sont des dunites serpentinizées qui se présentent sous forme de lentilles qui sont intercalées, le long de l'affleurement, avec les schistes à mica-quartz. Les plus gros amas ultramafiques ont développés une foliation et une direction de cisaillement d'orientation similaire à celle du schiste adjacent, suggérant un emplacement de 'type alpin'. La juxtaposition tectonique du schiste et des roches ultramafique s'est formée durant l'effondrement et la subduction d'un bassin d'arrière-arc sous la marge continentale nord americaine au Crétacé supérieur. Les analyses des isotopes d'oxygène ont enregistrées des valeur similaires aux serpentinites ophiolitiques connues. Les roches ultramafiques sont interprétées commes faisant partie d'une croûte océanique qui formait des reliefs topographiques durant la subduction et qui a été successivement cisaillée et tectoniquement intercalée avec des roches métasédimentaires durant le processus d'accrétion.

[1]*Edmonton, Alberta, Canada T6G 2E3*
current address: Johannes Gutenberg-Universität Mainz, Institut für Geowissenschaften, 55099 Mainz, Germany, mezger@mail.uni-mainz.de

INTRODUCTION

Ultramafic rocks are minor, but common constituents of accreted terranes in the northern Cordillera. Two types of ultramafic rocks, 'Alpine-type' and 'Alaskan-type,' are distinguished by their genetic origin. Alpine-type ultramafic rocks are generally fault-bounded, internally deformed and serpentinized. They are interpreted as segments of oceanic crust and/or mantle that were tectonically emplaced into their present position (Hall, 1987). A common feature of Alpine-type ultramafic rocks is the occurrence along tectonic zones, e.g., faults, shear zones and terrane boundaries. Slivers of serpentinite, serpentinized dunite and peridotite, associated with flysch deposits and mica schists, occur along the Denali Fault zone in the central and eastern Alaska Range. These ultramafic rocks may be the remnants of an ocean basin, possibly the basement of Wrangellia that collapsed during subsequent accretion in the Late Mesozoic (Nokleberg et al., 1985, Patton et al., 1994). Alaskan-type ultramafic rocks, found along a 560-km-long belt west of the Coast Plutonic Complex in southeastern Alaska, are concentrically zoned bodies with a dunite core and pyroxenite shells, generally associated with gabbro intrusions (Taylor, 1967; Himmelberg et al., 1985; Patton et al., 1994). They are interpreted as fractionated ultramafic intrusions (Taylor, 1967).

In the Coast Belt of southwestern Yukon, ultramafic rocks occur within the Kluane metamorphic assemblage (KMA). The KMA is a tectonically thickened package of graphitic mica schist and gneiss that is wedged between rocks of North American affinity (Yukon-Tanana Terrane) to the east and accreted terranes of the Insular Superterrane (Alexander Terrane) to the west. The KMA is separated from the Yukon-Tanana Terrane by the Paleocene-Eocene granodiorite of the Ruby Range Batholith, and from the Alexander Terrane by the Denali Fault zone (Fig. 1). The KMA does not appear to be correlated with any other sedimentary or metamorphic rock assemblage of the northern Cordillera. Its tectonic affinity remains enigmatic. On the most recent tectonic assemblage map of the Canadian Cordillera, the KMA is shown as "metamorphic rocks undivided" (Wheeler and McFeely, 1991).

The schist and gneiss of the KMA are characterized by north- to northeast-dipping regional foliation and a shallowly east-west-plunging mineral lineation (Mezger, 1997). The regional foliation overprints two earlier foliations that are preserved as graphitic inclusions in plagioclase porphyroclasts. Lacking original sedimentary structures, this regional foliation is referred to as S_{n+2}. At lower structural levels, the schists are mylonitic with a distinct fabric asymmetry, defined by shear bands and rotated porphyroclasts that indicate top-to-the-west sense of shear. At higher structural levels these fabrics are overprinted by contact metamorphism related to the Early Tertiary intrusion of the Ruby Range Batholith, the northern extension of the Coast Plutonic Complex (Mezger, 1997). The geochemical and Neodymium isotope character of the KMA is intermediate between juvenile and evolved sources, which suggests a back-arc basin setting for the sedimentary protolith (Mezger, 1996, 1997; Mezger and Creaser, 1996).

The objective of this paper is to describe ultramafic rocks of the KMA, discuss their possible origin, mode of emplacement into the mica schist, and the implications on the tectonic evolution of the KMA and the northern Cordillera. In addition to petrological and structural observations, oxygen isotope data are presented. It will be shown that the ultramafic rocks of the KMA are fragments of an oceanic crust that were tectonically interleaved with metasedimentary rocks during underplating and accretion to the overriding North American plate in the Late Cretaceous.

ULTRAMAFIC ROCKS OF THE KMA

The KMA forms a 150-km-long, southeast-trending belt, underlying approximately 3000 km^2 of the Ruby and Dezadeash ranges northeast of the Shakwak Trench in southwestern Yukon. It extends from the mouth of Kluane River to Dezadeash Lake, covering the Kluane Lake (115 G&F), Aishihik Lake (115 H) and Dezadeash (115 A) map sheets (Fig. 1). Ultramafic rocks are only minor constituents, occurring as interleaved lenses within a 12-km-thick unit of schist and gneiss in the western part of the KMA. As a result, these ultramafic rocks have largely gone unnoticed by previous workers, and were not mapped as separate units. The metamorphic assemblage was originally termed "Kluane Schist" by McConnell (1905). The term "Kluane metamorphic assemblage" was introduced by Mezger (1995) to include the ultramafic rocks which have undergone the same tectono-metamorphic evolution as the mica-quartz schist ("Kluane Schist" *sensu strictu*).

The ultramafic rocks in the KMA form four distinct ultramafic bodies that occur for 60 km along strike in the Ruby Range, from Doghead Point, northeast of Burwash Landing, to northwest of Kloo Lake. Their sizes vary from a width and thickness of a few tens of metres (Erdmer, 1990) to 15 km with a structural thickness of more than 1000 m (Figs. 2, 3). The two larger bodies are recognized by distinct positive magnetic anomalies on aeromagnetic maps (GSC, 1967, 1968).

The ultramafic rocks are serpentinized dunites that consist of varying amounts of Mg-rich olivine (Fo=90, 10-80 vol.%), serpentine (15-60 vol.%), talc (0-40 vol.%), as well as iddingsite, magnetite, chromite and pentlandite (5-10 vol.% combined), with traces of calcite (Table 1). Olivine is preserved in rounded pods, up to one centimetre in diameter, and is characterized by mesh-like inclusions of chromite, overgrown by chromium-magnetite (Figs. 4, 5, 8). At some localities of the large Doghead Point ultramafic body, spinning of the compass needle can be observed. Iddingsite forms yellowish alteration rims around olivine. Abundant serpentine and talc give the rock a light greenish colour and a soapy touch.

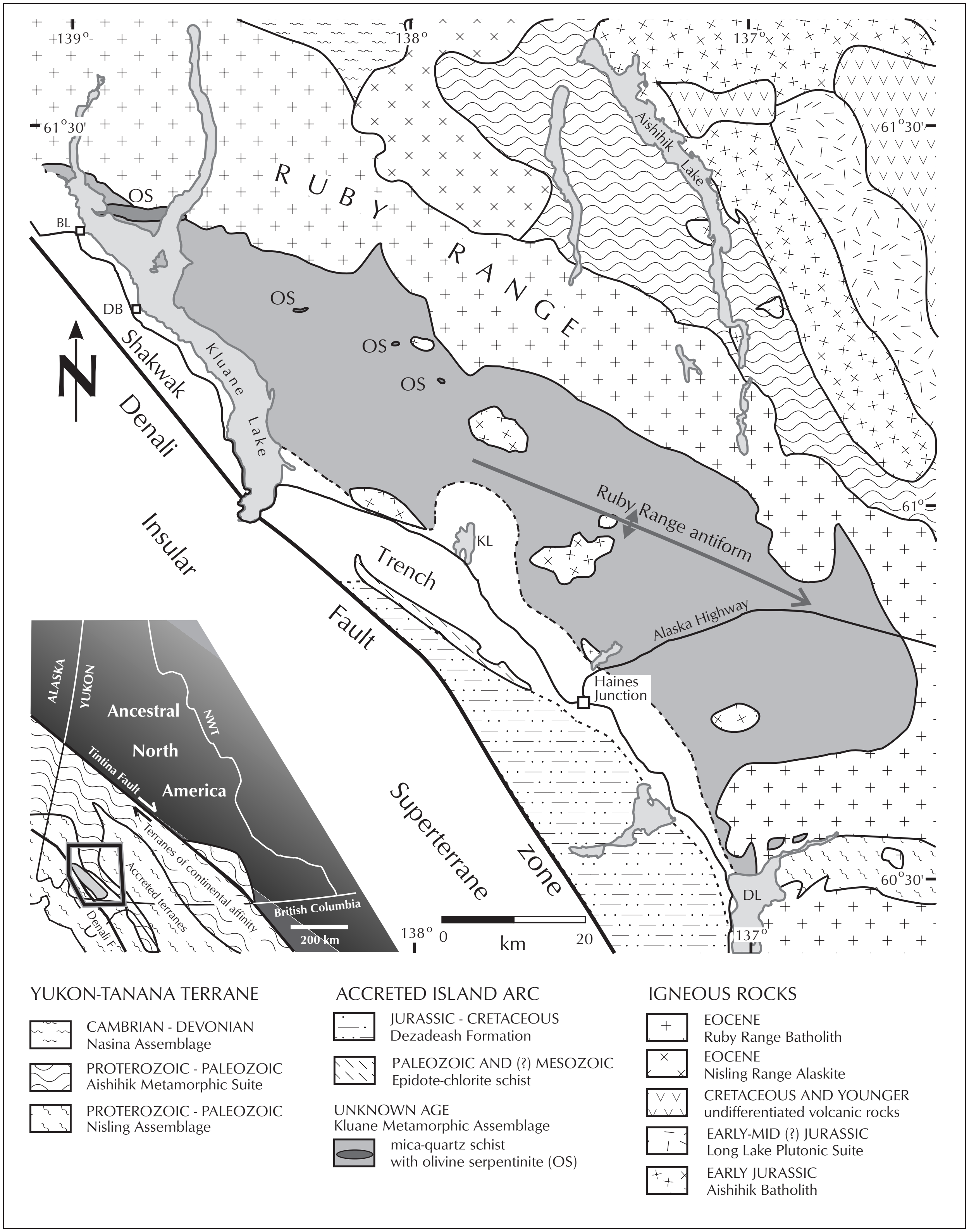

Figure 1. *Geological overview map of the Kluane metamorphic assemblage. Additional information from Kindle (1952), Muller (1967), Tempelman-Kluit (1974), Wheeler and McFeely (1991), Dodds and Campbell (1992) and Johnston and Erdmer (1995). BL: Burwash Landing; DB: Destruction Bay; DL: Dezadeash Lake; KL: Kloo Lake.*

DOGHEAD POINT ULTRAMAFIC

By far the largest ultramafic body is located near Doghead Point on the northern shore of Kluane Lake, opposite of Burwash Landing (Fig. 2). It forms a 1260-m-high east-trending ridge and can be traced for 9 km from the north end of an unnamed lake across Talbot Arm to the eastern lakeshore. The ultramafic body is in contact with muscovite-chlorite schist in the south, and tonalitic intrusions of the Ruby Range Batholith in the north. Aeromagnetic data suggest that it extends further west to Sandspit Point, resulting in a total length along strike of 15 km. However, there is no exposure in the low-relief wooded area. The ultramafic body has a minimum structural thickness of 1000 m. The extent of the body is outlined by the 57,400 nT total magnetic field isoline, which closely follows the observed geological contact in the field. A maximum magnetic intensity of 1700 nT above the average for the schist (57,300 nT) suggests a massive body. The subsurface extension of the ultramafic body is not known. However, a steep-dipping internal foliation at its northern margin, and the lack of a distinct magnetic low to the north suggest it has a wedge-like shape which does not extend much further into subsurface beyond its exposed northern contact (Fig. 3).

The Doghead Point olivine serpentinite has a strongly developed schistosity, which can be correlated with the major regional schistosity S_{n+2} in the adjacent mica schist. Schistosity is defined by the alignment of serpentine grains in the cleavage domains (Fig. 4). Olivine is preserved in the less-sheared microlithons (Figs. 4, 5). The strike of schistosity is parallel to that of the underlying schist, dipping moderately to steeply to the north-northeast (Fig. 2). In the western part of the ridge, steeply,

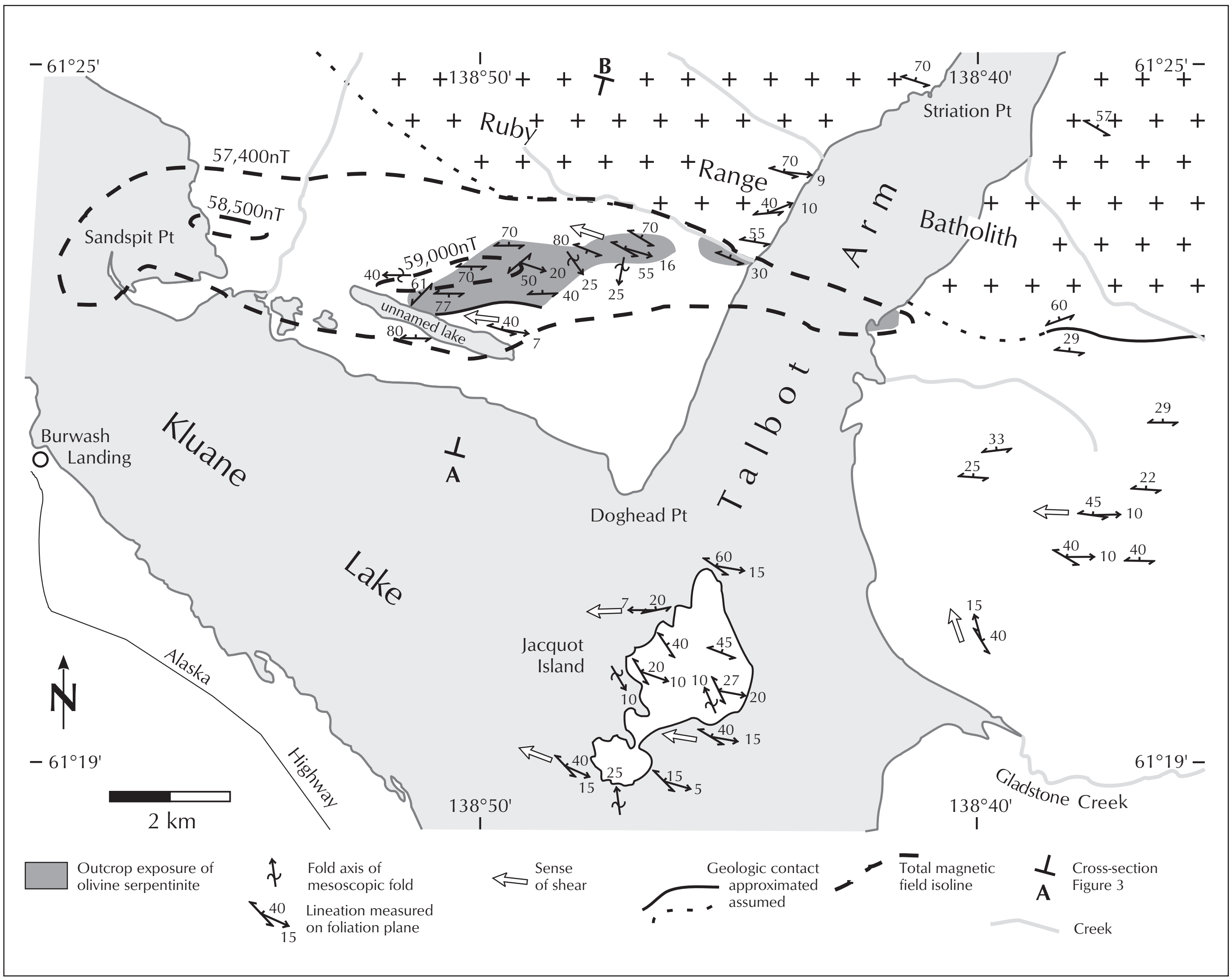

Figure 2. *The Doghead Point olivine serpentinite occurrence in the central Kluane Lake region. The surface exposure of the ultramafic body follows the 57,400 nT magnetic field isoline. Magnetic field data modified after GSC (1967).*

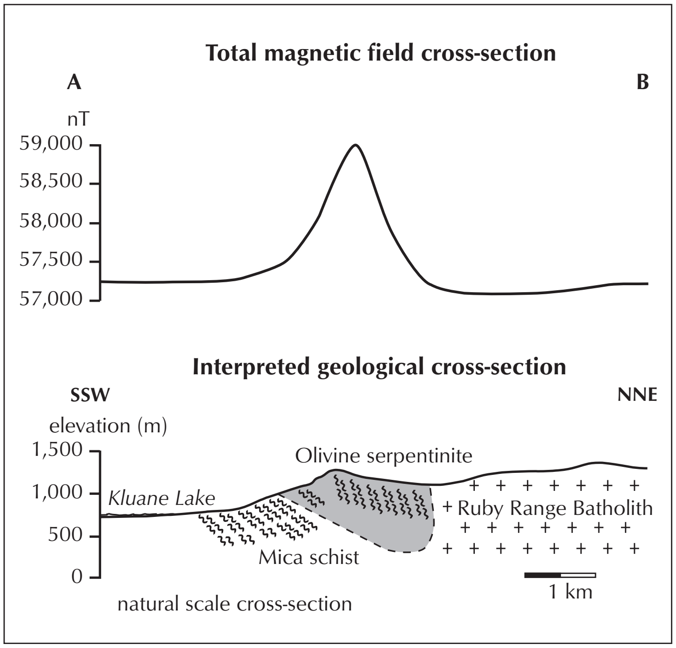

Figure 3. *Magnetic field cross-section and interpreted geological section through the Doghead Point ultramafic body. The subsurface extension of the serpentinite is speculative. See Figure 2 for location of section.*

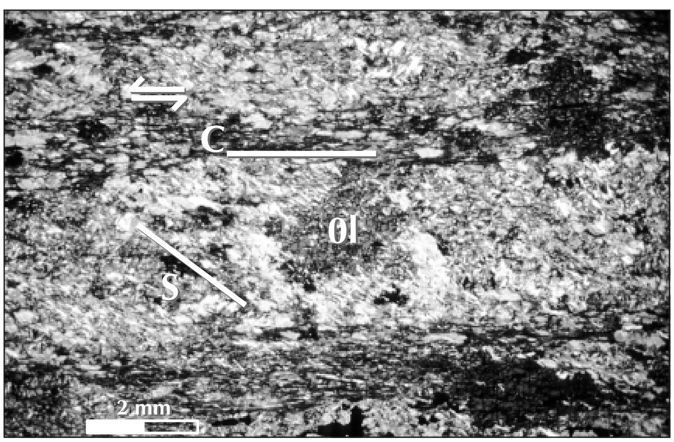

Figure 4. *Photomicrograph of the central Doghead Point olivine serpentinite with prominent asymmetrical fabric, interpreted as a c/s fabric of Berthé et al. (1979) and resembling fabrics described by Norrell et al. (1989) from serpentinites of the Josephine Ophiolite (compare with their Figure 6). Platy alignment of serpentine in the cleavage planes defines a schistosity c. S-planes are developed in 3-mm-wide microlithons between more intensely sheared cleavage planes. A top-to-the-left sense of shear can be deduced. Olivine porphyroclasts (Ol), preserved in the microlithons, display web-like alteration to chromite and magnetite. Scale bar: 2 mm. Crossed polarized light (XPL).*

southerly dipping schistosity can be observed. Less commonly, a mineral lineation defined by elongated serpentine flakes is developed in the serpentinite.

Locally, a secondary foliation S_{n+3}, axial planar, to northeast- to southwest-plunging, mesoscopic open F_{n+3} folds and millimetre-scale F_{n+3} crenulation folds, is developed in the olivine serpentinite (Fig. 6). S_{n+3} is restricted to the fold hinges, and as such does not form a penetrative foliation that can be mapped on a regional scale. F_{n+3} folds are also observed in the schist throughout the whole KMA, without development of an axial planar cleavage.

In places where a strong mineral lineation is developed, the serpentinite is mylonitic and displays an asymmetrical fabric. Narrow shear zones, 0.25-1 mm wide, parallel to the dominant foliation S_{n+2}, separate wider zones (1-3 mm) of oblique grain shape foliation defined by serpentine crystals (Fig. 4). The angle

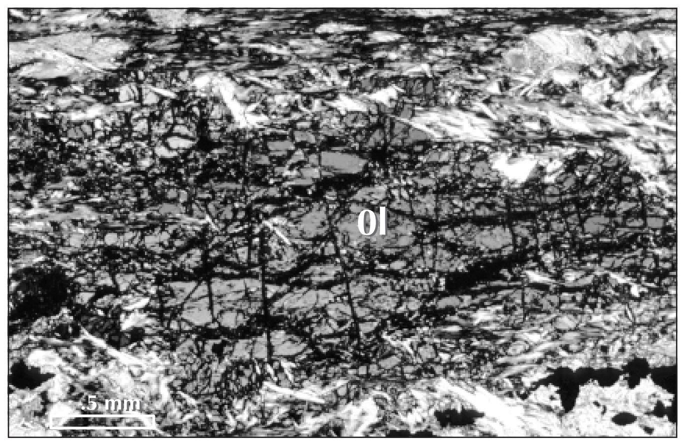

Figure 5. *Enlarged view of the lower right section of Figure 4 showing the web-like alteration of olivine. Scale bar: 0.5 mm. XPL.*

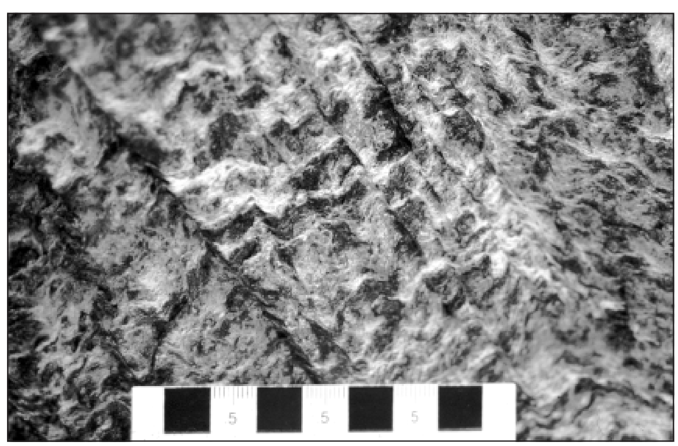

Figure 6. *Crenulation folding of the central Doghead Point olivine serpentinite. A 5-mm-spaced crenulation foliation S_{n+3} runs from upper left to lower right. Scale bar is in centimetres.*

between the foliation S_{n+2} and the oblique serpentine grains ranges between 35-45°. Similar fabrics have been described by Norrell et al. (1989) from partly serpentinized peridotites of the Josephine ophiolite of northern California. They interpret them as c/s fabrics after Berthé et al. (1979), synonymous to c-type shear bands of Passchier and Trouw (1996). The sense of shear deduced from the c/s fabrics is sinistral, top to the west, similar to that obtained from c′-type shear bands and rotated porphyroclasts in the adjacent muscovite-chlorite schist.

Locally, decimetre-sized boudins of altered gabbronorite aligned in layers parallel to the serpentinite schistosity can be observed (Fig. 7). Brownish orthopyroxene crystals are prominently weathered on the surface of the boudins (Fig. 8). Thin sections reveal that orthopyroxene in the gabbronorite is partly replaced by clinoamphibole (Fig. 9).

Schistosity orientation and shear sense indicators in the mica schists and olivine serpentinite are similar, suggesting a common deformation history. Along its northern contact with gneissic quartz diorite and tonalite of the Ruby Range Batholith, the ultramafic body appears more massive with less altered olivine crystals. This indicates recrystallization of olivine as a result of contact metamorphic overprinting by the batholith. Field observations suggest that the juxtaposition of ultramafic rock and mica schist occurred in the early stage of the major deformation phase D_{n+2}, and prior to the intrusion of the Ruby Range Batholith.

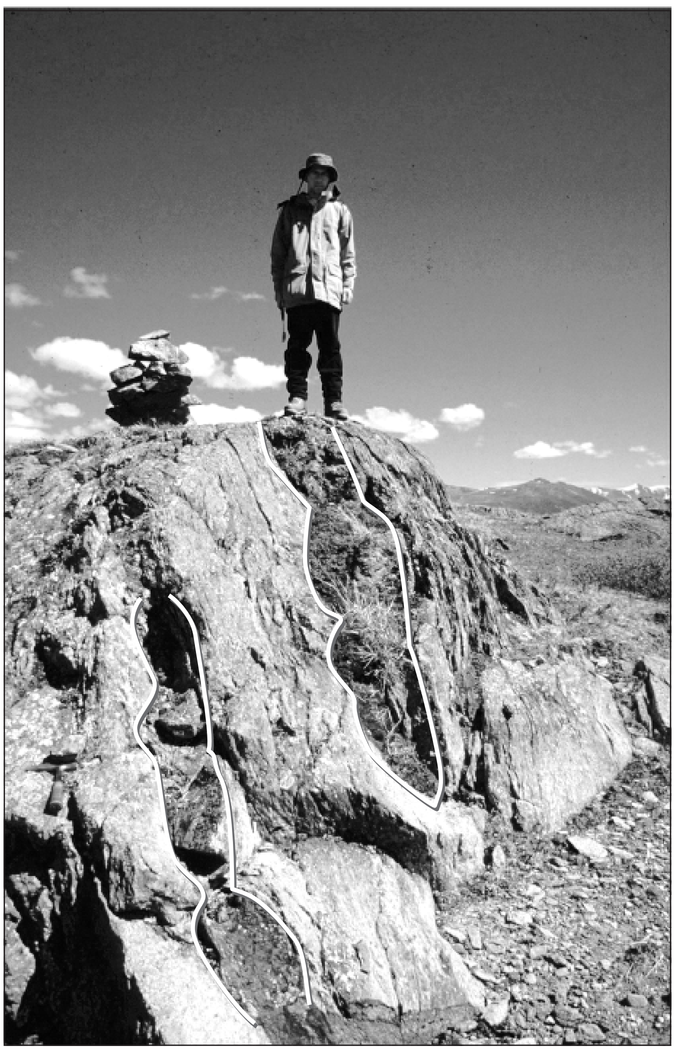

Figure 7: *Steeply dipping, foliated olivine serpentinite on the ridge north of Doghead Point. Two layers of boudinaged, altered gabbronorite are outlined. The layers have a thickness of 30-50 cm.*

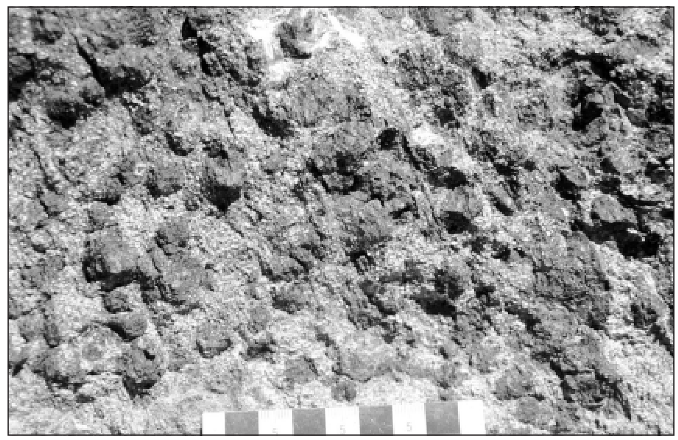

Figure 8. *Weathered surface of gabbronorite boudins showing brownish altered orthopyroxene phenocrysts. Scale bar is in centimetres.*

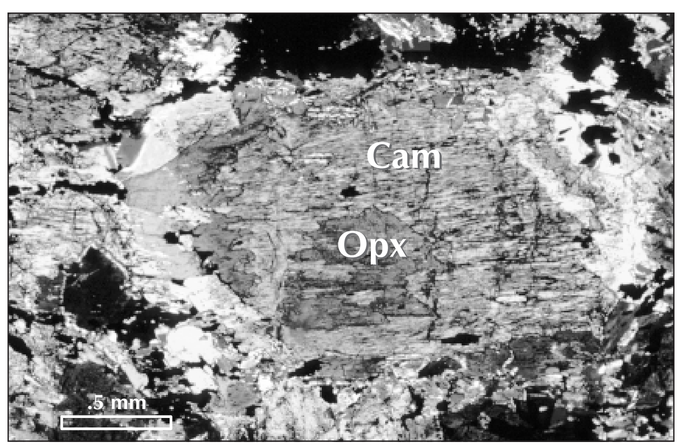

Figure 9. *Photomicrograph of gabbronorite. The original orthopyroxene (Opx) is almost completely replaced by clinoamphibole (Cam) and only preserved as a relic in the centre of the crystal. Scale bar: 0.5 mm. XPL.*

SWANSON CREEK ULTRAMAFIC

A smaller olivine serpentinite body is located on a ridge west of Swanson Creek (Fig. 10), and is recognized as a minor positive anomaly (+ 200 nT) on the aeromagnetic map (GSC, 1968). The body is wedge-shaped, less than a kilometre wide and approximately 150-200 m thick (Fig. 11). Its exposure is restricted to the ridge crest, tapering off downslope. The northerly dipping orientation of the wedge is parallel to the general attitude of the foliation in the surrounding schist. A penetrative foliation is developed close to the contact with the mica-quartz schist. The contact is fabric-parallel. Away from the contact, the ultramafic body is characterized by centimetre-scale cleavage zones anastomosing around decimetre-scale undeformed olivine serpentinite (Figs. 12, 13). Such structures are also described in less deformed, incohesive serpentinites of the Josephine Ophiolite (Norrell et al., 1989). The cleavage is moderately dipping towards north, similar to the orientation of the foliation in the adjacent schist, suggesting coeval development of cleavage and schistosity, similar to what is observed within the Doghead Point serpentinite locality.

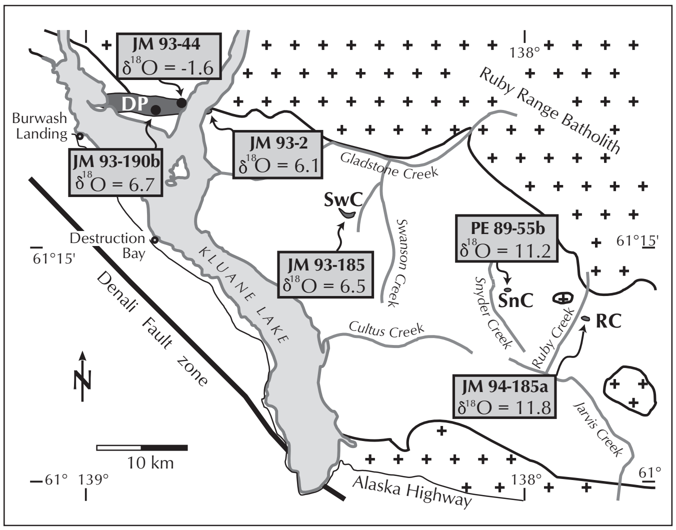

Figure 10. *Oxygen isotope data from the four known occurrences of olivine serpentinite (dark shaded areas) in the Kluane metamorphic assemblage. The data are listed as δ^{18}O SMOW. DP=Doghead Point; SwC=Swanson Creek; SnC=Synder Creek; RC=Ruby Creek.*

Figure 11. *View from southeast onto the Swanson Creek ultramafic lens, outlined by white line. The lighter colour of the olivine serpentinite is in contrast to the dark grey of the mica-quartz schist. Note that the ultramafic body tapers off downslope. It does not extend towards the bottom of the valley. The exposure of the ultramafic along the ridge is approximately 200 m.*

Figure 12. *The structural character of the Swanson Creek ultramafic body is different from that of the Doghead Point serpentinite. A penetrative foliation is restricted to the margins of the ultramafic body. More common is a foliation anastomosing around elongated, decimetre-scale, undeformed olivine serpentinites.*

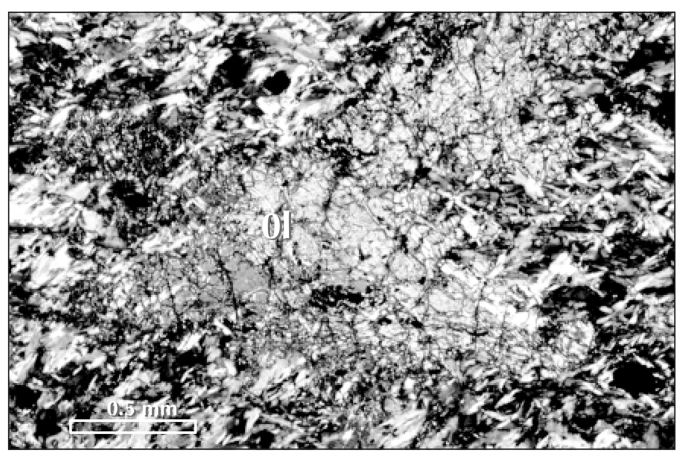

Figure 13. *Photomicrograph of an undeformed olivine (ol) serpentinite of the Swanson Creek lens. Serpentine and talc crystals are randomly oriented. Scale bar: 0.5 mm. XPL.*

SNYDER CREEK (SNC) AND RUBY CREEK (RC) ULTRAMAFIC BODIES

The two eastern olivine serpentinite bodies are too small to be distinguished on aeromagnetic maps. The Ruby Creek exposure forms a resistant knoll in the order of tens of metres on a plateau east of Ruby Creek. The contact with the mica-quartz schist is exposed. On a ridge east of Snyder Creek, Erdmer (1990) observed two small bodies at the scale of tens of metres. At both localities, the serpentinites are massive and show no conspicuous signs of deformation.

OXYGEN ISOTOPE STUDIES

RESULTS

Six olivine serpentinite samples, three from the Doghead Point lens, and one each from the other localities, were selected for oxygen isotope analysis. The objective was to compare the oxygen isotope signature of the KMA ultramafic rocks with those of serpentinites of known ophiolites and mantle material, and to examine the effects of hydrothermal alteration. Fred Longstaff of the University of Western Ontario performed whole-rock ^{18}O analyses. The results are listed as deviation from Standard Mean Ocean Water ($\delta^{18}O$ SMOW) in Table 1 and are shown on Figure 10.

Table 1: *Location, mineral composition and $d^{18}O$ values of olivine serpentinites of the Kluane metamorphic assemblage.*

Sample #	Location	Field relationship	Mineral paragenesis[1] (vol. %)	Yield (µmoles/mg)	$\delta^{18}O$ SMOW[2] (‰)
		Doghead Point ultramafic (DP)			
JM 93-2	eastern shore of Talbot Arm, Kluane Lake 138°41'40" W, 61°22'45" N	eastern margin contact not exposed	Ol, Srp, Mag, Chr	8.46	**6.1**
JM 93-44	western shore of Talbot Arm, Kluane Lake 138°44'40" W, 61°23'10" N	northern contact with Ruby Range Batholith	Ol (75), Srp (20), Mag, Chr (5)	10.09 (repeat) 9.88	**-1.1** (repeat) **-2.2**
JM 93-190b	southern slope of hill, north of Doghead Point 138°49'40" W, 61°23'05" N	central part of lens	Srp (70), Ol (10-15), Tlc (10), Idd (2-3), Pn, Chr, Mag (5)	13.65	**6.7**
		Swanson Creek ultramafic (SwC)			
JM 93-185	ridge west of Swanson Creek, Ruby Range 138°25'50" W, 61°15'20" N	central part of lens	Srp (65), Ol (30), Mag, Chr (5), Cc	11.74	**6.5**
		Snyder Creek ultramafic (SnC)			
PE 89-55b	ridge east of Snyder Creek, Ruby Range 138°03'00" W, 61°12'42" N	small outcrop	Tlc (50), Srp (35) Ol (15), Mag, Chr, C	12.08	**11.2**
		Ruby Creek ultramafic (RC)			
JM 94-185a	plateau east of Ruby Creek, Ruby Range 137°50'42" W, 61°10'42" N	small outcrop, in contact with mica schist	Tlc (50), Ol (25) Srp (20), Mag, Chr, Cr-En (5)	11.4	**11.8**

[1]Mineral composition estimated from thin section analysis. Cc: calcite; Chr: chromite; Cr-En: chrome-enstatite; Idd: iddingsite; Mag: magnetite; Ol: olivine; Srp: serpentine; Tlc: talc.

[2]Oxygen isotope analyses made by F. Longstaff, University of Western Ontario. Reproducibility of quartz standards ± 0.03‰.

The $\delta^{18}O$ SMOW values fall into three groups, -1.6‰, 6.5‰ and 11.5‰. Values from 6.1 to 6.7‰ were recorded from samples of the core zone (JM 93-190b) and the eastern margin (JM 93-2) of the Doghead Point ultramafic lens, and from the core of the Swanson Creek lens (JM 93-185; Fig. 10). These samples are characterized by a high serpentine content of 60-70 vol.% (Table 1). They are located at some distance (hundreds of metres) to the marginal zone of the ultramafic bodies. Higher $\delta^{18}O$ values, 11.2 and 11.8‰, are obtained from the samples of the two smaller talc-rich serpentinites in the east (PE 89-55b, JM 94-185). The lowest $\delta^{18}O$ value, -1.6‰, is measured in a sample (JM 93-44) from the northern margin of the Doghead Point ultramafic, close to the contact with the Ruby Range Batholith.

INTERPRETATION OF $\delta^{18}O$ DATA

The $\delta^{18}O$ values of 6-7‰ of the core zones of the larger bodies are similar to values reported from serpentinites of the Onverwacht Group ophiolites in South Africa (3-6‰, Hoffman et al., 1986) and intrusive rocks of the Bay of Islands ophiolite in Newfoundland (5.8‰, Muehlenbachs, 1986). These values deviate very little from pristine mantle values (Kyser, 1986), which implies that the water/rock ratio must have been small. This is the case regardless if serpentinization occurred *in situ* in an ocean floor setting, as a result of interaction with magmatic fluids (5-7‰) and sea water (0‰), or after obduction due to interaction with metamorphic (13-20‰) or meteoric waters (-20-0‰; Wenner and Taylor, 1973; Shepard, 1986). A similar small water/rock ratio can be inferred from serpentinization of an ultramafic intrusion within a sedimentary sequence (Alaskan-type), resulting from interaction with high $\delta^{18}O$ metamorphic fluids that were derived from pelitic sediments with $\delta^{18}O$ values of 13-20‰ (Taylor and Shepard, 1986). In all cases, a significantly large water/rock ratio would have changed the $\delta^{18}O$ values. To distinguish the source of serpentinization, further oxygen isotope studies of individual minerals and also δD (Deuterium) studies are necessary.

The high $\delta^{18}O$ values (11.2 and 11.8‰) and the high talc content (~50 vol.%) of the smaller ultramafic bodies indicate interaction with hydrothermal fluids derived from the mica-quartz schist (Deer et al., 1992). The existence of pristine olivine in these samples suggests that the water/rock ratio was not exceptionally high. The $\delta^{18}O$ values of pelitic sediments range from 13‰ to 20‰, and metamorphic fluids derived from dehydration of metasedimentary rocks during metamorphism record 3‰ to 20‰, at 300 to 600°C (Taylor and Shepard, 1986). This hydrothermal event could be caused by (a) fluids originating from dehydration of the sediment during initial metamorphism, (b) fluids driven out during the intrusion of the Ruby Range Batholith, or (c) post-intrusive localized fluids flowing through pervasive joints and fractures.

Present day meteoric waters of the North American Cordillera are relatively depleted in ^{18}O and can have $\delta^{18}O$ values of -20‰ and less (Shepard, 1986). The negative $\delta^{18}O$ value of -1.5‰ of sample 93-44 at the margin of the larger Doghead Point olivine serpentinite is most likely the result of localized alteration due to interaction with meteoric water during uplift of the KMA in post-Eocene time.

ORIGIN AND EMPLACEMENT OF THE KMA ULTRAMAFICS

The origin of the ultramafic rocks of the KMA cannot be unambiguously inferred from oxygen isotope data alone. Both intrusive and ophiolitic setting is possible. Their tectonic setting can be constrained when the ultramafic rocks are taken into context with the structural, geochemical and isotopic character of the surrounding mica schist. These metasedimentary rocks are remarkably homogeneous in their geochemical and isotopic composition. Their protolith was derived from more than one provenance region, and represents a mixing of evolved (continental) and juvenile (volcanic arc) sources (Mezger and Creaser, 1996; Mezger, 1997). The restricted occurrence of orthoamphibole gneiss with primitive isotopic signature and thin bands of actinolite fels suggest proximity to a volcanic arc, but not isolation from a continent. The most probable depositional setting for the sedimentary protolith of the KMA is a back-arc basin located between a volcanic arc (Insular Superterrane?) and the North American continental margin (Mezger et al., in review).

Graphitic inclusion trails are common features of plagioclase porphyroclasts of the KMA schist, and are indicative of two earlier foliations, an original lamination (?) and a slaty cleavage (Mezger, 1997). There is no compelling evidence for a penetrative ductile deformation predating the regional schistosity S_{n+2} that is developed in the mica schist and the olivine serpentinite. This implies that mica schist and ultramafic rocks were juxtaposed prior to, or in the early stage of D_{n+2} deformation.

Juxtaposition of the ultramafic rocks and schist could have resulted from (a) intrusion of ultramafic magma into the sedimentary protolith or mica schist of the KMA (Alaskan-type), or (b) by tectonic interleaving of disrupted lower portions of the oceanic crust/mantle (Alpine-type). Alaskan-type emplacement can be precluded due to absence of internal zoning of the ultramafic bodies, lack of intrusive relations with gabbros and no thermal overprinting of the schist at the contact. A foliation-parallel contact between schist and ultramafic rock, internal foliation of the larger ultramafic bodies, and location of the ultramafic rocks along strike of the regional foliation support an Alpine-type emplacement. It follows that mica schist and serpentinite were juxtaposed during accretion onto the Yukon-Tanana Terrane, after the back-arc basin had collapsed and subducted.

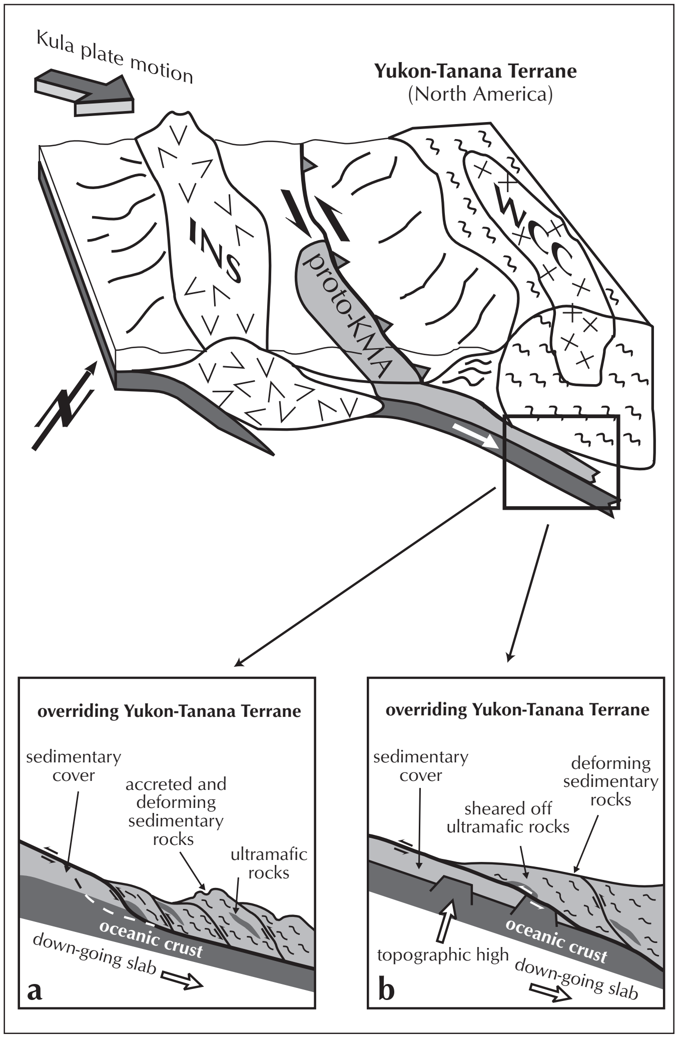

Figure 14. *Tectonic model of the accretion of the KMA onto the North American continental margin in the Late Cretaceous. The top block diagram shows the collapse of the back-arc basin into which the sedimentary protolith of the KMA was deposited. As the Kula plate changed motion towards the east at around 95 Ma (Engebretson et al., 1995), the Insular Superterrane (INS) was approaching the North American continental margin. This resulted in eastward oblique subduction of the KMA back-arc basin, and the development of a magmatic arc, possibly the Whitehorse Coffee Creek arc (WCC, J. Mortensen, pers. comm., 1999). The pair of black arrows indicates a sinistral strike-slip component. (a) Accretion of tectonically interleaved metasedimentary and ultramafic rocks by development of duplex structures (Platt, 1986). (b) Tectonic underplating by shearing off topographic highs of the oceanic crust and inter-foliating ultramafic with metasedimentary rocks along detachment zones (Karig and Sharman, 1975).*

The mode of tectonically interleaving ultramafic rocks with the schist is poorly understood. One model suggests that during underplating, detachment faults or shear zones could form (Fig. 14). These faults could cut through the sedimentary cover and oceanic crust of the down-going plate, resulting in duplex structures being accreted to the overriding plate (Fig. 14a; Platt, 1986). Alternatively, Karig and Sharman (1975) proposed that the ultramafic rocks represented topographic highs, such as horst structures or seamounts, that were sheared off and subsequently tectonically interleaved and deformed with the scraped off sedimentary rocks (Fig. 14b).

During the underplating process, the sedimentary rocks were ductilely deformed and metamorphosed to become mylonitic mica schist. Geobarometry on garnet cores indicate that this process took place at depths of 20-25 km (Mezger et al., in review). The direction of underplating or underthrusting can be deduced from the orientation of mineral lineation and sense of shear derived from rotated plagioclase porphyroclasts and c′-type shear bands in mylonitic schist. These indicate uniform eastward underthrusting of the KMA underneath the Yukon-Tanana Terrane. The oblique angle of underplating, implying a sinistral strike-slip component, could explain the presence of the ultramafic bodies along strike of the regional foliation. The four ultramafic lenses could be fragments of one large body that became disrupted during oblique underplating. Tectonic underplating of the KMA occurred in the Late Cretaceous. It is constrained by the change of motion of the Kula plate towards an easterly direction relative to North America, at around 95 Ma (Engebretson et al., 1995), and by intrusion of late deformational mafic dykes into the KMA at 72 Ma (Mezger et al., in review).

The tectonic setting of the KMA serpentinites is comparable to similar ultramafic bodies in the central and eastern Alaska Range, which are also located near the Denali Fault zone, and are interpreted to be Alpine-type (Nokleberg et al., 1985; Patton et al., 1994). With the exception of the Chulitna Terrane of central Alaska (Jones et al., 1980), serpentinites in Alaska and the Yukon are not correlated to any ophiolitic sequence. In absence of ophiolitic sequences, Alpine-type ultramafic rocks may be considered fragments of subcontinental mantle or oceanic crust or mantle. Bucher-Nurminen (1991) interpreted peridotites of the Scandinavian Caledonides interleaved with predominantly continental-derived metamorphic rocks, including quartzite and quartz-rich mica schist, as fragmented subcontinental mantle material. However, in eastern Alaska and the Yukon, the ultramafic rocks are generally associated with marine sedimentary, as well as other sedimentary rocks that are partly derived from juvenile island arcs. The sediments were most likely deposited in an oceanic back-arc basin, so that the ultramafic rocks associated with them probably represent fragments of oceanic crust or mantle.

CONCLUSIONS

Inter-foliation with mica schist, similar ductile fabrics in schist and ultramafic rocks, lack of internal zoning, and lack of intrusive relations with gabbro, suggest that the serpentinites of the KMA are Alpine-type ultramafic rocks. Though oxygen isotope studies cannot unequivocally prove ophiolitic origin of the olivine serpentinites, they record $\delta^{18}O$ values that are comparable to known ophiolitic serpentinites. It is concluded that the ultramafic rocks of the KMA represent remnants of an oceanic crust associated with a Mesozoic back-arc basin onto which the sediments of the proto-KMA were deposited. The basin collapsed in the Late Mesozoic. Fragments of it, the ultramafic and metasedimentary rocks of the KMA, were accreted onto the overriding North American plate. During accretion, the metasedimentary rocks and the serpentinites were strongly deformed and tectonically interleaved prior to the Early Tertiary intrusion of the Ruby Range Batholith. The KMA and similar metamorphic assemblages containing Alpine-type ultramafic rocks are located along the Denali Fault zone. This suggests that the Denali Fault zone is the location of a major suture zone or terrane boundary resulting from the collapse of a large oceanic basin or back-arc basin, which extended from central Alaska to southern Yukon.

ACKNOWLEDGEMENTS

I am indebted to Philippe Erdmer who introduced me to the Yukon and its geology. This paper is the result of a Ph.D. thesis under his supervision. Discussions with Karlis Muehlenbachs of the University of Alberta helped to clarify the oxygen isotope data. Financial support was provided by grants to the author from the University of Alberta, the Canadian Circumpolar Institute (CCI) and the Geological Society of America, and through Philippe Erdmer by NSERC. The logistical support of the Yukon Geology Program during the initial field work in 1993-95 and helicopter sharing is gratefully acknowledged. Rob Brown, Kevin Brett and Brys Francis provided excellent field assistance. Kluane Helicopters of Haines Junction is thanked for safe and on-time services. Thanks to Paul Bons and Sandra Piazolo for critical reviews of the first draft. Moa Zahid and Jacques Morel provided the French translation.

REFERENCES

Berg, H.C. and Jones, D.L., 1974. Ophiolite in southeastern Alaska. Geological Society of America, abstracts with programs, vol. 6, p. 144.

Berthé, D., Choukroune, P. and Jegouzo, P., 1979. Orthogneiss, mylonite and non coaxial deformation of granites: The example of the South Armerican shear zone. Journal of Structural Geology, vol. 1, p. 31- 42.

Bucher-Nurminen, K., 1991. Mantle fragments in the Scandinavian Caledonides. Tectonophysics, vol. 190, p. 173-192.

Deer, W.A., Howie, R.A. and Zussman, J., 1992. An introduction to the rock-forming minerals, 2nd edition. Longman, 696 p.

Dodds, C.J. and Campbell, R.B., 1992. Geology of NE Yakutat (114O) and Tatshenshini River (114P) map areas, British Columbia. Geological Survey of Canada, Open File maps 2191, 1:250 000 scale.

Engebretson, D.C., Kelley, K.P., Burmester, R.F., Russell, R. and Blake, M.C., 1995. North American plate interactions revisited. Geological Association of Canada/Mineralogical Association of Canada, abstract with programs, vol. 20, p. A 28.

Erdmer, P., 1990. Studies of the Kluane and Nisling assemblages in Kluane and Dezadeash map areas, Yukon. Geological Survey of Canada, Paper 90-1E, p. 107-111.

Geological Survey of Canada, 1967. Aeromagnetic map, Burwash Landing, Yukon Territory. Geophysical Paper 4313, 1:63 360 scale.

Geological Survey of Canada, 1968. Aeromagnetic map, Gladstone Creek, Yukon Territory. Geophysical Paper 4327, 1:63 360 scale.

Hall, A., 1987. Igneous petrology. Longman, Harlow, 573 p.

Himmelberg, G.R., Brew, D.A. and Ford, A.B., 1985. Ultramafic bodies in the Coast Plutonic-metamorphic Complex near Skagway, southeastern Alaska. *In:* Accomplishments in Alaska 1984, United States Geological Survey, Circular 967, p. 92-93.

Hoffman, S.E., Wilson, M. and Stakes, D.S., 1986. Inferred oxygen isotope profile of Archean oceanic crust, Onverdacht Group, South Africa. Nature, vol. 321, p. 55-58.

Johnston, S.T. and Erdmer, P., 1995. Magmatic flow and emplacement foliations in the Early Jurassic Aishihik Batholith, southwest Yukon. *In:* Jurassic magmatism and tectonics of the North American Cordillera, D.M. Miller and C. Busby (eds.), Geological Society of America, Special Paper 299, p. 65-82.

Jones, D.L., Silberling, N.J., Csejtey, Jr., B., Nelson, W.H. and Blome, C.D., 1980. Age and structural significance of ophiolite and adjoining rocks in the upper Chulitna District, south-central Alaska. United States Geological Survey, Professional Paper 1121-A, 21 p.

Karig, D.E. and Sharman, G.F., 1975. Subduction and accretion in trenches. Bulletin of the Geological Society of America, vol. 86, p. 377-389.

Kindle, E.D., 1952. Dezadeash map-area, Yukon Territory. Geological Survey of Canada, Memoir 268, 68 p.

Kyser, T.K., 1986. Stable isotope variations in the mantle. *In:* Stable isotopes in high temperature geological processes, J.W. Valley, H.P. Taylor, Jr. and J.R. O'Nions (eds.), Mineralogical Society of America, Reviews in Mineralogy, vol. 16, p. 141-164.

McConnell, R.G., 1905. The Kluane Mining District. Geological Survey of Canada, Annual Report 16, p. 1A-18A.

Mezger, J.E., 1995. The Kluane Metamorphic Assemblage, SW Yukon - first steps towards developing a tectonic model. Cordilleran Tectonics Workshop Meeting 1995, Ottawa-Carleton Geoscience Centre, February 10-12, 1995, p. 11.

Mezger, J.E., 1996. The Kluane Metamorphic Assemblage, SW Yukon - an accretionary wedge of backarc basin affinity. Geological Association of Canada/Mineralogical Association of Canada, abstract with programs, vol. 21, p. A 65.

Mezger, J.E., 1997. Tectonometamorphic evolution of the Kluane metamorphic assemblage, SW Yukon: Evidence for Late Cretaceous eastward subduction of oceanic crust underneath North America. Unpublished Ph. D. thesis, University of Alberta, Edmonton, Alberta, 306 p.

Mezger, J.E. and Creaser, R.A., 1996. Backarc basin setting of the Kluane Metamorphic Assemblage and sinistral strike-slip along a proto-Denali Fault: Evidence from isotope and microtectonic studies in the SW Yukon. Geological Society of America, Abstract with Programs, vol. 28 (7), p. A 312.

Muehlenbachs, K., 1986. Alteration of the oceanic crust and the ^{18}O history of seawater. *In:* Stable isotopes in high temperature geological processes, J.W. Valley, H.P. Taylor, Jr. and J.R. O'Nions (eds.), Mineralogical Society of America, Reviews in Mineralogy, vol. 16, p. 425-444.

Muller, J.E., 1967. Kluane Lake map-area, Yukon Territory (115G, 115F E1/2). Geological Survey of Canada, Memoir 340, 137 p.

Norrell, G.T., Teixell, A. and Harper, G.D., 1989. Microstructure of serpentine mylonites from the Josephine ophiolite and serpentinization in retrogressive shear zones, California. Bulletin of the Geological Society of America, vol. 101, p. 673-682.

Nokleberg, W.J., Jones, D.L. and Silberling, N.J., 1985. Origin and tectonic evolution of the Maclaren and Wrangellia terranes, eastern Alaska, Alaska. Bulletin of the Geological Society of America, vol. 96, p. 1251-1270.

Passchier, C.W. and Trouw, R.A.J., 1996. Microtectonics. Springer Verlag, Berlin, 289 p.

Patton, W.W., Box, S.E. and Grybeck, D.J., 1994. Ophiolites and other mafic-ultramafic complexes in Alaska. *In:* The geology of Alaska, G. Plafker and H.C. Berg (eds.), Geological Society of America, Boulder, Colorado, vol. G-1, p. 671-686.

Platt, J.P., 1986. Dynamics of orogenic wedges and uplift of high-pressure metamorphic rocks. Bulletin of the Geological Society of America, vol. 97, p. 1037-1053.

Sheppard, S.M.F., 1986. Characterization and isotopic variations in natural waters. *In:* Stable isotopes in high temperature geological processes, J.W. Valley, H.P. Taylor, Jr. and J.R. O'Nions (eds.), Mineralogical Society of America, Reviews in Mineralogy, vol. 16, p. 227-272.

Taylor, H.P., Jr., 1967. The zoned ultramafic complexes of southeastern Alaska. *In:* Ultramafic and related rocks, P.J. Wyllie (ed.), John Wiley and Sons, New York, p. 96-116.

Taylor, H.P. and Sheppard, S.M.F., 1986. Igneous rocks: I. Process of isotopic fractionation and isotope systematics. *In:* Stable isotopes in high temperature geological processes, J.W. Valley, H.P. Taylor, Jr. and J.R. O'Nions (eds.), Mineralogical Society of America, Reviews in Mineralogy, vol. 16, p. 227-272.

Tempelman-Kluit, D.J., 1974. Reconaissance geology of Aishihik Lake, Snag and part of Stewart River map-areas, west-central Yukon (115A, 115F, 115G and 115K). Geological Survey of Canada, Paper 73-41, 97 p.

Wenner, D.B. and Taylor, Jr., H.P., 1973. Oxygen and hydrogen isotope studies of the serpentinization of ultramafic rocks in oceanic environments and continental ophiolite complexes. American Journal of Science, vol. 273, p. 207-239.

Wheeler, J.O. and McFeely, P., 1991. Tectonic assemblage map of the Canadian Cordillera. Geological Survey of Canada, Map 1712A, 1:2 000 000 scale.