VOLUMINA JURASSICA, 2011, IX: 43–60

The Jurassic succession at Lisadele Lake (Tulsequah map area, British Columbia, Canada) and its bearing on the tectonic evolution of the Stikine terrane

Farshad SHIRMOHAMMAD[1], Paul L. SMITH[1], Robert G. ANDERSON[2], Vicki J. McNICOLL[3]

Key words: ammonites, chronology, Stikinia, terranes, Lower and Middle Jurassic, British Columbia.

Abstract. Jurassic rocks in the central Tulsequah map area include conglomerates and interbedded fossiliferous finer clastics of the Takwahoni Formation (Laberge Group) which unconformably overlie Triassic rocks. Ammonite collections document the Pliensbachian, Toarcian and Bajocian stages. We refine the age and provenance of episodes of coarse clastic input and confirm the progressive change of dominant clast lithology from reworked sedimentary rocks above the Triassic-Jurassic unconformity to volcanic, plutonic and then metamorphic clasts in the Upper Toarcian. The uppermost coarse clastic unit is a Bajocian chert-pebble conglomerate which, along with the immediately underlying black mudstone, we include in the Bowser Lake Group. Together with regional correlations, this confirms that the age of the basal part of the Bowser Lake Group is diachronous, younging southwards into Stikinia.

Sandstone petrofacies trends and changes in conglomerate clast composition indicate arc uplift and dissection followed by Middle Jurassic orogen recycling. The isotopic ages of detrital zircons and granite clasts compared with the biochronologically constrained ages of the enclosing strata suggests that processes of intrusion, arc uplift, unroofing, and clastic deposition during the Early Jurassic occurred over intervals of significantly less than five million years.

INTRODUCTION

The Stikine terrane (or Stikinia) is the largest volcanic arc terrane in the Canadian Cordillera. Basinal elements of Stikinia include the Lower to Middle Jurassic Whitehorse Trough (fore-arc basin; Wheeler, 1961; Souther, 1971, 1991; Bultman, 1979) and the successor Bowser Basin, which contain the geological record of the interaction of Stikinia and adjacent terranes (Fig. 1). The Whitehorse Trough located along the northeast flank of Stikinia is separated from the Hazelton Trough to the south by the Triassic-Jurassic volcano-plutonic rocks along the Stikine Arch (Wheeler, 1961; Souther, 1971; Tipper, Richards, 1976). In northwestern British Columbia, the Whitehorse Trough is mainly bounded by the King Salmon and Nahlin faults, the latter juxtaposing Stikinia and Cache Creek terrane. The Nisling terrane (*sensu* Wheeler, McFeely, 1991), which is made up of metamorphosed sedimentary and volcanic rocks, lies on the northwest flank of Stikinia. The geometry of these terranes, their pre-amalgamation history and the timing of their accretion remain the subject of debate (Gabrielse, Yorath, 1991; Ricketts *et al*., 1992; Currie, Parrish, 1993; Mihalynuk *et al*., 1994, 1995, 1999, 2004; English, Johnston, 2005).

---

[1] Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, British Columbia; e-mail: fshirmoh@eos.ubc, capsmith@eos.ubc.ca

[2] Geological Survey of Canada, Vancouver, British Columbia; e-mail: boanders@nrcan.gc.ca

[3] Geological Survey of Canada, Ottawa, Ontario; e-mail: vmcnicol@nrcan.gc.ca

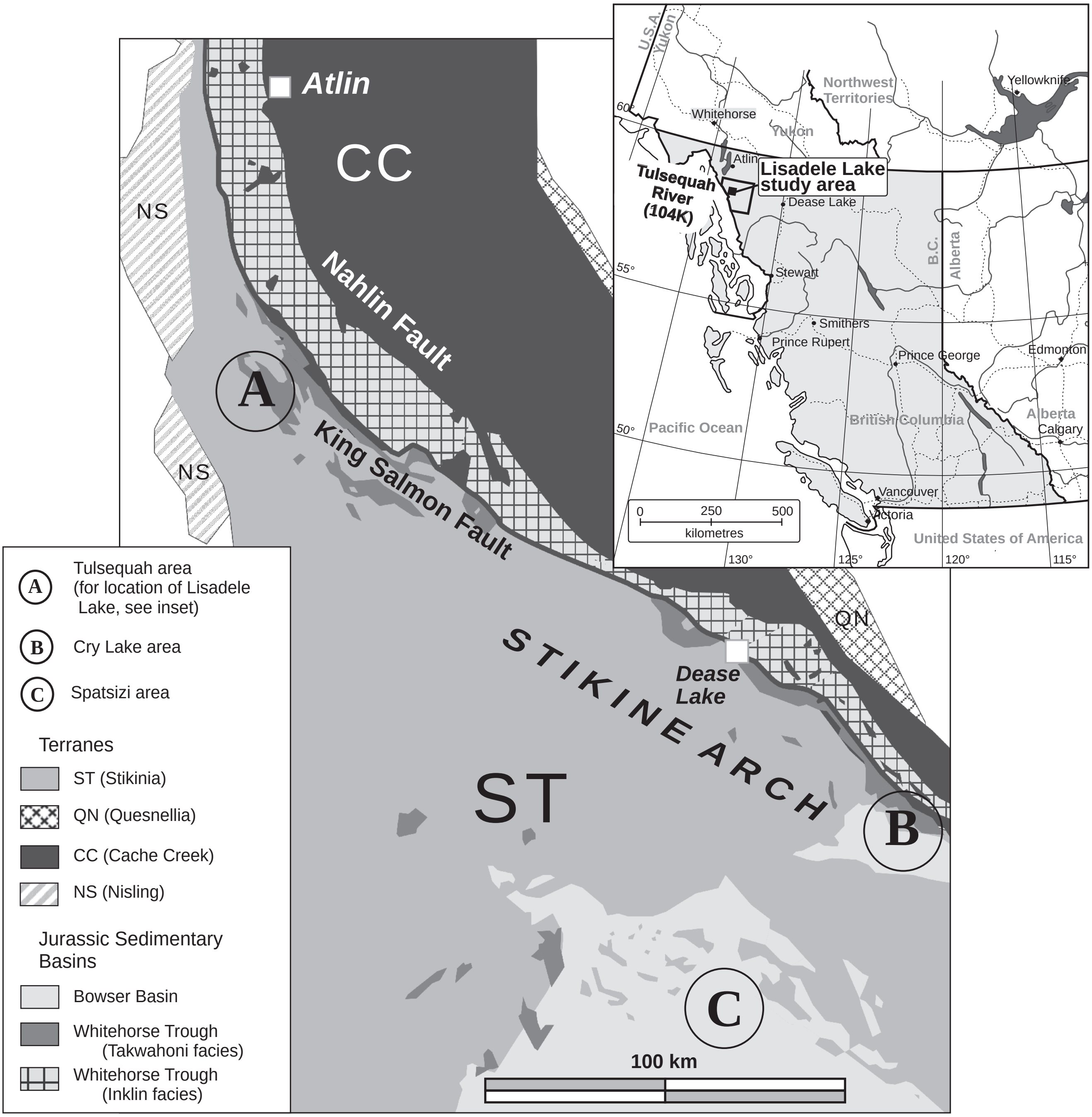


Fig. 1. Map showing the location of the study area, principal regional tectonic elements, and localities mentioned in the text

The Laberge Group and overlying strata in the Whitehorse Trough are interpreted as an overlap assemblage that contains a partial record of amalgamation of the Stikine and Cache Creek terranes. The Laberge Group comprises distal, fine-grained clastic rocks (the Inklin Formation) in the area between the Nahlin and King Salmon faults. It becomes coarser-grained and more reflective of shallow water environments (the Takwahoni Formation) southwest across the King Salmon Fault where the outlier at Lisadele Lake in northwestern British Columbia is located (Fig. 1).

The later-stage evolution of Stikinia includes a complex, episodic Mesozoic magmatic history which partly predates, but is mostly synchronous with, the sequence of rocks in the study area at Lisadele Lake (*e.g*., Armstrong, 1988; Monger *et al*., 1991; Woodsworth *et al*., 1991; Anderson, 1993; Breitsprecher *et al*., 2007). Important magmatic episodes of volcanism and plutonism potentially relevant to the Lisadele Lake sequence occurred at about 222, 202, 195, 191, 186, 182 and 175 Ma (Johannson, McNicoll, 1997; Johannson *et al*., 1997; Breitsprecher *et al*., 2007). Regionally overlying the Laberge Group is the Bowser Lake Group which records an influx of clastic material derived from obduction of the Cache Creek oceanic terrane.

At Lisadele Lake, Mihalynuk *et al*. (2004) documented a succession of Lower to Middle Jurassic conglomerates whose dominant clast composition changed systematically up-section. Our study of the strata at Lisadele Lake contributes the following: (1) it establishes more precise ages for the coarse clastic units within the Takwahoni Formation; (2) it explores concordant changes in conglomerate clast lithology and sandstone petrofacies that help shed light on the tectonic evolution of the area; (3) it makes a comparison of the depositional age of sedimentary rocks with the age of enclosed detrital components in order to infer the rate of arc unroofing; and (4) it contributes to our understanding of the regional transition from deposition of the Laberge Group to deposition of the Bowser Lake Group which records the linking of the Cache Creek and Stikine terranes.

GEOLOGICAL SETTING

The Whitehorse Trough is an elongate, arc-marginal marine sedimentary basin. It is dominated by submarine-fan deposition with volcanic and plutonic detritus derived from the Late Triassic and Early Jurassic magmatic arcs (Stuhini and Hazelton groups and associated granitoid suites) to the west and southwest along the Stikine Arch (Souther, 1971; Tempelman Kluit, 1979; Dickie, Hein, 1995; Hart *et al*., 1995; Johannson *et al*., 1997). It is believed that the Whitehorse Trough was a fore arc basin on the north-eastern flank of Stikinia that evolved as a result of convergence of the Stikine and Quesnel arc terranes during Early Jurassic destruction of the intervening Cache Creek oceanic terrane. The Whitehorse Trough was tectonically shortened during the Middle Jurassic collisional event that involved the west-directed emplacement of the Cache Creek terrane over the Whitehorse Trough and Stikinia (Ricketts *et al*., 1992). This is interpreted as marking the closure of the Cache Creek ocean and the accretion of Stikine terrane to the composite western edge of the North American plate (Monger *et al*., 1991; Ricketts *et al*., 1992; Mihalynuk *et al*., 1999). Paleoflow-direction studies indicate that the clastic sedimentary rocks were derived mainly from a source to the west and southwest of the basin during the Early Jurassic (Johannson *et al*., 1997; Wight *et al*., 2004). A marked change in both paleoflow and provenance happened in Early Bajocian time when chert granules were delivered into the basin by west-directed currents. Sedimentological observations suggest a prograding fan-delta setting with distal equivalents (Bultman, 1979; Dickie, 1989; Dickie, Hein, 1995).

The Jurassic succession exposed in the Lisadele Lake area consists of a nearly 3 km thickness of clastic sedimentary rocks that rest with angular unconformity on limestone of the Upper Triassic Sinwa Formation of the Stuhini Group (Fig. 2). The homoclinal sequence dips approximately 55º southwest, and forms the northeast limb of a large syncline (Shirmohammad *et al*., 2007). Figure 3 summarises the

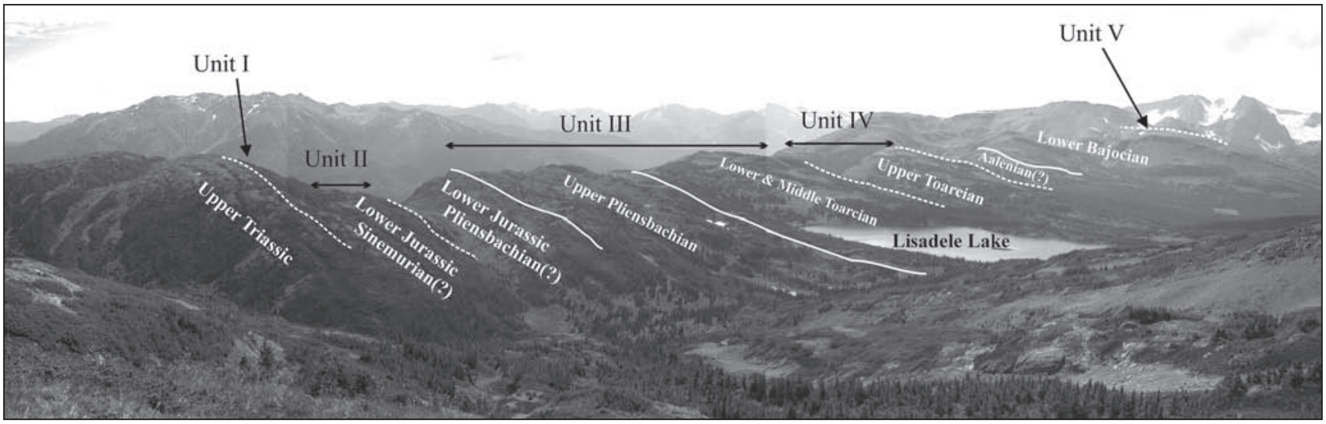


Fig. 2. Panoramic view of the Lower and Middle Jurassic succession in the Lisadele Lake area
For scale, the Lake is approximately 400 × 700 m). View is to the southeast. Geologic ages and the approximate positions of conglomerate units I through V are indicated

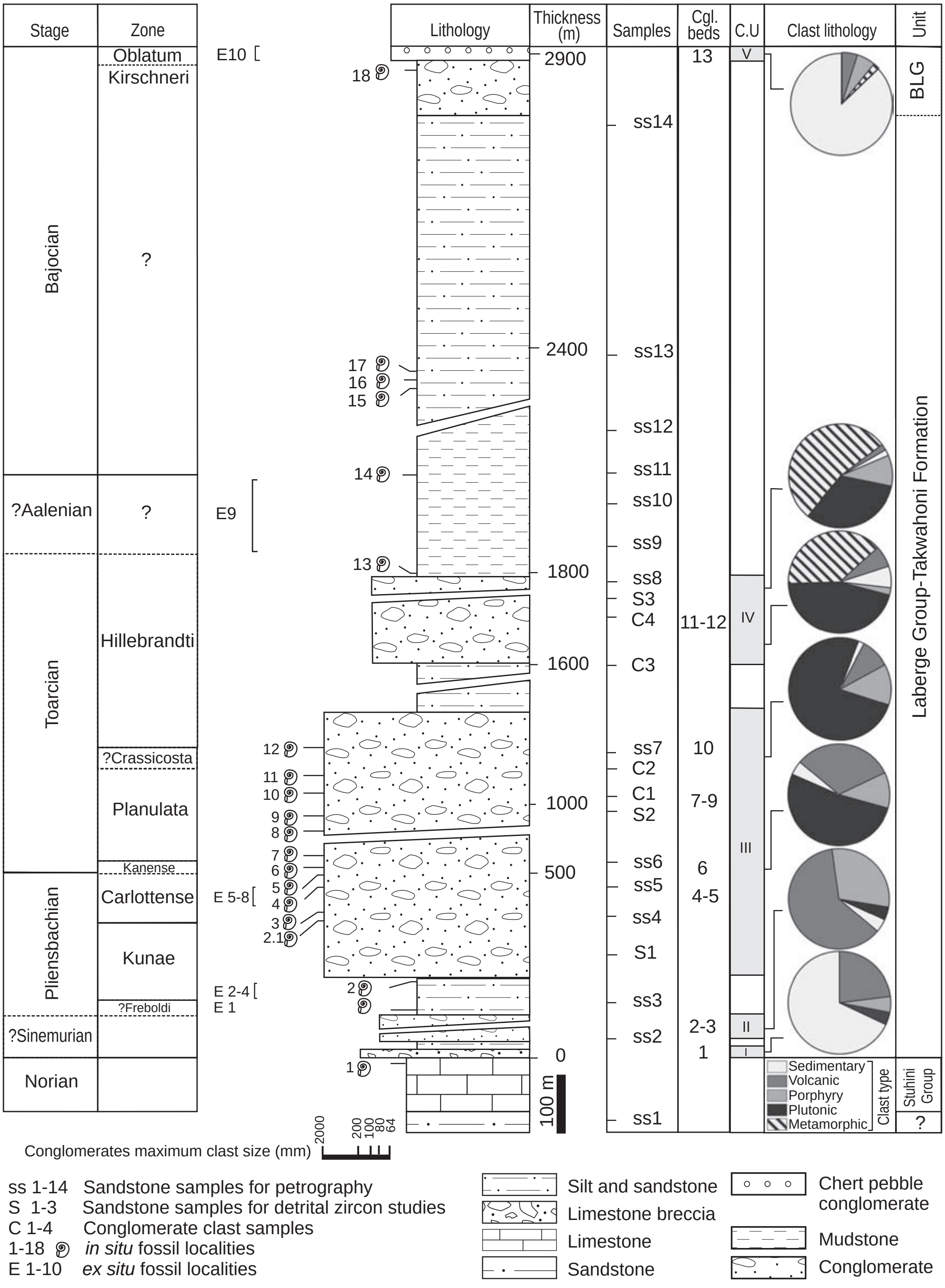


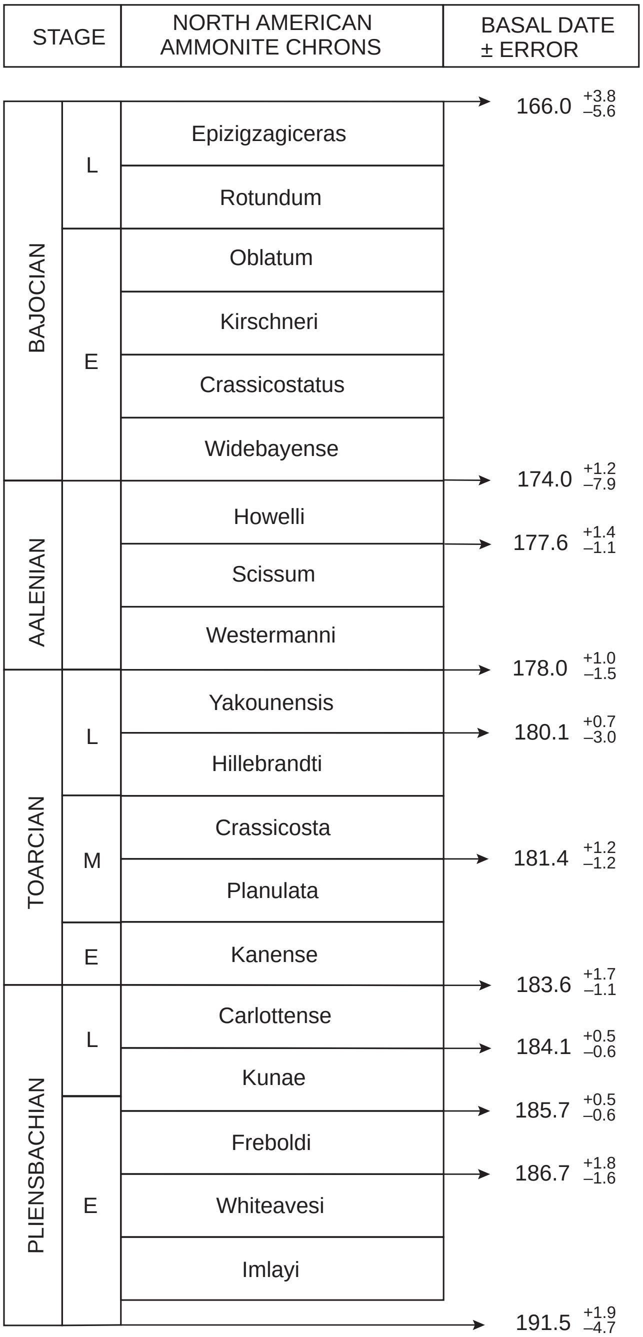
Fig. 3. Stratigraphic section measured east and north of Lisadele Lake showing the lithostratigraphy, biochronology and sample localities

Breaks in the section (which were omitted for drafting purposes) represent intervals of conformable, homogenous, unfossiliferous strata. Ammonite zones and the faunas used to recognize them are documented in Figs 4 and 5. Conglomerate beds 1–14 and sandstone petrography localities ss1–14 provided the data on which Fig. 6 is based. Geochronologic data came from localities marked S and C. The pie diagrams show the proportions of conglomerate clast lithologies at the stratigraphic levels indicated. BLG – Bowser Lake Group; C.U. – Conglomerate Units; cgl. – conglomerate stratigraphy at Lisadele Lake and indicates the fossil localities and sample sites that form the basis of this study. The lower part of the section is dominated by coarse-grained clastic rocks, primarily conglomerates of the Laberge Group (Takwahoni Formation), which will be discussed in more detail below. The conglomerate units are commonly separated by ammonite-bearing siltstones and sandstones which provide biochronologic age constraints. The sequence becomes progressively finer grained up-section where mudstone and siltstone predominate. It is capped by a unit of chert-pebble conglomerate correlated with the lower Bowser Lake Group. The 100 m thickness of strata beneath the chert-pebble conglomerate that we also assign to the Bowser Lake Group differs from the underlying upper Laberge Group rocks in that it contains finer grained, thinly bedded, dark mudstones rather than brownish siltstones and sandstones. However, the contact with the Laberge Group is not exposed and so we do not know their exact stratigraphic relationship. We include them in the Bowser Lake Group because, like the overlying chert-pebble conglomerates, they are lithostratigraphically correlative with the Ashman Formation exposed in many areas of the Bowser Basin to the south (Tipper, Richards, 1976; Thomson *et al*., 1986). However, as we discuss later, the Ashman Formation and its equivalents exposed in the Bowser Basin have recently been included in a suite of informal ‘Lithofacies Assemblages’ (Evenchick, Thorkelson, 2005; Evenchick *et al*., 2010) but we see no purpose in extending this informal terminology to this northern outlier.

BIOCHRONOLOGIC FRAMEWORK

A Jurassic biochronologic time scale based on ammonites and calibrated with a geochronologic scale based on U-Pb and ^{40}Ar-^{39}Ar dating of rocks in western North America (Pálfy *et al*., 2000a, b) is critical to this study (Fig. 4). The pertinent Lower and Middle Jurassic ammonite zones and their calibrated age in millions of years are given in Figure 4 (Hall, Westermann, 1980; Smith *et al*., 1988; Poulton, Tipper, 1991; Jakobs *et al*., 1994). New, *in situ* ammonite collections from the Takwahoni Formation in the Lisadele Lake area were added to previous collections available in the Geological Survey of Canada repository. Ammonoids range from Early Pliensbachian to Bajocian age. The taxa identified and their stratigraphic ranges are summarised in Figure 5, which serves as a basis for recognizing the zones as plotted on Figure 3.

Representative diagnostic taxa are illustrated in Plate 1. Specimens of *Omojuvavites* (Pl. 1: 1) and *Ectolcites* from locality 1 approximately 7 m below the unconformable contact between the Sinwa and the Takwahoni formations, indicate a Norian age. The age of the basal 150 m of the Takwahoni Formation is poorly constrained. It is possible that this interval could be as old as Sinemurian based on analogy with the succession in the Atlin Lake area where echioceratids (Late Sinemurian) have been collected at this stratigraphic level (Johannson *et al*., 1997).



STAGE		NORTH AMERICAN AMMONITE CHRONS	BASAL DATE ± ERROR
			166.0 $^{+3.8}_{-5.6}$
BAJOCIAN	L	Epizigzagiceras	
		Rotundum	
	E	Oblatum	
		Kirschneri	
		Crassicostatus	
		Widebayense	174.0 $^{+1.2}_{-7.9}$
AALENIAN		Howelli	177.6 $^{+1.4}_{-1.1}$
		Scissum	
		Westermanni	178.0 $^{+1.0}_{-1.5}$
TOARCIAN	L	Yakounensis	180.1 $^{+0.7}_{-3.0}$
		Hillebrandti	
	M	Crassicosta	181.4 $^{+1.2}_{-1.2}$
		Planulata	
	E	Kanense	183.6 $^{+1.7}_{-1.1}$
PLIENSBACHIAN	L	Carlottense	184.1 $^{+0.5}_{-0.6}$
		Kunae	185.7 $^{+0.5}_{-0.6}$
	E	Freboldi	186.7 $^{+1.8}_{-1.6}$
		Whiteavesi	
		Imlayi	
			191.5 $^{+1.9}_{-4.7}$

Fig. 4. North American Early and Middle Jurassic ammonite biochronological units. Modified after Pálfy *et al.* (2000a)

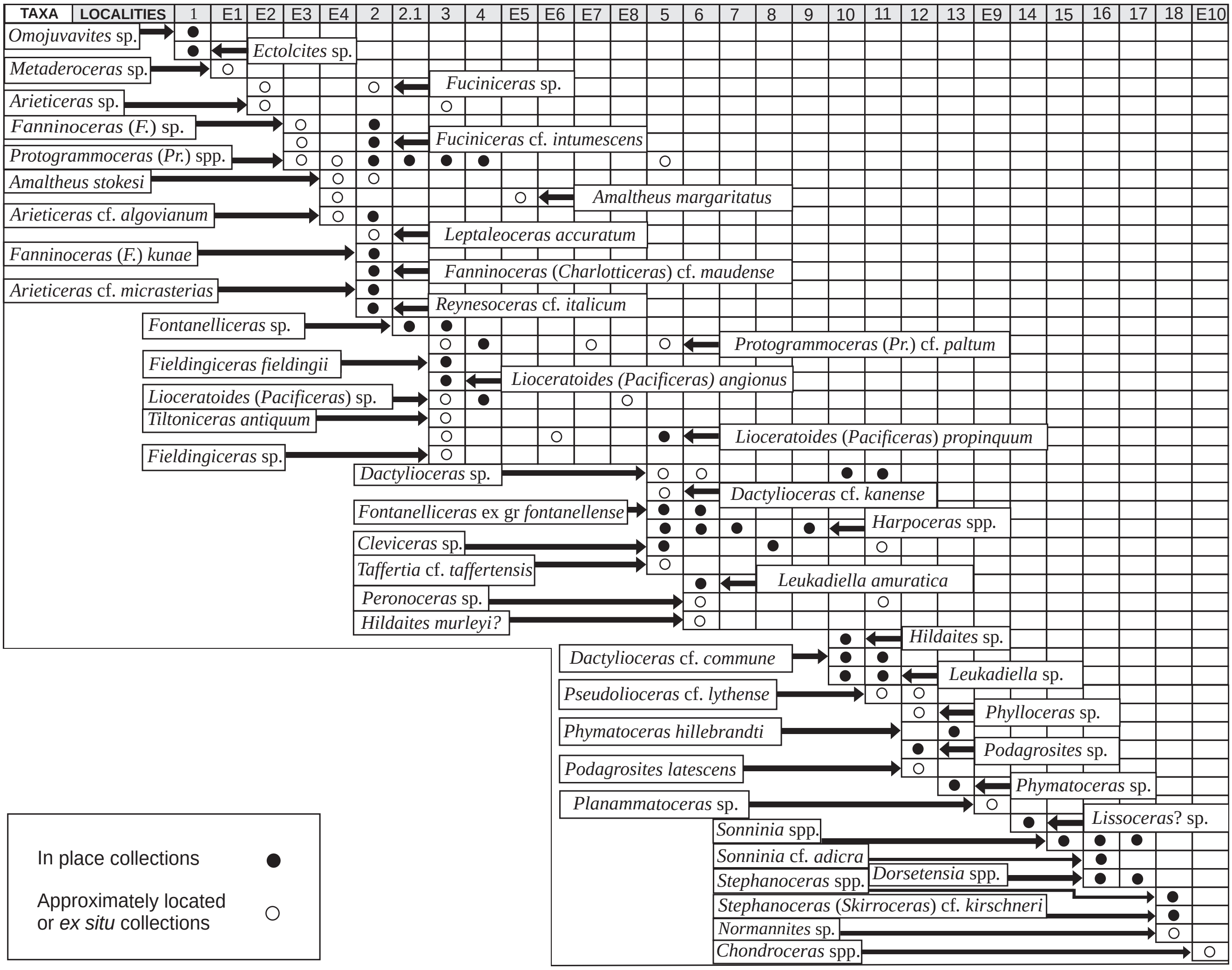


Fig. 5. Faunal distribution chart showing ammonite taxa collected from the Lisadele Lake area

The stratigraphic positions of these localities are shown in Figure 3

A single specimen of the Early Pliensbachian ammonite *Metaderoceras* sp. from locality E1 is the oldest Jurassic ammonite collected from the Lisadele Lake area (reported in Mihalynuk *et al*., 1999). However, the oldest relatively abundant ammonites are from the Kunae Zone of the Upper Pliensbachian (localities 2 and E2–4 in Figures 3 and 5). The most important indicative taxa include *Fanninoceras* (*Fanninoceras*) *kunae* (Pl. 1: 2), *F*. (*Charlotticeras*) cf. *maudense*, *Amaltheus stokesi* (Pl. 1: 14), and *A. margaritatus* (Pl. 1: 15 (*ex situ*)) as well as the hildoceratids *Arieticeras* cf. *micrasterias* (Pl. 1: 4), *A*. cf. *algovianum* (Pl. 1: 3), *Fuciniceras* cf. *intumescens* (Pl. 1: 5), *Leptaleoceras accuratum* and the dactylioceratid *Reynesoceras italicum* (Pl. 1: 10). Specimens characteristic of the uppermost Pliensbachian Carlottense Zone (localities E5–8 and 2.1–4 in Figs 3, 5) include *Lioceratoides* (*Pacificeras*) *propinquum* (Pl. 1: 6), *Protogrammoceras* spp., *Fontanelliceras* sp., *Arieticeras* sp., *Fieldingiceras* sp., and *Amaltheus margaritatus*.

The Kanense Zone at the base of the Toarcian is marked at locality 5 by the appearance of *Dactylioceras* cf. *kanense* (Pl. 1: 8) and *Taffertia* cf. *taffertensis* (Pl. 1: 9) occurring with holdovers from the Late Pliensbachian such as *Lioceratoides* (*Pacificeras*) *propinquum* and *Fontanelliceras* ex gr. *fontanellense* (Pl. 1: 7). About 15 meters above the Kanense Zone localities, the appearance of *Leukadiella amuratica* (Pl. 1: 11) marks the base of the Middle Toarcian Planulata

Zone (localities 6–11) which also yields *Dactylioceras* cf. commune as well representatives of the genera *Harpoceras*, *Peronoceras* and *Cleviceras*. This is the most northerly occurrence of the Tethyan genus *Leukadiella* which was previously only known from Haida Gwaii (formerly the Queen Charlotte Islands) of the Wrangell terrane, and from the Spatsizi and Hazelton areas of the Stikine terrane (Jakobs *et al*., 1994; Jakobs, 1995, 1997). Specimens characteristic of the Upper Toarcian Hillebrandti Zone collected from localities 12 and 13 include *Phymatoceras hillebrandti* (Pl. 1: 12) and *Podagrosites* sp. (Pl. 1: 13).

Shell pavements of the bivalve *Bositra* sp. are widespread south of Lisadele Lake in Middle to Upper Toarcian strata. They are also present in Whitehorse Trough strata in Yukon and the Atlin Lake area of northern British Columbia (Aberhan, 1998; Clapham *et al*., 2002). Elsewhere, *Bositra* forms shell pavements in rocks as old as Middle Toarcian (Damborenea, 1987). A coarse-grained fossiliferous sandstone about 50 meters below locality 13 yields abundant bivalves including *Weyla* sp.

Unequivocal Aalenian index fossils have not been collected from the study area. A single locality (E9) has yielded two small fragments of possible *Planammatoceras* that may be of Aalenian age as recorded by Poulton and Tipper (1991). We also found three ex situ fragments of probable *Planammatoceras* in the area between fossil localities 13 and 14 but the specimens are not complete enough to be compared with known species.

The Lower Bajocian is marked by the occurrence of a poorly preserved fragment at locality 14 referred to ?*Lissoceras* sp. and the occurrence at fossil localities 15–16 of specimens of *Sonninia* cf. *adicra*, and *Dorsetensia* spp. High in the section at locality 18, the presence of numerous stephanoceratids including *Stephanoceras* (*Skirroceras*) cf. *kirschneri*, indicate the Kirschneri Zone. The presence of *Chondroceras* (possibly including *C. allani*) in the uppermost part of the section indicates the Oblatum Zone, the highest Zone of the Lower Bajocian.

CLASTIC UNITS AND PETROFACIES

CONGLOMERATE

The Jurassic sequence at Lisadele Lake consists of about 3000 m of conglomerate, sandstone, siltstone, and mudstone which includes five distinct conglomerate units (Figs 2, 3). For each conglomerate unit, abundance of clast type and maximum clast size were determined in order to constrain provenance and energy regime. An average of 50 clasts was counted at conglomerate sample sites and their lithology and size range was recorded. Thin-sections of 41 clasts provided more detailed lithological information to supplement field observations. The five conglomerate units are characterized in stratigraphically ascending order by a predominance of sedimentary, volcanic, plutonic, metamorphic, and chert clasts as previously determined by Mihalynuk *et al*. (1999).

Conglomerate unit I makes up the lowermost five metres of the Takwahoni Formation. It consists of poorly sorted, matrix-supported limestone-pebble to cobble breccia and conglomerate with clasts ranging in size from 5 to more than 200 mm. The white to light grey, poorly sorted, sub-angular to angular clasts occur in a reddish-brown weathering sandstone and siltstone matrix. The clasts are likely in situ fragments derived from erosion of the Triassic basement. Conglomerate I unconformably overlies the latest Norian Sinwa Formation but, except for a possible correlation with the Sinemurian succession exposed in the Atlin Lake area (Johannson *et al*., 1997), its age is poorly constrained.

Conglomerate unit II conformably overlies conglomerate unit I and varies in thickness between 100–160 metres. It consists of channel deposits of pebble- to cobble-sized clasts (10–80 mm in diameter) that are moderately to well-sorted and sub-rounded to rounded. Clasts have fine-grained igneous textures and range from leucocratic to mesocratic (light to moderate) color index. The occasional dark grey and green weathering clasts are feldspar-, hornblende- and augite porphyries which resemble dominant lithologies within Upper Triassic Stuhini Group (*e.g*., Monger *et al*., 1991; Anderson, 1993; Mihalynuk *et al*., 1999). These are part of the Late Triassic (Carnian–Norian) arc construction phase and were the first to be eroded following removal of the capping Norian limestone. Biochronological age control has been difficult to obtain but Mihalynuk *et al*. (1999) reported a Lower Pliensbachian *Metaderoceras* from immediately above the unit.

Conglomerate unit III is the thickest in the sequence (approximately 1200 m thick) and is dominated by pebble to boulder-sized plutonic clasts that are most commonly 5–400 mm but may reach as much as 2 metres in diameter. The conglomerates are poorly sorted and the large clasts show high sphericity. Normal and locally reversed grading are evident. Common clast lithologies include leucogranite, diorite, monzonite and quartz monzonite. Intermediate to felsic volcanic rocks are minor components and carbonate sedimentary clasts, possibly derived from the Sinwa Formation, are rare. Thin-bedded sandstone layers contain locally abundant, fragmented plant fossils, suggesting shallow water deposition and sedimentation rates that locally exceeded subsidence rates.

The age of unit III is constrained by 12 Upper Pliensbachian to Middle Toarcian ammonite collections distributed more or less evenly from 250 to 1350 metres above the base of the section (Fig. 3). The lowest locality is a few metres below the base of the unit III. The 5 localities of fossiliferous finer clastics interbedded with the lower part of conglomerate unit III yield Upper Pliensbachian ammonites typical of the Kunae Zone.

Conglomerate beds comprising unit IV have an aggregate thickness of about 200 metres and contain abundant metamorphic rock clasts. Conglomerate beds within unit IV are less dominant than in unit III but locally reach thicknesses of about 30 metres. They contain white or light to dark grey pebble- to cobble-sized (10–100 mm) clasts in a dark to locally orange or brown-orange matrix. Of secondary abundance are plutonic clasts. The clasts are poorly sorted but well-rounded with local current-generated imbrications suggesting northeast-directed paleocurrents. The upper parts of unit IV display well-sorted pebble to cobble conglomerates (mainly 10–15 mm, maximum size up to 70 mm) interbedded with brown to light grey coarse-grained sandstone. Quartz-rich mica schist and foliated gneiss are the most common clast lithologies. Biotite is common in the clasts but attempts to provide age constraints using Ar-Ar analyses proved unsuccessful. Two ammonite localities bracket conglomerate unit IV, one approximately 200 meters below the base of the unit and the other from a directly overlying bed of sandstone. Both localities yield Late Toarcian species of the genera *Phymatoceras* and *Podagrosites*.

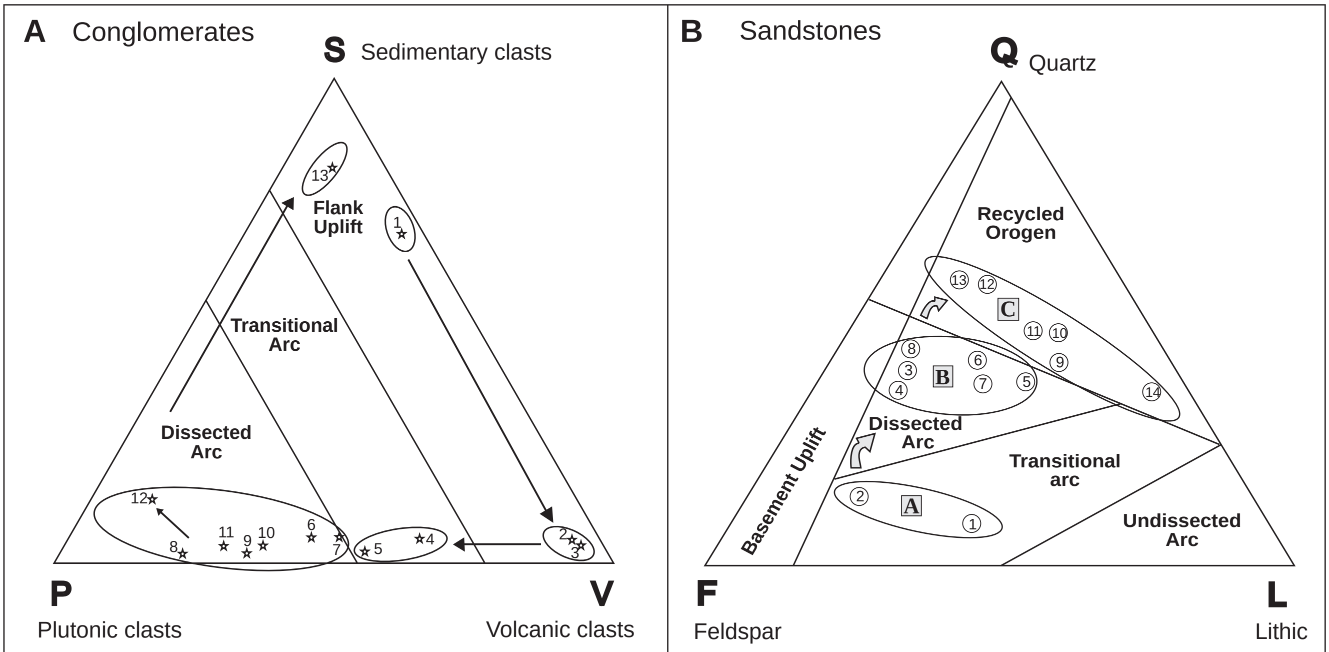
Conglomerate unit V caps the upper ~1000 metres of the Jurassic succession which is dominated by siltstone and mudstone. Unit V makes up the uppermost 5–10 metres of the section and consists of angular to sub-angular and well-sorted, chert granule to pebble conglomerate. Variegated clasts include black, dark green, white, red, and light to medium yellow varieties of chert. Mihalynuk *et al*. (1999) report that some clasts within this unit contain radiolarians, ranging in age from Early Permian through Early Jurassic. Ammonites from the extensive siltstone-mudstone interval indicate an Early Bajocian age (localities 15–18; Fig. 3). Stephanoceratids from about 20 metres below conglomerate unit V (locality 18) indicate a Kirschneri Zone age and Mihalynuk *et al*. (1999) reported Oblatum Zone age ammonites from within the chert pebble conglomerate (locality E10; Fig. 3) which together indicate an Early Bajocian age for the chert pebble conglomerate unit V.

The pie charts in Figure 3, showing the relative abundance of conglomerate clast lithologies, demonstrate that the abundance of each clast type is broadly unimodal and the dominant lithology changes progressively up section. However, the plot for sedimentary clasts is bimodal with one peak in the ?Sinemurian and the other in the Early Bajocian. At the base of the section, just above the unconformity, limestone clasts derived from the underlying Sinwa Formation predominate. Volcanic and porphyritic clasts become frequent in the lower part of the section but by the Toarcian, plutonic clasts dominate. There is a further provenance shift during the Toarcian reflecting a new source of clastics derived from a metamorphic source and/or unroofing the arc roots due to further arc exhumation. The uppermost conglomerate indicates a return to a sedimentary source of clasts but dominated by chert. The change in relative clast compositional proportions for 13 conglomerate beds is shown in an SPV (sedimentary-plutonic-volcanic) ternary diagram (Fig. 6A; sample locations indicated on Fig. 3). It indicates a change in provenance sources from flank uplift to transitional arc by the Late Pliensbachian, to dissected arc sources by the Late Toarcian.

SANDSTONE PETROFACIES

Petrographic analysis of sandstones was conducted to complement the data on conglomerate clasts. Samples were collected from all levels within the stratigraphic sequence, as indicated in Figure 3. The Gazzi-Dickinson method of point counting was employed and between 200–250 points counted within each thin section in order to generate statistically acceptable modes (Van Der Plas, Tobi, 1965; Ingersoll *et al*., 1984). The sandstones are both texturally and compositionally immature. The textural immaturity is shown by the moderate to poor sorting, angular to sub-rounded grains, and the common presence of finer matrix. The sandstones are compositionally dominated by feldspar and quartz, with variable amounts of lithic fragments. As shown in Figure 6B, the relative proportions of lithic fragments, feldspar, and quartz in the rocks define three distinct suites when plotted on a ternary tectonic discrimination diagram (Dickinson *et al*., 1983), designated sandstone petrofacies A through C.

Upper Triassic and Lower Jurassic (Sinemurian/Pliensbachian) lithic arkoses and arkoses of Petrofacies A contain a low proportion of quartz grains typical of those derived from a transitional arc. Upper Pliensbachian and Toarcian sandstones of Petrofacies B show a progressive increase in the percentage of quartz grains, a trend indicating a change in provenance from a transitional arc to a dissected arc. Upper Toarcian and Lower Bajocian sandstones of Petrofacies C contain mainly feldspar and quartz fragments but relatively more abundant lithic fragments compared to Petrofacies B; they indicate a recycled orogen source. The Lower Bajocian sandstone sample number 14 (Figs 3, 6B) shows the highest percentage of lithic fragments.



Samples	Age	Conglomerate units
1	Early Jurassic (Sinemurian?)	Unit I
2–3	Early Jurassic (Sinem./Pliens.?)	Unit II
4–5	Late Pliensbachian (Carlottense Z.)	Unit III
6	Early Toarcian (Kanense Z.)	
7–9	Middle Toarcian (Planulata Z.)	
10	Middle / Late Toarcian	
11–12	Late Toarcian (Hillebrandti Z.)	
13	Early Bajocian (Oblatum Z.)	Unit V

Sample # s	Age	Petrofacies
①	Late Triassic	A
②	Sinemurian/Pliensbachian?	
③	Early Pliensbachian	B
④–⑤	Late Pliensbachian	
⑥–⑦	Middle Toarcian	
⑧	Late Toarcian	
⑨ ⑩	Late Toarcian/Aalenian?	C
⑪ ⑭	Early Bajocian	

Fig. 6. A. Ternary diagram of Takwahoni Formation conglomerates. Poles represent clast modes for plutonic (P), volcanic (V), and combined sedimentary (S) clasts. Ternary diagram after Dickie and Hein (1995). The lower panel shows age constraints and lithologic units. B. QFL ternary diagram showing plots of Takwahoni Formation sandstone petrofacies. Poles show quartz (Q), feldspar (F) and lithic fragment (L) occurrence with respect to tectonic setting. Ternary diagram after Dickinson *et al.* (1983). The lower panel shows age constraints and sampled petrofacies

ISOTOPIC AGE OF DETRITAL COMPONENTS

Isotopic age determination of the clastic components of sedimentary rocks is a well-established tool for evaluating the relationship between tectonic activity, sediment provenance, and rates of sediment deposition. Age distributions of detrital zircons can act as a fingerprint for provenance areas and help to constrain the rate of tectonic uplift.

U-Pb geochronological studies of the Lower Jurassic strata were completed at the Geological Survey of Canada Geochronology Laboratory in Ottawa. The data, discussed herein, include U-Pb SHRIMP (Sensitive High Resolution Ion Microprobe) analyses of detrital zircons in sandstone samples and U-Pb ID-TIMS (isotope dilution thermal ionization mass spectrometry) dating of two plutonic clasts collected from conglomerate beds (Fig. 3). U-Pb ID-TIMS analytical methods utilized in this study are outlined in Parrish *et al*. (1987) and treatment of analytical errors follows Roddick (1987). SHRIMP analyses were conducted using analytical and data reduction procedures described by Stern (1997) and Stern and Amelin (2003).

Clastic zircon populations with a wide age range indicate recycling from a clastic source or derivation from a variety of unimodal sources. A narrow range of ages points to little or no clastic recycling and relatively few unimodal zircon sources. Zircons extracted from granitoid conglomerate clasts should reflect the age of the source pluton. Comparison of well-calibrated biochronologic units (giving the age of enclosing beds) with the crystallization age of contained clastic components constrains the timing and speed of unroofing. Small age differences imply a tectonically dynamic environment and little delay between erosion and rock deposition.

Two samples of granitic conglomerate clasts were dated by U-Pb ID-TIMS methods. Clast sample C1 was collected from Conglomerate Unit III (Fig. 3). Middle Toarcian (Planulata Zone) index fossils about 50 meters stratigraphically below (fossil localities 6–9) and about 30 meters above (fossil localities 10, 11) the C1 sample provide age constraints on the deposition of the conglomerate. A concordia age calculated is 186.6 ± 0.5 Ma (mean square of the weighted deviations (MSWD) of concordance and equivalence = 1.2), which is interpreted as the crystallization age of the granite body from which the clast was derived. Clast sample C2 was also obtained from Conglomerate Unit III but about 100 meters stratigraphically above sample C1and from a bed a few meters above the last occurrence of Middle Toarcian ammonites (fossil locality 11) and about 250 meters below the first occurrence of Upper Toarcian ammonites (fossil locality 12). A concordia age is calculated to be 221 ±1 Ma (MSWD of concordance and equivalence = 1.7) and is interpreted to be the crystallization age of the granitic clast.

U-Pb SHRIMP analyses of detrital zircons from three sandstone samples were obtained. Sandstone sample S1 was collected from within Conglomerate Unit III (Fig. 3). Ammonites from several meters below the sandstone sample (fossil locality 2) indicate the Kunae Zone of the Upper Pliensbachian. The superjacent fossil localities (2.1 and 3) are about 100 meters above the sample and indicate the Carlottense Zone of the Upper Pliensbachian (Fig. 3) suggesting a possible range of Kunae to Carlottense zone for the S1 sample although Kunae Zone is most likely. A total of 31 detrital zircons was analyzed from this sample. These data are interpreted to all comprise one age population and, therefore, most likely are derived from one source. The age of this detrital population is 189.6 ±1.0 Ma (MSWD = 0.9). Sandstone sample S2 was also collected from within Conglomerate Unit III (Fig. 3). The age of the sample is constrained by Middle Toarcian (Planulata Zone) index fossils stratigraphically below (localities 6–9) and above (localities 10, 11). The majority of the detrital zircons analyzed from this rock comprise one statistical population with an age of 184.4 ±1.2 Ma (MSWD = 1.6, n = 35). There are a few older detrital grains with ages of ca. 192 Ma and *ca*. 197 Ma. Sandstone sample S3 was collected from Conglomerate Unit IV (Fig. 3). Upper Toarcian (Hillebrandti Zone) index fossils about 400 meters stratigraphically below (at fossil locality 12) and about 100 meters above (fossil locality 13) sample S3 provide the age constraint (Fig. 3). One detrital zircon yielded an age of 1420 ±36 Ma but the dominant youngest detrital population in the sample has an age of 184.4 ±1.0 Ma (MSWD = 1.0, n = 38). This statistical age population has the same age as that obtained from sample S2, likely reflecting

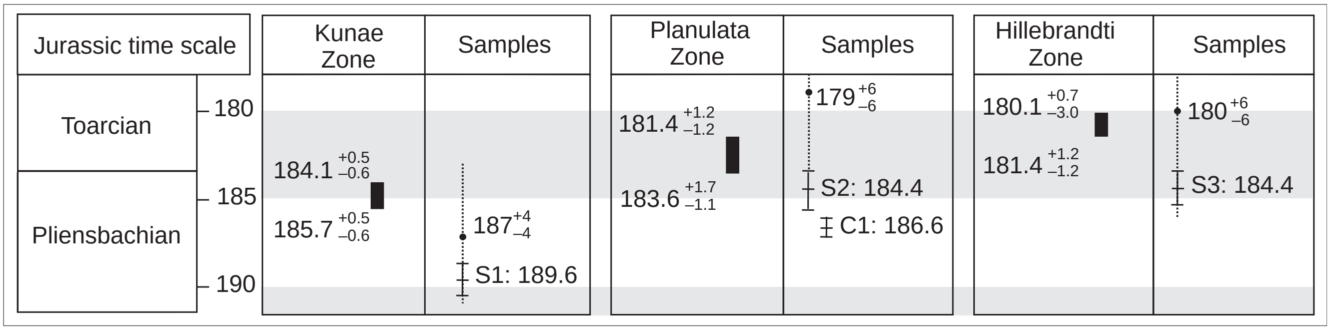


Fig. 7. Geochronological and biochronological results plotted on the Jurassic time scale for sandstone zircon samples S1 to S3 and conglomerate clast sample C1

Samples S1, S2 and C1 originate from conglomerate unit III and sample S3 originates from conglomerate unit IV (Fig. 3). The Kunae Zone is Late Pliensbachian, the Planulata Zone is Middle Toarcian and the Hillebrandti Zone is Late Toarcian. Estimates and errors for the age of the upper and lower zone boundaries are indicated. Bold lines in the ‘Samples’ column show the age and error of the detrital zircon population and the dotted lines show the age and error of the youngest detrital zircons. There is little difference between clast and zircon ages and the age of the enclosing sediments, suggesting rapid unroofing. The Jurassic time scale is from Pálfy *et al.* (2000a) the same source. Five other detrital zircons from sandstone S3 have ages of ca. 192, 194, 205, 215 and 220 Ma.

In summary, large zircon populations from the igneous rocks of the conglomerate clasts and the detrital zircon populations in the sandstone samples point to source magmas of the following approximate ages: 185, 187, 200 and 221 Ma. Anomalous single crystals in the populations indicate sources of 192, 194, 197, 205, 215 and 220 Ma. Conglomerate clast C2 (221 Ma) was derived from a Late Triassic (Carnian) source, perhaps genetically related to the subjacent Stuhini volcanic rocks. Three detrital zircons in the Toarcian sandstone sample S3 also yielded an age of 220 Ma, approximately the same Late Triassic age as conglomerate clast C2. There is only a single detrital zircon in the sample S3 that yielded an age of 1420 Ma, which suggests a cratonic source, or perhaps recycled detritus originally from a cratonic source.

The enclosing sedimentary strata for samples S1, S2 and S3 as well as the granitic conglomerate clast C1 are of Pliensbachian or Toarcian age. In Figure 7, the data are plotted against the calibrated ages of the zones (chrons) from which the samples were collected (Kunae (Pliensbachian); Planulata and Hillebrandti (Toarcian)). The age of the detrital zircon population from each of the sandstone samples is plotted, as well as the age and error of the youngest single detrital zircon in the sample. The age of the youngest detrital zircon in the samples and the average age of the chron in which the sample is contained is approximately 2 million years or less, although the error on each analysis is large. The average age of the entire zircon population differs from average age of the chron by significantly less than 5 million years.

DISCUSSION AND CONCLUSIONS

Clast and sandstone petrofacies data are in good agreement. Carbonate clasts in the basal Takwahoni Formation were produced by the development of an erosional unconformity during the Early Jurassic (?Sinemurian) which cut into the subjacent Triassic limestones and volcanics. An unconformity between Upper Triassic and Sinemurian arc-related strata is widespread in Stikinia (*e.g.*, Souther, 1971; Anderson, 1993).

Arc building and erosion that occurred into the Pliensbachian provided the volcanic (*e.g.*, Nordenskiold Dacite; Johannson, McNicoll, 1997) and porphyry clasts that predominate at this level. Some of the porphyritic rock types are similar to typical volcanic rocks of the Upper Triassic Stuhini Group in the Stikine terrane. The large volume of granitic clasts in Toarcian strata implies extensive exposure of plutons within the source area. The known or inferred ages for clasts and probable igneous detrital zircons correlate well with important magmatic episodes in the Stikine terrane at 221 Ma and 186 Ma (*e.g.*, Breitsprecher *et al*., 2007).

In summary, flank uplift and erosion in the volcano-plutonic centres predominate in the oldest part of the Jurassic succession (?Sinemurian –Early Pliensbachian) followed by arc dissection for much of the Pliensbachian and Toarcian. The Late Toarcian and Middle Jurassic are dominated by flank uplift, with sandstones of this interval plotting in the recycled orogen field of the QFL ternary diagram (Fig. 6B). Small differences between the age of detrital components (zircons and conglomerate clast) and the age of the enclosing strata suggest rapid Pliensbachian-Toarcian uplift of the source area and/or shallow emplacement of plutons.

Accelerated uplift producing arc dissection was possibly achieved in part by intra-arc strike-slip faulting as suggested by Johannson *et al*. (1997) for Inklin strata in the Atlin Lake area, about 100 kilometres to the north of Lisadele Lake (Fig. 1). In contrast to the Lisadele Lake area, the youngest Early Jurassic conglomerates in the Atlin Lake area are Sinemurian and although Pliensbachian rocks are common, no Toarcian rocks are present (Johannson *et al*., 1997). Toarcian conglomerates are present further north, however, in the Yukon and in northern BC in the Tagish-Atlin area (Hart *et al*., 1995; Mihalynuk *et al*., 1999). The high abundance of metamorphic clasts in Toarcian conglomerates of the Takwahoni Formation is unique to the Lisadele Lake area. They make up 50% of the clasts whereas they rarely exceed 1–2% in conglomerates of similar age in the Yukon (Hart *et al*., 1995).

The Middle Jurassic obduction of the Cache Creek Terrane, preceded by a narrowing and restricting of the Cache Creek ocean, caused the deposition of black muds quickly followed by the erosion and influx of chert-rich materials into the Whitehorse Trough and across Stikinia. This important part of the sequence in the Lisadele Lake area (conglomerate unit V and the underlying black mudstone) is here placed in the Bowser Lake Group and correlated lithostratigraphically with the Ashman Formation as recognized by Tipper and Richards (1976) and Thomson *et al*. (1986). The Early Bajocian age of both conglomerate V and the underlying mudstone unit is demonstrated by several ammonite horizons (Fig. 3).

Further north, in the northern Whitehorse Trough in Yukon, Early Bajocian chert-pebble conglomerates are found in the Fish Lake Syncline southwest of the city of Whitehorse (Wheeler, 1961; Tempelman Kluit, 1984; Clapham *et al*., 2002). These Bajocian beds are equivalent to the Ashman Formation. They were tentatively correlated with the basal Tantalus Formation by Clapham *et al*. (2002) but it is clear from the work of Lowey and Hills (1988) that the Tantalus Formation, where it occurs in west-central Yukon, is Early Cretaceous. Further south in the Cry Lake map area (Figs 1

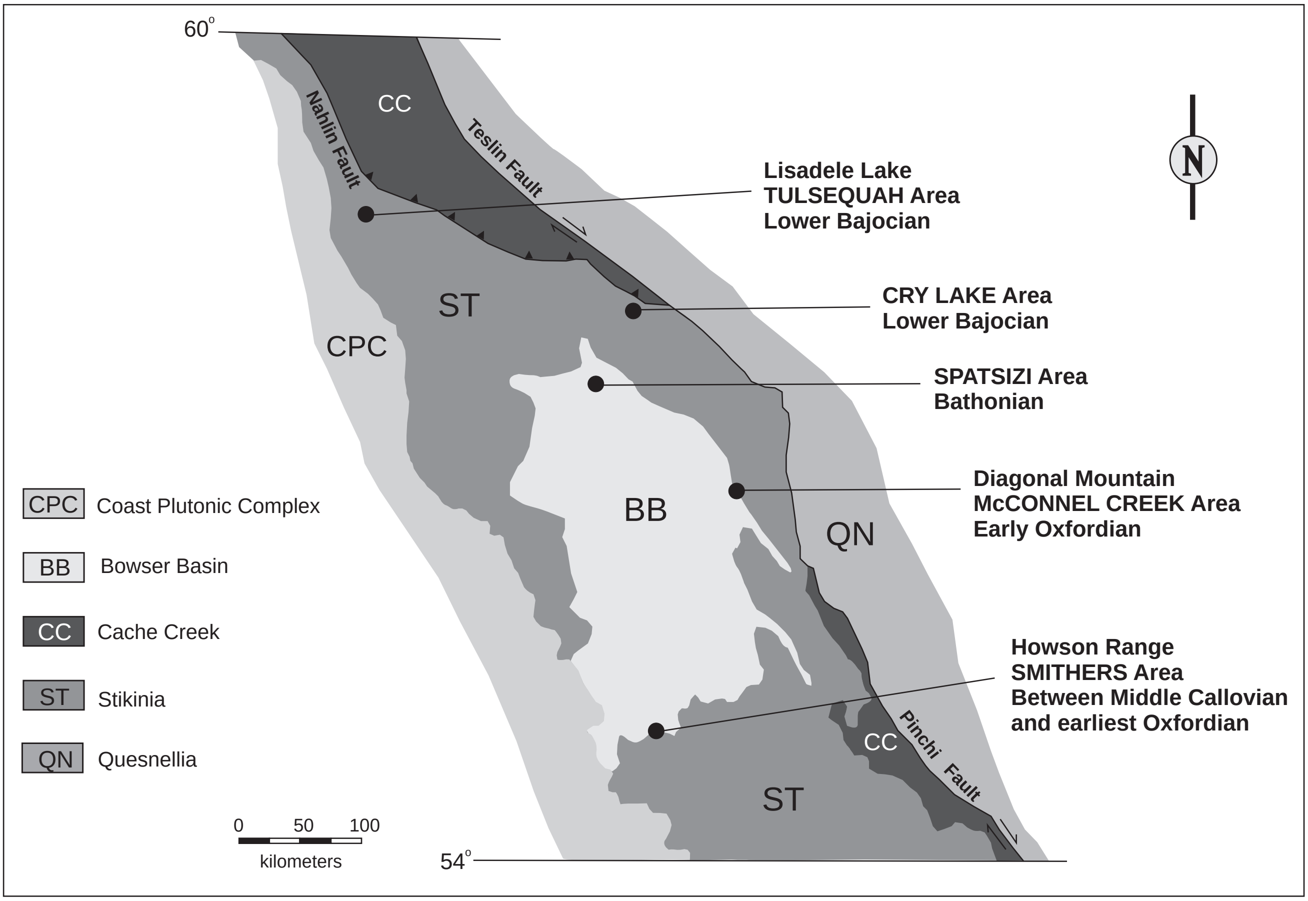


Fig. 8. Simplified geological map showing the Cache Creek and Quesnel terranes as well as the principal areas of Jurassic outcrop on Stikinia

Black dots show location and age of the transition from Lower Jurassic volcanic and volcaniclastic rocks to the coarse clastic, chert-rich, rocks of the Bowser Lake Group (after Smith *et al.*, 2010; Evenchick *et al.*, 2010)

and 8), the Ashman Formation is Early Bajocian, the same age as the beds in the Lisadele Lake area and the Yukon (Tipper, 1978; Gabrielse, 1998). It should be noted that the Middle Bajocian age reported by Tipper (1978) in the Cry Lake area is equivalent to Early Bajocian in modern terminology. This is because the Aalenian stage, which was formally recognized in 1980, is now equivalent to the former Lower Bajocian. The Ashman Formation is of Bathonian age in the Spatsizi area on the south flank of the Stikine Arch where the basal contact shows a slight angular discordance (Tipper, Richards, 1976; Thomson *et al.*, 1986; Evenchick, Thorkelsen, 2005). We recently noted the young ages of the basal Bowser Lake Group in these northerly localities and speculated that the contact was diachronous southwards across the Bowser Basin (Smith *et al.*, 2010). This was confirmed by Evenchick *et al.* (2010) who published a detailed study of the entire Bowser Basin south of the Stikine Arch (located in Figs 1 and 8). Recognition of the basal beds of the Bowser Lake Group becomes more difficult to the south for two reasons. Firstly, volcanism there (and to the north in the Cry Lake Area) caused ash beds to be interbedded with mudrocks, an association that is more characteristic of the underlying Hazelton Group. Secondly, the chert-pebble conglomerates are less frequent. Because of these difficulties, Evenchick *et al.* (2010) and Evenchik and Thorkelson (2005) advocated abandonment of the name Ashman Formation and the adoption of a complex suite of informal lithologic assemblage names to describe the basal Bowser Lake Group. Nonetheless they clearly confirm a regional diachronism, with basal Bowser Lake beds younging to the south. At Diagonal Mountain in the McConnel Creek map area, the basal Bowser Lake Group is of Early Oxfordian age whereas even further south in the Howson Range of the Smithers map area it is of Middle Callovian to earliest Oxfordian in age (Evenchick *et al.*, 2010) (Fig. 8).

In summary, the Jurassic sequence at Lisadele Lake records the rapid unroofing of a volcanic arc on the flank of the Stikine terrane. Initiation of Bowser Lake Group sedimentation marks the closing of the Cache Creek Ocean and initiation of a pulse of rapid subsidence in the Bowser Basin, probably resulting from sediment loading (Gagnon *et al*., 2009). The obducting Cache Creek terrane provided a source of chert and other sedimentary clasts that were deposited first in the north during the Early Bajocian spreading as far south as the Smithers map area some 10 million years later.

Acknowledgments. This research was partly funded under the Geological Survey of Canada's Northern Resources Program Project Y15, Cordilleran Minerals and Energy. This is GSC Contribution number 20080497. Research also supported in part by NSERC grant 8493 to Paul Smith who gratefully acknowledges the advice of the late H.W. Tipper during field work in the Lisadele Lake area in 1981. We thank Jozsef Pálfy, Mitch Mihalynuk and Grant Lowey for their helpful comments on the project. We appreciate insightful and thoughtful reviews of the manuscript provided by Jim Haggart and Terry Poulton. Farshad Shirmohammad would like to thank HDI (Hunter Dickinson Inc.) for providing support and facilitation during the final revision of this paper.

REFERENCES

ABERHAN M., 1998 — Early Jurassic Bivalvia of western Canada. Part I. Subclasses Palaeotaxodonta, Pteriomorphia, and Isofilibranchia. *Beringeria*, **21**: 57–150.

ANDERSON R.G., 1993 — A Mesozoic stratigraphic and plutonic framework for northwestern Stikinia (Iskut River area), northwestern British Columbia, Canada. *In*: Mesozoic Paleogeography of the Western United States II (Eds. G. Dunne, K. McDougall). Society of Economic Palaeontologists and Mineralogists, Pacific Section, **71**: 477–494.

ARMSTRONG R.L., 1988 — Mesozoic and early Cenozoic magmatic evolution of the Canadian Cordillera; *Geological Society of America, Special Paper*, **218**: 55–91.

BREITSPRECHER K., SCOATES J.S., ANDERSON R.G., WEIS D., 2007 — Geochemistry of Mesozoic Intrusions, Quesnel and Stikine Terranes (NTS 082; 092; 093), south-central British Columbia: preliminary characterization of sampled suites. *In*: Geological Fieldwork, 2006, *British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper* **2007-1**: 247–258.

BULTMAN T.R., 1979 — Geology and tectonic history of the Whitehorse Trough west of Atlin, British Columbia. Ph.D. thesis, Yale University, New Haven, CT.

CLAPHAM M.E., SMITH P.L., TIPPER, H.W., 2002 — Lower to Middle Jurassic stratigraphy, ammonoid fauna and sedimentary history of the Laberge Group in the Fish Lake syncline, northern Whitehorse Trough, Yukon, Canada. *In*: Yukon Exploration and Geology 2001 (Eds. D.S. Emond *et al*.), Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada: 73–85.

CURRIE L.D, PARRISH R.R., 1993 — Jurassic accretion of Nisling terrane along the western margin of Stikinia, Coast Mountains, northwestern British Columbia. *Geology*, **21**: 235–238.

DAMBORENEA S.E., 1987 — Early Jurassic Bivalvia of Argentina, Part 2: Superfamilies Pteriacea, Buchiacea and part of Pectinacea. *Palaeontographica* (A), **199**: 113–216.

DICKIE J.R., 1989 — Sedimentary response to arc-continent transpressive tectonics, Laberge conglomerates (Jurassic) Whitehorse Trough, Yukon Territory. Unpublished M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

DICKIE J.R., HEIN F.J., 1995 — Conglomeratic fan deltas and submarine fans of the Jurassic Laberge Group, Whitehorse Trough, Yukon Territory, Canada: fore-arc sedimentation and unroofing of a volcanic island arc complex. *Sedimentary Geology*, **98**: 263–292.

DICKINSON W.R., BEARD L.S., BRAKENRIDGE G.R., ERJAVEC J.L., FERGUSON R.C., INMAN K.F., KNEPP R.A., LINDBERG F.A., RYBERG P.T., 1983 — Provenance of North American Phanerozoic sandstones in relation to tectonic setting. *Geological Society of America Bulletin*, **94**: 222–235.

ENGLISH J.E., JOHNSTON S.T., 2005 — Collisional orogenesis on the northern Canadian Cordillera: implications for Cordilleran crustal structure, ophiolite emplacement continental growth and the terrane hypothesis. *Earth and Planetary Science Letters*, **232**: 333–344.

EVENCHICK C.A., POULTON T.P., MCNICHOLL V.J., 2010 — Nature and significance of the contact between the Hazelton and Bowser lake Groups (Jurassic), north-central British Columbia. *Bulletin of Canadian Petroleum Geology*, **58**: 235–267.

EVENCHICK C.A., THORKELSON D.J., 2005 — Geology of the Spatsizi River map area, north-central British Columbia. *Geological Survey of Canada, Bulletin*, **577**.

GABRIELSE H., 1998 — Geology of the Cry Lake and Dease Lake map areas, north-central British Columbia. *Geological Survey of Canada, Bulletin*, **504**.

GABRIELSE H., YORATH C.J., 1991 — Outstanding problems in Geology of the Cordilleran Orogen in Canada. *In*: the Geology of North America, Geology of Canada, no. 4 (Eds. H. Gabrielse, C.J. Yorath), Geological Survey of Canada (also Geological Society of America) **G-2**: 817–823.

GAGNON J.-F., EVENCHICK C.A., WALDRON J.W.F., CORDEY F., POULTON T.P., — 2009 Jurassic subsidence history of the Hazelton Trough-Bowser Basin in the area of Todagin Mountain, north-central British Columbia, Canada. *Bulletin of Canadian Petroleum Geology*, **57**: 430–448.

HALL R.L., WESTERMANN G.E.G., 1980 — Lower Bajocian (Jurassic) cephalopod faunas from western Canada and proposed assemblage zones for the Lower Bajocian of North America. *Palaeontographica Americana*, **9**: 1–93.

HART C.J.R., DICKIE J.R., GHOSH D.K., ARMSTRONG R.L., 1995 — Provenance constraints for Whitehorse Trough conglomerate: U-Pb zircon dates and initial Sr ratios from granitic clasts in Jurassic Laberge Group, Yukon Territory. *In*: Jurassic

Magmatism and Tectonics of the North American Cordillera (Eds. D.M. Miller, C. Busby). *Geological Society of America*, *Special Paper*, **299**: 47–63.

INGERSOLL R.V., BULLARD T.F., FORD R.L., GRIMM J.P., PICKLE J.D., SARES S.W., 1984 — The effect of grain size on detrital modes: a test of the Gazzi-Dickinson point-counting method. *Journal of Sedimentary Petrology*, **54**: 103–116.

JAKOBS G.K., SMITH P.L., TIPPER, H.W., 1994 — An ammonite zonation for the Toarcian (Lower Jurassic) of the North American Cordillera. *Canadian Journal of Earth Sciences*, **31**: 919–942.

JAKOBS G.K., 1995 — New occurrences of *Leukadiella* and *Paroniceras* (Ammonoidea) from the Toarcian (Lower Jurassic) of the Canadian Cordillera. *Journal of Paleontology*, **69**: 89–98.

JAKOBS, G.K., 1997 — Toarcian (Early Jurassic) ammonoids from western North America. *Geological Survey of Canada*, *Bulletin*, **428**.

JOHANNSON G.G., SMITH P.L., GORDEY S.P., 1997 — Early Jurassic evolution of the northern Stikinian arc: evidence from the Laberge Group, northwestern British Columbia. *Canadian Journal of Earth Science*, **34**: 1030–1057.

JOHANNSON G.G., MCNICOLL V.J., 1997 — New U–Pb data from the Laberge Group, northwest British Columbia: implications for Stikinian arc evolution and Lower Jurassic time scale calibrations. *In*: Current Research, part F, Geological Survey of Canada, **1997-F**: 121–129.

LOWEY G.W., HILLS L.V., 1988 — Lithofacies, petrography and environment of deposition, Tantalus Formation (Lower Cretaceous) Indian River area, west-central Yukon. *Bulletin of Canadian Petroleum Geology*, **36**: 296–310.

MIHALYNUK M.G., SMITH M.T., HANCOCK K.D., DUDKA S., NELSON J., PAYNE J., 1994 — Geology of the Tulsequah River and Glacier areas (104K/12 & 13); B.C. Ministry of Energy, Mines and Petroleum Resources, Open File 1994-7.

MIHALYNUK M.G., MELDRUM D., SEARS W.A., JOHANNSON G.G., 1995 — Geology of the Stuhini Creek area (104K/11). *In*: Geological Fieldwork 1994 (Eds. B. Grant, J.M. Newell), *B.C. Ministry of Energy, Mines and Petroleum Resources, Paper* **1995-1**: 321–342.

MIHALYNUK M.G., ERDMER P., GHENT E.D., ARCHIBALD D.A., FRIEDMAN R.M., CORDEY F., JOHANNSON G.G., BEANISH J., 1999 — Age constraints for emplacement of the northern Cache Creek terrane and implications of blueschist metamorphism. *In*: Geological Fieldwork 1998, *B.C. Ministry of Energy, Mines and Petroleum Resources, Paper* **1999-1**: 127–141.

MIHALYNUK M.G., ERDMER P., GHENT E.D., CORDEY F., ARCHIBALD D.A., FRIEDMAN R. M., JOHANNSON G.G., 2004 — Coherent French Range blueschist: Subduction to exhumation in <2.5 m.y.? *Geological Society of America Bulletin*, **116**: 910–922.

MONGER J.W.H., WHEELER J.O., TIPPER H.W., GABRIELSE H., HARMS T., STRUIK L.C., CAMPBELL R.B., DODDS C.J., GEHRELS G.E., O'BRIEN J., 1991 — Part B. Cordilleran terranes. *In*: the Geology of North America, Geology of Canada, no. 4 (Eds. H. Gabrielse, C.J. Yorath), Geological Survey of Canada, (also Geological Society of America), **G-2**: 281–327.

PÁLFY J., MORTENSEN J.K., SMITH P.L., FRIEDMAN R.M., McNICOLL V.J., VILLENEUVE M., 2000a — New U-Pb zircon ages integrated with ammonite biochronology from the Canadian Cordillera. *Canadian Journal of Earth Sciences*, **37**: 549–568.

PÁLFY J., SMITH P.L., MORTENSEN J.K., 2000b — A U-Pb and ^{40}Ar/^{39}Ar time scale for the Jurassic. *Canadian Journal of Earth Sciences*, **37**: 923–44.

PARRISH R.R., RODDICK J.C., LOVERIDGE W.D., SULLIVAN R.W., 1987 — Uranium-lead analytical techniques at the Geochronology Laboratory, Geological Survey of Canada. *In*: Radiogenic age and isotopic studies, Report 1: *Geological Survey of Canada Paper* **87-2**: 3–7.

POULTON T.P., TIPPER H.W., 1991 — Aalenian ammonites and strata of western Canada. *Geological Survey of Canada*, *Bulletin*, **411**.

RICKETTS B.D., EVENCHICK C.A., ANDERSON R.G., MURPHY D.C., 1992 — Bowser Basin, northern British Columbia: Constraints on the timing of initial subsidence and Stikinia-North America terrane interactions. *Geology*, **20**: 1119–1122.

RODDICK J.C., 1987 — Generalized numerical error analysis with applications to geochronology and thermodynamics; *Geochimica et Cosmochimica Acta*, **51**: 2129–2135.

SHIRMOHAMMAD F., SMITH P.L., ANDERSON R.G., LOXTON J., MCNICOLL V.J., 2007 — Preliminary report on the Triassic and Jurassic stratigraphy and paleontology of the Sinwa and Takwahoni formations, near Lisadele Lake, Tulsequah map-area, northwestern British Columbia. *Geological Survey of Canada Current Research*, **2007-A9**: 1–11.

SMITH P.L., SHIRMOHAMMAD F., ANDERSON R.G., MCNICOLL V. J., 2010 — British Columbia and the Jurassic time scale: contributions and applications. Earth Science Frontiers, **17**: 85–86.

SMITH P.L., TIPPER H.W., TAYLOR D.G., GUEX J., 1988 — An ammonite zonation for the Lower Jurassic of Canada and the United States: the Pliensbachian. *Canadian Journal of Earth Sciences*, **25**: 1503–1523.

SOUTHER J.G., 1971 — Geology and mineral deposits of the Tulsequah map area, British Columbia. *Geological Survey of Canada*, *Memoir* **362**.

SOUTHER J.G., 1991 — Volcanic Regimes. *In*: The Geology of North America, Geology of Canada, no. 4 (Eds. H. Gabrielse, C.J. Yorath), Geological Survey of Canada, (also Geological Society of America), **G-2**: 457–490.

STERN R.A., 1997 — The GSC Sensitive High Resolution Ion Microprobe (SHRIMP): analytical techniques of zircon U-Th-Pb age determinations and performance evaluation. *In*: Radiogenic age and isotopic studies, Report 10: *Geological Survey of Canada Current Research* **1997-F**: 1–31.

STERN R.A., AMELIN Y., 2003 — Assessment of errors in SIMS zircon U-Pb geochronology using a natural zircon standard and NIST SRM 610 glass; *Chemical Geology*, **197**; 111–142.

TEMPELMAN KLUIT D.J., 1979 — Transported cataclasite, ophiolite and granodiorite in Yukon: evidence of arc–continent collision. *Geological Survey of Canada, Paper* **79-14.**

TEMPELMAN KLUIT D.J., 1984 — Laberge and Carmacks map areas. Geological Survey of Canada, Open File 1101, two 1:250,000 scale maps and legends.

THOMSON R.C., SMITH P.L., TIPPER H.W., 1986 — Lower to Middle Jurassic (Pliensbachian to Bajocian) stratigraphy of the northern Spatsizi area, north-central British Columbia. *Canadian Journal of Earth Sciences*, **23**: 1963–1973.

TIPPER H.W., RICHARDS T.A., 1976 — Jurassic stratigraphy and history of north central British Columbia. *Geological Survey of Canada, Bulletin*, **270**.

TIPPER H.W., 1978 — Jurassic biostratigraphy, Cry Lake map-area, British Columbia. *In*: Current Research, Part A. *Geological Survey of Canada, Paper* **78-1A**: 25–27.

VAN DER PLAS L., TOBI A.C., 1965 — A chart for judging the reliability of point counting results. *American Journal of Sciences*, **263**: 87–90.

WHEELER J.O., 1961 — Whitehorse map-area, Yukon Territory. *Geological Survey of Canada Memoir*, **312**.

WHEELER J. O., McFEELY P., 1991 — Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America. Geological Survey of Canada map 1712A.

WIGHT K.L., ENGLISH J.M., JOHNSTON S.T., 2004 — Structural relationship between the Laberge Group and Sinwa Formation on Copper Island, southern Atlin Lake, northwest British Columbia. *In*: Summary of Activities 2004, BC Ministry of Energy and Mines, 137–156.

WOODSWORTH G.J., ANDERSON R.G., ARMSTRONG R.L., 1991 — Plutonic Regimes. *In*: the Geology of North America, Geology of Canada, no. 4 (Eds H. Gabrielse, C.J. Yorath), Geological Survey of Canada, (also Geological Society of America), **G-2**: 491–531.

PLATE 1

Fig. 1. *Omojuvavites* sp. Loc. 1 (GSC Loc. C-210277; type 42749); Sinwa Formation; Norian (Triassic)

Fig. 2. *Fanninoceras (Fanninoceras) kunae* McLearn. Loc. 2 (GSC Loc. C-210278; type 42750); Kunae Zone (Pliensbachian)

Fig. 3. *Arieticeras* cf. *algovianum* (Oppel). Loc. 2 (GSC Loc. C-210278; type 42751); Kunae Zone (Pliensbachian)

Fig. 4. *Arieticeras* cf. *micrasterias* (Meneghini). Loc. 2 (GSC Loc. C-210278; type 42752); Kunae Zone (Pliensbachian)

Fig. 5. *Fuciniceras* cf. *intumescens* (Fucini). Loc. 2 (GSC Loc. C-210278; type 42753); Kunae Zone (Pliensbachian)

Fig. 6. *Lioceratoides (Pacificeras) propinquum* (Whiteaves). Loc. E6 (GSC Loc. C-210279; type 42754); Carlottense Zone (Pliensbachian)

Fig. 7. *Fontanelliceras* ex gr. *fontanellense* (Gemmellaro). Loc. 6 (GSC Loc. C-210280; type 42755); Kanense Zone (Toarcian)

Fig. 8. *Dactylioceras* cf. *kanense* (McLearn). Loc. 5 (GSC Loc. C-208235; type 42756); Kanense Zone (Toarcian)

Fig. 9. *Taffertia* cf. *taffertensis* Guex. Loc. 5 (GSC Loc. C-208235; type 42757); Kanense Zone (Toarcian)

Fig. 10. *Reynesoceras italicum* (Fucini). Loc. 2 (GSC Loc. C-210278; type 42758); Kunae Zone (Pliensbachian)

Fig. 11. *Leukadiella amuratica* Renz. Loc. 6 (GSC Loc. C-210280; type 42759); Planulata Zone (Middle Toarcian)

Fig. 12. *Phymatoceras hillebrandti* Jakobs *et al*. Loc. 13 (GSC Loc. C-86529; type 42760); Hillebrandti Zone (Toarcian)

Fig. 13. *Podagrosites* sp. Loc. 12 (GSC Loc. C-86529; type 42761); Hillebrandti Zone (Toarcian)

Fig. 14. *Amaltheus stokesi* (J. Sowerby). Loc. E4 (GSC Loc. C-86511; type 42762); Kunae Zone (Pliensbachian)

Fig. 15. *Amaltheus margaritatus* (de Montfort). Loc. E4/E5 *ex situ* (GSC Loc. C-86511; type 42763); Takwahoni Formation; Kunae/Carlottense Zones (Pliensbachian)

Fig. 16. *Sonninia* cf. *adicra* (Waagen). Loc. 16 (GSC Loc. C-210285; type 42764); Bajocian

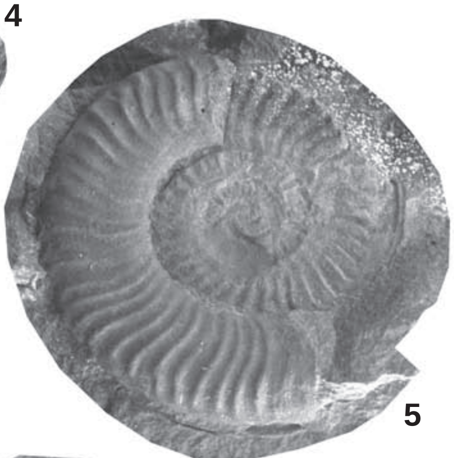
Scale bar is 2 centimetres. The specimens are deposited in the type collections of the Geological Survey of Canada (GSC)


1


2


3


4


5


6


7


8

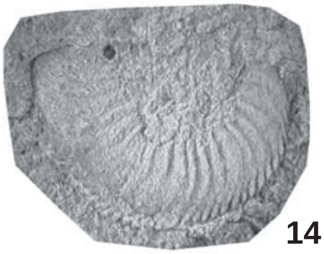

9


10


11


12


13


14


15


16

2 cm