‘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

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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 septentroniale 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 américaine au Crétacé supérieur. Les analyses des isotopes d’oxygène ont enregistrées des valeurs similaires aux serpentinites ophiolitiques connues. Les roches ultramafiques sont interprétées comme 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.
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 terrace boundaries. Slices of serpentine, 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 Wrangelia 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 graphic 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 shallow 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, underlaying approximately 3000 km² 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, chrome 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 chrome, 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.
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 Sn+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 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 microolithons, display web-like alteration to chromite and magnetite. Scale bar: 2 mm. Crossed polarized light (XPL).

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 \( S_{m3} \) 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 boudined, 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 δ18O 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>
<thead>
<tr>
<th>Sample #</th>
<th>Location</th>
<th>Field relationship</th>
<th>Mineral paragenesis$^1$ (vol. %)</th>
<th>Yield (μmoles/mg)</th>
<th>$delta^{18}$O SMOW$^2$ (%o)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JM 93-2</td>
<td>eastern shore of Talbot Arm, Kluane Lake 138°41'40&quot; W, 61°22'45&quot; N</td>
<td>eastern margin contact not exposed</td>
<td>Ol, Srp, Mag, Chr</td>
<td>8.46</td>
<td>6.1</td>
</tr>
<tr>
<td>JM 93-44</td>
<td>western shore of Talbot Arm, Kluane Lake 138°44'40&quot; W, 61°23'10&quot; N</td>
<td>northern contact with Ruby Range Batholith</td>
<td>Ol (75), Srp (20), Mag, Chr (5)</td>
<td>10.09 (repeat) 9.88 (repeat)</td>
<td>-1.1</td>
</tr>
<tr>
<td>JM 93-190b</td>
<td>southern slope of hill, north of Doghead Point 138°49'40&quot; W, 61°23'05&quot; N</td>
<td>central part of lens</td>
<td>Srp (70), Ol (10-15), Tlc (10), Idd (2-3), Pn, Chr, Mag (5)</td>
<td>13.65</td>
<td>6.7</td>
</tr>
<tr>
<td>JM 93-185</td>
<td>ridge west of Swanson Creek, Ruby Range 138°23'50&quot; W, 61°15'20&quot; N</td>
<td>central part of lens</td>
<td>Srp (65), Ol (30), Mag, Chr (5), Cc</td>
<td>11.74</td>
<td>6.5</td>
</tr>
<tr>
<td>PE 89-55b</td>
<td>ridge east of Snyder Creek, Ruby Range 138°03'00&quot; W, 61°12'42&quot; N</td>
<td>small outcrop</td>
<td>Tlc (50), Srp (35) Ol (15), Mag, Chr, C</td>
<td>12.08</td>
<td>11.2</td>
</tr>
<tr>
<td>JM 94-185a</td>
<td>plateau east of Ruby Creek, Ruby Range 137°50'42&quot; W, 61°10'42&quot; N</td>
<td>small outcrop, in contact with mica schist</td>
<td>Tlc (50), Ol (25) Srp (20), Mag, Chr, Cr-En (5)</td>
<td>11.4</td>
<td>11.8</td>
</tr>
</tbody>
</table>

$^1$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 δ18O 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 δ18O 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 δ18O 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 δ18O DATA**

The δ18O 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 δ18O metamorphic fluids that were derived from pelitic sediments with δ18O values of 13-20‰ (Taylor and Shepard, 1986). In all cases, a significantly large water/rock ratio would have changed the δ18O values. To distinguish the source of serpentinization, further oxygen isotope studies of individual minerals and also δD (Deuterium) studies are necessary.

The high δ18O 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 δ18O values of pelitic sediments range from 13‰ to 20‰, and metamorphic fluids derived from dehydration of metasedimentary rocks during metamorphism record 3‰ at 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 δ18O and can have δ18O values of -20‰ and less (Shepard, 1986). The negative δ18O 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 ANDEMPLACEMENT 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 Superterranne (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-folating 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 δ18O 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.

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