AGE CONSTRAINTS FOR EMPLACEMENT OF THE NORTHERN CACHE CREEK TERRANE AND IMPLICATIONS OF BLUESCHIST METAMORPHISM

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KEYWORDS: regional geology, Cache Creek terrane, blueschist, isotope geochronology, biogeochronology, fossil, tectonics, French Range Formation, Kutcho Formation, massive sulphide, structure

INTRODUCTION

Ophiolitic and accretionary units and associated blueschists of the Cache Creek terrane constitute the most complete evidence of a coherent subduction zone within the Canadian Cordillera. The rocks occupy a central position in the Intermontane Superterrane, a complex of arcs that includes most of the accreted crust in British Columbia (Figure 1). The Cache Creek terrane contains exotic fossil fauna interpreted to have originated in the equatorial Tethyan realm. In contrast, coeval rocks in adjacent terranes contain fossils endemic to ancestral North America. How this arrangement of terranes can be explained has been the focus of much speculation (see Mihalynuk *et al.*, 1994). It is clear that the Cache Creek terrane plays a central role. Data constraining its history bear on the geodynamic evolution of the Cordillera as a whole.

One of the most complete crustal sections is preserved in the part of the northern Cache Creek terrane known as the Atlin complex (Figure 1; Mihalynuk, 1999). Current understanding of the regional stratigraphy and fossil age range derives from the work of Monger (1969, 1975). Northern parts of the Atlin complex have been mapped by Hart and Radloff (1990), Hart (1997), and Gordey and Stevens (1994). Studies with a topical focus include those on the origin of enclosed ultramafic rocks (Terry, 1977), their geochemical character, and their recognition as mantle tectonites (Ash, 1994). Isotopic characterization and detailed mapping in the northern Atlin complex by Jackson (1992) revealed that sandstones were derived from the Stikine terrane. Microfossil biostratigraphic studies by Cordey *et al.* (1991, and F. Cordey unpublished data, 1990) showed that the radiolarian-bearing strata range in age from Permian to Early Jurassic. In contrast, the southern portion of the Atlin complex has been less studied. Recent studies include a regional geological compilation by Gabrielse (1998) and detailed mapping of volcanic rocks in the French Ranges near Dease Lake by Mihalynuk and Cordey (1997). Data reported here complement work by Mihalynuk and Cordey (1997) in the French Ranges and Teslin Lake area, and by Mihalynuk *et al.* (1995a,b) in the Tulsequah area.

FRENCH RANGE

Regional units in the French Range were established by Gabrielse (1994) and Monger (1969). Units include Permian mafic volcanic flows and tuff (PFRv) and undifferentiated tuff

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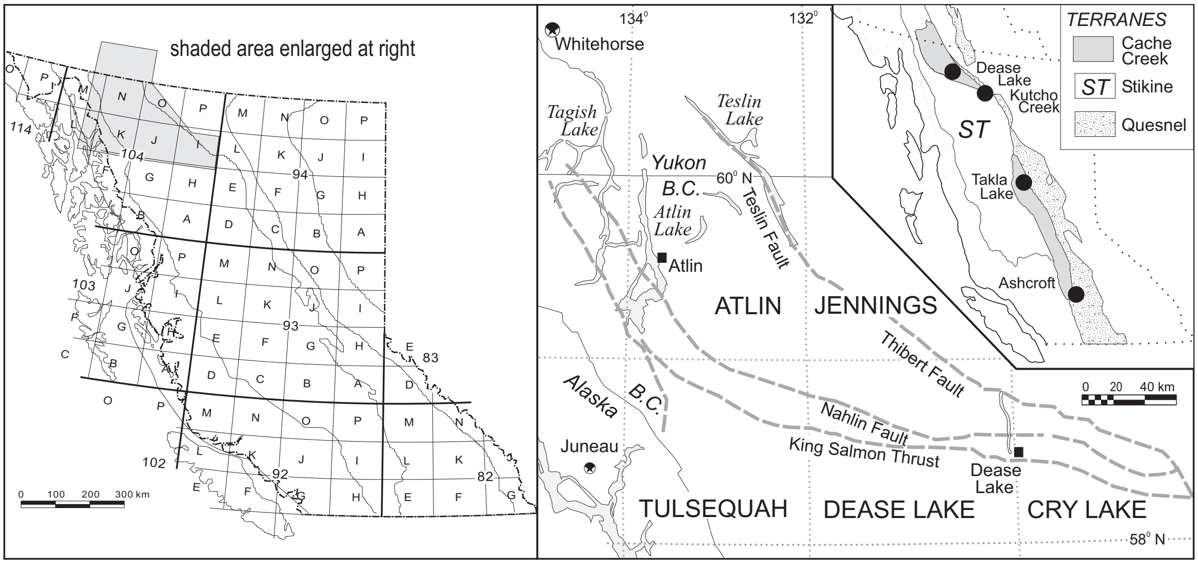


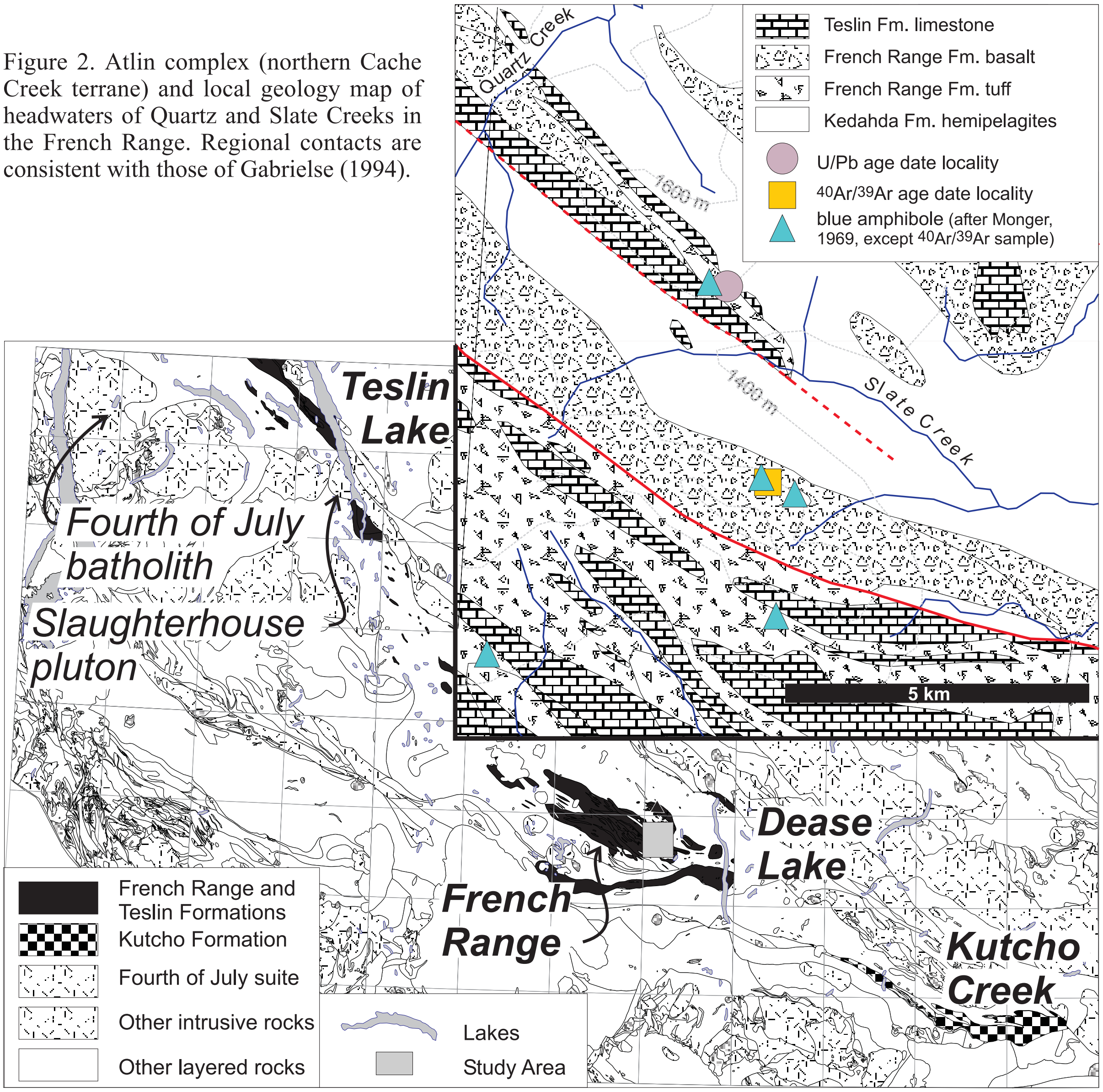
Figure 1. Study areas within and adjacent to the Northern Cache Creek Terrane, named here the Atlin complex. The inset shows the extent of the Cache Creek Terrane and adjacent Stikine (ST) and Quesnel (QN) terranes which together comprise most of the Intermontane Superterrane. Also shown are sites within the Cache Creek terrane where felsic volcanic rocks have been isotopically dated.

(PFRt) of the French Range Formation, Permian limestone of the Teslin Formation (PT) and stratigraphically and structurally underlying hemipelagic rocks of the Kedahda Formation (MTK, Figure 2). Rocks included regionally in the Kedahda Formation range from Carboniferous to Triassic in age (Gabrielse, 1994). Near the British Columbia - Yukon boundary similar rocks range up to Early Jurassic in age (Jackson, 1992). Over a small area studied in the French Range, radiolarians in the Kedahda formation are Guadalupian (Lower Late Permian) in age. Fusulinids extracted from the Teslin Formation are Leonardian to Guadalupian in age (Monger, 1969, uses the North American stage names *cf*. Figure 8). Detailed geological mapping in the French Range revealed the presence of tholeiitic rhyodacite, correlated on the basis of geochemistry and apparent stratigraphic age with the Kutcho Formation (Mihalynuk and Cordey, 1997). Such a correlation is economically significant because the Kutcho Formation includes cogenetic volcanogenic massive sulphide accumulations. U-Pb isotopic dating of the rhyodacite showed it to be Early Permian (*see* Isotopic Dating below) and significantly older than the Kutcho Formation, although within the range of age determinations (Table 1) from rocks belonging to a belt of felsic volcanic rocks deposited on the Cache Creek terrane that extends to Ashcroft in southern British Columbia (Figure 1, *see* Table 1 for references).

Basalt tuff, massive fine-grained flow and pillowed flow units are ridge-forming strata at the headwaters of Slate and Quartz Creeks. Individual units are typically 1m to 15m thick. Accumulations of basalt such as on the east end of the Slate Creek ridge attain thicknesses of several hundred metres. Basalt flow rocks contain sparse amygdales of calcite, chlorite, and, outside the area detailed in Figure 2, stilpnomelane. Basalt to trachyandesite lapilli tuff is locally interlayered with flow units. Basalt tuff is mint green, locally with up to 20% highly vesicular clasts containing coarse bladed plagioclase. Trachyandesite tuff is generally red and displays a weak to moderate foliation. It locally has gradational contacts with limestone or carbonate debris flow units. Some tuffaceous layers appears reworked and display vague ripple cross-stratification.

Rhyodacite tuff contains fine embayed quartz phenocrysts. Clasts display a eutaxitic texture in outcrop (Photo 1). Alteration and blueschist metamorphism are inferred to have destroyed any relict pumice outlines that may have been present, and it is not possible to demonstrate that the banded and flattened nature of volcanic clasts is due to welding rather than to compaction following lithification.

Figure 2. Atlin complex (northern Cache Creek terrane) and local geology map of headwaters of Quartz and Slate Creeks in the French Range. Regional contacts are consistent with those of Gabrielse (1994).



Volumetrically minor but conspicuous ferruginous chert layers up to 0.5 metres thick occur throughout the tuff succession. A red ribbon chert layer about 8 metres thick containing abundant recrystallized radiolarians crops out at two localities within the mafic succession in the middle of the ridge southwest of Slate Creek. Argillaceous partings in the chert are blue as a result of abundant included fine-grained, blue amphibole (Photo 2; Figure 3). Samples of this unit dated by $^{40}Ar/^{39}Ar$ technique return a cooling age of about 173 Ma (*see* Isotopic Dating below).

Photo 1. An outcrop of rhyodacitic lapilli tuff that has eutaxitic textures.

Table 1. Comparison of age data from the Kutcho Fm., Sitlika Assemblage and French Range rhyodacite.

Sample No.	Lithology	Location	Age	Reference
Oldest to youngest				
MMI96-17-7	French Rg. Rhyodacite	Dease Lake	263.1 +1-1.4	This report
"locality C"	metadacite	Taseko Lakes	259±2	Read, 1993
SA-GC-01	Mount Bodine rhyolite	Takla Lake	258+10-1	Childe, 1997
see reference	granodiorite	Taseko Lakes	258±5	Friedman and Van der Heyden, 1992)
"locality B"	leucoquartz monzonite	Taseko Lakes	254±1.2	Read, 1993
97PSC97-22-2	Driver Lake rhyolite	Takla Lake	248.4 ±0.3	Schiarizza et al., 1999
KC-GC-04	footwall rhyolite	Cry Lake	246 +7-5	Childe and Thompson, 1997
KC-GC-03	quartz-feldspar porphyry	Cry Lake	244 ±6	Childe and Thompson, 1997
97PSC97-19-3	Maclaing Ck. tonalite	Takla Lake	243 ±3	Schiarizza et al., 1999
96A-7	tonalite	Ashcroft	242+/-2	Childe et al., 1997
KC-GC-01	hangingwall rhyolite	Cry Lake	242 ±1	Childe and Thompson, 1997
PSC95-16-4	Diver Lake tonalite	Takla Lake	241+/-1	Childe, 1997

Teslin Formation limestone occurs in generally poorly bedded sections that are 400m thick or less and have a combined strike length of at least 5 kilometres. Poorly-bedded sections weather white, buff or pink and are light to dark grey on fresh surfaces. Where sections are well bedded they tend to be dark grey to black with individual beds generally 3 to 15 cm thick. Interbeds of black or red chert and green or maroon ash tuff are common.

Kedahda Formation hemipelagites are dominated by grey-green to tan ribbon chert. In contrast to structurally and stratigraphically higher units, these rocks are strongly disrupted. High amplitude chevron folds (Photo 3) pass downward into strongly transposed layering in quartz-mica phyllite (Photo 4). This structural disharmony may be the locus of a regionally extensive, low to moderate-angle fault zone. Above the discontinuity, clear evidence of gradational contacts between Kedahda Formation chert and both French Range Formation volcanics and Teslin Formation limestone is present.

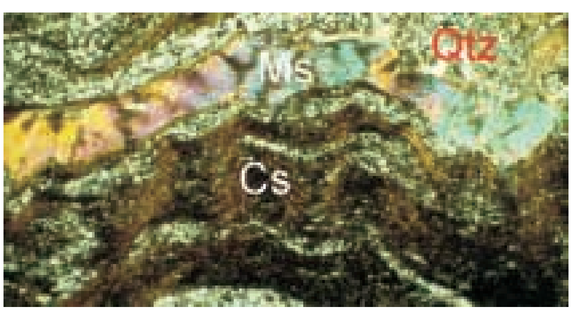


Photo 2. Photomicrograph of argillaceous partings in ribbon chert showing the development of muscovite (Ms) and crossite (Cs) layers with polygonal quartz (Qtz). A weak crenulation folds, but does not recrystallize, the authigenic minerals. The sample is number MMI97-17-4, viewed under cross polarized light. Long dimension of the photograph represents 2.5 mm.

TESLIN LAKE AREA

The French Range, Teslin, and Kedahda formations are well exposed west of Teslin Lake where they display similar deformation and contact relationships as in the French Range. Within the broad valley occupied by the southern part of Teslin Lake, the southeast extension of this belt of rocks is mostly covered by thick glacial and alluvial deposits. It is apparently cut (Aitken, 1959) by an undeformed to moderately-foliated quartz diorite body, named the Slaughterhouse pluton (Mihalynuk *et al*., 1998). Fabric within the pluton is parallel to Teslin Lake and to the Teslin fault, interpreted to underlie the lake. The pluton fabric is inferred to be related to motion on the Teslin fault. As suggested by the contact relationships shown on the map of Aitken (1959), the quartz diorite body is neither strongly elongate nor infolded with the sedimentary succession, and post-dates thrust emplacement of the Cache Creek terrane. The pluton has been dated in two localities by the

U-Pb technique with a Middle Jurassic age indicated (*see* Isotopic Dating below).

TULSEQUAH AREA

Dominantly arc-derived clastic strata of the Whitehorse Trough border the entire 450 kilometre long southwest margin of the Atlin complex, yet they offer no sedimentological indication of its proximity (Johannson, 1994), except in the youngest Laberge Group strata in the Tulsequah area. Thorstad and Gabrielse (1986) reported clasts of the Kutcho and Sinwa formations in the Cry Lake area, but correlation between these units and the Cache Creek Terrane *sensu stricto* is equivocal.

Whitehorse Trough strata in the Tulsequah area are dominated by the conglomerate facies of the Takwahoni Formation (Figures 4 and 5). Macrofossils collected mainly from fine-grained interbeds indicate an age range of Pliensbachian to Bajocian (Table 2, Figure 4). Successively younger conglomerate units contain volcanic, plutonic, and metamorphic clasts, in ascending order, indicative of progressive arc exhumation (Figure 4). Paleoflow directions are dominantly eastward, consistent with location of the most probable source terrain to the west. A marked change in both paleoflow and provenance occurred in Early Bajocian time. West-directed currents delivered chert granules from the Atlin Complex. Numerous well preserved specimens of the ammonites *Chondroceras* cf. *allani* and *Chondroceras defontii*? from fine clastic units interbedded with chert granule conglomerate indicate an age of latest Early Bajocian (Table 2).

Radiolarians in chert clasts (Table 3) range from Early Permian through Lower Jurassic in age, which overlaps with the ages of all but the oldest (Carboniferous) chert of the Atlin Complex. A minimum age of the chert source is based on the radiolarian species *Praeconocaryomma* cf. *immodica* Pessagno and Poisson which ranges from Pliensbachian to Toarcian in age. Thus, in Early Bajocian time, all but the lowest levels of the Kedahda Formation appear to have been tectonically exhumed.

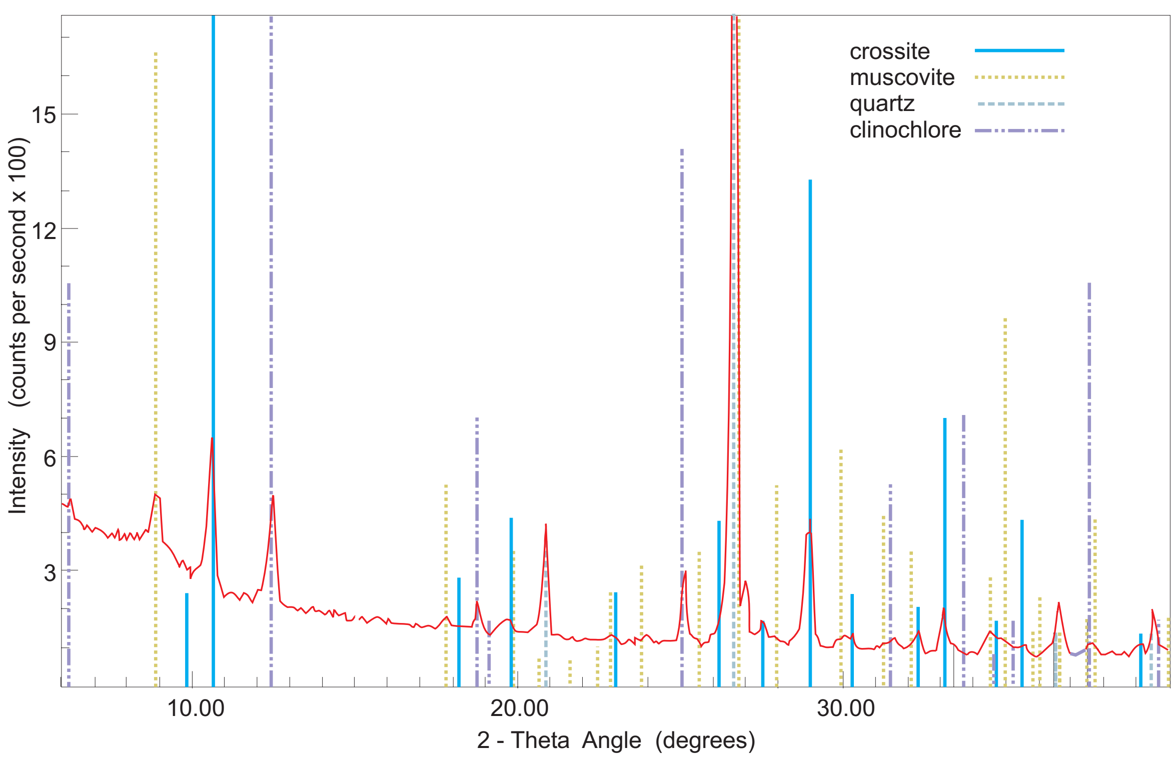


Figure 3. Interpreted X-ray diffraction spectrum from blueschist sample MMI96-17-4 showing that the mineralogy is dominated by quartz, muscovite, crossite and ferroan clinochlore.

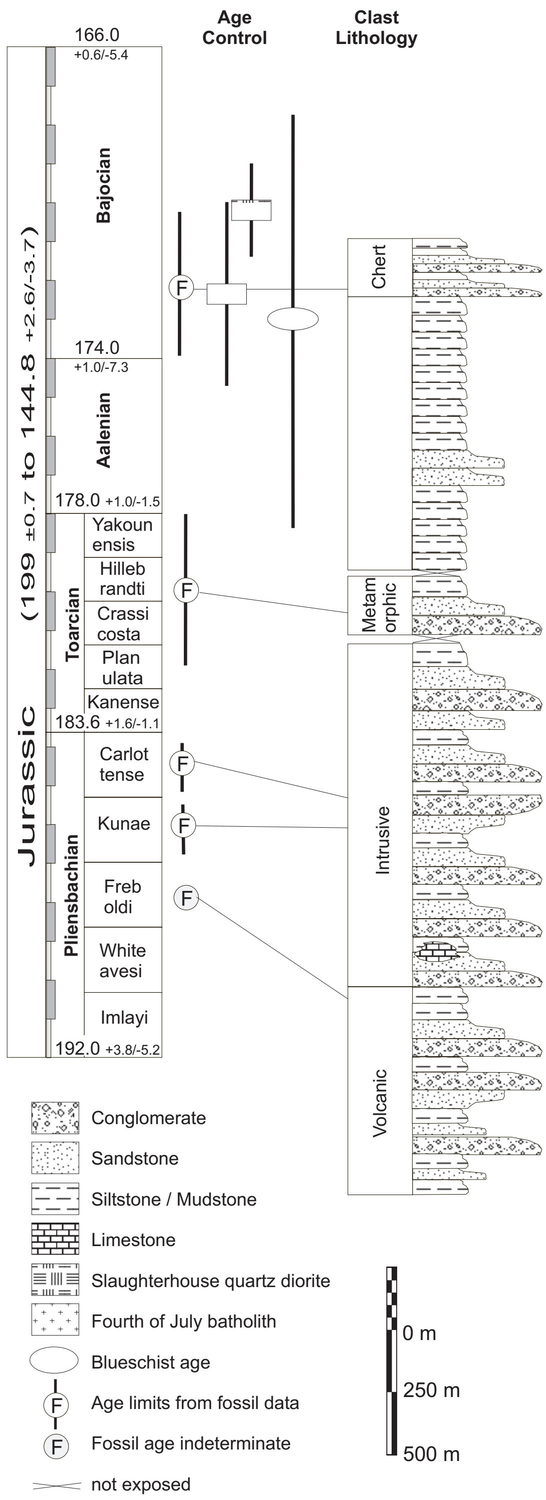


Figure 4. Laberge Group stratigraphy of the northeast Tulsequah area. Conglomerate composition records unroofing of the Stuhini arc. Youngest conglomerates are chert-rich and derived from the Cache Creek terrane. The fossil ages are calibrated against the revised Jurassic time scale of Pálfy *et al.* (1998).

Photo 3. High-amplitude chevron folds deform ribbon chert near the contact with overlying, relatively weakly deformed French Range Formation mafic volcanics.

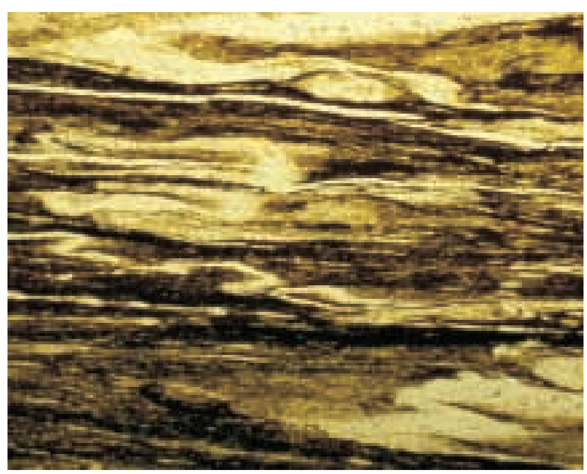


Photo 4. Photomicrograph of strongly transposed layering of deformed hemipelagite, now quartz-muscovite schist, located structurally below the rocks shown in Photo 3. Long dimension of the photograph represents 2.5 mm. Viewed in plane polarized light.

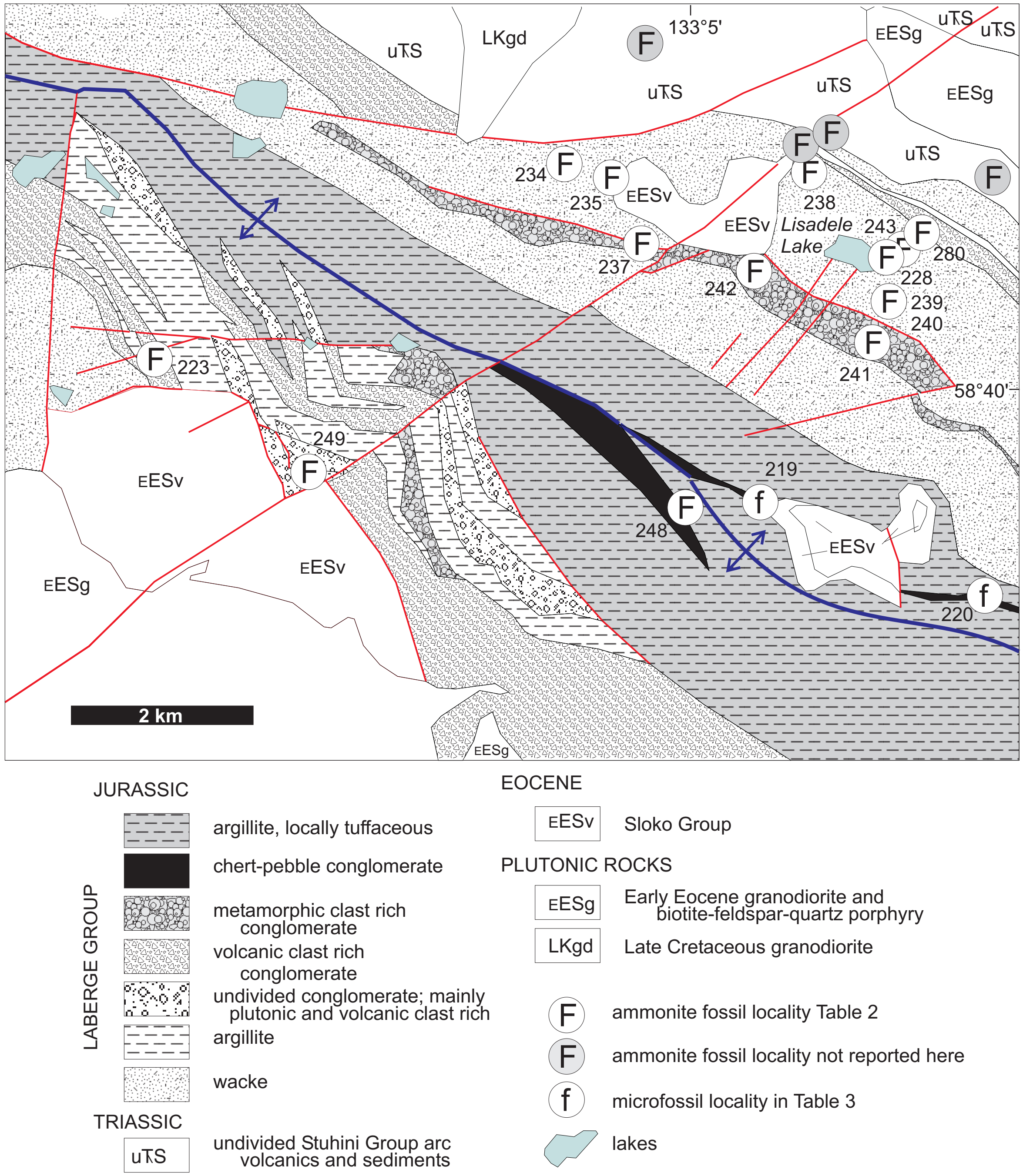


Figure 5. Simplified regional geology of the Lisadele Lake area, 104K/11NE, after Mihalynuk *et al.*, 1995b.

Table 2. Ammonite age determinations from the central Tulsequah area.

Field Number	Location	Fauna	Age
GJ094-41-8 GSC C208234	Bug Pk.	*Protogrammoceras paltum*, *Fieldingiceras fieldingii*?, *Lioceratoides* sp., *Arieticeras*?,sp. Comments: Numerous specimens of complete and fragmentary ammonites. Poorly- to well-preserved	Upper Pliensbachian -Carlottense Zone
GJ094-41-9 GSC C208235	Bug Pk.	*Dactylioceras kanense*?, *Dactylioceras* spp., *Taffertia tafferentis?, Protogrammoceras paltum*?, *Ovaticeras*? Sp. Comments: ten specimens of poorly- to well-preserved whole and fragmentary ammonites.	Lower Toarcian - base? of Kanense Zone
GJ094-4 1 -10 GSC C208237	Bug Pk.	Ammonite gen. et sp. indet. Comments: one large moderately preserved ammonite fragment. Collected from talus 300 m. SE. of GJ094-41-9 (L. Toarcian) from similar stratigraphic level.	Lower? Toarcian?
GJ094-42-5 GSC C208238	Lisadele Lk.	*Arieticeras* sp., *Fuciniceras*? sp., *Protogrammoceras*? sp. Comments: five complete and fragmentary ammonites. Poorly- to well-preserved.	Upper Pliensbachian
GJ094-42-12	Lisadele Lk.	*Protogrammoceras paltum*? Comments: two moderately- to well-preserved fragments.	Upper Pliensbachian probable Carlottense Zone
GJ094-43-1 GSC C208239	Lisadele Lk.	*Dactylioceras* sp., *Hildaites* cf. *murleyi* Comments: four moderately-preserved ammonite fragments.	Lower Toarcian -Kanense Zone
GJ094-43-1-2 GSC C208240	Lisadele Lk.	Ammonite gen. et sp. indet. Comments: seven poorly- to moderately-preserved whole and fragmentary ammonites. Collected - 80 m. upsection from GJ094-43 I (Lower Toarcian).	Lower? Toarcian
GJ094-43-3 GSC C208241	750m S of Lisadele Lk.	*Pseudolioceras* cf. *lythense* Comments: two specimens: moderately-preserved whole ammonite + small fragment. Associated with 'metamorphic' conglomerate.	Middle Toarcian -possibly upper Planulata Zone
GJ094-43-6 GSC C208242	1km WSW of Lisadele Lk.	*Podogrosites latescens* Comments: one very well-preserved whole ammonite. Associated with 'metamorphic' conglomerate.	Upper Toarcian - Hilldebrandti Zone
GJ094-44-2 GSC C208243	Lisadele Lk.	*Tiltoniceras antiquum, Arieticeras* sp., *Lioceratoides* spp. (including *L grecoi?), Protogrammoceras paltum?, Lioceratoides (Pacificeras)* spp., *Fieldingiceras?* Sp. Comments: numerous specimens of complete and fragmentary ammonites. Poorly to well-preserved.	Upper Pliensbachian - Carlottense Zone
GJ094-44-3 *N/A*	Lisadele Lk.	*Leptaleoceras accuratum, Amaltheus stokesi?, Protogrammoceras* spp., *Fanninoceras?* sp. Comments: missing collection. Fauna listed are from field identifications and cannot be verified but are certainly Upper Pliensbachian (e.g. *Amaltheus sp.).*	Upper Pliensbachian - Kunae Zone
CHA94-46-1 GSC C211256		*Metaderoceras?* sp., *Weyla bodenbenderi?, Vaugonia* sp., belemnoid Comments: five moderately- to well-preserved fragmentary specimens (includes 2 ammonites).	Lower? Pliensbachian
MM194-19-8 GSC C211248	3km SSW of Lisadele Lk.	*Chondroceras* cf. *allani, Chondroceras defontii?,* Ammonite gen. et sp. indet. Comments: numerous specimens of moderately to well-preserved fragmentary ammonites. Associated with 'chert' conglomerate.	latest Lower Bajocian
MM194-20-6 GSC C211249	7km SW of Lisadele Lk.	*Tiltoniceras antiquum?,* Protogrammoceras spp., *Fontanelliceras* sp., *Lioceratoides* sp Comments: numerous specimens of complete and fragmentary ammonites. Poorly- to well-preserved.	Upper Pliensbachian - Carlottense Zone

Table 3. Radiolarian age determinations from chert granules in Bajocian conglomerate.

SAMPLE No	LOCATION	RADIOLARIAN TAXA	AGES REPRESENTED
MMI94-19-6 (clasts) GSC: C-208219	104K/11 Lisadele Lk.	*Canesium lentum* Blome, *Canoptum* sp., *Capnodoce* sp. - *Capnuchosphaera* sp., Corum cf. *perfectum* Blome, *Pachus* sp., *Pseudoeucyrds(?)* sp., *Praesarla* sp., *Praeconocaryomma* cf. immodica Pessagno and Poisson *Pseudostylosphaera* cf. acrior Bragin, *Xipha striata* Blome, *Yeharaia elegans* Nakaseko and Nishimura COMMENTS: preservation is good, geological unit is Laberge Group, lithology is chert pebble conglomerate. The association is a mixing of radiolarians of various ages extracted from several chert clasts and chips. Also contains sponge spicules (non diagnostic).	Middle Triassic (late Anisian-Ladinian) Middle Triassic (late Anisian-early Ladinian) Late Triassic (Carnian-middle Norian) Late Triassic (late Carnian- Middle Norian) Early Jurassic (Pliensbachian-Toarcian)
SSE94-48-9 (matrix) GSC: C-208220	104K/11	occurrence of radiolarians not established COMMENTS: geological unit is Laberge Group, lithology is chert pebble conglomerate	undetermined
SSE94-48-9 (clasts) GSC: C-208220	104K/11	*Canoptum* sp., *Capnodoce anapetes* De Wever, *Capnodoce* sp., *Oertlispongidae* -type rods, *Pachus* cf. *longinquus* Blome, *Plafkerium* sp., *Pseudoalbaillelia* aff. *scalprata* Holdsworth and Jones, *Pseudoeucyrds* (?) sp., *Praeconocaryomma* cf. *immodica* Pessagno and Poisson, *Pseudostylosphaera* cf. *acrior* Bragin, *Quinqueremis* sp. COMMENTS: preservation is moderate, geological unit is Laberge Group, lithology is chert pebble conglomerate. The association is a mixing of radiolarians of various ages extracted from several chert clasts and chips. Also contains sponge spicules (non diagnostic).	Early Permian (Sakmarian-Artinskian) Middle Triassic (late Anisian-Ladinian) Late Triassic (Late Carnian-Middle Norian) Early Jurassic (Pliensbachian-Toarcian)
SVA94-2-4 (matrix) GSC: C-208221	104K/11	occurrence of radiolarians not established COMMENTS: geological unit is Laberge Group, lithology is chert pebble conglomerate. Also contains arge sphaeromorphs.	undetermined
SVA94-2-4 (clasts) GSC: C-208221	104K/11	*?Capnodoce* sp., *?Kalherosphaera* sp., *?Plafkerium* sp., *?Sarla* sp., *Thurstonia* sp. COMMENTS: preservation is poor, geological unit is Laberge Group, lithology is chert pebble conglomerate. The association is a mixing of radiolarians of various ages extracted from several chert clasts and chips.	possibly Middle or Late Triassic possibly Late Triassic (late Carnian-Middle Norian) Early Jurassic (Hettangian-Toarcian)

ISOTOPIC DATING

$^{40}Ar/^{39}Ar$ age for blueschist

Phyllitic to weakly schistose red and blue ribbon chert interlayered with volcanic rocks of the French Range Formation was selected for $^{40}Ar/^{39}Ar$ age determination. Red layers are ferruginous chert. Blue layers are metapelite composed of quartz, muscovite, crossite, and ferroan clinochlore (Figure 3). Layer-parallel schistosity in the metapelite is weakly crenulated, and both muscovite and crossite display undulatory extinction (Photo 2). The grain size of these minerals is 40 microns or less. A magnetic method of separation of minerals produced a non-magnetic split that was quartz rich, with resultantly low overall potassium content and relatively high uncertainty for the $^{40}Ar/^{36}Ar$ age obtained.

Analysis of a non-magnetic fraction of sample MMI96-17-4Bwr produced the spectrum shown in Figure 6. Four of ten heating steps accounted for more than 50% of the ^{39}Ar released and were combined to define a plateau date of **173.2 ±7.6** Ma (2σ), interpreted to be the closure age. Close correspondence between the plateau date, the integrated date of 175.2 ±9.2 Ma (2σ), and the correlation date of 171.1 ±9.6 Ma (2σ), as well as an $^{40}Ar/^{36}Ar$ ratio equal to atmospheric argon within error (325± 84) support the interpretation of a undisturbed closure notwithstanding the crenulation fabric of the blueschist minerals.

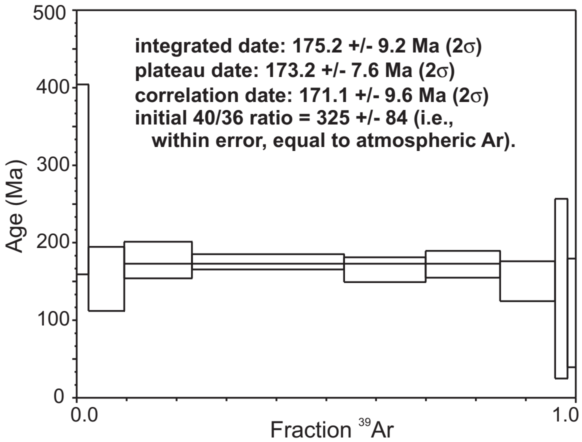


Figure 6. Step heating $^{40}Ar/^{39}Ar$ age spectrum for French Range blueschist sample MMI96-4Bwr.

U/Pb ages

Complete U-Pb age data for a sample of rhyodacite from the French Range Formation are reported here (Table 4). The data provide an absolute age for rocks of unequivocal Cache Creek Terrane affinity in the Atlin complex. A quartz porphyrytic rhyolite at the Kutcho deposit in the Cry Lake area was dated by Childe *et al.* (1997), but its relationship to the Cache Creek terrane is equivocal.

Zircon recovered from French Range Formation rhyodacite tuff (sample MMI96-17-7) is clear, colourless to pale pink, and of stubby to elongate prismatic morphology. Three analysed fractions are concordant at about 260 to 265 Ma. An age of **263.1+1.0/-1.4 Ma**, is based on the average $^{206}Pb/^{238}U$ results for concordant fractions A and C (Figure 7, Table 4).

Two samples of the Slaughterhouse quartz diorite from the south end of Teslin Lake were dated. As discussed above, this body appears to cut the deformed, inboard edge of the Cache Creek terrane. Preliminary U-Pb isotopic data yielded dates of **170.2±1.2 Ma** (Mihalynuk *et al.*, 1998) and **168 to 175 Ma**. These provisional dates confirm age constraints provided by the 171.7 ±3 Ma Fourth of July pluton, which cuts emplacement-related structures (Mihalynuk *et al.*, 1992) on the outboard edge of the Atlin complex.

AGE CONSTRAINTS: IMPLICATIONS AND DISCUSSION

Isotopic age data reported here have implications for the correlation of the French Range Formation, the position of the Guadalupian stage boundaries, the age of emplacement of the Atlin complex, and the mechanism of blueschist exhumation in the French Range.

Correlation of the French Range and Kutcho Creek formations was suggested by Mihalynuk and Cordey (1997) on the basis of: occurrence within the Cache Creek Terrane (*e.g.* Monger *et al.*, 1991), felsic volcanic character, comparative volcanic chemistry, and similar ages. However, absolute age constraints for Permian stage boundaries are poor (Harland *et al.*, 1990) and an isotopically determined protolith age for the French Range Formation was required to test the proposed correlation. The new U-Pb age data from the French Range rhyodacite show that the French Range rocks are significantly older than the Kutcho Formation (263 Ma versus 242 Ma; Table 1). Recent work on felsic strata of presumed Cache Creek terrane affinity revealed isotopic ages that range from 263 (the French Range Formation) to 241Ma to (the Kutcho Formation (see Table 1). The French Range rhyodacite is the oldest dated felsic unit, making it the earliest evidence of an intra-oceanic arc built upon oceanic crust of the Cache Creek terrane. If Kutcho Formation volcanic rocks represent part of the same arc, that arc was active for at least 20 m.y.. This possibility carries significant metallogenic and paleogeographic implications. The age of Cache Creek terrane

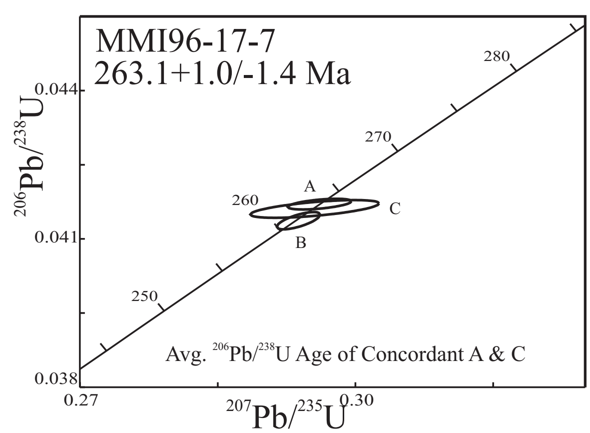


Figure 7. U-Pb concordia diagram for Sample MMI96-17-7.

Table 4. U/Pb isotopic data, French Range rhyodacite, sample MMI96-17-7.

Fraction[1]	Wt	U^2	Pb^{*3}	$^{206}Pb^4$	Pb^5	$^{208}Pb^6$	Isotopic ratios (1σ,%) [7]			Apparent ages (2σ,Ma) [7]	
	mg	ppm	ppm	^{204}Pb	pg	%	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
MMI96-17-7											
A c,N20,p	0.080	117	5	556	46	17.3	0.04170 (0.13)	0.2961 (0.59)	0.05150 (0.53)	263.4 (0.7)	263 (24)
B m,N20,p	0.088	110	5	1237	21	17.0	0.04137 (0.21)	0.2938 (0.40)	0.05151 (0.29)	261.3 (1.1)	264 (13/14)
C c,N20,p	0.142	85	4	194	178	16.0	0.04160 (0.21)	0.2956 (1.2)	0.05152 (1.1)	262.8 (1.1)	264 (48/50)

Notes: Analytical techniques are listed in Mortensen et al. (1995).

[1] Upper case letter fraction identifier; All zircon fractions air abraded; Grain size, intermediate dimension: cc 180 µm and 134µm, c 134µm and 104µm, m 104µm and 74µm, f 74µm. Magnetic codes:Franz magnetic separator sideslope at which grains are nonmagnetic (N) or Magnetic (M); e.g., N1 nonmagnetic at 1 ; Field strength for all fractions 1.8A; Front slope for all fractions 20 ; Grain character codes: b broken fragments, e elongate, eq equant, p prismatic, s stubby, t tabular, ti tips.

[2] U blank correction of 1-3pg ± 20%; U fractionation corrections were measured for each run with a double ^{233}U-^{235}U spike (about 0.005/amu).

[3]Radiogenic Pb

[4]Measured ratio corrected for spike and Pb fractionation of 0.0043/amu ± 20% (Daly collector) and 0.0012/amu ± 7% and laboratory blank Pb of 10 pg ± 20%. Laboratory blank Pb concentrations and isotopic compositions based on total procedural blanksanalysed throughout the duration of this study.

[5]Total common Pb in analysis based on blank isotopic composition

[6]Radiogenic Pb

[7]Corrected for blank Pb, U and common Pb. Common Pb corrections based on Stacey Kramers model (Stacey and Kramers, 1975) at the age of the rock or the $^{207}Pb/^{206}Pb$ age of the fraction.

rocks with potential for felsic volcanic associated massive sulphide deposits can now include Late Permian as well as earliest Triassic. Also, a geodynamic problem that may be resolved is the apparent narrow time constraint for transporting Cache Creek terrane strata from a Tethyan realm in the Late Permian to a north American realm in the Late Triassic. An intra-oceanic Permian-Triassic subduction zone, in addition to the one inferred beneath the Stikine and Quesnel terranes, would double the consumption of oceanic crust and increase the amount of conveyor belt-like transport of Cache Creek strata.

Stage boundaries of the Late Permian time scale are imprecise and currently under revision. Rhyodacite in the French Range appears to be over- and underlain by Early and Late Guadalupian limestone (Monger, 1969). Guadalupian age limits are not considered *sensu stricto* in the time scale of Harland *et al.* (1990), but the Kazanian stage, which encompasses most of the Guadalupian, is restricted to 254 +18.8/-7.2Ma and 250.5 +3.5/-13Ma (Figure 8; this is within a "permissive" range of 273 to 237.5 Ma). Recent, U-Pb age dating of a volcanic ash unit at the Permian-Triassic boundary has yielded an age of 251 Ma (Renne *et al.*, 1995; Bowring *et al.*, 1998); resolution of other Permian stage boundaries is lacking.

Our petrographic analysis of samples collected from both the Slate Creek and Quartz Creek ridges augments data of Monger (1969), who reported blueschist minerals in the area. Crossite, lawsonite, riebeckite, and?ferro-glaucophane occur over an area of at least 5 by 8 km. This areal distribution of min-

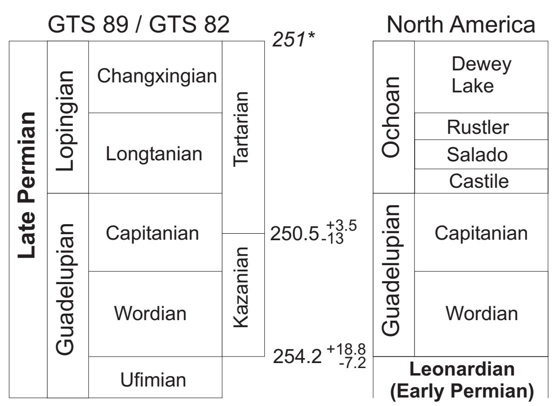


Figure 8. A comparison of International (Harland *et al.*, 1990) and North American stage boundaries for the Late Permian. A new Permian-Triassic boundary age from Renne *et al.* (1995, 251*Ma) is inconsistent with that of Harland and others.

eral assemblages indicates that a coherent crustal fragment several tens of square kilometres in size underwent blueschist facies metamorphism. Pressure and temperature conditions are shown in the shaded stability field of Figure 9.

The imprint of peak blueschist metamorphism is interpreted to have been recorded by the $^{40}Ar/^{39}Ar$ age spectra, and to be around 173 Ma. This is the youngest blueschist age in the Intermontane Superterrane (Erdmer *et al.,* 1998). On the basis of ages of crosscutting plutons, the blueschists must have been rapidly exhumed during emplacement of the Atlin complex along structures which ceased to be active by 172 to 170 Ma. Rapid exhumation at this time is recorded in sedimentation in the Whitehorse Trough with the introduction of chert pebbles derived from the Atlin complex. A late Early Bajocian age for this change is based on the occurrence of fossils in the Tulsequah area (see above, and Table 2). Revision of the Jurassic time scale (Pálfy *et al*., 1998) placed the Bajocian lower boundary at 174 +1.0/-7.3 (Figure 4). By interpolation, late Early Bajocian would be about 171Ma. The youngest chert clasts within the conglomerate are Pliensbachian to Toarcian (192 +3.8/-5.2Ma to 178 +1.0/-1.5Ma), similar in age to the youngest chert dated by radiolarians in the Atlin complex

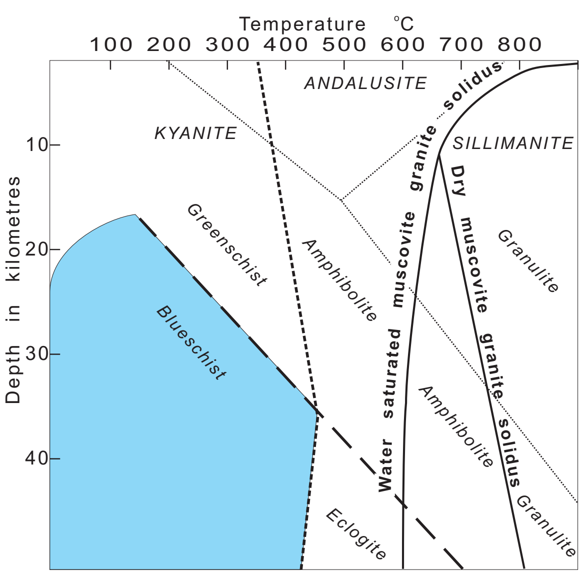


Figure 9. P-T stability limits for blueschists (shaded).

(Cordey *et al.*, 1991). The youngest chert-rich units display evidence of basin narrowing and instability. Wacke, rather than argillite, is interbedded with ribbon chert, and basin cannibalization is recorded by chert sharpstone conglomerate interbedded with chert layers. This time interval corresponds with a shift in either ocean current circulation or the paleolatitude of the Whitehorse Trough, as indicated by ammonite paleobiogeography. Late Pliensbachian ammonite faunas include the Tethyan taxa *Arieticeras, Leptaleoceras*, *Lioceratoides*, *Protogrammoceras*, *Fontanelliceras* and *Fieldingiceras*, and the Boreal taxa *Amaltheus* and *Tiltoniceras*, indicating a sub-Boreal paleogeography at this time (mixed faunal realm; Smith & Tipper, 1986). In contrast, Toarcian taxa are dominated by pandemic forms but include the Boreal species *Dactylioceras commune* and the high-latitude genus *Pseudolioceras*, indicating a Boreal paleogeography by Early to Middle Toarcian time.

Tectonic events causing changes in basin morphology and paleogeography recorded by changes in depositional and faunal character are speculative. However, the new data allow updating of the tectonic model presented by Mihalynuk *et al.* (1994). In that model, relicts of the Cache Creek ocean basin were consumed beneath two converging and oppositely polarized segments of the same subduction zone as a result of oroclinal bending of the arc complex (an updated model, which is constrained by the data presented here, is shown in Figure 10). As the basin narrowed, wacke derived from flanking arc segments clogged the trench and flowed toward the basin axis. Flexure of the old, colder oceanic crust formed horsts and grabens and widespread chert sharpstone deposition at fault scarps. Basin isolation in the Toarcian resulted in changes of ocean circulatory patterns, cooler water temperature, and a predominance of Boreal ammonite fauna, around 185Ma. Increasing flexure could not be sustained, and the oceanic crust ruptured in the Early Bajocian, at approximately 173Ma. (In north-central British Cloumbia, sediments of the Bowser Basin may preserve older evidence of incipient Cache Creek obduction. According to Ricketts *et al.* (1992) a condensed section of Aalenian shale records flexural subsidence due to earliest thrusting.) A rigid cratonic back-stop helped the inboard oceanic crustal fragment ride over hinterland rocks. Blueschists formed in the inboard subduction zone would have been rapidly exhumed by southwest-verging thrusts. The timing and sense of displacement of the structures inferred to have accommodated exhumation remain unclear but the process preserved the coherence of high-pressure metamorphosed rocks over areas of tens of square kilometres. The preserved coherent stratigraphy in the French Range rocks obviates the possibility of outcrop-scale structural dismembering commonly inferred for accretionary tectonic settings. Plutons cut emplacement fabrics at 172 and 170Ma. Clasts derived from chert of the exhumed oceanic crust invaded the Whitehorse Trough by about 171Ma.

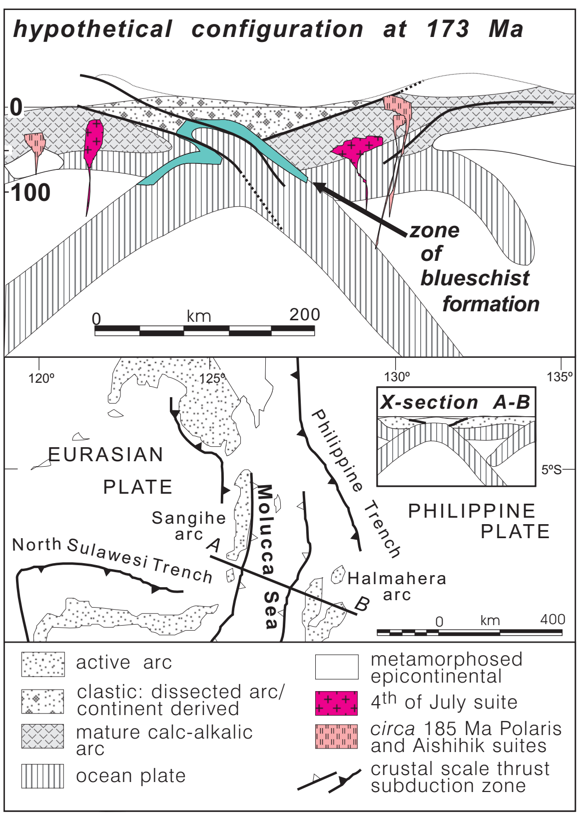


Figure 10. Model for blueschist emplacement at 173 Ma, modified after Mihalynuk *et al.* (1994). Top: a hypothetical cross section at about 173Ma shows rupture of doubly subducting Cache Creek oceanic crust. Bottom: a modern day analogue, the Molucca Sea region, in which a similar double subduction zone is interpreted.

REFERENCES CITED

Aitken, J.D., (1959): Atlin Map-area, British Columbia; *Geological Survey of Canada*, Memoir 307, 89 pages.

Ash, C.H. (1994): Origin and tectonic setting of ophiolitic ultramafic and related rocks in the Atlin Area, British Columbia (NTS 104N); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 94, 48 pages.

Bowring, S.A. and Erwin, D.H. (1998): A new look at evolutionary rates in deep time: uniting paleontology and high-precision geochronology; *GSA Today*, Volume 8, Number 9, pages 1-8.

Childe, F. and Thompson, J.F.H. (1997): Geological setting, U-Pb geochronology, and radiogenic characteristics of the Permo-Triassic Kutcho Assemblage, north-central British Columbia; *Canadian Journal of Earth Sciences*, Volume 34, pages 1310-1324.

Childe, F., Friedman, R.M., Mortensen, J.K. and Thompson, F.H. (1997): Evidence for Early Triassic felsic volcanism in the Ashcroft (92I) map area, British Columbia; *in* Geological Fieldwork 1996, *B.C. Ministry of Employment and Investment,* Paper 1997-1, pages 117-124.

Childe, F.C. (1997): U-Pb Geochronology , Geochemistry and Nd isotopic systematics of the Sitlika Assemblage, central British Columbia; *in* Geological Fieldwork 1996, *B.C. Ministry of Employment and Investment,* Paper 1997-1, pages 69-77.

Cordey, F. (1990): Comparative study of radiolarian faunas from the sedimentary basins of the Insular, Coast and Intermontane belts; unpublished manuscript, 57 pages.

Cordey, F., Gordey, S.P. and Orchard, M.J. (1991): New biostratigraphic data for the northern Cache Creek terrane, Teslin map area, southern Yukon; *in* Current Research, Part E, *Geological Survey of Canada*, Paper 91-1E, pages 67-76.

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*, Volume 110, pages 615-629.

Friedman, R.M. and van der Heyden, P. (1992): Late Permian U-Pb dates for the Farwell and Northern Mount Lytton plutonic bodies, Intermontane Belt, British Columbia; *in* Current Research, Part A; *Geological Survey of Canada*, Paper 92-1A, pages 137-144.

Gabrielse, H. (1994): Geology of the Cry Lake (104I) and Dease Lake (104J/E) map areas, north central British Columbia; *Geological Survey of Canada*, Open File 2779.

Gabrielse, H. (1998): Geology, Dease Lake, British Columbia; *Geological Survey of Canada*, Map 1908A, scale 1 250 000.

Gordey, S.P. and Stevens, R.A. (1994): Preliminary interpretation of bedrock geology of the Teslin area (105C), southern Yukon; *Geological Survey of Canada*, Open File 2886, scale 1:250 000.

Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G. and Smith, D.G. (1990): A geologic time scale 1989; *Cambridge University Press*, Cambridge, 263 pages.

Hart, C.J.R. (1997): A transect across Stikinia: Geology of the northern Whitehorse map area, southern Yukon Territory (105D/13-16); Exploration and Geology Services Division, Yukon, *Indian and Northern Affairs Canada*, Bulletin 8, 112 pages.

Hart, C.J.R. and Radloff, J.K. (1990): Geology of the Whitehorse, Alligator Lake, Fenwick Creek, Carcross and part of Robinson map areas (105D/11,6,3,2 & 7), Yukon Territory; *Indian and Northern Affairs Canada,* Open File 1990-4, 113 pages plus 4 map sheets.

Jackson, J.L. (1992): Tectonic analysis of the Nisling, northern Stikine and northern Cache Creek Terranes, Yukon and British Columbia; unpublished Ph.D. thesis, *The University of Arizona*, Tucson, 200 pages.

Johannson, G.G. (1994): Provenance constraints on Early Jurassic evolution of the northern Stikinian arc, Whitehorse Trough, Atlin Lake, northwestern British Columbia; unpublished M.Sc. thesis, *The University of British Columbia*, Vancouver, 300 pages.

Mihalynuk, M.G. (1999): Geology and Mineral Resources of the Tagish Lake Area, Northwestern British Columbia (NTS 104M/8, 9, 10E, 15, 104N/12W); *B.C. Ministry of Energy and Mines*, Bulletin 105 (in press).

Mihalynuk, M.G., Smith, M.T., Gabites, J.E., Runkle, D. and Lefebure, D. (1992): Age of emplacement and basement character of the Cache Creek Terrane as constrained by new isotopic and geochemical data; *Canadian Journal of Earth Sciences*, Volume 29, pages 2463-2477.

Mihalynuk, M.G., Nelson, J. and Diakow, L. (1994): Cache Creek Terrane entrapment: oroclinal paradox within the Canadian Cordillera; *Tectonics*, Volume 13, pages 575-595.

Mihalynuk, M.G., Meldrum, D., Sears, W.A., Johannson, G. G. (1995a): Geology of the Stuhini Creek area (104K/11); *in* Geological Fieldwork 1994, B. Grant and J.M. Newell, Editors*, B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 321-342.

Mihalynuk, M.G., Meldrum, D., Sears, W.A. and Johannson, G. G., Madu, B.E., Vance, S., Tipper, H.W. and Monger, J.W.H. (1995b): Geology and lithogeochemistry of the Stuhini Creek map area (104K/11*); B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1995-5.

Mihalynuk, M.G. and Cordey, F. (1997): Potential for Kutcho Creek volcanogenic massive sulphide mineralization in the northern Cache Creek Terrane: A progress report; *in* Geological Fieldwork 1996, *B.C. Ministry of Employment and Investment*, Paper 1997-1, pages 157-170.

Mihalynuk, M.G., Nelson, J. and Friedman, R.M. (1998): Regional geology and mineralization of the Big Salmon Complex; *in* Geological Fieldwork 1997, *B.C. Ministry of Employment and Investment*, Paper 1998-1, pages 6-1 to 6-20.

Monger, J.W.H. (1969): Stratigraphy and structure of Upper Paleozoic rocks, northeast Dease Lake map-area, British Columbia (104J); *Geological Survey of Canada*, Paper 68-48.

Monger, J.W.H. (1975): Upper Paleozoic rocks of the Atlin terrane, Northwest British Columbia and south-central Yukon, *Geological Survey of Canada*, Paper 74-47.

Monger, J.W.H., Wheeler, J.O., Tipper, H.W., *et al.* (1991): Part B. Cordilleran Terranes; *in* Chapter 8 of Geology of the Cordilleran Orogen in Canada, H. Gabrielse and C.J. Yorath, Editors; *Geological Survey of Canada*, Geology of Canada, Number 4, pages 281-327.

Mortensen, J. K., Ghosh, D.K. and Ferri, F. (1995): U-Pb geochronology of intrusive rocks associated with copper-gold porphyry deposits in the Canadian Cordillera; *in* Porphyry Deposits of the Northwestern Cordillera of North America, Schroeter, T.G., Editor, *Canadian Institute of Mining, Metallurgy and Petroleum*; Special Volume 46, pages 142-158.

Pálfy, J., Mortensen, J.K. and Smith, P.L. (1998): A U-Pb and 40Ar-39Ar time scale for the Jurassic. *5th International Symposium on the Jurassic System*, Vancouver, Canada, Abstracts and Program, page 72.

Read, P.B. (1993): Geology of northeast Taseko Lakes map area, southwestern British Columbia; *in* Current Research, Part A; *Geological Survey of Canada*, Paper 93-1A, pages 159-166.

Renne, P.R., Zhang, Z., Richards, M.A., Black, M.T. and Basu, A.R. (1995): Synchrony and causal relations between Permian-Triassic boundary crises and Siberian flood volcanism; *Science*, Volume 269, pages 1413-1416.

Ricketts, B.D., Evenchick, C.A., Anderson, R.G. and Murphy, D.C. (1992): Bowser basin, northern British Columbia: Constraints on the timing of initial subsidence and Stikinia-North America terrane interactions; *Geology*, Volume 20, pages 1119-1122.

Schiarizza, P. and MacIntyre, D.G. (1999): Geology of the Babine Lake-Takla Lake area, central British Columbia (93K/11, 12, 13, 14; 93N/3, 4, 5, 6); *in* Geological Fieldwork 1998, *B.C. Ministry of Energy and Mines*, Paper 1999-1, this volume.

Smith, P.L. and Tipper, H.W. (1986): Plate tectonics and paleobiogeography: Early Jurassic (Pliensbachian) endemism and diversity; *Palaois*, Volume 1, pages 399-412.

Stacey, J.S. and Kramers, J.D. (1975): Approximation of terrestrial lead isotope evolution by a two-stage model; *Earth and Planetary Science Letters*, Volume 26, pages 207-221.

Terry, J. (1977): Geology of the Nahlin ultramafic body, Atlin and Tulsequah map-areas, northwestern British Columbia; *Geological Survey of Canada*, Paper 77-1A, pages 263-266.

Thorstad, L.E., and Gabrielse, H. (1986): The Upper Triassic Kutcho Formation, Cassiar Mountains, north-central British Columbia; *Geological Survey of Canada*, Paper 86-16, 53 pages.